ACIS Memo #161
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To: ACIS Team
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Subject: ACIS Gain during OAC
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1 Introduction

This memo discusses gain characterization performed during OAC. The first and more detailed measurements resulted from nearly 250 ks of Internal Contamination Monitor (ICM) data. Due to the illumination pattern of the ICM source, gain could only be measured on nine output nodes (s2, s3 and quad A of s4). The second gain measurements were made possible by nearly 40 ks of Flight Contamination Monitor (FCM) data. The FCM illuminates a much larger portion of the focal plane, allowing gain calculations for all devices except chips s0 and s1.

2 ICM

2.1 Overview

A detailed description of the ICM can be found in the 1998 calibration report (§1.11). Here, we briefly summarize its properties. The ICM is an ^{55}Fe source located on the inside of the ACIS door. The radioactive iron atoms undergo electron capture, resulting in excited manganese atoms, which relax by emission of characteristic fluorescence lines. While the primary purpose of the ICM integrations was to check for contaminants on ACIS by monitoring the ratio of the Kα transition line to the L-shell transition-line-complex, sufficient lines are present in the resultant spectrum to measure the gain and spectral resolution of the detectors.

2.2 Lines

In addition to the Mn Kα and Kβ lines, the Mn K escape features and related Si Kα fluorescence line are also present. Each CCD also has Ni Kα and Au Lα lines, excited by cosmic rays interacting in the gold-nickel coating on the frame store covers. The relative weakness of some of these features preclude their use in the gain calculation. Table 1 lists the lines and energies used. All lines are taken from Bearden (1969). The energy used for for the Mn Kα feature is a weighted average of the α_1 and α_2 lines, computed from radiative transition probabilities (see, e.g., Markowicz 1993). The Au Lα_2 line at 9.628 is not considered here, as the expected transition probability is only $\sim$10% of the Lα_1 line, which is easily identifiable, but relatively weak. The measured FWHM of the Au Lα feature is consistent with a single line (see §2.3).

Table 1: Lines used for ICM gain calculations

Line	Energy (keV)	Line	Energy (keV)
Si K$\alpha_{1,2}$	1.7398	Mn Kβ_1	6.4905
Mn K$\alpha_{1,2}$ *esc*	4.1553	Au Lα_1	9.7133
M K$\alpha_{1,2}$	5.8951		

2.3 Gains

All available data from Timed Exposure, Graded 3×3 observations were summed together. The nominal temperature of the focal plane was T = -119°. Table 2 shows the gains and offsets calculated for the nine amplifier chains with sufficient data. In three cases, the relatively low flux required excluding one of the five lines.

All the nodes show a gain decrease of $1 - 3\%$, orders of magnitude larger than any temperature dependence measured on the ground. It is highly unlikely that the excess found in the bias maps (the so-called "paisley" pattern) can account for this shift. Usually, bias inaccuracies manifest themselves in a non-zero offset (in the FI chips) or a significant excursion from typical s3 offsets of ~ -20 ADU.

Table 2: ICM gains from OAC compared to calReport ground gains

	OAC		Ground	
Chip/ Node	Gain (ADU/eV)	Offset (ADU)	Gain (ADU/ev)	Offset (ADU)
s2–c0†	0.2527	-3.18	0.2602	0.03
s2–c1†	0.2610	0.71	0.2715	0.15
s2–c2	0.2541	0.57	0.2640	-0.51
s2–c3	0.2608	0.23	0.2692	-0.54
s3–c0	0.2220	-13.5	0.2262	-17.3
s3–c1	0.2117	-16.7	0.2158	-19.9
s3–c2	0.2143	-14.8	0.2186	-19.7
s3–c3	0.2226	-25.8	0.2273	-22.8
s4–c0‡	0.2313	3.37	0.2328	-1.09

†Mn Kα escape line not used
‡Si Kα line not used

2.4 Spectral Resolution

The possibility that the bias errors are responsible for the shift is further excluded by resolution of the line features. Table 3 lists the FWHM for each line that is fit for the gain calculation. Typical values for FI (BI) chips from sub-asssembly calibration were: 85 eV (110 eV) at 1.74 keV, 145 eV (168 eV) at 6.40 keV and 173 eV (181 eV) at 8.04 keV. The in-orbit performance is identical to that of the ground. The poorer resolution of s3–c3 is consistent with that measured during ground calibration.

