An Improved and Time-Dependent HRC-S Gain Map

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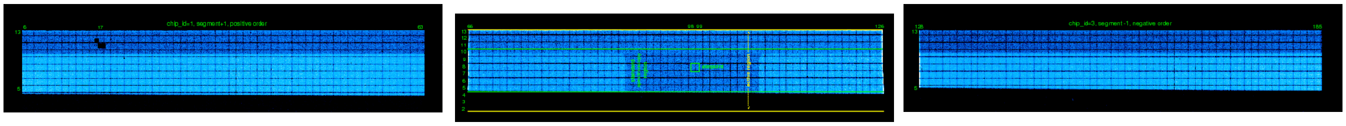

Fig. 1. Intensity plots for the C-K flat field data in raw coordinates. U (x) is the short axis, V (y) is the long axis. Numbers along the edges denote tap numbers (CRSV, CRSU). Lab data cover nearly all of the standard LETG spectroscopy region (CRSU=5:10) except for part of CRSU=5 on Chip3. The darker "T" region has fewer counts because of extra absorption by thicker Al on the uv/ion shield. The two rectangular excisions on Chip1 are for hotspots that do not appear on-orbit.

Abstract

The first HRC-S gain map was completed in 2000, primarily for use in pulse-height filtering of LETG/HRC-S data. Since that time the detector gain, which was mapped using mean PHA values on a 1/2-tap grid, has dropped significantly, with a roughly 20% drop occurring within one year of launch followed by a slow but steady decline. We describe the ongoing development of a newe time-dependent gain map derived from analysis of laboratory and flight data using scaled SUMAMPS values on a 1/3-tap grid. The new gain map will forms the basis of a new pulse-height filter which will provide improved background reduction.

Introduction

Although its energy resolution is insufficient for non-dispersive spectroscopy, the HRC-S does have enough resolution to permit useful discrimination between X-ray and particle-induced events. Background reductions of 50-70% with <1% loss of valid X-ray events can be obtained in LETG spectra using the current HRC-S gain map and associated pulse-height filter.

The current gain map is based on mean PHA values obtained from pre-flight laboratory flat-field calibration of the HRC-S at up to 8 energies, B-K (183 eV0 through Fe-K (~6400 eV). Those results were then scaled to approximately match the gains determined from analysis of flight data collected during the first six months of Chandra's operation. The in-flight gain was determined to be ~14% higher than the lab gain, but since then the gain has been observed to decrease by 20-25%, bringing it quite close to the lab gain. Although the conservative "light" pulse-height filter developed in concert with the 2000 gain map is still valid and does not produce any adverse effects when applied to even the most recent LETG/HRC-S data, corrections for the gain drop will permit more effective filtering if used with an improved gain map.

The new gain map currently under development will have several advantages over the old:

- Use of scaled SUMAMPS values instead of PHA
- A finer spatial grid (1/3-tap vs 1/2-tap)
- Gain corrections as a function of detector position and event amplitude
- Corrections for time dependence

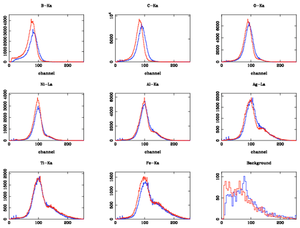

Fig. 2. Comparison of PHA and SAMP pulse height distributions at several photon energies. These data are selected from subtaps with similar gains, revealing the intrinsic energy resolution of the HRC-S.

Spatial Gain Variations and SAMP vs PHA

Currently, PHA (Pulse Height Amplitude) is used as the primary measure of an event's signal strength, with PI (Pulse-height Invariant) equal to PHA divided by the local detector gain as specified in the gain map. The PHA signal is the analog-sum of all the HRC position charge-amplifier signals (128 amplifiers, 64 per axis). Since nearly all of the charge produced by the MCP during an X-ray event is concentrated in a small spot, the event signal strength can also be measured using the signals for event position determination: AU1, AU2, AU3 (for U-axis positions) and AV1-3 (for the V axis). The sum of all six is recorded in Level 1 event files in the SUMAMPS column. The AMP_SF value, ranging from 1 to 3, reflects the amplifier gain setting for the event, which is automatically switched by the signal-processing hardware based on the size of the MCP signal.

