Instrument Science Report WFC3 2007-28

WFC3 TV2 Testing: IR Gain Results

B. Hilbert
December 05, 2007

ABSTRACT

Over the course of Thermal Vacuum 2 (TV2) testing during the summer of 2007, we obtained several datasets that allowed us to calculate the gain of the IR1 (FPA129) detector. At the nominal flight gain setting of 2.0 e^-/ADU, we measure gain values between 2.12 – 2.16 e^-/ADU, after accounting for inter-pixel capacitance (IPC). This corresponds to 2.41 – 2.45 e^-/ADU before the IPC correction. For the other (unsupported) gain settings of 2.5, 3.0, and 4.0 e^-/ADU, we calculate actual gain values of 2.78 – 2.88, 3.33 – 3.48, and 4.50 – 4.76 e^-/ADU respectively, after IPC correction.

Introduction

WFC3 underwent a second round of thermal vacuum (TV) testing during the summer of 2007. This round of TV testing utilized the IR Build 1, which contains FPA129. As with the detector used in TV1 (FPA64), this detector is considered a flight backup. Similar to the gain testing done in TV1, the goal of this study was to determine the true gain value associated with this IR detector. The nominal flight gain setting for this detector, chosen early in TV2 testing, is 2.0 e^-/ADU. This setting provided the best sampling resolution of the IR detector, up to full well. Other available (but unsupported) gain settings on the IR channel are 2.5, 3.0, and 4.0 e^-/ADU. Data were taken at all 4 gain settings, in order to investigate the true gain values in each case.

Data

The characteristics of the data collected for this test were dictated by two SMSs. In the first, IR02S11, each iteration of the SMS produced 25 identical ramps. The detector was illuminated by the CASTLE Tungsten lamp through the F125W filter. Each ramp was composed of 9 reads sampled using the SPARS10 sequence. The gain value of the detector was set to the nominal flight value of 2.0 e^-/ADU. The SMS was run three times durng TV2 testing: July 2, September 6, and September 28.

The second SMS used for gain calculations was IR02S02. This script collected IR data at each of the 4 available gain settings, in order to examine the true differences in gain from one setting to the next. Again, illumination was provided by the CASTLE tungsten lamp. In this case, IR02S02 focused primarily on collecting data at a gain setting of 2.5 e-/ADU, as this was the nominal flight gain setting prior to the beginning of TV2. As noted above, this has changed. IR ramps were also collected at gain settings of 3.0 and 4.0 e-/ADU. IR02S02 was run twice during TV2 testing: June 28 and August 8. Table 1 summarizes the data collected during each run of the two SMSs. All data were collected through the F125W broadband filter.

Gain Setting (e^-/ADU)	Number of Ramps	Sample Sequence	Reads per Ramp	CASTLE Lamp	Filter	Ramp Exposure Time (sec)
IR02S11						
2.0	25	SPARS10	10	Tungsten	F125W	82.9
IR02S02						
2.0	2	SPARS10	10	Tungsten	F125W	82.9
2.5	10	SPARS10	10	Tungsten	F125W	82.9
3.0	2	SPARS10	10	Tungsten	F125W	82.9
4.0	2	SPARS10	10	Tungsten	F125W	82.9

Table 1: Gain data collected during TV2 testing.

Analysis

Before the gain calculations were begun, all ramps were processed through the WFC3 IDL data reduction pipeline. (Hilbert, 2004) This used the reference pixels and initial read of each ramp to remove bias signal and pixel-to-pixel variations in the zero level of the signal. We also found that the application of the non-linearity correction and mask produced in the TV2 non-linearity analysis (Hilbert, 2007) significantly improved the quality of later steps in these data analyses. This will be described in more detail below.

As was done in TV1 testing, we used the mean-variance method to calculate the gain in these data. This method uses two ramps to calcualate gain values, and is described in detail in Baggett (2005) and Hilbert (2005). First, we create a summed ramp, by adding together, read-by-read, two of the original ramps. We also create a differenced ramp by subtracting the same two original ramps. In this case, the original ramps were composed of 9 reads, leading to summed and differenced ramps of the same size. Mean and variance values were calculated separately for each quadrant of each read, using the following method.

Beginning with the summed ramp, we calculated a histogram of the data values in each read. The peak value of a best-fit Gaussian to this histogram was recorded as the "mean" value for that read. To calculate variance values, the same recipe was used on the difference ramp, where the width of the Gaussian was recorded. Therefore, for each pair of ramps, we ended up with 9 mean-variance pairs for each quadrant. Using these pairs, we produced plots similar to Figure 1. The inverse of the slope of a line fit to the mean-variance pairs gave a measure of the gain.