Table 3: Spectral resolution of the principal ICM lines

Chip Node	Si Kα 1740 eV	Mn Kα *esc* 4155	Mn Kα 5895 eV	Mn Kβ 6491 eV	Au Lα 9713 eV
s2–c0	89.5	—	137	151	181
s2–c1	98.4	—	133	164	163
s2–c2	98.3	97.7	132	148	178
s2–c3	132	110	131	143	173
s3–c0	95.7	149	166	178	236
s3–c1	113	158	178	191	228
s3–c2	108	150	169	181	210
s3–c3	124	134	173	192	258
s4–c0	—	109	136	155	181

All values listed are FHWM in eV.

2.5 Gain Stability

The ICM flux on quadrant D, s2 is strong enough to allow gain accurate gain calculations for relatively short ($\sim$5000 frames or 4.5 hours) data sets. We paired all the IntCal science runs into 12 data sets with roughly equal number of exposures. Gains were calculated from four lines: Mn Kα and Kβ, the Kα escape, and Si Kα. Table 4 lists the gains and offsets for each set of science runs. The weighted mean and standard deviation are 0.2610 ± 0.0002, where the weights scale as $1/\sqrt{\text{Frames}}$ (i.e. poisson statistics). Of particular note are Science Runs 24 and 63−64, which are Graded Histogram data and 3×3 CC data. Both of these sets are indistinguishable from the 10 sets of Graded Event data.

Table 4: Gains measured during an eight day span of ICM science runs

Science Runs	gain (ADU/eV)	offset (ADU)	Science Runs	gain (ADU/eV)	offset (ADU)
24†	0.26109	1.18	58−59	0.26122	-0.99
25−28	0.26095	0.09	61−62	0.26104	-1.03
28−30	0.26132	-1.94	63−64‡	0.26069	-2.91
32−34	0.26107	-0.21	70−71	0.26147	-2.75
38−40	0.26090	0.77	72−73	0.26098	-1.16
56−57	0.26125	-1.76	74−76	0.26104	-0.78

† Graded Histogram data ‡ 3×3 continuous clocking

3 FCM

The FCM is an array of 16 radioactive ^{109}Cd and ^{55}Fe sources installed on the Sun Shade door. Its purpose is conceptually similar to the ACIS ICM: the ratio of Mn K lines to the Au-L line complex measured in-orbit is compared to the ground meaurement to look for contamination on the HRMA. The richness of Ag L lines between 2.6 – 3.7, shown in Figure 3, makes using them for gain calculation difficult.

