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WFC3/IR Persistence as Measured in Cycle 17 using Tungsten Lamp Exposures

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ABSTRACT

Like most IR arrays, the IR detector incorporated into WFC3 exhibits persistence, an afterglow in science pixels that have been saturated in earlier exposures. Here we report on the results of an attempt to characterize the persistence in the WFC3/IR detector using the internal Tungsten flat field lamp to illuminate the array. We find that the persistence is well described by a power law as a function of time with a slope of -0.9. Ignoring one anomalous visit, the average persistence persistence 1000 s after the end of a saturated exposure rises from 0.33 to 0.52 e s^{-1} as the fluence increases from 2x to 20x saturation. Unfortunately, one visit with a mean fluence of 2x saturation, or 140,000 e, showed much more persistence (0.65 e s^{-1} at 1000 s) than two other nearly identical visits executed several months later (0.32-0.34 e s^{-1}). It is unclear why the first visit was anomalous. Partially as a result, a much more extensive set of observations to characterize persistence will be carried out in Cycle 18.

Keywords: WFC3, IR detector, Persistence

Introduction

Essentially all IR detectors exhibit persistence, that is, afterimages in response to a pixel exposed to flux levels that are near saturation. The IR detector on WFC3 is no exception. Persistence was measured in the WFC3/IR detector on the ground during thermal vacuum (TV) testing and has subsequently been observed on orbit. Based on WFC3 ground data, McCullough and Deustua (2010) found that the persistence R, measured in electrons/s from a heavily overexposed pixel (2×10^{8} e), decayed as a power law of the form:

$$Rate = C\left(\frac{t}{1000}\right)^{-\alpha}$$

where t is the time in seconds since the end of the exposure, a is the power law exponent and C is the overall normalization. Based on the TV3 test results, they suggested that a C of 0.74 and a

power law exponent α of 1.25 was a good average value to use.[1] They also noted variations around the mean power law slope.

A variety of attempts have been made to characterize persistence using on-orbit data acquired either as part of the normal science observing progam and in a few cases with special calibration observations. This ISR describes one set of special internal observations (Progam ID 12089) conducted as a supplemental calibration in Cycle 17 using the Tungsten flat field lamp as a source. Here we report the results of this program.

Table 1 - Observations

Visit	Intflat Dataset	Date	Exposure time (s)	Fluence (e)
01	ibel01p1q	9-May-10	203	143,000
02	ibel02g7q	21-May-10	73	51,000
03	ibel03e2q	15-May-10	653	460,000
04	ibel04l3q	11-May-10	2003	1,400,000
05	ibel05s2q	23-May-10	32	23,000
11	ibel11l5q	31-Aug-10	203	143,000
12	ibel12gbq	30-Aug-10	203	143,000

Data

The program was comprised of 7 visits which executed between 2010 May and 2010 August. Each visit consisted of a single multiaccum flat field exposure with the internal Tungsten lamp through the F105W filter followed by a sequence of darks which extended for about 5500 s after the end of the Tungsten lamp exposure. With this filter and lamp, pixel values increase at an average rate of 705 e s^{-1}. As it typical of a flat field exposure, the rate varies somewhat across the detector as a function both of the illumination and of quantum efficiency of the detector. By adjusting the length of the multi-accum exposures, the total charge (or fluence) was varied from about 23,000 to 1,400,000 e, that is from about 0.3 to 20x of saturation, where saturation is taken to be 70,000 e. The various fluences are shown in figure Figure 1 overlaid on fairly typical example of persistence measured following the an observaton of a very bright star, Fomalhaut.

[1] Note that McCullough and Deustua used hours as the fiducial time rather than 1000 s. We have converted their results to our convention everywhere.

Three of the visits were designed to be identical in terms of the amount of light placed on the detector: Visits 01, 11, and 12. Most of the visits had the identical set of 15 darks, with SPARS25, NSAMP=15 readouts. Visit 04 was similar, except that a dark with RAPID, NSAMP=15 was inserted as the first multiaccum after the Tungsten lamp exposure to provide better sampling at short time intervals. Visit 12 was intended to test whether the readout pattern affects the measured persistence, and the sequence of darks was 1 RAPID, NSAMP=15 followed by 8 SPARS50, NSAMP=15 readouts. A summary of the observations is presented in Table 1. There were no obvious anomalies in any of the observations, and in particular, the count rates obtained from the Tungsten lamp were the same to within 1-2% in all of the various visits.