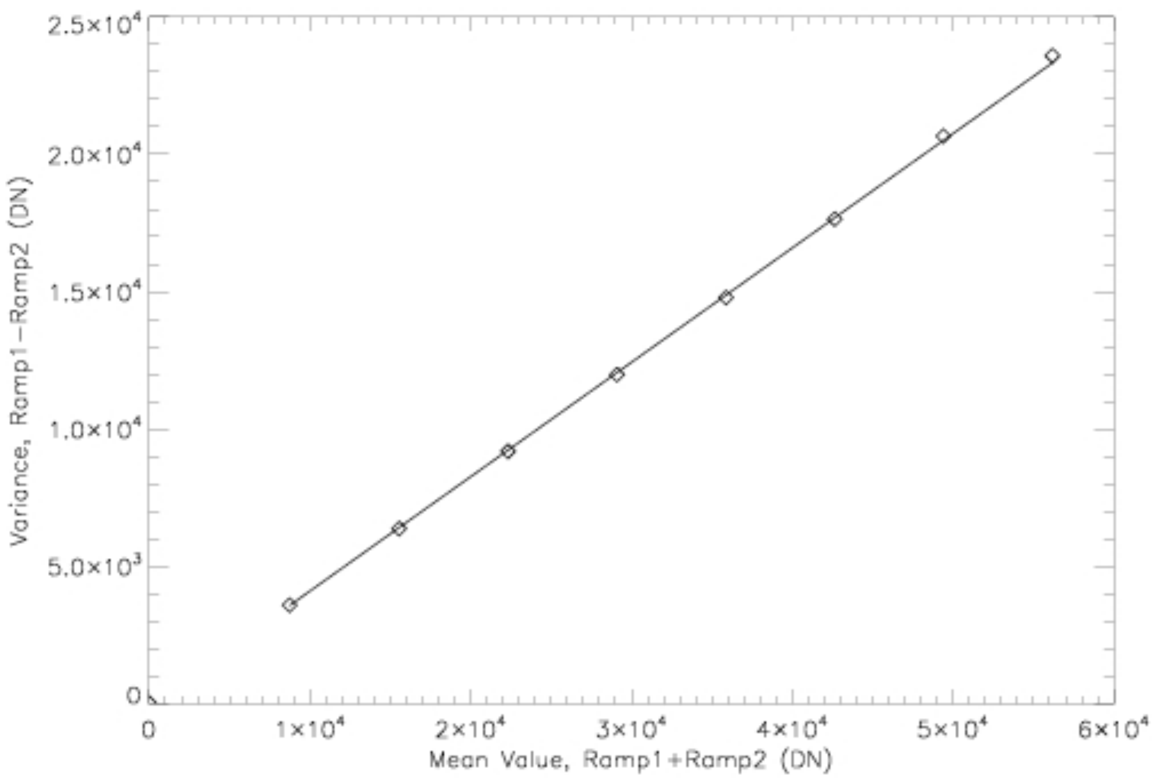

Figure 1: Mean versus variance plot for one quadrant of one pair of ramps. The gain is the inverse of the slope.

As mentioned above, the application of the previously derived nonlinearity correction was essential for calculating accurate gain values. Figure 2 is a mean-variance plot, similar to Figure 1, that shows the difference between the non-linearity corrected and uncorrected cases. In the uncorrected case, as the signal level increases and pixels begin to go non-linear, they under-measure the true signal. This depresses both the mean signal and variance, leading to a lower slope in Figure 2. Note there is also a curvature to the uncorrected data which is not present in the corrected points. As signal increases and more pixels go non-linear, the variance across the detector begins to decrease more quickly. The corrected data show a more linear behavior across the range of measured signals.

The gain values derived from the uncorrected data are ~15% higher than those from the corrected data. In this case, for quadrant 4 of the detector, the uncorrected data give a gain value of 2.81 +/- 0.03 e^-/ADU. Applying the non-linearity correction to these ramps prior to calculating the gain yields a value of 2.42 +/- 0.02 e^-/ADU, closer in line to the gain value we expect (2.0 e^-/ADU) after the inter-pixel capacitance correction, which is discussed in the Conclusions.

