

RE-VISITING THE AMPLIFIER GAINS OF THE HST / ACS WIDE FIELD CHANNEL CCDs

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ABSTRACT

For the first time since *HST* Servicing Mission 4 (SM4) in May 2009, we present an analysis of the amplifier gains of the Advanced Camera for Surveys (ACS) Wide Field Channel (WFC) CCDs. Using a series of in-flight flat-field exposures taken in November 2017 with a tungsten calibration lamp, we utilize the photon transfer method to estimate the gains of the WFC1 and WFC2 CCD amplifiers. We find evidence that the gains of the four readout amplifiers have changed by a small, but statistically significant, 1–3% since SM4. We further discuss how the flat-fields will be used to determine the relative gains and update the gain values used in the CALACS calibration pipeline.

1. INTRODUCTION

The ACS is a third generation instrument onboard *HST* and was installed in March 2002. The WFC is comprised of two butted SITe 4096 x 2072 pixel, back-illuminated CCDs cut from the same silicon wafer, with each CCD optimally designed to be read out by two readout amplifiers (Figure 1), which convert the measured signal in each pixel to a digital number. This conversion is dictated by the amplifier gain, which is independent for each amplifier. The gains of the readout amplifiers were last measured after the successful recovery of the ACS/WFC in May 2009 following a failure of the electronics in January 2007.

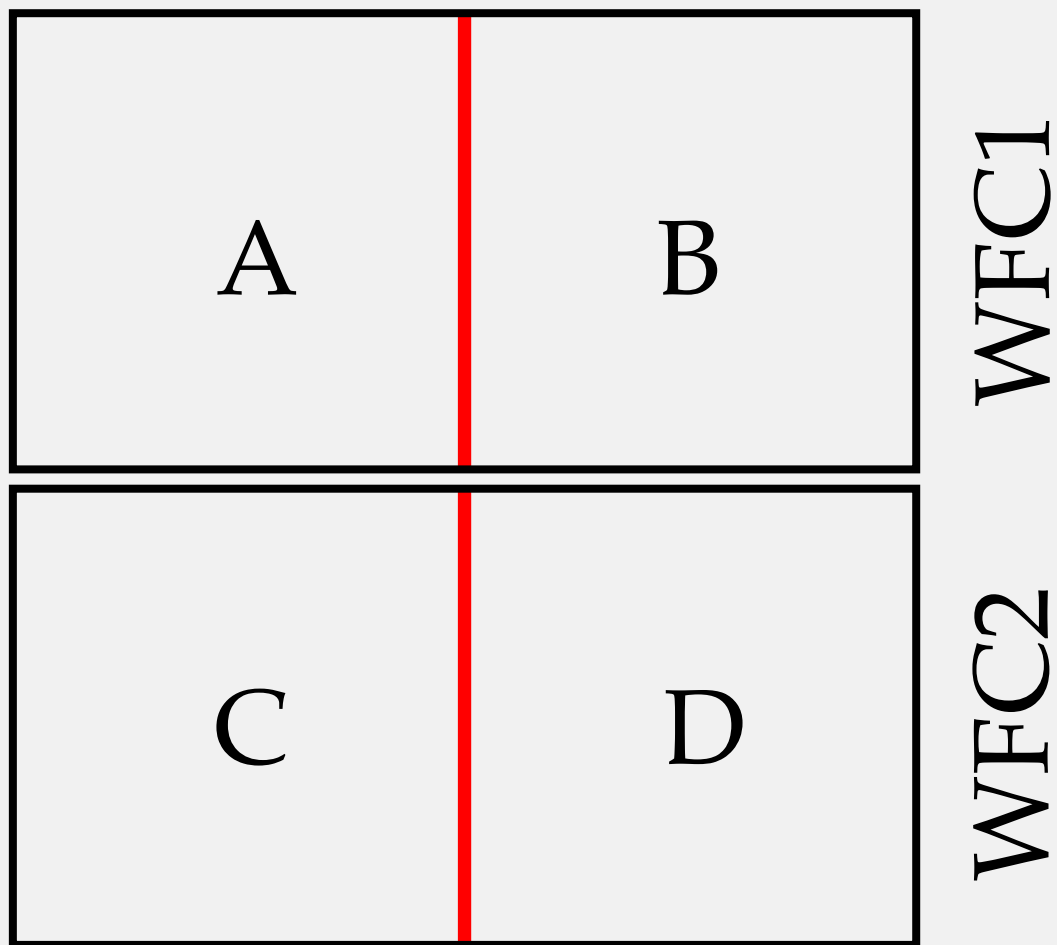


Figure 1: Layout of the ACS/WFC CCDs with amplifier regions and CCD chip number show.