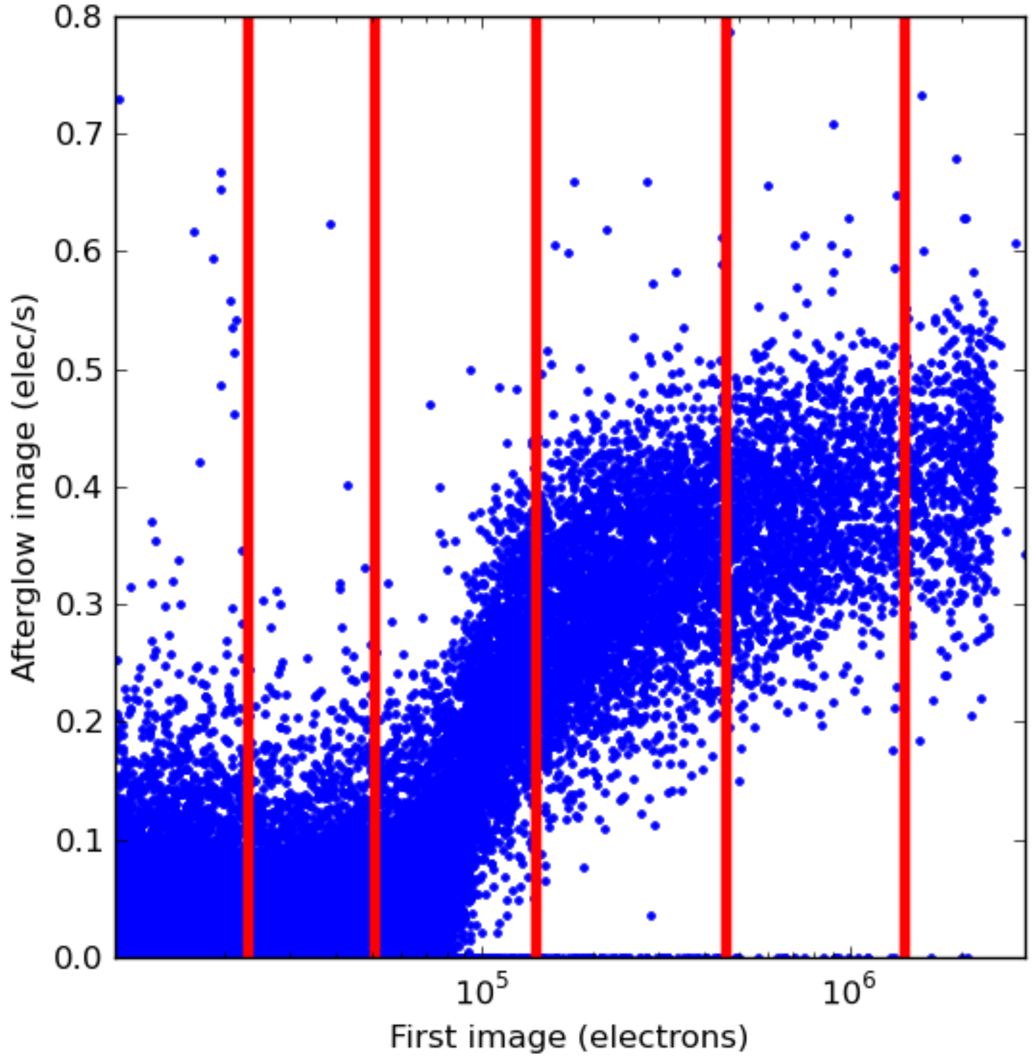

Figure 1 - The persistence as observed individusl pixels in a Dark exposure shortly after the IR deector had been illuminated by a very bright star, in this case Fomalhaut. The x-axis shows the illumination in electrons of the last of the Fomalhaut exposures while the y-axis shows the persistence in e s^{-1}. The red vertical lines shows the five levels to which the array was illuminated with the Tungsten lamp in this calibration program.