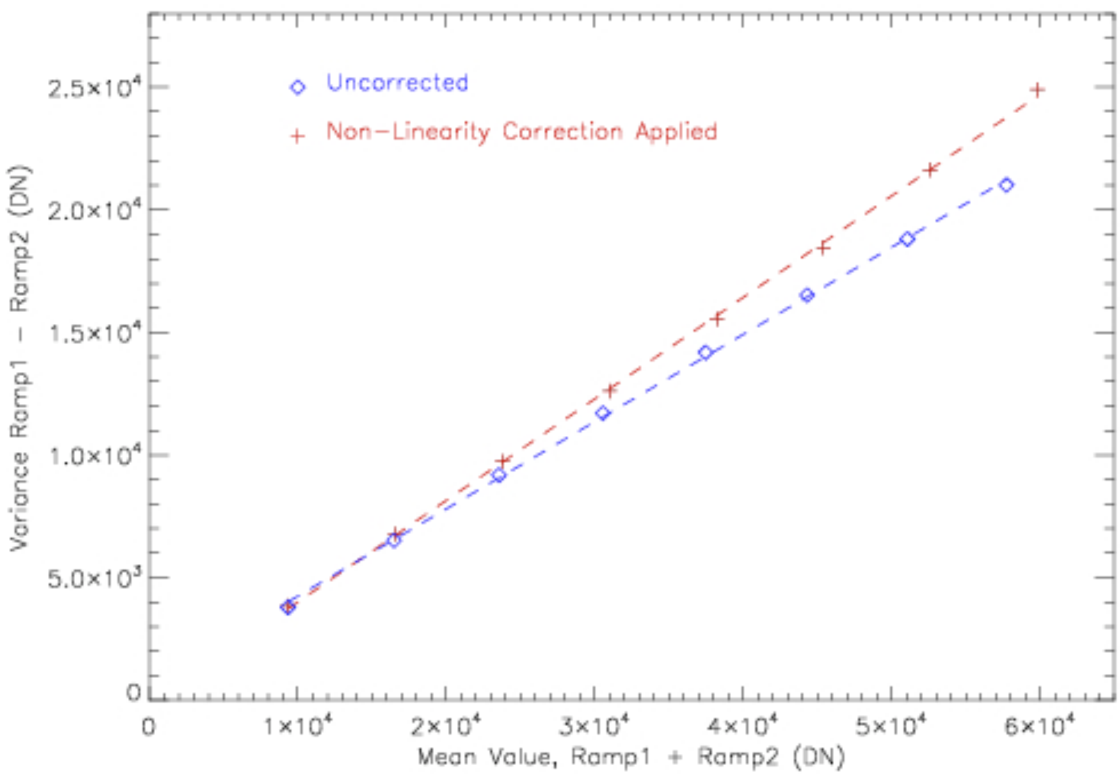

Figure 2: Non-linearity corrected VS uncorrected mean and variance values. The effects of non-linear pixels are apparent in the blue curve.

IR02S11

As described above, IR02S11 was run three times during TV2 testing, producing 25 ramps during each run. We analyzed each run separately, to look for any changes in gain over the duration of the TV2 testing. Initially, 24 pairs of ramps were created from each 25 ramp dataset. We paired each ramp with the ramp immediately following (ie 1+2, 2+3, 3+4), rather than creating independent pairs (ie 1+2, 3+4, 5+6). By including each ramp in two pairs, we hoped that correlation would help us to identify any single ramp with unexpected behavior. Because of this, the figures below have 24 points rather than the 12 that would be expected if each pair was completely independent from the rest.

Calculating the gain for each pair of ramps revealed an unexpected but very repeatable pattern. Every third pair of ramps produced gain values that were roughly 15% below those from the other ramp pairs. We discovered that during the run of the SMS, ramps were taken in groups of three, with a data dump between each group. Consecutive ramps taken within each group of three were separated by only ~2 minutes, while roughly 12 minutes separated the last ramp of each group from the first of the next group. By blindly pairing consecutive ramps, every third pair contained ramps separated in time by about 12 minutes. These pairs invariably produced lower gain results. This was caused by the variance values calculated with these ramp pairs. The mean signal values remained the same relative to other ramp pairs, but the variance values were elevated relative to the other ramp pairs. This resulted in a mean-variance plot with a higher slope, and therefore a lower gain. This is shown in Figure 2. Each point in the upper panel of this plot represents the mean value measured in the final read of the summed ramp created from a pair of ramps. Similarly, each point in the bottom panel shows the variance calculated from the final read of the differenced ramp. The variance values exhibit a spike in every third pair. As a result of this behavior, we only calculated gain values from pairs of ramps within the same data dump. This minimized the time between ramps. With these constraints, we used 15 pairs of ramps from each run of IR02S11 in our calculations.

