MIT Kavli Institute   Chandra X-Ray Center

MEMORANDUM
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Subject:

Interface Control Document: HRC-S PI Reference Data & Algorithm

Revision:

1.3

URL:

`http://space.mit.edu/cxc/docs/docs.html#hrcstgain`

File:

`/nfs/cxc/h3/dph/CXC/HRCS_pifilt/Doc/hrcs_spi_icd-1.3.tex`

v1.3 changes: column names *GRID; column dimension notation explicit; hpe interface change: no new parameters needed

1 Overview of HRC-S PI Computation

A new algorithm for computing the HRC-S pulse height (PI, for Pulse Invariant Amplitude) is documented in the memo *"A New Gain Map and Pulse-Height Filter for the Chandra LETG/HRC-S Spectrometer"* by B. J. Wargelin, P. W. Ratzlaff, and M. Juda,[1] henceforth referred to as the *Memo*. This algorithm can result in a reduction of HRC-S background by about a factor of two. There are two new parts to the processing:

1. Computation of the PI for every event, which requires a new Calibration Database (`CALDB`) file and algorithmic support in the tool, `hrc_process_events`.

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[1] http://cxc.harvard.edu/cal/Letg/GainFilter/gain.pdf, November 25, 2008

2. Application of a position-dependent filter before binning an LETGS spectrum, which requires a new CALDB region file.

This memo will define the new CALDB files, the processing algorithm for hrc_process_events, and the filter application method.

2 PI Computation

The essence of the the PI computation is given by Equation 5 in the *Memo*, rewritten slightly here as:

$$P_n = \frac{a_1}{m_{ij}} \left(\frac{D_n}{C_i(t)S_{ij}^{norm}} - b_{ij} \right) + a_0.$$ (1)

We have changed the notation slightly to make the two-dimensional nature of the calibration data explicit in detector raw coordinates by subscripts ij, and we have removed explicit numerical values which are subject to calibration updates. We use a "row, column" notation, in which row i is a RAWY index, and column j indexes RAWX. For HRC-S, the LETG dispersion is along RAWY. In this equation the terms are

P_n the desired value for PI for the nth event, at detector raw pixel coordinate (RAWX, RAWY), which will be mapped to calibration bin, (i, j).

D_n represents the uncorrected event pulse-height data value ("SAMP" in *Memo* terms), for the nth event.

Other terms are calibration data, two of which are scalars (a_n), three are two-dimensional maps (m, S, and b), and another is a time-dependent term with one spatial dimension (C).

For purposes of efficiency in CALDB representation and event processing, we can collect terms into a more compact form:

$$P_n = G_{ij0} + \frac{G_{ij1}}{C_i(t)} D_n$$ (2)

G_{ijk} is the "Gain Map", with two spatial dimension, i and j, and one polynomial order dimension, k.

$C_i(t)$ is the time-dependent gain correction, with one spatial dimension, i.

The CALDB file will hold one 3D image, G_{ijk}, one 2D image, C_{in}, and coordinate grids for each axis. Since the grids may be non-uniform, axes will be enumerated rather than specified by FITS image coordinate terms.

2.1 File Structure: HRC-S Gain Coefficients

2.1.1 File Names

The `CALDB` type for time dependent gain is `tgain`. File names will be of the form

    hrcsD1999-07-22tgainNnnnn.fits

in which $nnnn$ is a 4-digit version counter.

2.1.2 HDU Components

The following table describes the file structure by Header-Data Unit number, type, extension name, content, and HDU classes. An asterisk (*) denotes the principal HDU.

HDU	HDU	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	AXAF_TGAIN	1	CDB_HRCS_TGAIN	ASC DETCHAR TGAIN	Binary table extension listing coefficients for PI gain correction as a function of time & position.

2.1.3 Columns and Coordinate Systems

Columns for HRC-S gain coefficients are given in the following table. Column ordering in the FITS table is arbitrary.

v1.3 update: grids, notation

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
RAWXGRID	pixel	n_xE	0	?	RAWX grid, low bin edges. n_x is the number of elements in the RAWX grid.
RAWYGRID	pixel	n_yE	0	?	RAWY grid, low bin edges. n_y is the number of elements in the RAWY grid.
TIMEGRID	MJD	n_tD	N/A	N/A	Time axis for data stored in column TGAIN. Units are MJD. MJDREF is 50814, which corresponds to `1998-01-01T00:00:00` (TT), and $MJD = JD - 2400000.5$. n_t is the number of elements in the TIME grid.
GAINMAP	1	$2n_xn_y$E	N/A	N/A	Coefficients map vs raw coordinate. $2 \times n_x \times n_y$ is the total length fo the array.
TGAIN	1	n_tn_yE	N/A	N/A	Normalization coefficient vs time and RAWY. $n_t \times n_y$ is the total length of the array.

