ACIS Memo # 182
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To: ACIS Team
From: Catherine Grant
Subject: Quantum efficiency of ground irradiated device as a function of row and energy
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This memo presents analysis of the quantum efficiency (QE) of a FI CCD which has suffered radiation damage similar to the ACIS flight devices. A lab CCD (w459c1) was irradiated warm by soft protons at Goddard Space Flight Center along the entire length of node 2. Node 0 was undamaged. Calibration data was then taken in the lab using a number of calibration sources (C-K, O-K, Fe-L, Al-K, Mn-Kα) at -110 and -120 C. A gamma ray source (Co-60) was used to simulate the cosmic ray environment seen by the flight devices. The performance degradation of the damaged portion of the CCD is similar to the degradation of S2. Except where noted, the event lists were created using standard data analysis tools with an event threshold of 38, a split threshold of 13, including only grades G02346. Lab data and initial eventlists are from Steve Kissel.

One way to investigate the affect of CTI on the QE of the ACIS CCDs as a function of incident photon energy and position on the detector is to compare the relative QE of node 2 (radiation damaged) to node 0 (undamaged). An implicit assumption is that the source illumination is flat along the x direction (along a row) so that any residual vertical structure can be removed by comparison between node 0 and node 2. The Fe-L and Al-K sources appear to be offset by 45 pixels in the y-direction, i.e. a histogram of counts versus ccdy for node 2 resembles the same histogram for node 0 with ccdy(node0)-45. I have offset the node 0 Fe-L and Al-K data so that the vertical structure in each quadrant is similar.

Relative QE was calculated using all the counts in the entire spectrum. This includes photons not in the main spectral peak, such as pile-up peaks, K-β peaks, and cosmic rays. The original ground QE calibration used a different method restricted to events within $\pm 3\sigma$ of a Gaussian fit to the main spectral peak. The poor spectral resolution of the damaged region makes this method problematic because features such as K-β and pile-up lines are included within $\pm 3\sigma$ in the damaged region and excluded in the undamaged region.

Figure 1 shows the relative QE of Node 2 to Node 0 as a function of energy over all rows. At lower energies, the QE at the C-K line is substantially degraded by the CTI, while the O-K, Fe-L and Al-K lines are relatively unaffected. This is because for C-K at high row numbers the event threshold of 38 is of order the pulseheight of the spectral line. At higher energies the loss of QE is from grade morphing of valid X-ray events into 'bad' grades, primarily G7.

Figure 2 shows the dependence of QE on row number for each of the spectral lines. The C-K line shows a strong dependence of QE on row number. Below row 400, little QE degradation is seen. By rows 900-1000, the relative QE of node 2 to node 0 has decreased to 40% (-110 C) and 50% (-120 C). The O-K, Fe-L, and Al-K lines show little row dependence of QE. The Mn-Kα line shows a drop of 20% in relative QE to $\sim$ 80% for both temperatures. The leveling off of row-dependent QE at Mn-Kα may indicate a saturation of grade morphing, as grades susceptible to morphing into bad grades are exhausted. These are primarily grade 6 events which morph into grade 7.

Figure 3 demonstrates a second way of examining the decrease of QE at low energies in the damaged node as a function of row number. For this example, the data is grouped into 32 bins of 32 rows each and a Gaussian is fit to the summed pulseheight from G02346 events. The event threshold has been lowered to 13 ADU to study the QE behavior around 38 ADU. Results of Gaussian fits from analysis by Bev LaMarr. The top panels show the peak location (μ) and sigma (σ) from a Gaussian fit to the C-K line as a function of row number at -110 and -120 C. The Gaussian width decreases at the highest row numbers as counts are lost below the 13 ADU threshold. The line centroid drops below the flight event threshold around row 750 (-110 C) and 850 (-120 C).

One can define a critical row number y_{crit} where the decrease in QE from radiation damage becomes significant, i.e. ΔQE $>$ 1%. A Gaussian integrated from μ - 3σ to ∞ includes 99% of the flux. The bottom left panel shows the Gaussian peak minus three sigma ($\mu - 3\sigma$) as a function of row. The event threshold of the flight instrument (38 ADU) is shown as a horizontal line. y_{crit} is $\sim$ 200 at -110 C and $\sim$ 250 at -120 C. The bottom right panel shows the fraction of the integrated counts under the Gaussian that are above 38 ADU. At the top of the CCD, the fraction above 38 ADU is less than 20%. This result differs from Figure 2 because Figure 2 calculates the QE loss from the entire spectrum including piled up counts and therefore underestimates the true loss of QE from CTI. At -110 C, ΔQE $\approx$ 10% at row 450 and 50% at row 750. At -120 C, ΔQE $\approx$ 10% at row 575 and 50% at row 800.