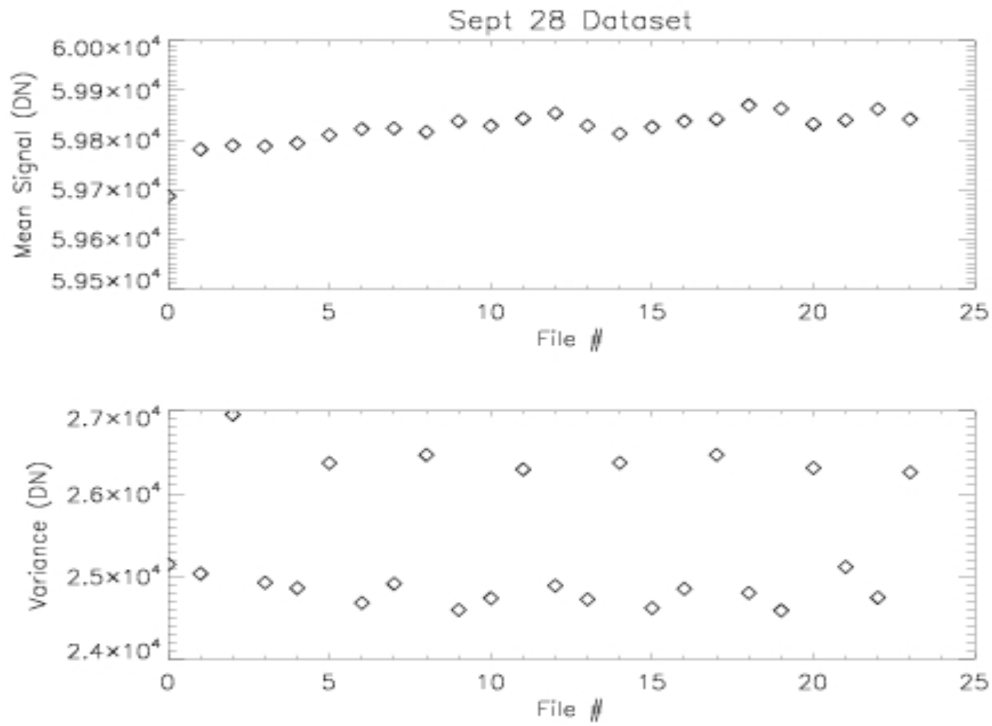

Figure 3: Mean signal values and variances in the final read of summed and differenced ramps. By blindly pairing consecutive ramps, we found that ramps separated by the data dump (and therefore 12 minutes rather than 2 minutes) exhibited much higher variance values, as seen in the bottom panel.

Another peculiarity observed in the IR02S11 data was the mean signal value in the July 2 dataset. Figure 3 shows the mean signals and variances plotted separately for these data. Figure 4 shows the same plot for the September 28 dataset, for comparison. Note the much smaller variation in mean signal level for the September data.

In the July 2 data, over the course of the SMS, the mean value (of the sum of each pair) appeared to increase in a roughly periodic pattern. However, changes in the variance over time appear to have compensated for the varying mean values, as can be seen by the consistent gain value between the July 2 iteration of the SMS with the other two iterations, seen in Tables 2 and 3. The only exception to this is in the first several ramp pairs of the July 2 data, where the measured gain is low. From Figure 3, we see that for these files, the mean signal levels are relatively low, while the measured variance values are relatively high.