Results

Figure 2 shows the mean persistence measured from all "good" pixels (defined by the flags in the DQF or data quality extension) as a function of time after the end of the Tungsten lamp exposure in each of the visits. The means were measured from re-calibrated flt files, with keywords such as DARKCORR, FLATCORR, and UNITCORR set so that dark counts were subtracted and units converted from DN to e s^{-1}. As is evident, persistence is long-lived in the IR detector, and roughly does follow a power-law decay. At 1000 s, the maximum amount of persistence is about 0.6 e s^{-1}, not too different from that anticipated from the ground data results by McCullough and Deustua. The persistence levels as a function of the prior illumination level are slightly lower than those measured from point sources in images of 47 Tuc (Riess, 2010).

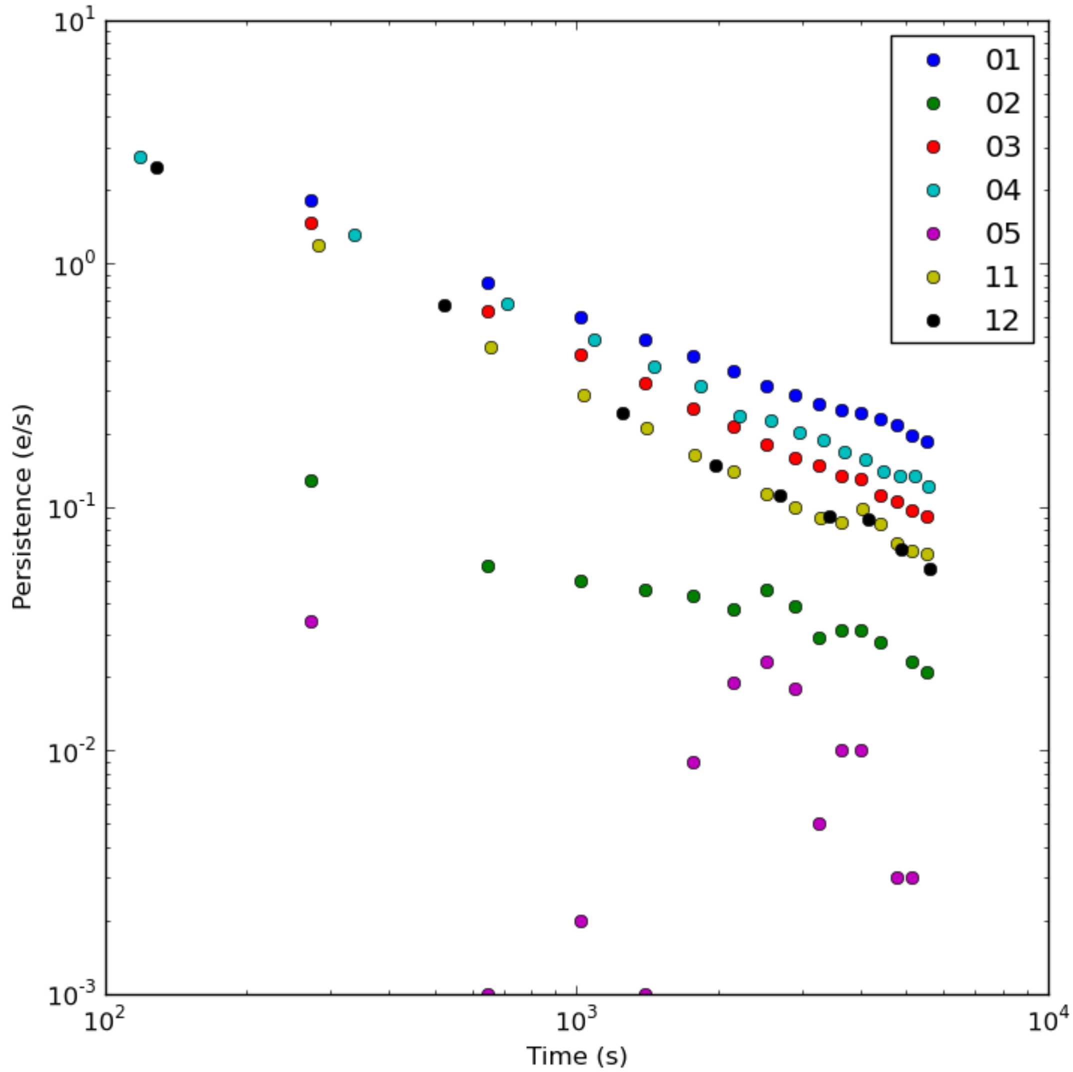

Figure 2 A log-log plot of the persistence in electrons s^{-1} as a function of time from the end of the Tungsten lamp exposure. The legend provides the color-coding identifying each visit.