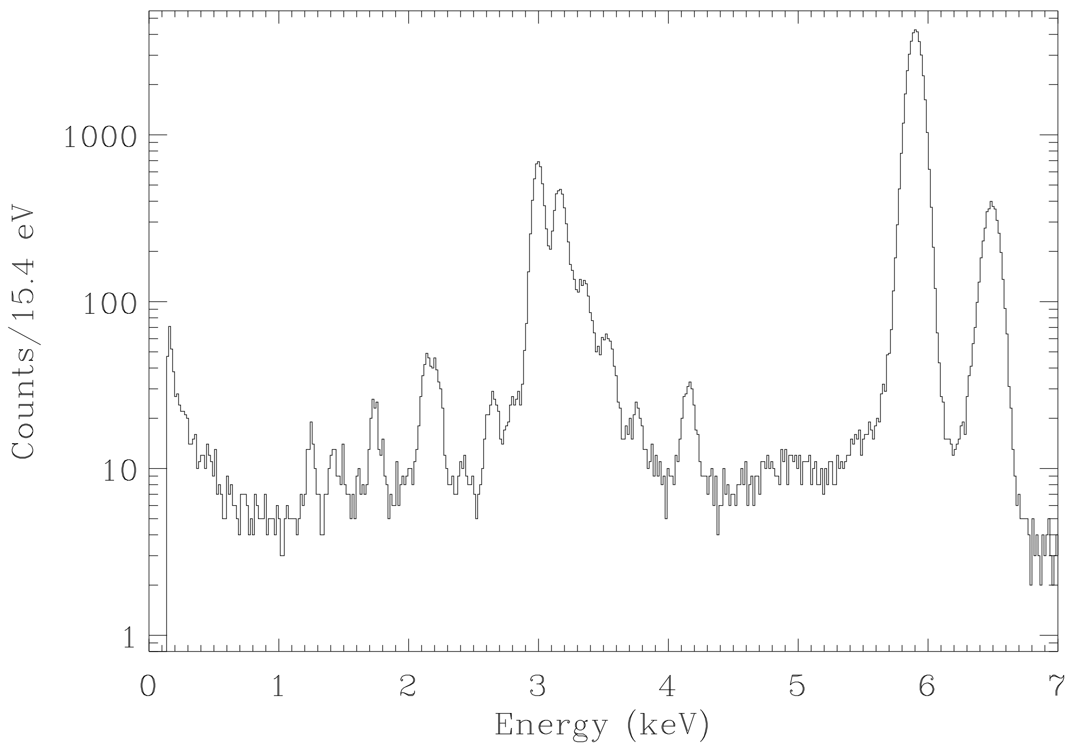

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Figure 1: Co-added FCM spectrum from s2, quadrants B and D, from 40 ks of Timed Exposure data. Notice the wealth and complexity of Ag L lines around 3 keV.

However, the Mn K lines and Au Lα line used above are sufficiently bright to allow gain measurements for 8 of the ACIS chips (flux on s0 and s1 is too weak to get reliable fits). When the FCM flux is high enough to produce noticable Si Kα fluorescence and Mn Kα escape, we include these line in the gain calculations. Table 5 compares in-flight gains with those measured on the ground. Note that the focal plane temperature during FCM measurements was T = -90°, 30° warmer than the nominal operating temperature.

Table 5: ICM gains from OAC compared to calReport ground gains

Chip	FCM -90°		Ground -120°		Perc.	Chip	FCM -90°		Ground -120°		Perc.
Node	Gain (ADU/eV)	Offset (ADU)	Gain (ADU/eV)	Offset (ADU)	Change	Node	Gain (ADU/eV)	Offset (ADU)	Gain (ADU/eV)	Offset (ADU)	Change
i0–c0	0.2596	3.66	0.2636	0.81	-1.53%	s2–c0	0.2518	0.21	0.2602	0.03	-3.21%
i0–c1	0.2512	0.43	0.2573	0.65	-2.37%	s2–c1	0.2605	2.11	0.2715	0.15	-4.04%
i0–c2	0.2612	-8.66	0.2662	0.77	-1.88%	s2–c2	0.2534	3.54	0.2640	-0.51	-4.02%
i0–c3	0.2534	-1.90	0.2582	0.60	-1.86%	s2–c3	0.2604	0.70	0.2692	-0.54	-3.28%
i1–c0	0.2525	2.88	0.2622	0.38	-3.70%	s3–c0	0.2225	-5.02	0.2262	-17.33	-1.63%
i1–c1	0.2479	2.42	0.2559	-0.09	-3.13%	s3–c1	0.2136	-8.02	0.2158	-19.88	-1.01%
i1–c2	0.2504	-0.78	0.2596	0.36	-3.53%	s3–c2	0.2154	-6.91	0.2186	-19.65	-1.46%
i1–c3	0.2527	3.15	0.2616	0.07	-3.41%	s3–c3	0.2244	-10.4	0.2273	-22.80	-1.27%
i2–c0	0.2594	1.85	0.2731	-0.98	-5.02%	s4–c0	0.2317	-3.78	0.2328	-1.09	-0.45%
i2–c1	0.2629	3.89	0.2839	-1.07	-7.41%	s4–c1	0.2257	1.38	0.2272	-0.58	-0.66%
i2–c2	0.2647	-0.07	0.2825	0.07	-6.31%	s4–c2	0.2275	3.27	0.2301	-0.72	-1.14%
i2–c3	0.2595	3.2	0.2745	0.43	-5.46%	s4–c3	0.2380	-6.08	0.2391	-0.96	-0.46%
i3–c0	0.2541	1.5	0.2582	1.19	-1.57%	s5–c0	0.2535	-0.83	0.2534	-0.16	0.04%
i3–c1	0.2522	4.21	0.2588	1.25	-2.54%	s5–c1	0.2544	2.10	0.2576	-0.13	-1.23%
i3–c2	0.2490	1.97	0.2542	1.25	-2.08%	s5–c2	0.2564	5.46	0.2601	0.18	-1.40%
i3–c3	0.2542	4.01	0.2592	1.09	-1.94%	s5–c3	0.2222	-0.23	0.2114	0.46	5.12%