Figure 4 shows the same results for the O-K line. At this energy, very little QE is being lost at the top of the CCD. At -110 C, ΔQE $\approx$ 6% at row 1000. At -120 C, ΔQE $<$ 1% at row 1000.

While these results suggest that lowering the on-board event threshold would improve the low energy quantum efficiency at high row numbers, lowering the event threshold would also admit many more non-X-ray events quickly saturating telemetry. The gain in quantum efficiency would be offset by a loss of observing efficiency as many CCD frames would be dropped by the on-board software and lost.

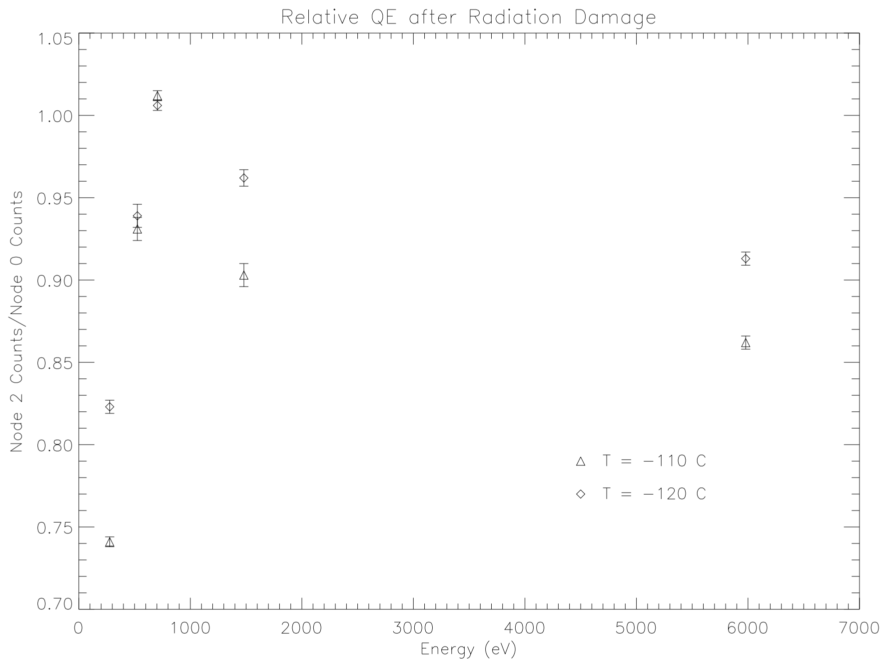

Figure 1: The relative QE of the radiation damaged node to the undamaged node at a temperature of -110 and -120 C.