One can therefore calculate an alternative pulse height amplitude from SUMAMPS with appropriate scaling. We have defined this alternative measure as "scaled SUMAMPS" =SAMP= [SUMAMPS * $2^{(AMP\_SF-1)}$]/128, which yields a value typically ~10% smaller than PHA. As seen in Figure 2, SAMP and PHA spectra are very similar and the same analysis methods can be used on both parameters. Although slightly less electric charge is measured by SAMP than by PHA, there seems to a large reduction in the amount of signal "noise," particularly near tap centers (see Figures 3 and 4).

We have therefore adopted SAMP as the basis for the new gain map analysis, and calculate mean and median SAMP values for each subtap (3x3 per tap). At this point it is not clear whether means or medians are the best choice for our metric. Results are usually very similar and we show plots using both.

As seen in Figure 3, mean values of SAMP show a much smoother variation than those of PHA, making analysis easier and also allowing use of coarser spatial sampling when necessary to obtain adequate statistics, such as for data from thick-filter regions on the outer plates (1 and 3); subtaps in those regions (see dimmer areas in Fig. 1) have only ~25 counts for B data, versus a typical value of 400 per subtap for most other energies and regions.

Figure 4 is an illustration of the same results but focusing on a single strip along the entire detector, specifically the CRSU=8 tap, upon which most of the LETG-dispersed photons fall.

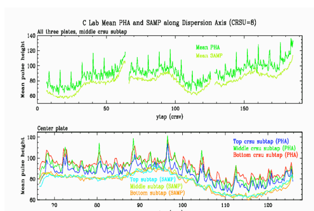

Fig. 4. Comparison of mean PHA and SAMP values from C lab data.

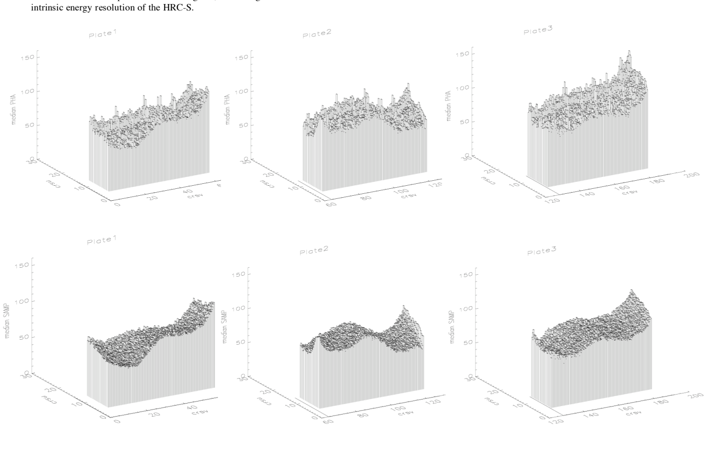

Fig. 3. Surface plots of PHA and SAMP mean values for the C-K flat field data, with 1/3-tap grid. Statistical uncertainties are less than 1 channel.

Energy Dependent Gain Variations

As seen in Figure 5, the spatial behavior of median (and mean) SAMP values is very similar for different X-ray energies, and to first order a simple gain map populated by constants (as is done for the exiting gain map) can be used to characterize the HRC-S gain. As shown in Figure 6, which plots the ratio of median (and mean) SAMP ratios for Al-K and C-K X-rays, higher-order corrections are needed to fully parameterize the detector gain as a function of both position and photon energy.

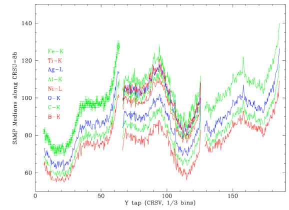

Fig. 5. Median SAMP values along the middle-third tap of CRSU=8, Typical uncertainties are shown for Al-K data on Plate1. Note that Ni_l, Ag-L, Ti-K, and Fe-K data are only available on the central plate.

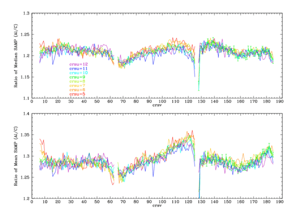

Fig. 6. Ratios of median (and mean) SAMP values from C-K and Al-K data as a function of position (CRSV and CRSU). If the detector gain had no energy dependence the traces would all be flat and lie on top of one another. The observed deviations from flatness do not correlate with absolute gain or any other identifiable parameter.