2. PHOTON TRANSFER CURVE

The photon transfer curve (PTC; Janesick+ 1987) uses the noise properties of a CCD to measure several characteristics of it: gain, read noise, full-well, and linearity. The technique uses a series of uniformly illuminated image pairs at various exposure levels. Here, we have used the ACS/WFC tungsten calibration lamp observed with the F435W filter and five different exposure times to sample different levels of signal. Differencing these pairs removes fixed-pattern noise and allows us to measure the shot noise as a function of signal level.

Below the full-well limit, the WFC CCDs have a very linear response. For a given exposure time, the signal level (S) in DN is thus proportional to gIE , where g is the analog-to-digital gain, I is the incident intensity, and E is the exposure time. The variance of S is proportional to g^2IE . Thus, we can determine the gain from the slope of a linear fit to the variance as a function of signal level. Figure 2 shows a schematic of the PTC.

We bias-subtracted our flats and removed the effects of bias striping in ACS/WFC images. Dark current was intentionally left in each image. We measured the variance and median signal in a 5x5 grid of evenly spaced boxes on each amplifier region measuring 40 pixels on a side (Figure 3). Fitting was performed using a robust linear least-squares regression algorithm. An example for amplifier A is shown in Figure 4.

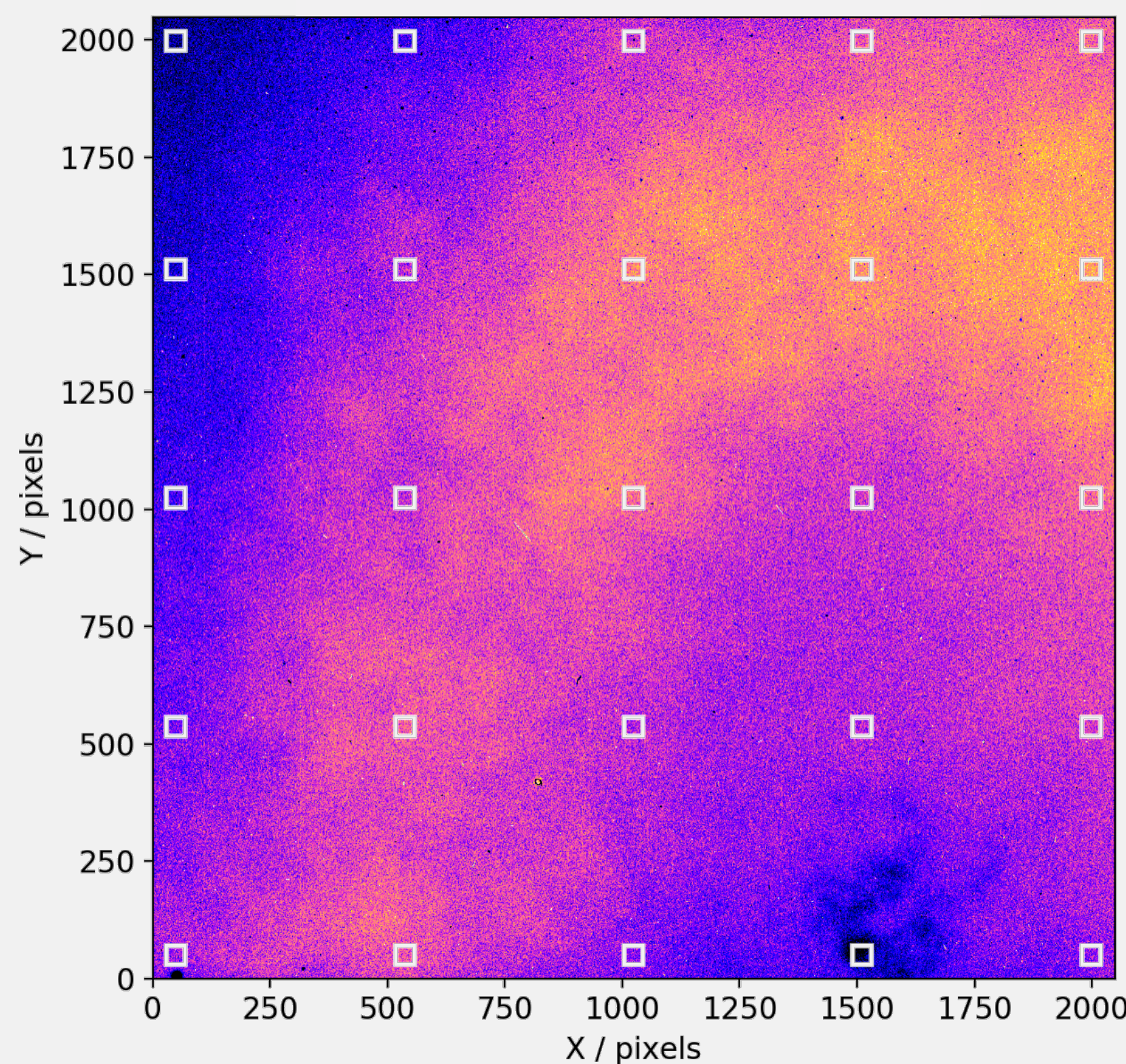


Figure 3: Image of the ACS/WFC amplifier A flat-field in the filter F435W with an exposure time of 0.7955 seconds. We measured the median signal and signal variance in each box, which measure 40 pixels on a side. Note this image is for reference and that the analysis is performed on the difference of two such flats.