Grids are required to be monotonic and in ascending order. They are, however, not necessarily uniform. Hence, the grids are tabulated rather than specified by standard FITS World Coordinate System (WCS) image keywords, `CRPX`, `CDLT`, and `CRVL`.

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2.1.4 Special Coordinate Keywords

The image column require several keywords in order to define its coordinate system and relation to other columns. These follow the conventions given in "Representation of celestial coordinates in FITS", by Greisen and Calabretta (Sept. 9, 1996)[2].

iCTYPn: These string-valued keywords define the axes of image columns.

> For GAINMAP we require:

> > 1CTYPn = 'ORDER'
> > 2CTYPn = 'RAWX',
> > 3CTYPn = 'RAWY'.

> Here, n, is the column index for GAINMAP. ORDER refers to the order of the polynomial coefficient (not spectral diffraction order).

> For TGAIN, we require:

> > 1CTYPn = 'RAWY',
> > 2CTYPn = 'TIME'.

> with n being replaced by the column number of TGAIN.

TDIMn: This string-valued keyword specifies the dimensionality of each axis of image columns. It has the form, '(N_z, N_x, N_y)'

> For GAINMAP we require:

> > TDIMn = '$(2, n_y, n_x)$'.

> For TGAIN we require:

> > TDIMn = '(n_y, n_t)'.

CREFn: This keyword has a string value which maps the image axes to TTYPEn keywords which specify grids for those axes.

> For GAINMAP we require:

> > CREFn = '(ORDER, RAWX, RAWY)'.

> For TGAIN we require:

> > CREFn = '(RAWY, TIME)'.

For non-enumerated axes (uniform grids), the coordinate strings would be what the WCS mapping requires (i.e., 2CRPX, 2CDLT, and 2CRVL).

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[2]http://www.cv.nrao.edu/fits/documents/wcs/wcs.all.ps

2.1.5 Relevant Header Keywords

Relevant keywords are:

`INSTRUME:`   The only allowed value is `HRC`.

`DETNAM:`   The only allowed values are `HRC-S` (current) and `HRC-I` (TBD).

`CIP`n`:`   For configuration control, this keyword (or list if n is present to enumerate several keywords) names the input CIP, or Calibration Interface Product files delivered by calibration and formatted into this ARD. For example, the original calibration prototype file was called `spimean.fits`.

`CIPREF:`   For configuration control, this keyword cites a relevant calibration memo (or preferably, URL). The origninal calibration prototype was provided at

