ACIS Memo #177

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To: ACIS Team
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Subject: Time constants of electron traps in the CCD channel.
Part 2: Sacrificial charge analysis
Date: 3 December 1999

We are attempting to characterize traps that may exist in the ACIS FI CCDs as a result of radiation damage. It is these traps which cause CTI and thus reduce the possible spectral resolution of the instrument. One type of trap with an emission time scale of order 100 μsec was found by Gregory Prigozhin (ACIS Memo #176) by examining the amount of charge emitted by the trap into the pixels following an X-ray event. I report on the detection of a second type of trap with a time constant of order milliseconds using a different data analysis method. This technique was first presented by Gendreau, et al. (1995) and considers the time history of the traps seen by an X-ray event. In this model, the amount of charge lost by an X-ray event to traps is dependent on the distance between the event, or beneficiary charge packet (BCP), and a preceding event, or sacrificial charge packet (SCP). The SCP will fill traps as it is transfered to the framestore. If the BCP is transfered through the same pixels before the traps re-emit the captured charge, the BCP will be degraded less than a similar event without a SCP.

The capture time scale of traps is extremely short and will be assumed to be instantaneous. The traps then emit the captured electrons on a time scale of

$$\tau_e = \frac{e^{E_t/kT}}{\sigma_t v_{th} N_c}$$

where E_t is the energy level of the trap below the conduction band, σ_t is the electron capture cross section, v_{th} is the thermal velocity of free electrons and N_c is the effective density of states in the conduction band.

Assuming that each trap holds only one electron, the amount of charge lost from an X-ray event to traps is equal to the number of vacant traps encountered by the charge packet as it is clocked to the framestore. This is given as:

$$N_{loss}(x,d) = N_t d + N_t x(1 - e^{-dc/\tau_e})$$

where d is the distance between the SCP and BCP, x is the distance between the SCP and framestore, N_t is the number density of traps per pixel (assuming the trap capacity is one electron), c is the time it takes to transfer charge from one pixel to the next during the image to framestore transfer (40 μsec for standard ACIS clocking), and τ_e is the emission time constant of the trap and is a function of the focal plane temperature. The first term, $N_t d$ is the charge lost to traps encountered only by the BCP. The second term is the charge lost to traps encountered by both the

BCP and SCP, where $(1 - e^{-dc/\tau})$ is the probability of a trap being vacant when the BCP arrives. The number density of traps per pixel seen by the X-ray event, N_t, is dependent on the size of the charge packet, and thus the energy of the original X-ray photon. For uniform illumination, the average charge lost as a function of d is given as:

$$N_{avg}(d) = N_t d + N_t \frac{(x_{max} + 1)}{2}(1 - e^{-dc/\tau_e})$$

where x_{max} is the maximum allowed value of x for a given d, i.e. $x_{max} = 1024 - d$. This function can be fit to data to determine the parameters N_t and τ_e. If there is more than one trap species, the total charge loss is the sum of the charge loss from each trap species.

Because much of the charge seen on orbit is from cosmic ray events which are not telemetered in faint mode, I am using raw mode data taken on 27 October 1999 of the external calibration source. Events were recognized in a similar manner to the on-board flight software and Mn-Kα events were selected by applying a row-dependent pulseheight filter. 1881 events in grades G02346 were selected as candidate BCPs and are shown in Figure 1. In each frame, the column of the BCP was searched for a preceding charge packet at or above the Mn-Kα threshold. This resulted in 601 events with a SCP and 1280 events without a SCP. The pulseheight of the BCPs versus distance to the SCP is shown in Figure 2. The fact that this relationship appears to have a curvature indicates that a trap must exists with a time scale of order milliseconds.

