To: ACIS Team
From: Catherine Grant
Subject: Preliminary Sacrificial Charge Correction
Date: 19 April 2002

This memo describes preliminary work on correcting individual event pulseheights based on their sacrificial charge history and is excerpted from a poster presented at the April 2002 HEAD meeting entitled, "Sacrificial Charge and the Spectral Resolution Performance of ACIS CCDs".

1   Sacrificial Charge

Measured CTI is a function of fluence or, more specifically, the amount of charge deposited on the CCD. As the fluence increases, traps filled by one charge packet may remain filled as a second charge packet is transferred through the pixel. The second charge packet sees fewer unoccupied traps as a result of the previous "sacrificial charge" and loses less charge then it would have otherwise.

Since each X-ray event sees traps with different charge histories, the measured pulseheight for each event can be substantially higher or lower than the average. The importance of sacrificial charge to the overall performance is determined by the emission time constants of the charge traps and the frequency of sacrificial charge deposition. During a typical calibration source run, an average of 2% of the pixels have more than 40 ADU of charge - much of that due to cosmic rays. On average an X-ray event will encounter sacrificial charge of at least this magnitude every 60 rows as it is transfered to the framestore. One of the ACIS traps has a time constant similar to the average time between sacrificial charge events ($\sim$ 2 msec = 50 rows), so the traps encountered by each event can be in a wide range of occupancy states, which is a source of spectral resolution degradation.

Figure 1 illustrates how detrapping time constants and sacrificial charge frequency interact. The idealized input charge distribution fills the charge traps every 200 transfer pixels. The charge is drained away exponentially with a time constant of 100 μsec (blue), 1 msec (green) or 1 sec (red). The millisecond trap spends much of the time in intermediate states, while the shortest and longest traps are either empty or full.

2   CTI Correction

Since the charge loss process can be modeled, it is possible to apply a post-facto correction algorithm to replace the lost charge and recover some of the detector's spectral resolution. Townsley et al. (2000, ApJ, 532, L139) describe a CTI correction algorithm in which a position and pulseheight dependent correction is made to each pixel in the event island. Their model also accounts for
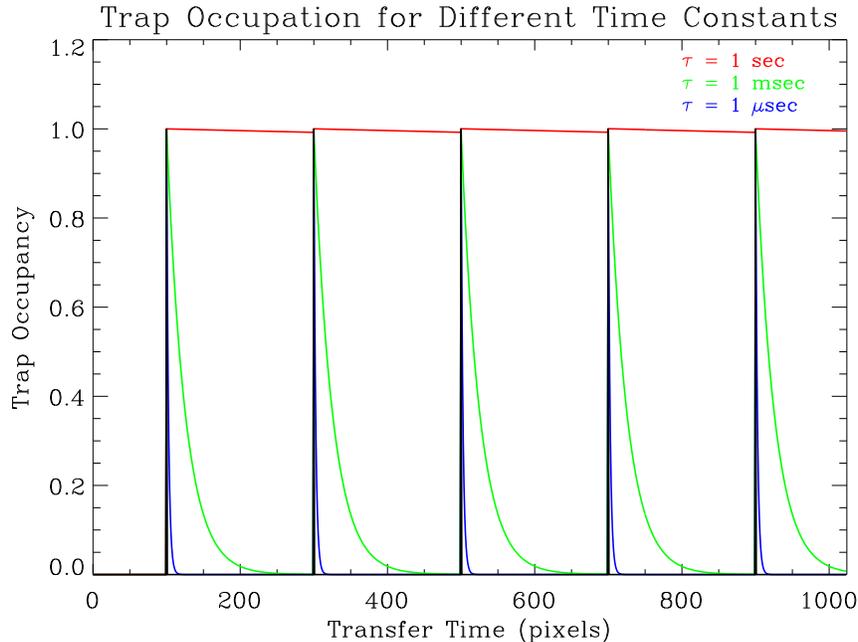
Figure 1:

sacrificial charge shielding and charge trailing within the event itself. A similar but not identical algorithm is being implemented by the Chandra X-ray Center as part of `acis_process_events`. Charge loss in this algorithm is parameterized as a power law function of energy with a power law index, α, close to 0.5. CTI correction removes the position dependence of pulseheight and provides substantial improvement in spectral resolution. While a CTI corrector can be calibrated to match charge loss induced by differing global levels of sacrificial charge, the spectral resolution degradation caused by sacrificial charge remains.