All of the visits, except Visit 05, which has a nominal fluence of 22,000 e, show clear evidence of persistence. Visit 05 does generally show a very slight excess in the average count rate over zero, but the (median) dark count rate in the detector is 0.048 e s^{-1} (Dressel et al. 2010) and so the positive signals that we see for this visit are most like attributable to small errors in the dark subtraction.

Close inspection of Figure 2 does reveal a problem, as shown more clearly in Figure 3. The three visits with Tungsten lamp exposures intended to reach fluences of 140,000 e, namely Visits 01, 11, and 12, do not follow the same persistence curves. In particular, Visit 01, which occurred in 2010 May, shows more persistence than either of the two visits, 11 and 12, which were obtained within a day of one another in late August.[2] Indeed, the persistence inVisit 01 is higher than in any of the other visits, including those with 10x the fluence on the detector. It is also clear that the power slope of the decline is less steep for Visit 01 than for the other two observations. Excluding Visit 01, the amount of persistence increases with overall Tungsten lamp exposure.

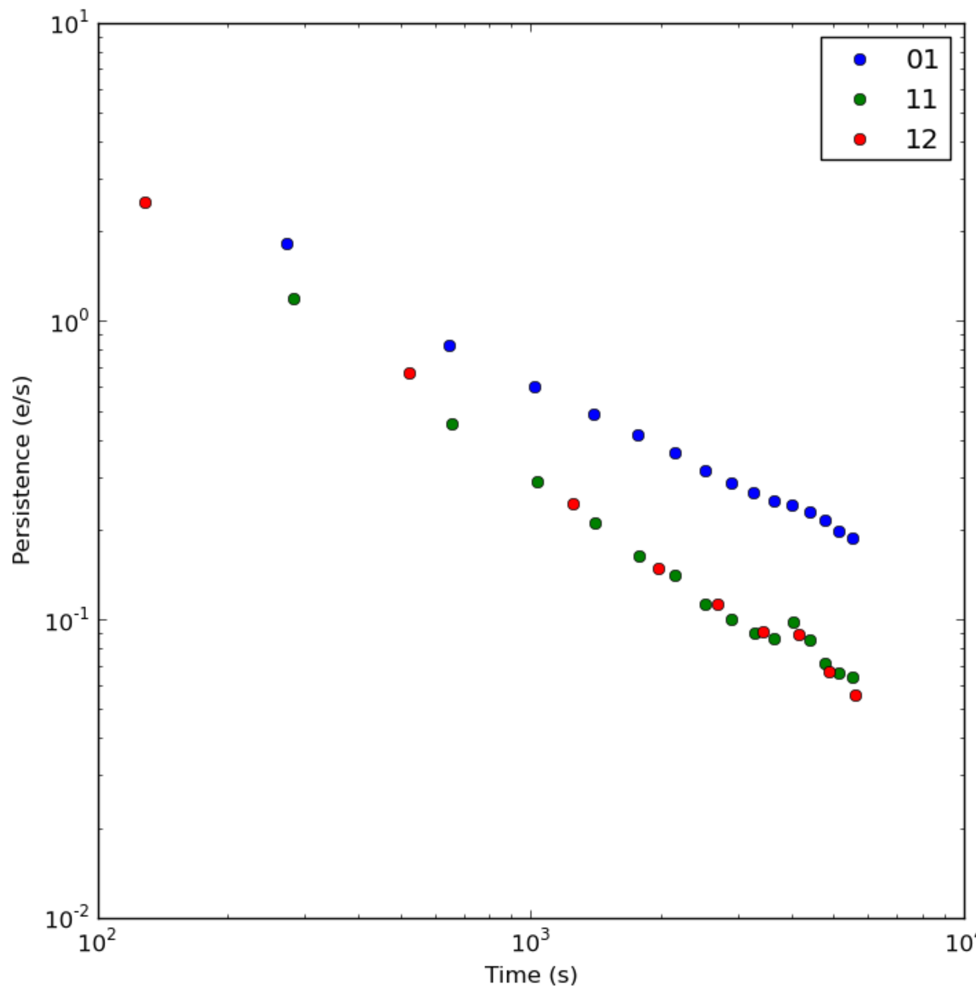

Figure 3 - The persistence from the 3 visits which had Tungsten lamp exposures of about 140,000 e. Note that the color scheme is not the same as in Figure 1.