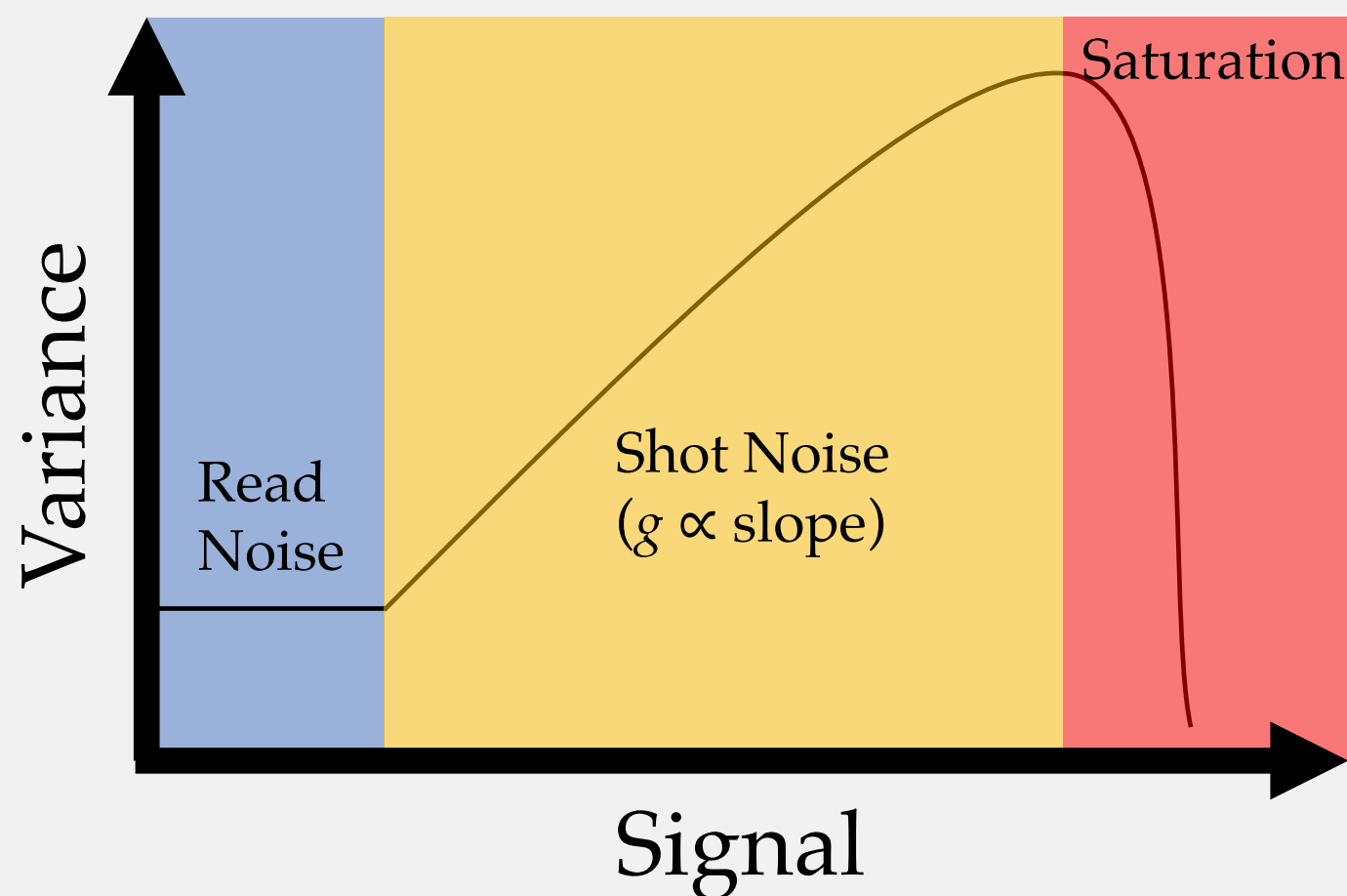


Figure 2: Schematic of the photon transfer curve. A linear fit to data in the shot noise regime can be used to obtain the gain for an individual readout amplifier.

Using 1,000 simulations of PTC data, we verify that we recover the gain to within an average residual of 0.1% and a residual RMS of 0.8%. This residual RMS is nearly identical to the average 1-sigma uncertainty in our measurements.