3   Data

Because most of the sacrificial charge deposited on the CCD is from cosmic rays that are rejected by on-board event processing, standard ACIS event lists are insufficient for this study and raw data are required. Since May 2001, ACIS has periodically been taking External Calibration Source data in a special telemetry format that packs raw data such that many consecutive data frames can be telemetered (Primary spectral features are Al-K at 1.5 keV, Ti-Kα at 4.5 keV and Mn-Kα at 5.9 keV). Only a 16-column wide strip of I3 node 3 is telemetered. The data used in this study represent approximately 200 ksec taken over 10 months immediately before and after radiation belt passages. The focal plane temperature was -120C. The raw frames were processed to select events, much like on-board, and to record the distance and pulseheight to each of the precursor charges for each event. Only precursors that have more charge than any preceding precursors are included.

4   Sacrificial Charge Correction

We are attempting to develop algorithms to correct X-ray event pulseheights based on their sacrificial charge history. For each X-ray event X, we define Z_X, which represents the sacrificial charge history of the event as an equivalent difference in transfer distance induced by the presence of sacrificial charge.

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$$Z_X = \sum_{i=1}^{N} \left[\left(\frac{p_i}{p_X} \right)^{\alpha} - \left(\frac{p_{i-1}}{p_X} \right)^{\alpha} \right] (y_X - d_i) \, e^{-d_i/\tau}$$

where,

(p_X, y_X)	are the pulseheight and CHIPY of the X-ray event ($p_0 \equiv 0$)
(p_i, d_i)	are the pulseheight and distance to precursor charge i
	(if $p_i > p_X$ then $p_i = p_X$)
α	is a power law index such that p^{α} is proportional to the volume occupied
	by charge p ($\alpha \sim 0.5$)
τ	is the time constant of the charge traps expressed in rows
	(1 row = 40 μs, $\tau \sim 25$ rows)

Events with large values of Z are most influenced by sacrificial charge. Figure 2 demonstrates the dependence of pulseheight on Z at 5.9 keV. At high Z, the pulseheight is nearly a linear function of Z, while at very small values of Z the dependence has been modeled as an exponential function. The line is a fit to the data of a linear plus an exponential function. Our preliminary precursor correction uses this function to correct the pulseheight of each event and, as seen in the performance comparison figures, does improve the spectral resolution.
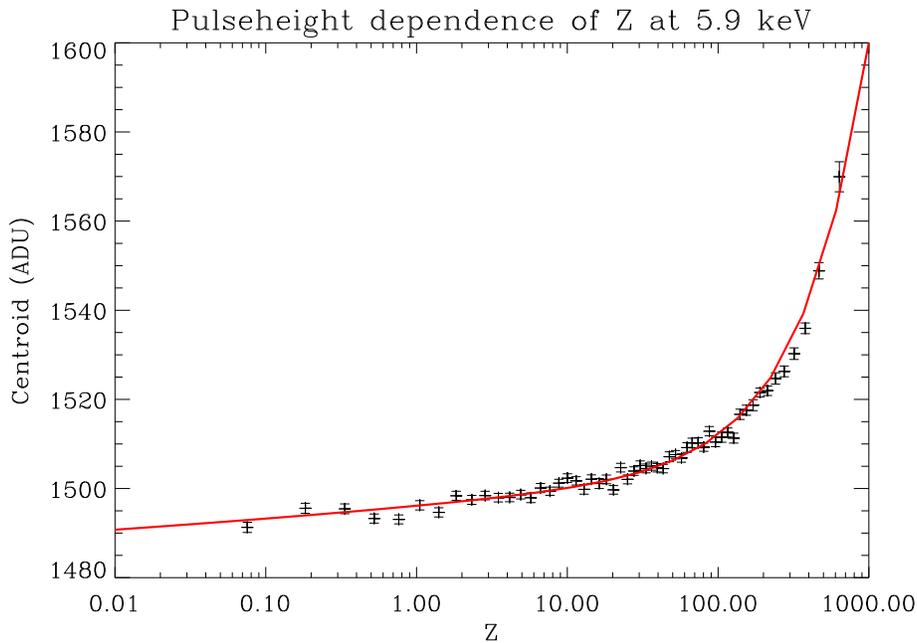