$$\mathrm{http://cxc.harvard.edu/contrib/letg/GainFilter/.}$$

2.1.6 `CALDB` Keywords

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'T_GAIN'
CVSD0001  1999-07-22T00:00:00
CVST0001  00:00:00
CDES0001  'Detector gain map coefficients'
```

2.2 Size and File Number Estimates

There will be one HRC-S coefficients file which will cover the time of the mission. The minimal spatial gain map is 576×48 real-valued elements, and the minimal temporal map is 576×18 real-valued elements. Including the 2-plane gainmap and grids for each axis, the size is about 500 kB. With finer grids, this could be 4 to 8 times the size, or up to 4 MB.

3 HRC-S Time-dependent Gain Correction Algorithm Specification

The time-dependent gain correction and PI computation is to be a part of the `hrc_process_events` program. The new algorithm's PI values will become the PI column of the output event file.

1. Read the `DATE-OBS` from the event or reference file.

2. Read the gain file, either from the `CALDB` or as per the `hrc_process_events` parameter, "`gainfile`". The gain file elements are the `GAINMAP` 3D image, the `TGAIN` 2D image, and the corresponding enumerated coordinate grids, `RAWX`, `RAWY`, `TIMEGRID`.

3. Interpolate `TGAIN` to the observed date. `TGAIN` is comprised of one array in `RAWY` for each MJD of the `TIMEGRID`. Each element along the `RAWY` axis should be linearly interpolated in time to produce a new array in `RAWY`.

   Find the times in the `TIMEGRID` grid which bracket the observed date, t_{obs}.

   If the observed date is after the greatest `TIMEGRID`, then use the greatest `TIMEGRID`.

   Otherwise, linearly interpolate. If j is the index for the greatest `TIMEGRID` less than the observed date, and i is the `RAWY` grid index, then for each i,

   $$\texttt{TGAIN}_i(t_{\mathrm{obs}}) = \texttt{TGAIN}_{i,j} + \left(\frac{t_{\mathrm{obs}} - \texttt{TIMEGRID}_j}{\texttt{TIMEGRID}_{j+1} - \texttt{TIMEGRID}_j} \right) (\texttt{TGAIN}_{i,j+1} - \texttt{TGAIN}_{i,j}) \tag{3}$$

   The result, $\texttt{TGAIN}_i(t_{\mathrm{obs}})$, is a 1D array of the same length as `RAWY`.

4. Divide each column (index j) of the `GAINMAP`'s linear coefficient by the interpolated `TGAIN`:

   $$\texttt{GAINMAP}'_{ij1} = \texttt{GAINMAP}_{ij1} / \texttt{TGAIN}_i(t_{\mathrm{obs}}) \tag{4}$$

   The result is a 2D map of the same size as $\texttt{GAINMAP}_{ij1}$.

5. For each event, n, read the $\texttt{RAWX}_n$, $\texttt{RAWY}_n$, $\texttt{AMP\_SF}_n$, and $\texttt{SUMAMPS}_n$ from the event file.

6. Compute the data value,

   $$D_n = \texttt{SUMAMPS}_n \times 2^{(\texttt{AMP\_SF}_n - 8)} \tag{5}$$

7. From the event's raw coordinates, use the gain file's enumerated grids to look up the indices of the gain-correction coefficients. Let $\mathcal{I}$ be the row index (`RAWY` coordinate), and $\mathcal{J}$ be the column index (`RAWX` coordinate). Then

   $$\mathcal{I} = \mathrm{search}(\texttt{RAWY} \leq \texttt{RAWY}_n) \tag{6}$$
   $$\mathcal{J} = \mathrm{search}(\texttt{RAWX} \leq \texttt{RAWX}_n) \tag{7}$$

   In words, this means *"Find the greatest index in the `RAW` grid such that the grid's value there is less than or equal to the event's `RAW` coordinate."*

8. Compute the new PI value and write to the output event file:

   $$PI_n = \texttt{GAINMAP}_{\mathcal{IJ}0} + \texttt{GAINMAP}'_{\mathcal{IJ}1} \times D_n \tag{8}$$

The result may contain non-physical values $PI < 0$ and $PI = NaN$. These represent less than 0.5% of the events and should be set to 0.

Values of $PI > 1023$ should be set to 1023.

The data written to the FITS file should be of integer type.