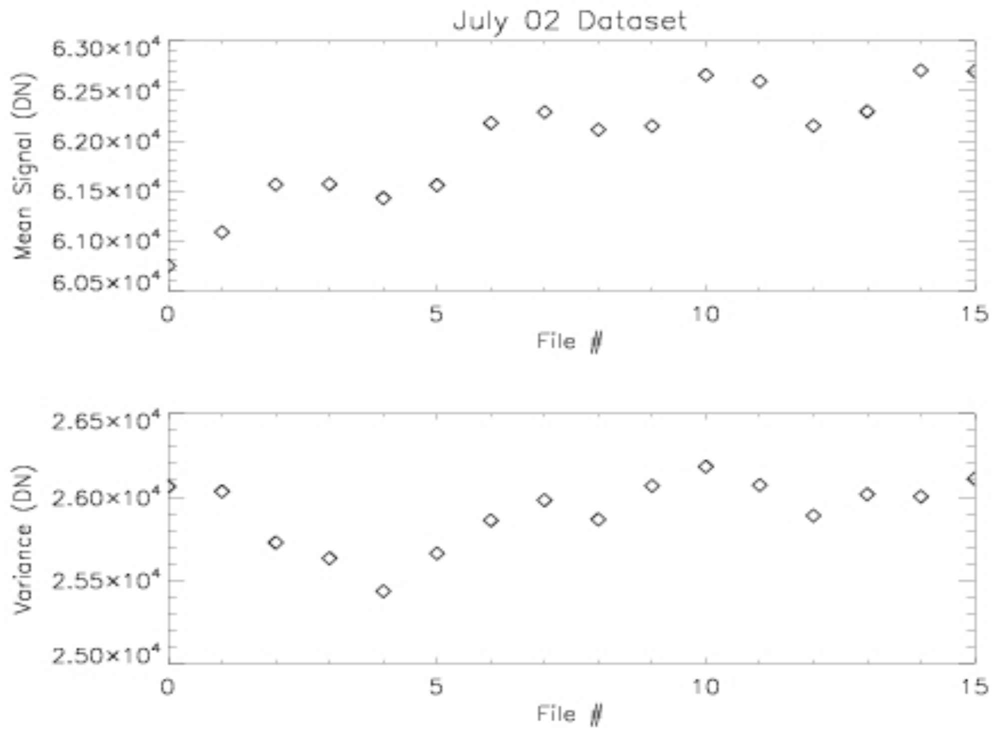

Figure 4: Mean and variance values calculated for the July 2 dataset.

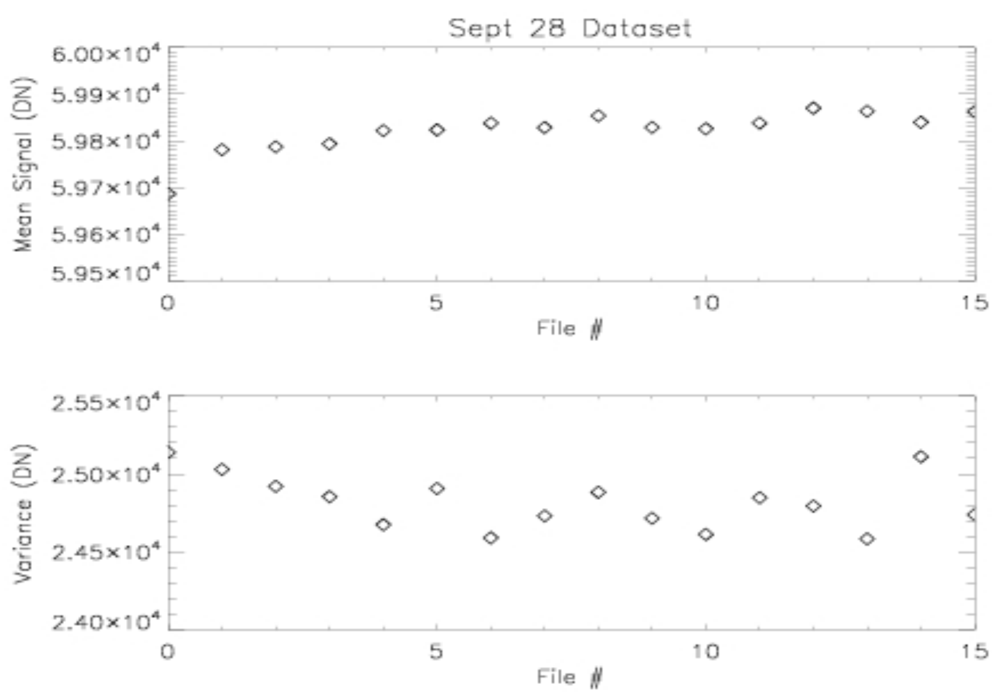

Figure 5: Mean and variance values for the September 28 dataset. Note that the mean values are much more consistent across the test than in the July 2 data.

Using the mean and variance values calculated for all three IR02S11 datasets, we calculated gain values for each pair of FPA129 ramps, using plots such as that in Figure 1. Figures 5, 6, and 7 show these values for each quadrant of each ramp pair for the July 2, September 6, and September 28 datasets, respectively.