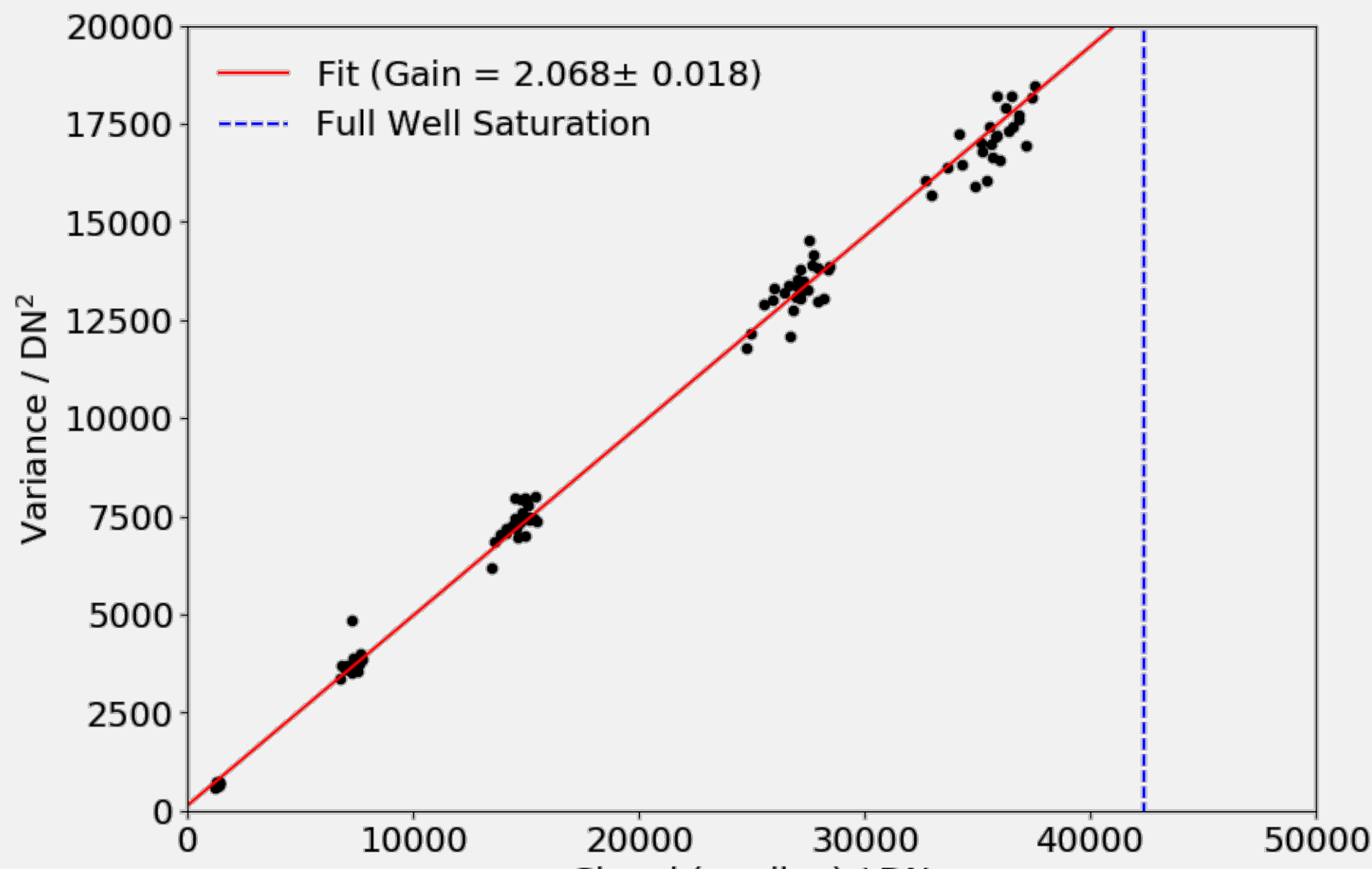


Figure 4: PTC analysis for ACS/WFC amplifier A using data from November 2017. The solid red line shows the fit to the data, while the dashed blue line indicates the full-well limit.

3. RELATIVE GAIN CALCULATION

The calibration of the ACS CCDs is designed such that a source placed in any amplifier region will stimulate the same number of photoelectrons. This is accomplished by repartitioning the “absolute” gain measured via the PTC into a “relative” gain. The relative gains of the four WFC amplifiers match the signal across both the amplifier boundaries and the chip gap between the CCDs. Thus, we can measure the relative gains by solving a system of equations:

$$\begin{aligned} G_1 S_1 &= G_2 S_2 \\ G_A S_A &= G_B S_B \\ G_C S_C &= G_D S_D, \end{aligned}$$

where G and S are the gain and signal, respectively. Numerical subscripts indicate CCD numbers, while alphabetical subscripts represent readout amplifiers (refer to Figure 1). We fix the average of the amplifier relative gains to be the average of the absolute gains and the gains of the CCDs are fixed to the average absolute gain for their respective amplifiers, e.g., G_1 in the equations above is the average absolute gain of amplifiers A and B. For the signal values in the equations, we assume uniform sensitivity in the F625W filter. We then average the smoothed signal in strips along the amplifier boundaries and the chip gap (see Figure 5).