3.1 Interface Changes to `hrc_process_events`

The event processing program, `hrc_process_events`, requires no interface changes to support the new time-dependent gain correction. Instead, the code will detect the type of calibration file, if explicitly named via the `gainfile` parameter, and then implement the proper algorithm.

v1.3 update: no par changes now. Table and "Special Logic" deleted.

Downstream Contingencies: The use of `tgain` in `hrc_process_events` is important for proper use of event filtering in `tgextract`. If the gain file name is of type, "`tgain`", then the new filter should be used.

v1.3 update: removed params, warning. Added comment on filtering.

The standard recommendation for filtering HRC events is to exclude $PHA = 255$. This will no longer be necessary.

4 Spectral Filtering

The computation of PI is the first step in LETGS background reduction. A filter on coordinates (tg_mlam, PI) must be applied before binning into a spectrum. We define a new CALDB file which defines a polygonal filter region appropriate for filtering HRC-S`tgain`-corrected events. [3]

4.1 File Structure: LETGS Tgain Region Filter

4.1.1 File Names

The CALDB type for time dependent gain corrected events filter is `pireg_tgain`. File names will be of the form

    letgD1999-07-22pireg_tgain_N$nnnn$.fits

in which $nnnn$ is a 4-digit version counter.

4.1.2 HDU Components

The following table describes the file structure by Header-Data Unit number, type, extension name, content, and HDU classes. An asterisk (*) denotes the principal HDU.

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[3]This is similar to the current user-option to apply a (tg_lam, PI) filter which offers mild background reduction. The `tgmask2` files are in the CALDB, but are not applied during pipeline processing. There are made available for application at the user's discretion.

HDU	HDU	EXTNAME	EXTVER	CONTENT	HDUCLASS	Description
0	PRIMARY	N/A	N/A	N/A	N/A	NULL
1 (*)	BINTABLE	REGION	1	TGPIMASK2	ASC TG	Binary table extension holding a region for filtering HRC-S tgain-corrected events before binning LETGS spectra.

4.1.3 Columns and Coordinate Systems

Columns for LETGS tgain-corrected events filter are given in the following table.
Column ordering in the FITS table is arbitrary.

TTYPE	TUNIT	TFORM	TLMIN	TLMAX	Description
SHAPE	1	nA	N/A	N/A	Region shape designation, of value "POLYGON".
TG_MLAM	angstrom	nD	N/A	N/A	Array of grating event file tg_mlam coordinates, of length n.
PI	channel	nD	0	N/A	Array of HRC-S event file tgain-corrected coordinates, of length n, which must correspond to the tg_mlam length.

Other region-specific columns are not required for the POLYGON shape.

4.1.4 Relevant Header Keywords

Relevant keywords are:

INSTRUME: The only allowed value is HRC.

DETNAM: The only allowed value is HRC-S.

MFORM1: is a CXC datamodel column association; the only allowed value is 'TG_MLAM,PI'.

MTYPE1: is a CXC datamodel column association name; the only allowed value is 'mlam_pi'.

CIPn: For configuration control, this keyword (or list if n is present to enumerate several keywords) names the input CIP, or Calibration Interface Product files delivered by calibration and formatted into this ARD. For example, the original calibration prototype file was called spimfilter.spec.

CIPREF: For configuration control, this keyword cites a relevant calibration memo (or preferably, URL). The origninal calibration prototype was provided at

$$http : //cxc.harvard.edu/contrib/letg/GainFilter/.$$

4.1.5 `CALDB` **Keywords**

The required `CALDB` keywords are as follows:

```
CCLS0001  'BCF'
CDTP0001  'DATA'
CCNM0001  'TGPIMASK2'
CBD20001  'GRATING(LETG)'
CBD30001  'GRATTYPE(LEG)'
CVSD0001  1999-07-22T00:00:00
CVST0001  00:00:00
CDES0001  'LETGS m*lambda - PI region filter'
```

4.2 Size and File Number Estimates

There will be one to a few LETGS region filter files which will cover the time of the mission. Each has a size of about 10 kB.

4.3 Filter Application

The filter can be applied as a data-model virtual file specification on the input to `tgextract` or by applying the filter with `dmcopy` to create an actual filtered event file, as in these examples:

```
tgextract
    infile=evt2"[(tg_mlam,pi)=region(letgD1999-07-22pireg_tgain_N0001.fits)]"
    outfile=pha2
dmcopy
    infile=evt2"[(tg_mlam,pi)=region(letgD1999-07-22pireg_tgain_N0001.fits)]"
    outfile=evt2_filtered
```

4.4 Caveats

Effective area vs. order has not been re-calibrated to include the effects of the PI filter for high orders. The filter has been optimized for first orders; it will clip the PI distributions for different the different energies at a given location by different amounts. The magnitude of the effect is, however, presumed to be very small compared with other calibration uncertainties (TBR).

A   Prototype & Tests

A prototype was written in ISIS to read the calibration file, an events file, and compute the TGAIN-corrected PI. This was compared to the output of the Calibration Group scripts. The latter scripts' output was also run through spectral extraction with application of the new filter file. The following plots show some of the characteristics of the calibration data and of resulting events and spectra for standard processing and for TGAIN-corrected data.
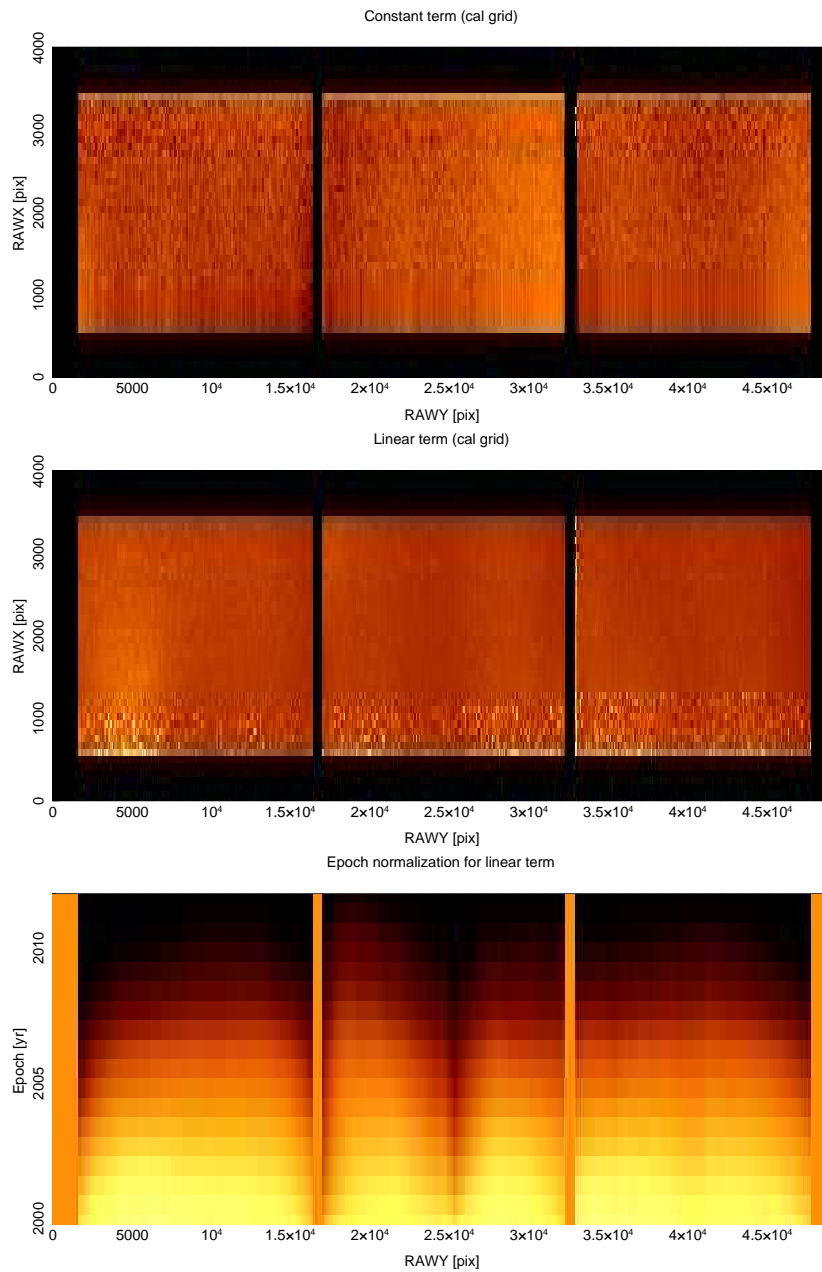
Figure 1: Tgain-correction coefficient maps. Top: constant term; Middle: linear term; Bottom: time-dependent factor.