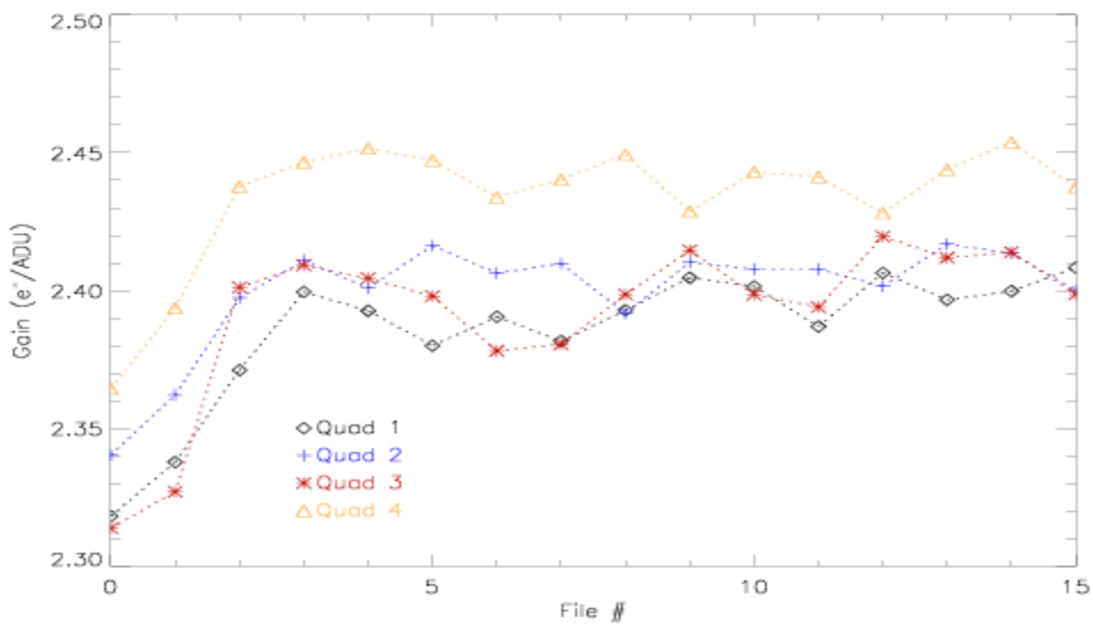

Figure 6: July 2 gain values.

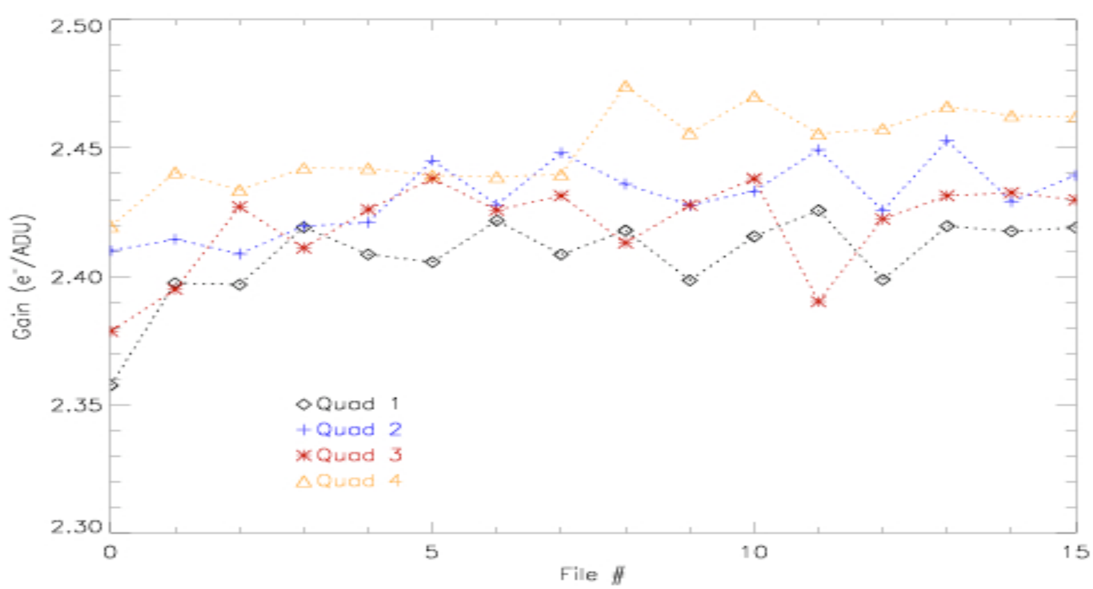

Figure 7: September 6 gain values.