In order to obtain consistent Pulse-height Invariant (PI) values across the entire detector we must therefore model the gain's energy dependence. In the top panel of Figure 7 we plot mean SAMP valus at six locations on Plate 2 with widely varying gains for 8 X-ray energies. In the bottom panel the data are normalized to the local average of the mean SAMP values for B-K, C-K, O-K, and Al-K. After applying this first-order gain correction the data points at a given energy cluster fairly closely together but with some scatter due to the energy dependent effects seen in Figure 6.

Note that the steepness of the gain's energy dependence seen in Figure 6 is reflected in Figure 7, e.g., the blue points in Figure 7 have the largest slope and represent data fro CRSV=115 (see Fig. 6) where energy-dependent gain effects are relatively large. The roughly proportional relationship between SAMP and log(Energy) means that we can easily model the gain energy dependence. Flight data will be sampled to obtain results at lower energies--the LETG range extends to below 70 eV--and guide model extrapolations.

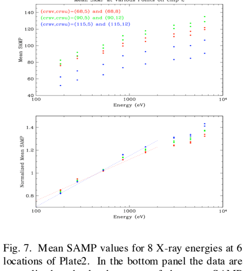

Fig. 7. Mean SAMP values for 8 X-ray energies at 6 locations of Plate2. In the bottom panel the data are normalized to the local average of the mean SAMP values for B, C, O, and Al X-rays. Statistical errors are of order the size of the data points. Straight lines through the blue and red sets of B,O,Al points are drawn to guide the eye and emphasize differences in gain steepness at different locations on the detector.

Time Dependence

Detector gain is monitored with regular LETG/HRC-S observations of calibration targets such as HZ43 (twice a year for low energies) and PKS 2155-304 (for higher energies). A relatively rapid drop in gain was observed early in the mission but the rate of change is currently only 1-2% per year (see Figure 8).

All gain-monitoring data will be reanalyzed based on SAMP values instead of PHA, using more careful corrections for background contamination, and also taking into account Chandra's aimpoint drift, which slightly shift the relationship between detector position and LETG wavelength. The measured gain changes will be applied to the gain map derived from lab data, producing a set of epoch-appropriate (yearly?) gain maps.

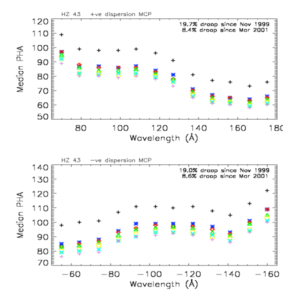

Fig. 8. Median PHA values from wavelength intervals of the HZ43 spectrum observed by LETG/HRC-S. These and other more recent data will be (re)analyzed to parameterize the HRC-S gain change as a function of time.

Background Filtering

The ultimate objective of producing an improved gain map is to enable better filtering of LETG/HRC-S data. The basis of that filtering is the difference in pulse height distributions for X-ray and particle events. As seen in Figure 9, a large fraction of background events have pulse heights larger than the ~largest amplitude X-ray events, particularly for low-energy X-rays.

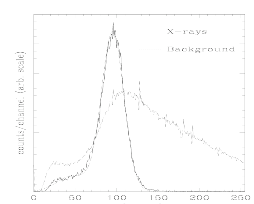

Fig. 9. Mean PHA values for ~150 eV photons and on-orbit background, taken from detector regions with similar gains.

After applying a gain map that converts PHA (SAMP in the new map) to PI, event filtering based on PI and dispersed photon wavelength removes events with PI above (or below) a specified threshold, removing background events with minimal loss of valid X-ray events. The effectiveness of the current PI-TG_LAM filter is shown in Figure 10. The "light" filter removes between 1/2 and 2/3 of the background with less than 1% loss of X-ray events, but more aggressive filtering may discard an unacceptably large fraction of X-ray events at a few locations mostly because of PHA "noisiness" and the lack of energy-dependent gain corrections. The new gain map, based on better behaved SAMP values and with higher-fidelity gain corrections, will produce more consistent PI values and allow more aggressive filtering with a reliable level of X-ray event loss.

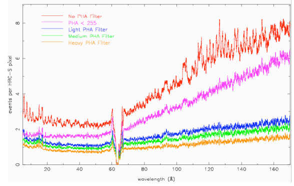

Fig. 10. Background reduction from application of existing LETG/HRC-S pulse height filters.