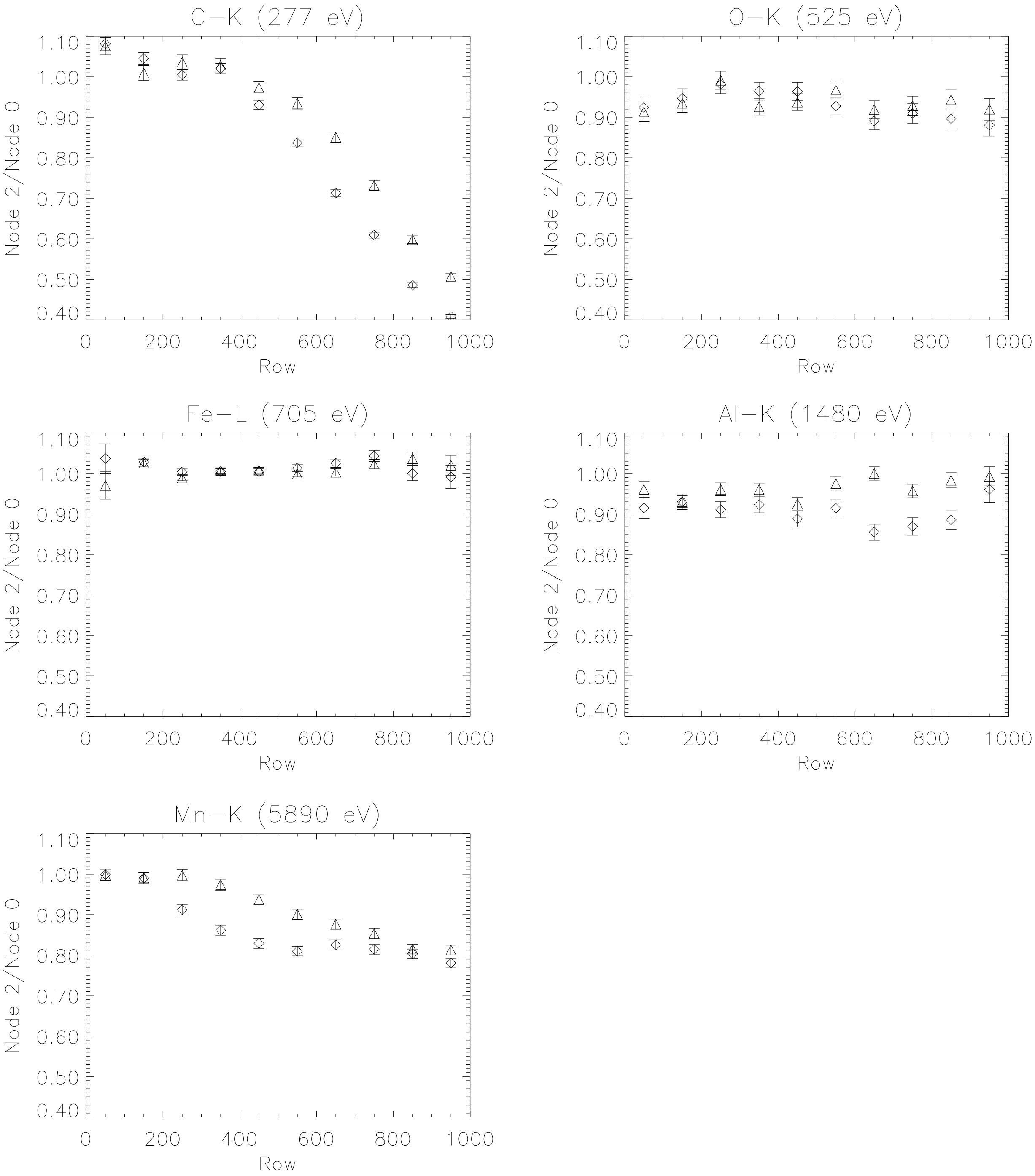

Figure 2: Relative QE as a function of row for each spectral line at -110 C (⋄) and -120 C (△).