[2] In Cycle 18, we are repeating this program and will conduct 3 visits at each level separated by about a month.

We have investigated whether there might have been a problem associated with Visit 01. Inspection of the commanding for Visit 01 in the SMS indicates that the lamp was turned on and off at the appropriate times. The time between the beginning of the Tungsten lamp exposure and the beginning of the first Dark exposure also occurred when expected, and is very similar to that in Visits 11 and 12. The calibration files and software used to process the data were identical. The countrates in Visit 01, 11, and 12 are the same to within ~1%. Visit 01 occurred nearer to an SAA passage (128 min) than the other two visits (257 min and 168 min for 11 and 12, respectively), but the IR channel on WFC3 has not shown evidence for elevated dark rates following SAA passages, and differences of the magnitude required would have been observed. None of the 3 visits followed sub-array exposures, which are known to produce banding some of the time in subsequent full-frame exposures.

There is nothing to indicate that the IR detector had been exposed to excessive amounts of light prior to the beginning of Visit 01. Observations from GO program 11602, Visit 05, immediately preceded Visit 01 from the calibration program. The GO images are normal for a high latitude field, and have few, if any, overexposed pixels. They did not have abnormally high background levels or anything that on visual inspection looked unusual.

The difference in the count rate in Visit 01 and that in Visits 11 and 12 is not a simple offset. Instead, it declines from from about 0.6 e s^{-1} at 300 s to 0.17 e s^{-1} at 5000 s, as one would expect if the signal from Visit 01 was due to persistence. Darks are acquired on a fairly regular basis for the IR channel of WFC3 IR, and in Cycle 17 these were obtained through program ID 11929. As it happened, several visits from this program executed shortly after Visit 01. More specifically, Visit 01 ended at 2010-05-09 23:18:35 and Visit 4T from the dark calibration program began on 2010-05-10 01:59:27, that is, about 2 and a half hours later. A second Visit, 4U, from the normal dark program began at 2010-05-10 03:01:10, nearly 4 hours after the end of Visit 01 from the persistence program, and more than 5 hours after the Tungsten lamp was turned off at 2010-05-09 21:43:49. Data obtained from both of these visits shows elevated count rates compared to other darks obtained with the same type of multiaccum sequences. In summary, there does appear to be an afterglow, likely persistence, in Visit 01 but we do not have an explanation for why the persistence in Visit 01 was greater than in Visits 11 and 12. Unless otherwise indicated, we have simply excluded Visit 01 from the remainder of the analysis.

As shown in Figures 4 and 5 below,the persistence is not completely uniform across the array. The Tungsten lamp illumination, shown in the upper left image, is not completely uniform but has a gradient, brighter near the “wagonwheel” feature in the lower right quadrant of the array (an area of generally lower QE). The persistence in the first dark (flt) obtained as part of Visit 02, which began with a nominal Tungsten lamp exposure of 50,000 e (somewhat less than saturation), clearly resembles the Tungsten lamp exposure illumination pattern. However, in the first dark from Visit 04, which began with a nominal Tungsten lamp exposure of about 1,400,000 e (~20x saturation), there is a clear gradient in the persistence (~15%), which is more prominent at both low and high column numbers in the detector. All of the darks for visits in which the Tungsten lamp exposure exceeded full well have this character. Moreover, in Visit 11 (the lower right image), there appear to be “splotchy” regions where the persistence is ~10% less than elsewhere, superimposed on the general trend. Both Visits 11 and 12 (140,000 e tungsten exposures) which were obtained in late August have these splotchy features. The features appear at roughly the same positions in both visits, and persistence "within" the features decays at about the same rate as persistence in regions that do no show the "splotches". As shown in Figure 1, 140,000 e is the point at which the persistence flattens out, and one can speculate that this level is one that might be expected to reveal differences between pixels. Another interesting fact is that the "wagonwheel" is prominent in persistence images in which the fluence of the Tungsten lamp is only a few times saturation, but becomes less apparent at very high levels. This is as expected if the "wagonwheel" is a region of low quantum efficiency but normal persistence properties.