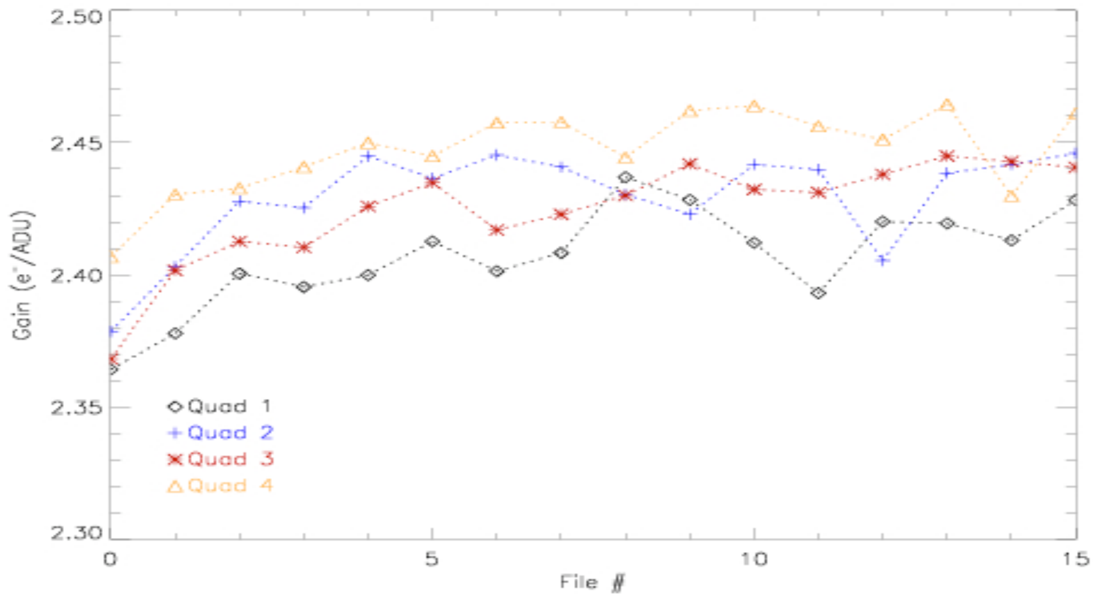

Figure 8: September 28 gain values.

IR02S02

Data ramps acquired using the IR02S02 SMS were analyzed in the same manner as those from the IR02S11 SMS. We paired only ramps taken within the same data dump, in order to avoid the previously discussed increases in variance values. In this SMS, a single pair of ramps were taken at 3 of the 4 gain settings (2.0, 3.0, 4.0 e^-/ADU), meaning that we were able to obtain only a single measure of the gain in these cases. This SMS was created when the nominal flight gain value was 2.5 e^-/ADU. With the emphasis on obtaining the best gain values for that gain setting, we obtained 6 pairs of gain=2.5 e^-/ADU ramps. Gain results from IR02S2 data are tabulated in the next section.

Conclusions

All calculations and plots to this point do not include the effects of inter-pixel capacitance (IPC). This effect, caused by capacitive coupling between pixels, artificially decreases the photon shot noise seen by an individual pixel. A decrease in the variance will translate into a decrease in the slope of Figure 1, resulting in an artificial increase in the gain. Our best estimates conclude that IPC effects can be removed by scaling measured signal down by a factor of 0.88 (T. Brown priv. comm.).

Tables 2 and 3 show the final gain results for WFC3-IR from TV2 testing before and after IPC correction. For gain settings where more than one pair of ramps existed, we report the mean of the gain values calculated for all ramp pairs. Errors represent uncertainties on the calculation of coefficients in the line-fitting of the mean-variance plot.

The results are largely consistent between all three IR02S11 datasets. Given the anomalous behavior observed in the July data, we believe that the gain values from the September datasets are the best to use on data taken with this IR detector.

This testing was performed on FPA129, which is currently designated as third on the list of FPAs to have in the instrument for flight. For the upcoming TV3 testing, we expect to have the preferred flight part, FPA165, in the instrument. At that point, this study will be repeated, to obtain gain values for that detector.