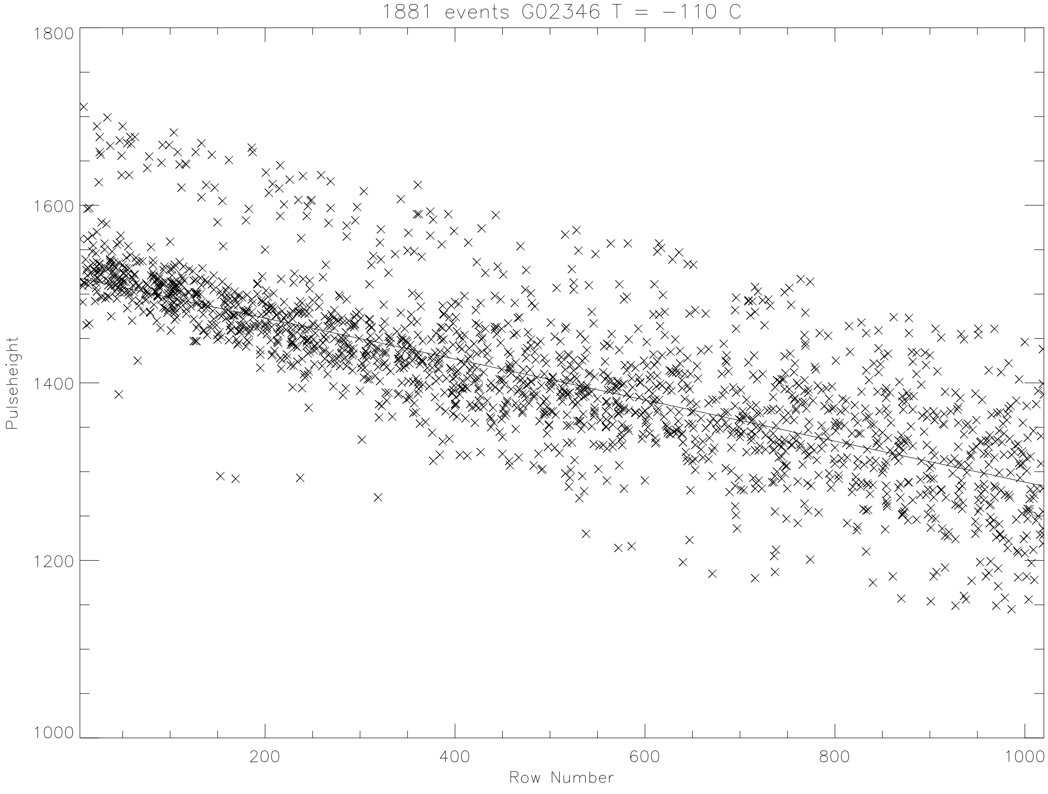

Figure 1: Pulseheight of the summed event island versus row number for the candidate Mn-Kα beneficial charge packets. The solid line is the fitted CTI. The effect of CTI on both the gain and spectral resolution is quite apparent. Some Mn-Kβ events are also being selected, particularly at low row numbers.

The sacrificial charge model described above can be fit to the data to determine the existence and the relative importance of traps with different time scales. I have assumed the existence of a trap with a time constant of 110 μs as determined by Gregory Prigozhin. For a long time scale trap, such as is caused by P-V defects, the time constant is unconstrained by this data and the charge loss is just $N_t d$ since any sacrificial charge will fill all the traps. The results are shown in Table 1 and Figure 3. The long time scale trap density is consistent with zero, so I have also fit the data with only the short and medium length traps. This is consistent with lab data and with the characteristics of the P-V trap which should be frozen out at these temperatures. For comparison I have also fit the data to a single trap, the 110 μs trap, which we know exists. The one trap fit is significantly worse than either fit including a medium time scale trap. The trap density found for the short trap is an underestimate since I am summing the trailing pixel into the event and correcting for some of the short trap charge loss. A trap with a time scale of milliseconds does appear to exist in the flight CCDs. Figure 4 shows the relative importance of each trap as a function of d.

Table 1:

Short trap		Medium trap		Long trap		
τ_e μsec	N_t traps/pixel	τ_e msec	N_t traps/pixel	N_t traps/pixel	χ^2_ν	ν
Three trap model						
110 (fixed)	0.032 ± 0.030	3.6 ± 1.6	0.189 ± 0.030	0.030 ± 0.042	1.88	6
Two trap model						
110 (fixed)	0.044 ± 0.003	4.9 ± 0.5	0.198 ± 0.004	⋯	1.64	7
One trap model						
110 (fixed)	0.212 ± 0.004	⋯	⋯	⋯	7.63	9

We are conducting a search of the literature to find a defect to match the new millisecond trap but have thus far been unsuccessful. Further measurements at different temperatures are being conducted to allow us to measure the energy and cross section of the trap which should aid in identification. We are also investigating using these results to correct X-ray events for the charge loss to traps. A better analysis is forthcoming which will include a more complete treatment of the trap history and the event island.

References

Gendreau, K.C., Prigozhin, G.Y., Huang, R.K., & Bautz, M.W. 1995, IEEE Trans. Electron Devices, 42, p. 1912