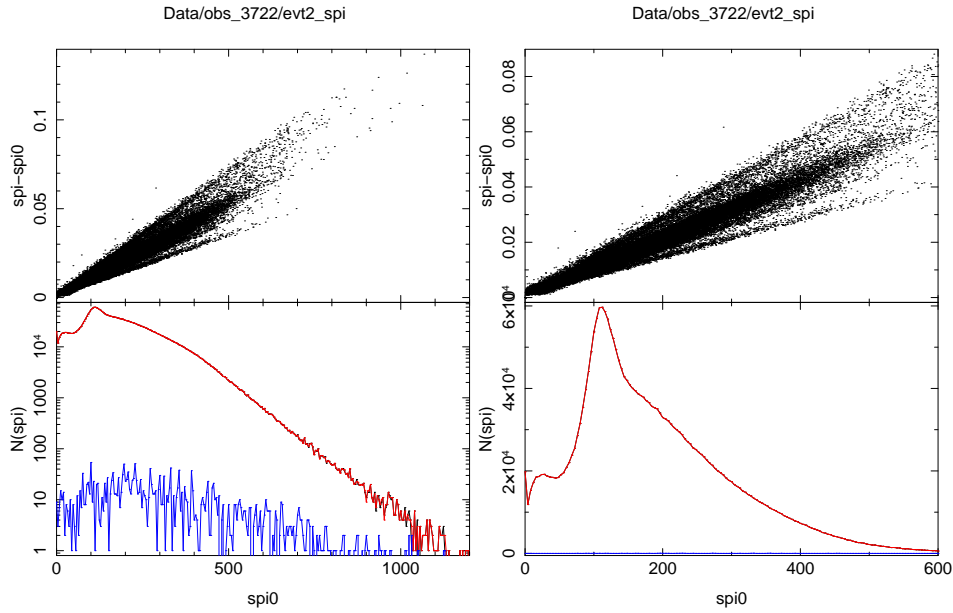
Figure 2: PI residuals, compared to Cal script output, $spi0$. Top panels: PI residuals by event. Bottom panels: PI histograms and difference. The right-hand plot has a linearly scaled histogram (lower panels) and a smaller $spi0$ range. Filter cutoffs range from $PI \sim 120 - 300$ (see Figure 3).
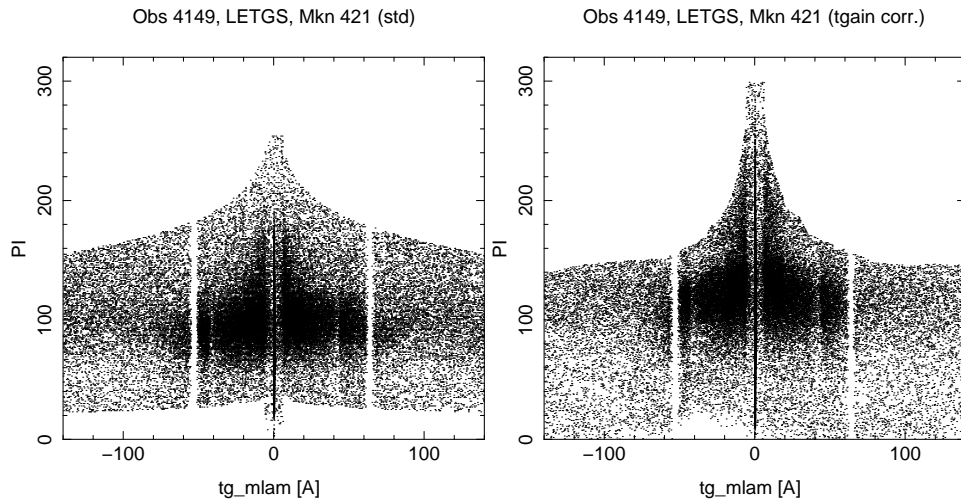

Figure 3: The PI-region filters as a function of `tg_mlam`. Left: current filter. Right: TGAIN-PI filter. The events are shown for ObsID 4149, Mkn 421.
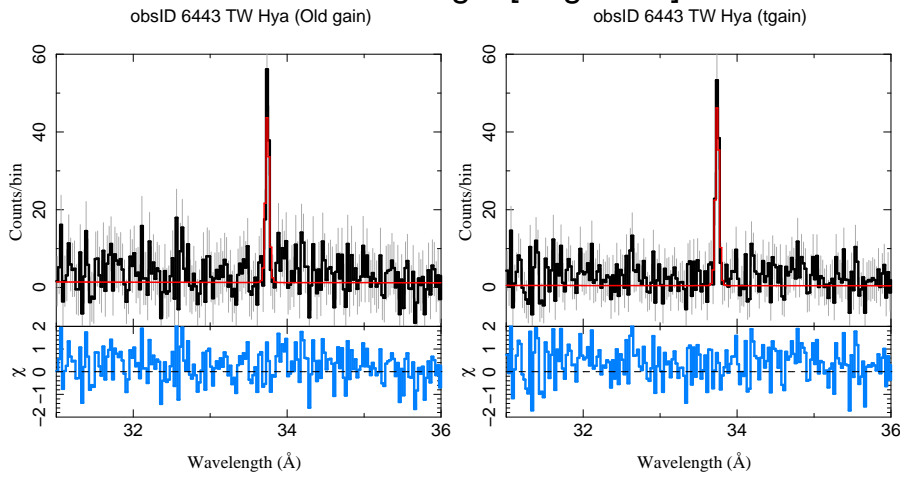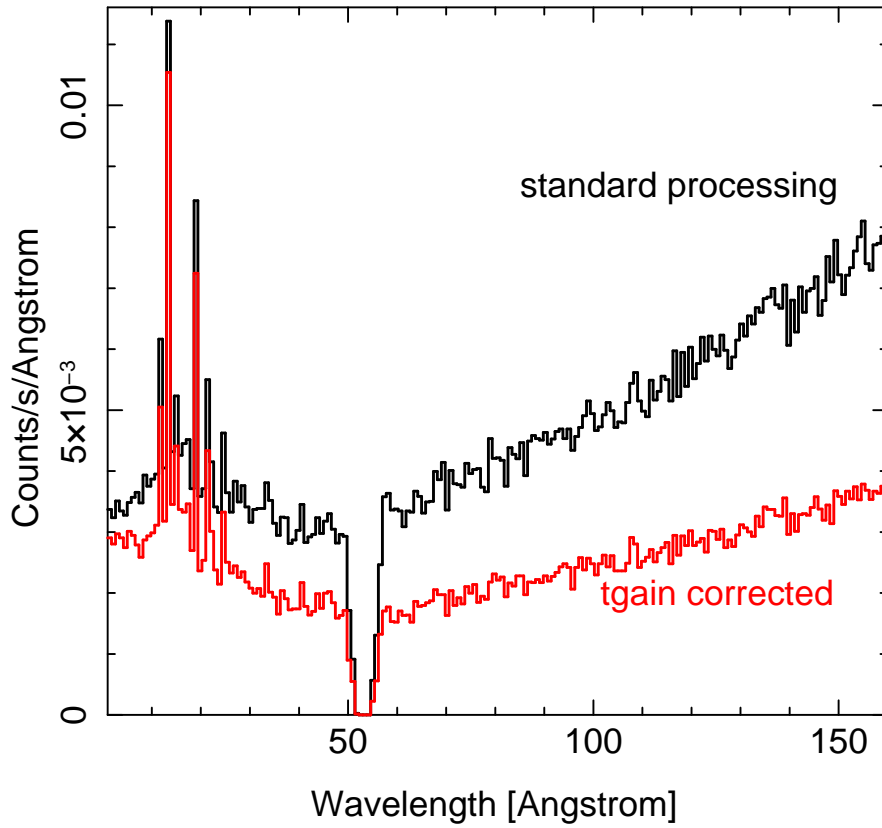
Figure 4: TW Hya, ObsID 6443. Top: comparison of the count rate density for -1st order for standard processing (black) and for tgain-corrected data (red), binned to 0.8 A/bin. Bottom: detail of the C VI 33.7 Å line net counts for standard processing (left) and TGAIN-corrected (right).