Figure 2:

5   Performance Comparison

Figure 3 shows the pulseheight of each X-ray event versus its row number.

Top panel - Uncorrected data The pulseheight of each spectral line drops with increasing transfer distance. The spectral resolution is also a function of position and degrades with increasing
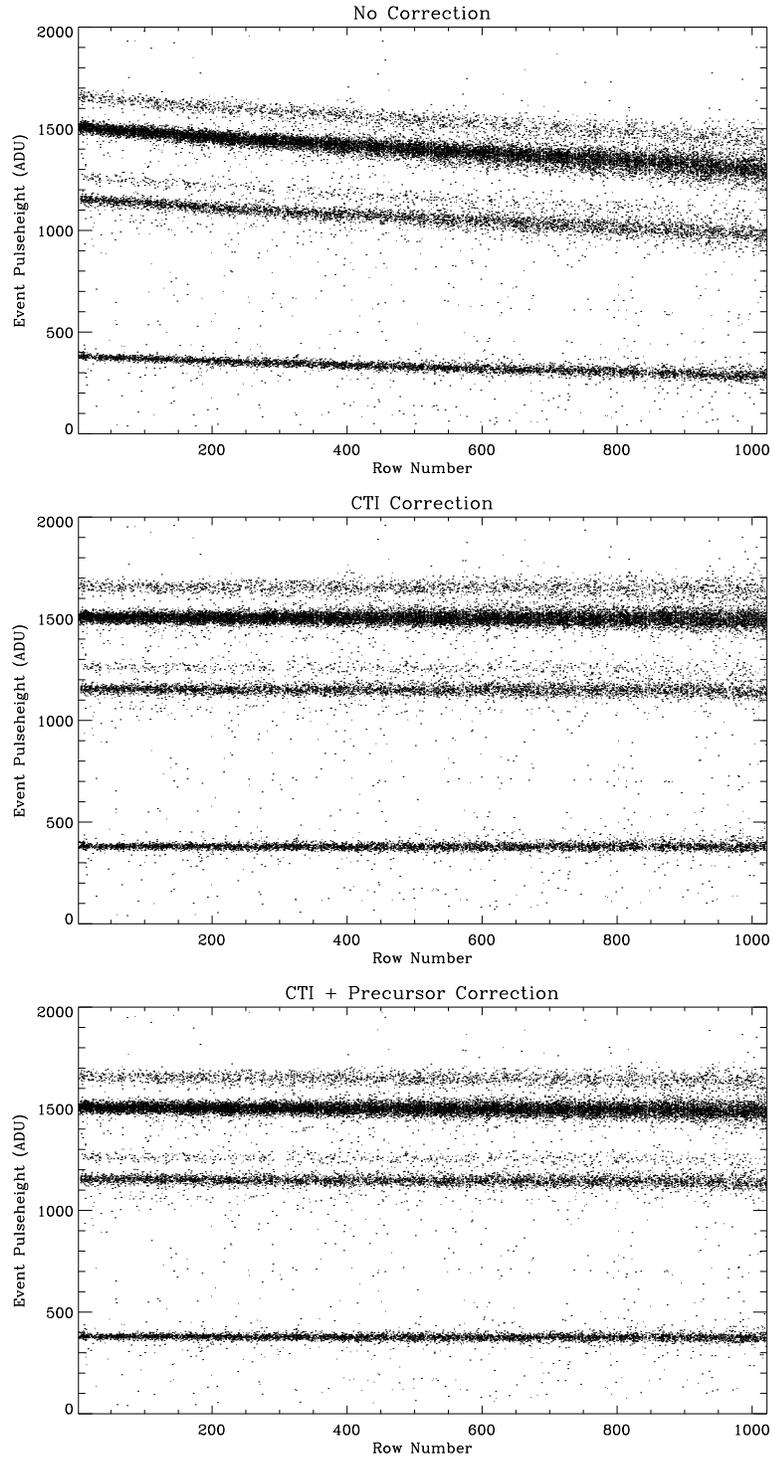
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Figure 3: This figure shows the pulseheight of each X-ray event versus its row number for data that is uncorrected (top), has been corrected for CTI (middle) and has been corrected for CTI and precursor charge (bottom)