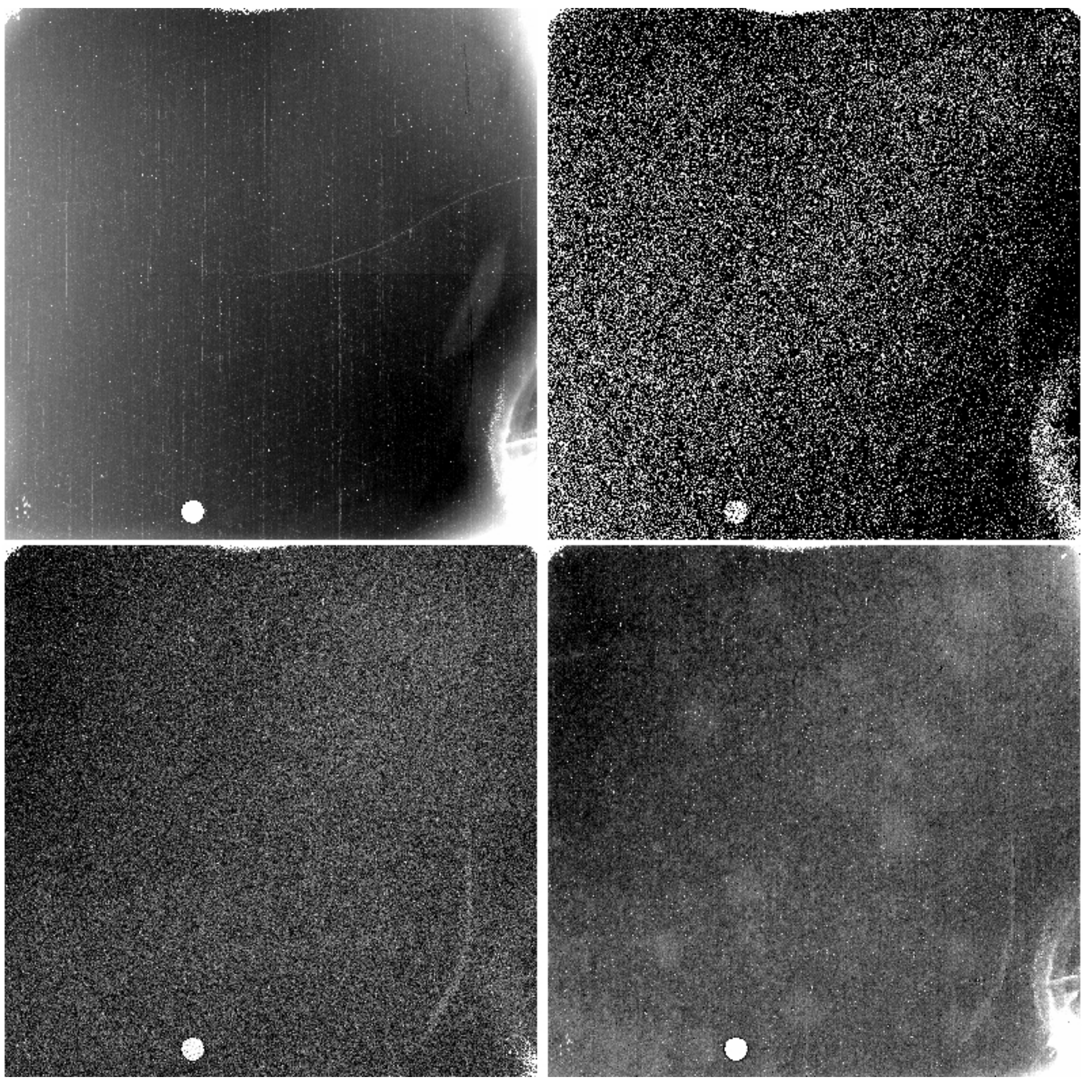

Figure 4 - Upper left - The image of one of the unsaturated Tungsten lamp exposures. Upper right - The image from the first dark from Visit 02 (after a tungsten exposure with level ~50,000 e, just under saturation). Lower left - The image from the first dark from Visit 04 (after a tungsten exposure with level ~1,400,000 e, about 20x saturation). Lower right - The image of the first dark from Visit 11 (after a tungsten exposure with level ~140,000 e, ~2x saturation).