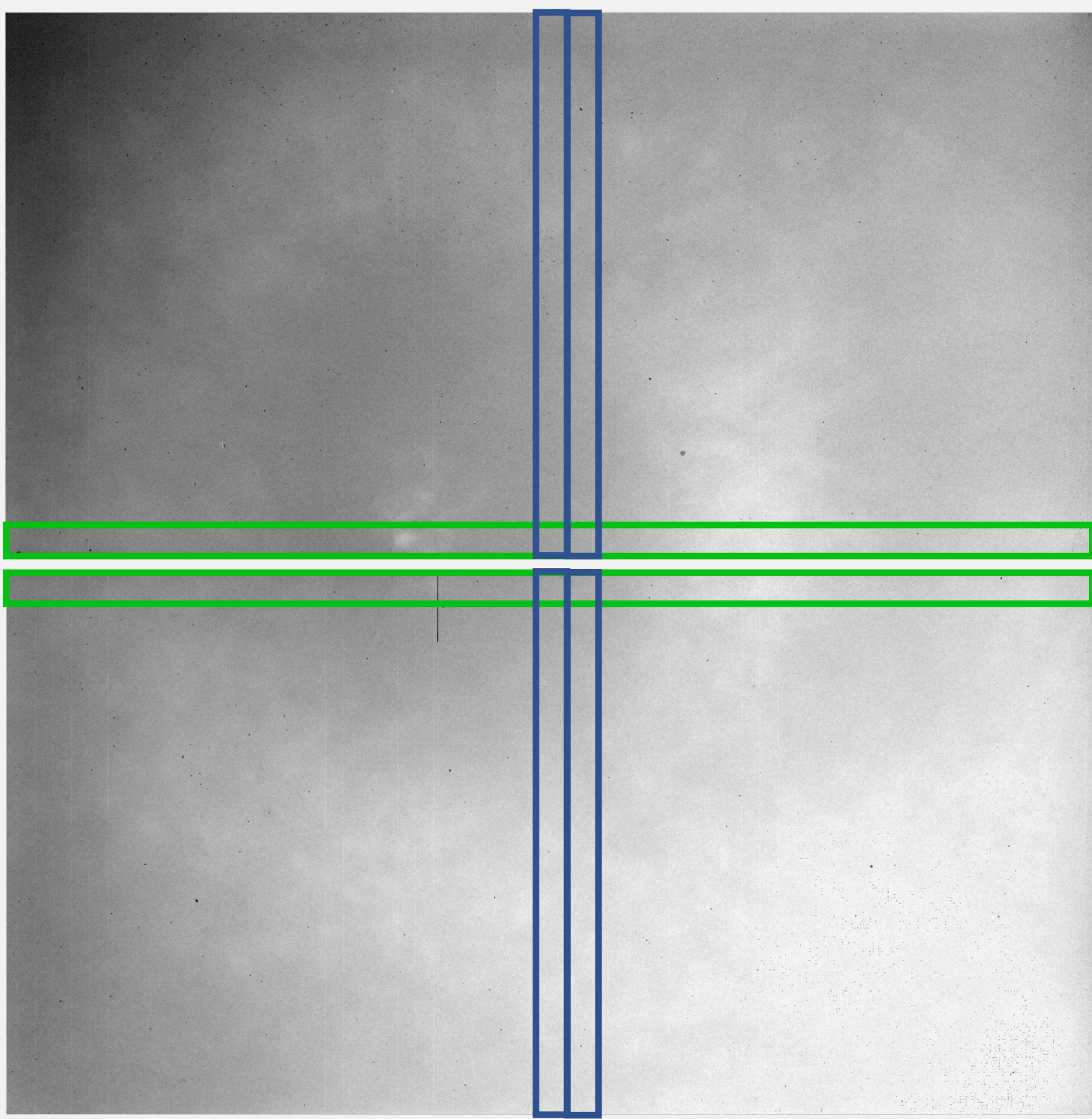


Figure 5: ACS/WFC flat-field image taken in the F625W filter. The image is oriented the same as the schematic in Figure 1. The green regions illustrate the approximate areas where signal was measured to match across the chip gap, whereas blue regions show the approximate areas used to match sensitivities across amplifier regions.

4. SCALING TO GLOBULAR CLUSTER 47 TUC

The relative gains ensure that the measured counts of a source in electrons is independent of position on the WFC CCDs. We also wish to ensure that the measured number of counts for a given source is also independent of time, i.e., it does not suffer from sensitivity loss. The gain values used after SM4 by the CALACS pipeline were adjusted to account for this sensitivity difference.

The ACS CCD Stability Monitor observes the same field located $\sim 7'$ West of the core of the globular cluster 47 Tuc (NGC 104). These observations are carried out four times per year in several ACS filters. The fluxes of several thousand stars are compared to a truth measurement taken in April – May, 2002 in the F606W filter. The relative gains were then adjusted for the average magnitude offset between the 2002 epoch and observations that are nearly concurrent with the PTC measurements.

5. CONCLUSIONS

Using the photon transfer curve, we find that the absolute gain of the ACS/WFC CCDs has changed since it was last measured after Servicing Mission 4. We find that the absolute gains show a statistically significant systematic decrease of 1 – 3%, with the largest difference in amplifier C. Further work is required to examine the impact to the relative gains and ACS photometry.

Year	Type	Amp A	Amp B	Amp C	Amp D	Reference
2009	Absolute	2.090	1.918	2.092	2.045	Golimowski+ (2011)
2009	Relative	2.074	1.936	2.071	2.065	Bohlin+ (2009)
2009	Scaled	2.020	1.886	2.017	2.011	Mack, J. (private comm.)
2017	Absolute	2.068 ± 0.019	1.913 ± 0.018	2.034 ± 0.015	2.034 ± 0.018	This work