transfer distance. Near the framestore, at low row numbers, the performance of the device is essentially the same as before the radiation damage.

Middle panel - CTI corrected data A position and pulseheight dependent correction has been made to each pixel in the event island. The pulseheight of each spectral line is now independent of row. The spectral resolution is improved, although some position dependence remains.

Bottom panel - CTI and precursor corrected data After a standard CTI correction, the event pulseheights have been further corrected for the presence of precursor charge along the transfer direction. This further improves the spectral resolution as a function of row which can best be seen by the better separation of the Mn and Ti K-α and K-β lines.
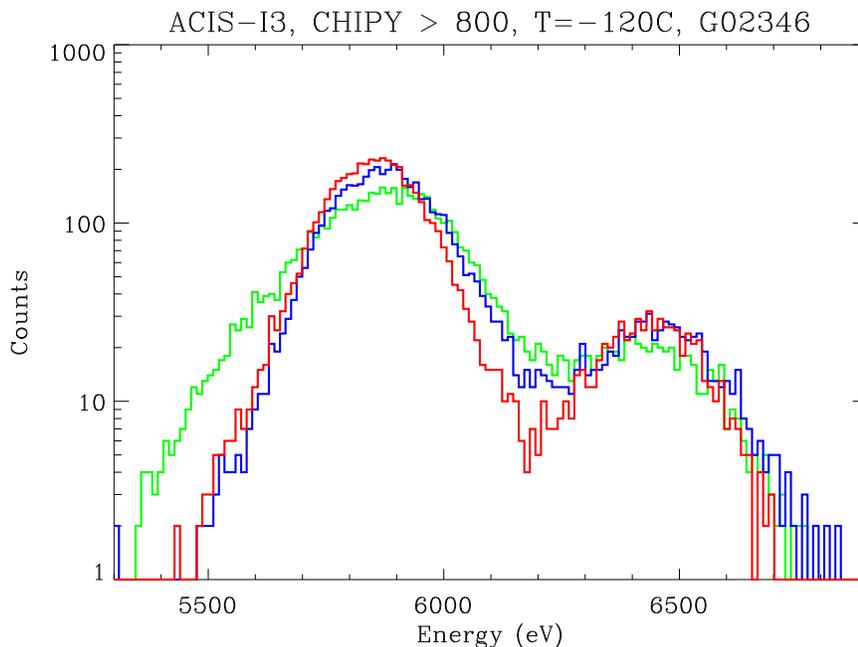

Figure 4: Figure 4 compares the pulseheight spectra at 5.9 keV for data above row 800. **Green - Uncorrected data**, **Blue - CTI corrected data**, **Red - CTI and precursor corrected data**

Figure 4 shows the pulseheight spectra at 5.9 keV for data above row 800 (The I3 aimpoint is at row 964). An offset has been added to the uncorrected pulseheights to account for the position dependent gain. The precursor correction removes the high energy shoulder of the response and clearly improves the separation of the Mn-Kα and Kβ lines.