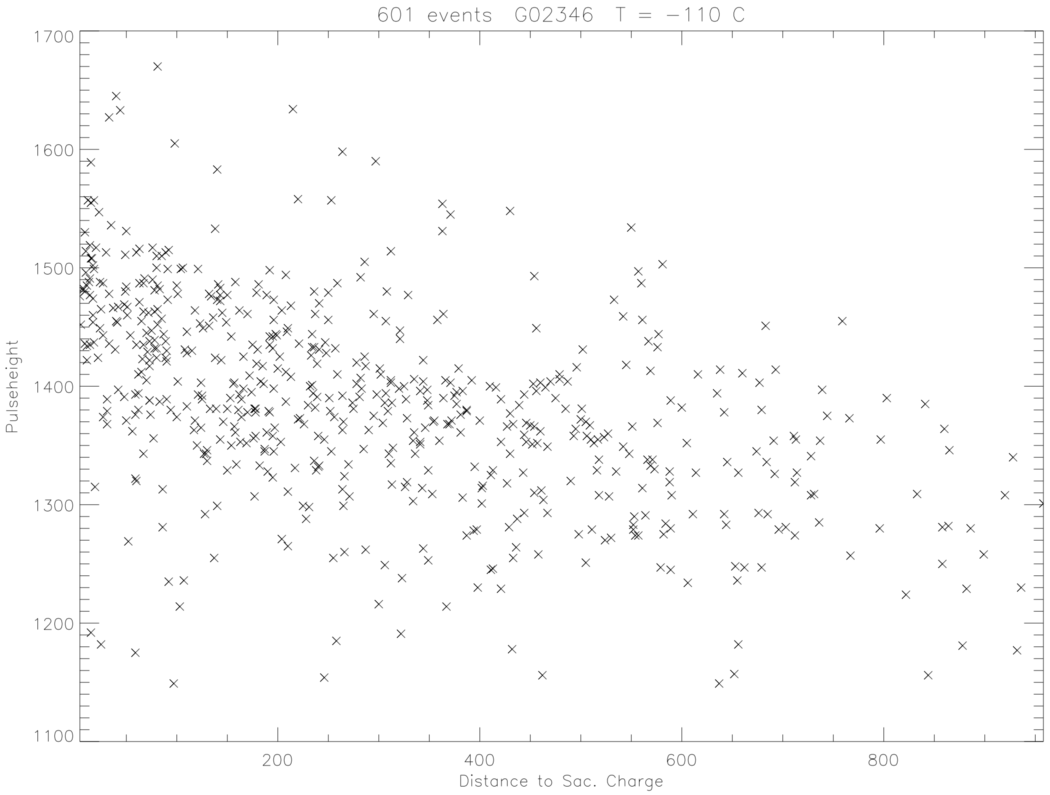

Figure 2: Pulseheight of the summed event island versus distance to the sacrificial charge packet.

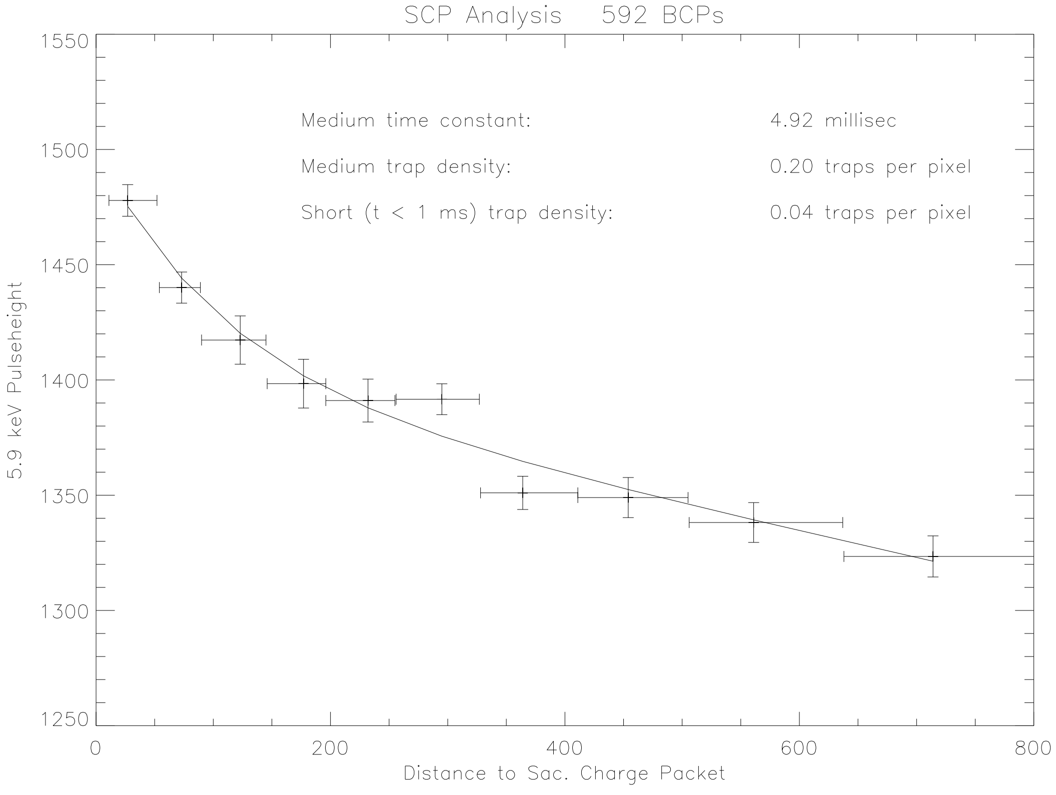

Figure 3: Using sacrificial charge analysis to fit trap parameters. The data from figure 2 excluding events with d $<$ 10 pixels has been adaptively binned into 10 bins of 59 Mn-Kα events each. The line is the trap model.