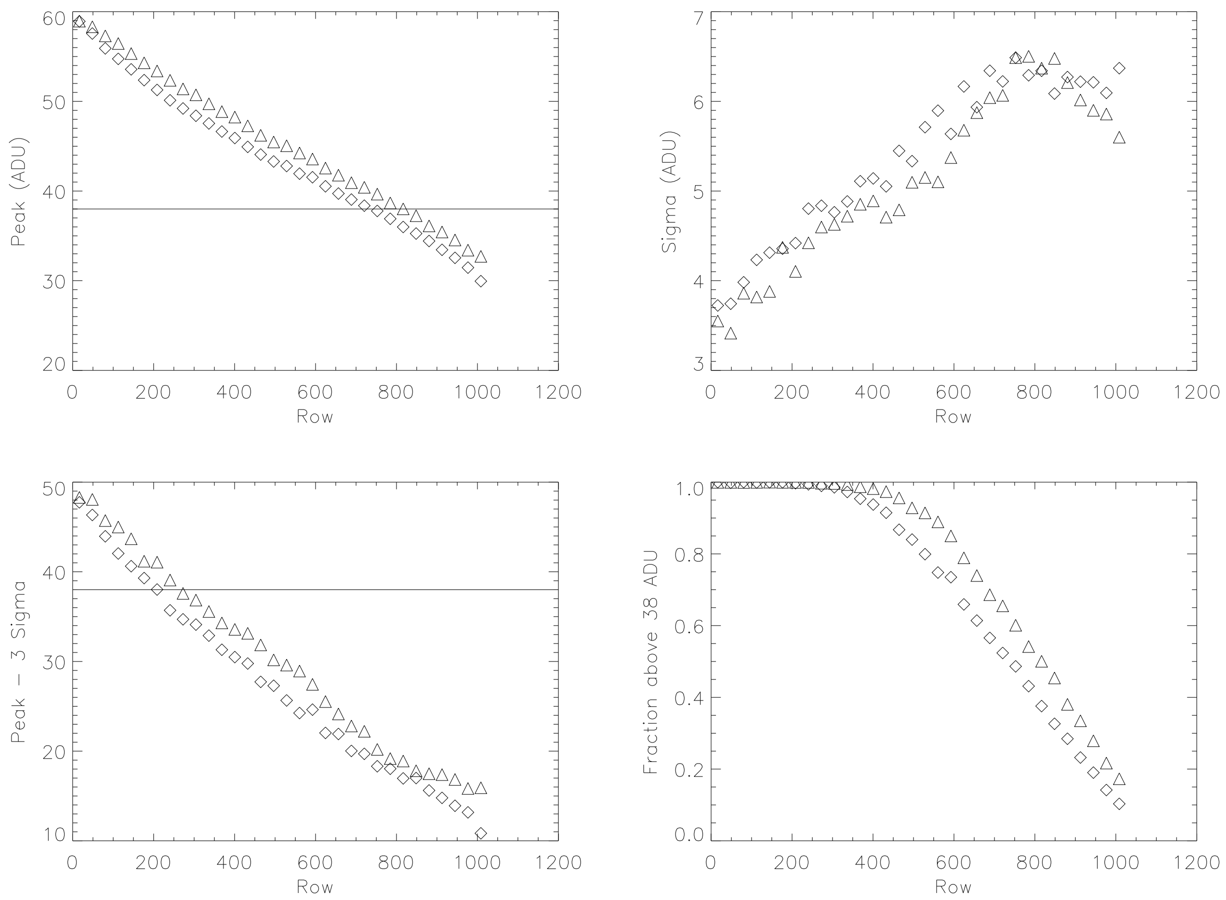

Figure 3: Results of Gaussian fits to the C-K line (277 eV) in the damaged portion of the CCD at -110 C (◇) and -120 C (△). See the text for explanation. The horizontal line indicates the flight instrument event threshold of 38 ADU.

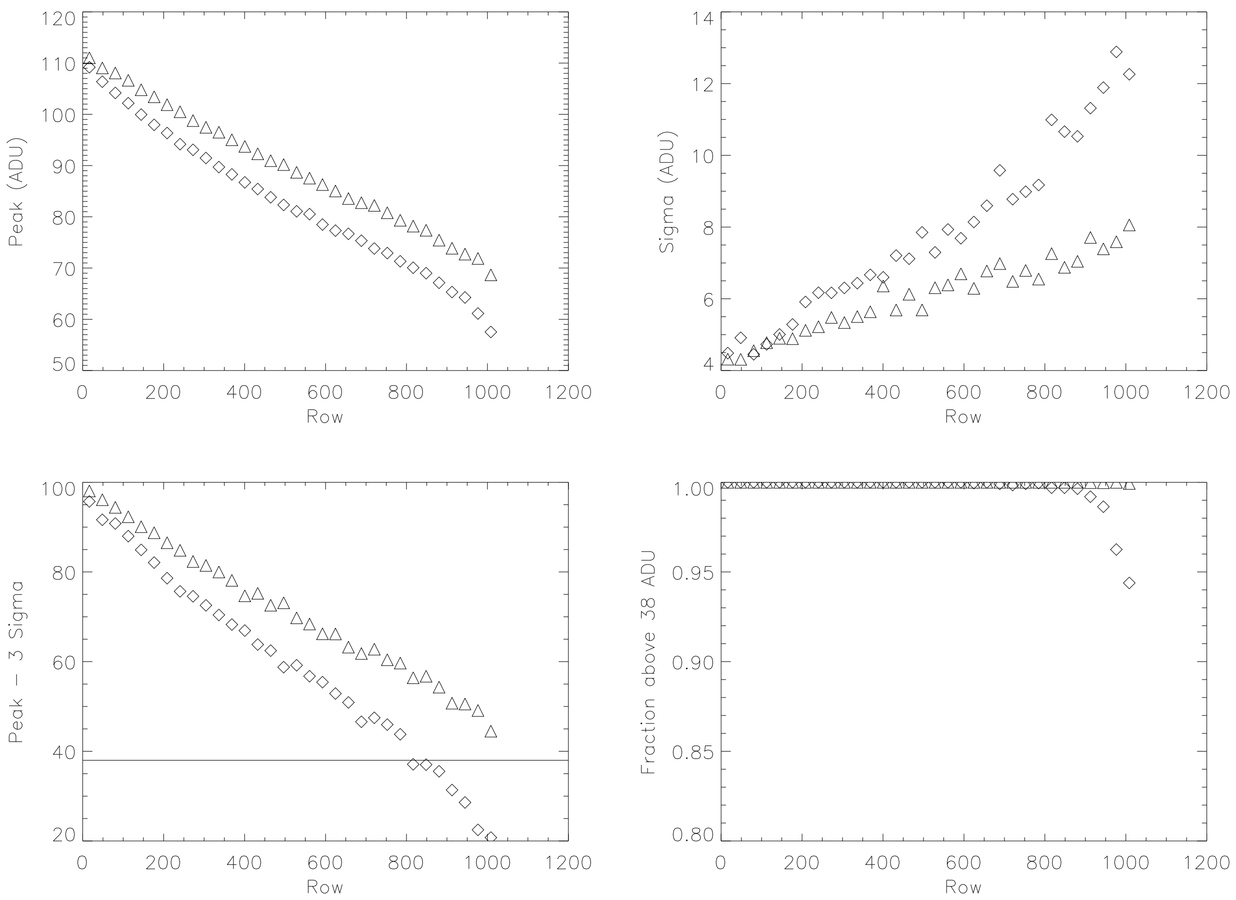

Figure 4: Same as figure 3 for the O-K line (525 eV).