Figure 5 shows the FWHM of the spectral lines at 5.9 keV and 1.5 keV as a function of row number (The I3 aimpoint is at row 964). Applying the precursor correction as well as the CTI correction improves the FWHM by up to 10% at 5.9 keV and up to 9% at 1.5 keV. At the highest row bin, the FWHM at 5.9 keV improves from 386 ± 6 eV with no corrections, to 277 ± 3 eV with CTI correction alone, and to 247 ± 3 eV with CTI and precursor correction. The improvement is smaller at 1.5 keV, even though one might expect that sacrificial charge would become more important at lower energies.
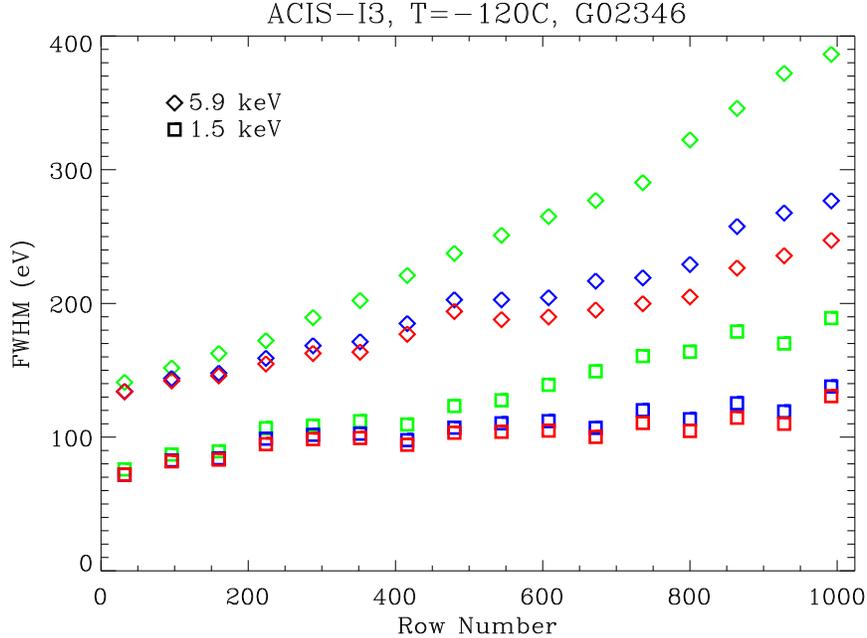
Figure 5: This figure shows the FWHM of the spectral lines at 5.9 keV and 1.5 keV as a function of row number. **Green** - **Uncorrected data**, **Blue** - **CTI corrected data**, **Red** - **CTI and precursor corrected data**

6 Discussion and Future Improvements

While our preliminary sacrificial charge correction algorithm does offer some improved performance, we believe that a more substantial improvement may be possible. It may also prove possible to define a filter in Z which removes the events most affected by sacrificial charge without significantly degrading the detection efficiency. Future improvements may include the following.

- More accurate values for α, the charge volume power law index, and τ, the trap time constant.

- Re-examination of the parameterization of Z.

- Better parameterization of the energy dependence. Current correction is calibrated at 5.9 keV and scaled to apply to all energies; better results at low energies may be possible by a different energy scaling.

- Consideration of sacrificial charge in all three columns of the event island; currently only sacrificial charge in the center column is included.

If a correction or filtering scheme does provide significant performance improvement, its implementation will require changes to the flight software to telemeter additional information about the precursor charge with each event without making a significant impact on telemetry saturation. Such a patch is under development by the ACIS team.