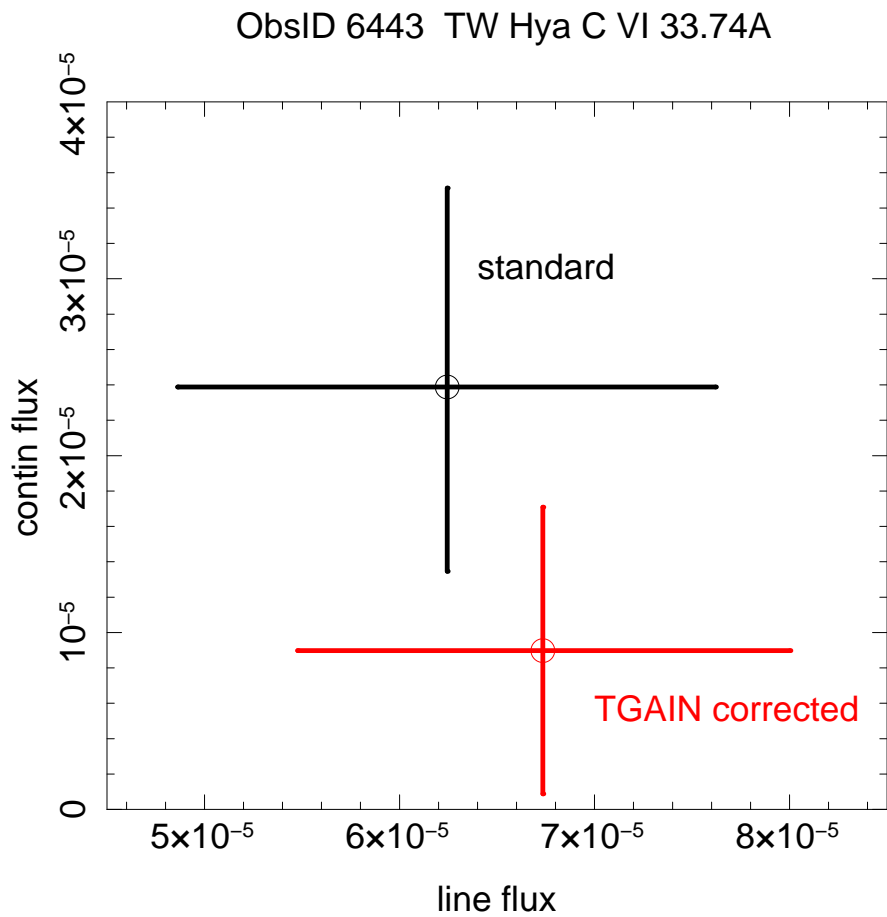
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Figure 5: TW Hya, ObsID 6443; Comparison of fits of a constant plus Gaussian function to the C VI 33.7 Å line region shown in Figure 4. The x-axis is the line flux, the y-axis is the continuum flux density. The best fit and 90% confidence intervals are shown for standard processing (black) and for TGAIN-corrected data (red). Error-bars are slightly smaller for the TGAIN corrected data.
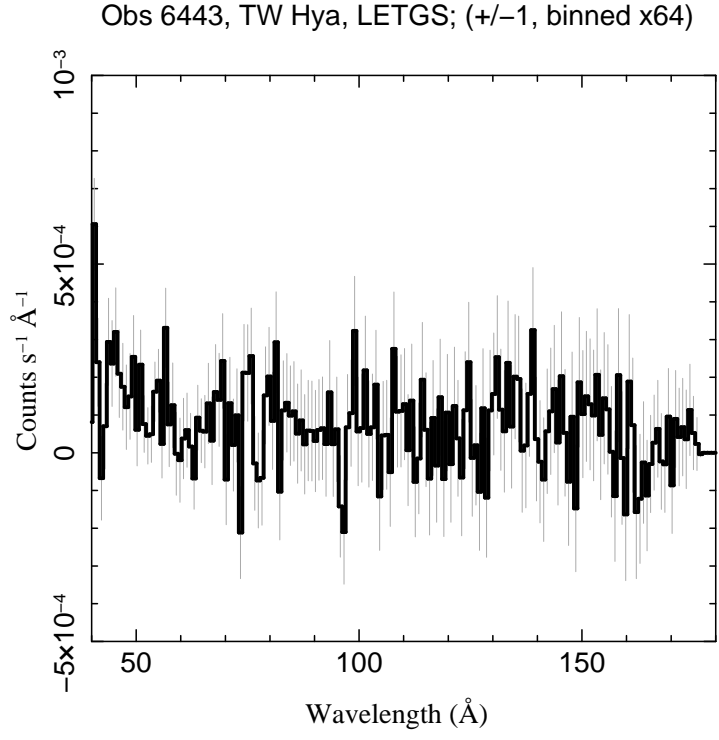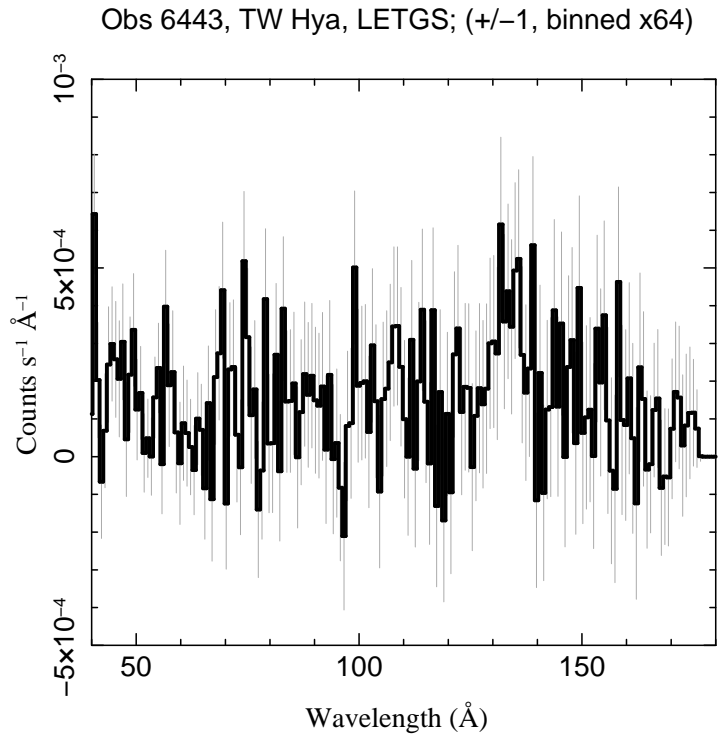
Figure 6: TW Hya, ObsID 6443; Comparison of the continuum net count rate density binned to 0.08 Å/bin for standard processing (top), and TGAIN-corrected data (bottom) in a spectral range where background dominates. Reduction of the noise is apparent in the TGAIN-corrected extraction.