5 lines were used for chips s2,s3 and i3. 3 lines were used for the remaining chips.

Two trends are evident in the data. First, nealy every quadrant shows a gain decrease. Second, the size of the shift seems to vary from chip to chip, but is fairly constant (about ~1% variation) among the four quadrants of a given chip. This last trend is suggestive of a change in an operating parameter that would shift all the outputs by roughly the same amount, e.g. V_{dd} or V_{ref}. Preliminary analysis of the house keeping data, however, indicate no changes in either of these voltages.

3.1 Temperature Dependence on Gain

The chips with gain measurements from both FCM and ICM data can be used to measure the in-orbit gain dependence on temperature. Table 6 caculates the logarithmic shift d(ln G)/dT for the nine quadrants with reliable gain measurements at T = -90°and T = -120°. For the two FI chips, the measured shift agrees well with those measured during thermal vac tests at Lincoln (see the calReport for details). On ground, the average value for s2 was $d(\ln G)/dT < 6 \times 10^{-5}$, while for s4 it was $d(\ln G)/dT = -8 \times 10^{-5}$. The behavior of s3 is not consitent with ground measurements, where the average value was $d(\ln G)/dT < 8\ times 10^{-5}$. In-orbit, the shift is now negative and on order of magnitude larger. However, given that s3 is a backside device and the ground measurement was performed over a different temperature range ($-110 < T < -130$), it is not unreasonable to expect different behavior for this chip. We also note that the gain in s3 is affected by CTI, which is much larger at T = -90° than a T = -120°. In all cases, the size of the gain shift is much smaller than the gross shifts of $1 - 6\%$ from sub-assembly calibration.

Table 6: Gain shifts as a function of temperature

Chip Node	FCM (T = -90°) Gain (eV/ADU)	ICM (T = -120°) Gain (eV/ADU)	Shift d(ln G)/dT (10^{-5})
s2–c0	3.971	3.957	11.7
s2–c1	3.838	3.831	6.2
s2–c2	3.947	3.935	9.9
s2–c3	3.841	3.834	5.5
s3–c0	4.494	4.505	-8.1
s3–c0	4.681	4.724	-31
s3–c0	4.642	4.666	-18
s3–c0	4.456	4.492	-28
s4–c0	4.315	4.323	-6.6

4 Conclusions

- On-orbit gains differ from ground measurements.
- The magnitude of the shift seems correlated with chip.
- Although shifted, the gain is temporarily stable ($< 0.1\%$ variation.)
- The gain-shift has not affected spectral resolution–energy resolution in both the FI and BI devices matches that measured in sub-assembly calibration.
- The measured gain dependence on temperature for the FI chips is consistent with that determined on the ground.