Prior to IPC Correction				
	Quadrant 1	**Quadrant 2**	**Quadrant 3**	**Quadrant 4**
Commanded Gain: 2.0				
July 2	2.39 +/- 0.02	2.41 +/- 0.02	2.40 +/- 0.02	2.44 +/- 0.01
September 6	2.41 +/- 0.01	2.43 +/- 0.01	2.43 +/- 0.01	2.45 +/- 0.02
September 28	2.41 +/- 0.01	2.43 +/- 0.01	2.43 +/- 0.02	2.45 +/- 0.02
June 28	2.32 +/- 0.02	2.33 +/- 0.01	2.31 +/- 0.02	2.38 +/- 0.02
August 8	2.36 +/- 0.01	2.33 +/- 0.01	2.35 +/- 0.01	2.39 +/- 0.01
Commanded Gain: 2.5				
June 28	3.20 +/- 0.01	3.19 +/- 0.02	3.18 +/- 0.02	3.27 +/- 0.02
August 8	3.18 +/- 0.02	3.17 +/- 0.02	3.16 +/- 0.03	3.27 +/- 0.02
Commanded Gain: 3.0				
June 28	3.84 +/- 0.03	3.84 +/- 0.03	3.87 +/- 0.02	3.95 +/- 0.04
August 8	3.78 +/- 0.02	3.82 +/- 0.01	3.80 +/- 0.02	3.92 +/- 0.02
Commanded Gain: 4.0				
June 28	5.27 +/- 0.05	5.28 +/- 0.05	5.23 +/- 0.04	5.41 +/- 0.07
August 8	5.11 +/- 0.02	5.11 +/- 0.03	5.22 +/- 0.04	5.22 +/- 0.04

Table 2: Calculated gain values for WFC3-IR in units of e^-/ADU. The values from the two September datasets (in red) should be used on all FPA129 TV2 data taken at the nominal gain setting of 2.0.

Including IPC Correction				
	Quadrant 1	**Quadrant 2**	**Quadrant 3**	**Quadrant 4**
Commanded Gain: 2.0				
July 2	2.10 +/- 0.02	2.12 +/- 0.02	2.11 +/- 0.02	2.15 +/- 0.01
September 6	2.12 +/- 0.01	2.14 +/- 0.01	2.14 +/- 0.01	2.16 +/- 0.02
September 28	2.12 +/- 0.01	2.14 +/- 0.01	2.14 +/- 0.02	2.16 +/- 0.02
June 28	2.04 +/- 0.02	2.05 +/- 0.01	2.03 +/- 0.02	2.09 +/- 0.02
August 8	2.08 +/- 0.01	2.05 +/- 0.01	2.07 +/- 0.01	2.10 +/- 0.01
Commanded Gain: 2.5				
June 28	2.82 +/- 0.01	2.81 +/- 0.02	2.80 +/- 0.02	2.88 +/- 0.02
August 8	2.80 +/- 0.02	2.79 +/- 0.02	2.78 +/- 0.03	2.88 +/- 0.02
Commanded Gain: 3.0				
June 28	3.38 +/- 0.03	3.38 +/- 0.03	3.41 +/- 0.02	3.48 +/- 0.04
August 8	3.33 +/- 0.02	3.36 +/- 0.01	3.34 +/- 0.02	3.45 +/- 0.02
Commanded Gain: 4.0				
June 28	4.64 +/- 0.05	4.65 +/- 0.05	4.60 +/- 0.04	4.76 +/- 0.07
August 8	4.50 +/- 0.02	4.50 +/- 0.03	4.59 +/- 0.04	4.59 +/- 0.04

Table 3: Gain values from Table 1, scaled down by a factor of 0.88, to account for the IPC correction.

References

Baggett, S. **WFC3 Thermal Vac Testing: UVIS Gain Results**. WFC3 ISR 2005-08. http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2005-08.pdf 24 Feb 2005.

Hilbert, B. **WFC3 TV2 Testing: IR Channel Non-linearity Correction and Unstable Pixel Masking**. WFC3 ISR 2007-25. http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2007-25.pdf 1 Nov, 2007.

Hilbert, B. **Results of Thermal Vacuum Testing: IR Channel Gain**. WFC3 ISR 2005-14. http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2005-14.pdf 11 April, 2005.

Hilbert, B. **Basic IDL DataReduction Algorithm for WFC3 IR and UVIS Channel**. WFC3 ISR 2004-10. http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2004-10.pdf 10 June 2004.