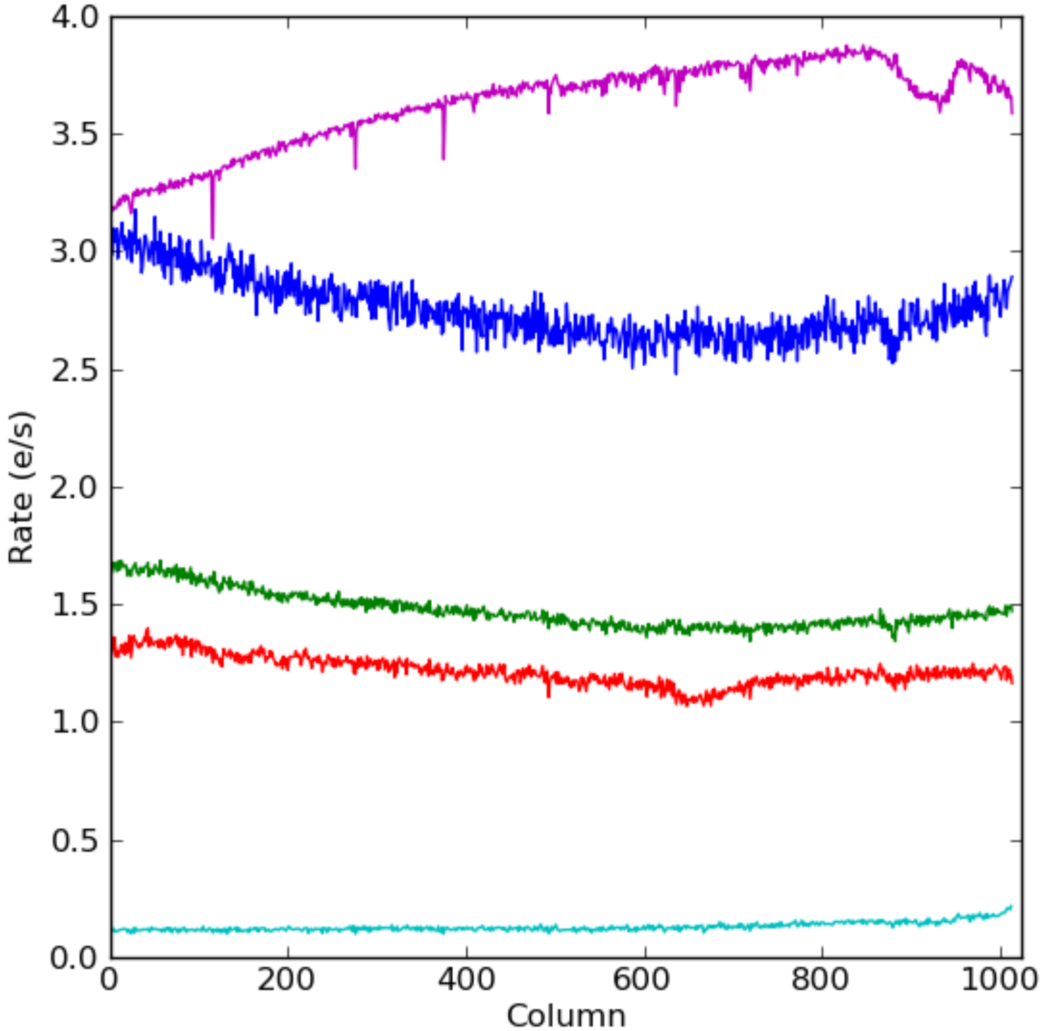

Figure 5 - Persistence as a function of row number. The magenta curve shows the median count rate of the lamp illumination divided by 200 in a 100 row wide region centered on row 500. The blue, green, red and cyan curves show the persistence as measured from the first (flt) dark from Visits 04 (1,400,000 e), 03 (460,000 e), 11 (140,000 e), and 02 (50,000 e).

Persistence Decay

Following McCullough & Deustua (2010), we have fit the persistence as measured in the calibrated flt files data to a power law normalized at 1000 s. The results for fits to the average persistence in each visit are shown in Table 2, organized in terms of increasing exposure with the Tungsten lamp. The model fits represent the persistence well. The difference between the model and the data is generally small (typically of order 0.02 e s^{-1}). We also carried out fits to 100 x 100 sections of the images. We find vary little variation in the fits made on this scale. As an example, for Visit 03 (460,000 e), the standard deviation of the value of the normalization constant was 0.03 e s^{-1}, compared to the normalization of 0.435 e s^{-1}. Similarly for the same visit, the standard deviation of the various fits to the power slope α was 0.014 compared to the mean value of 0.935. We caution that this does not necessarily mean that there are not significant varitions in α, just that these variations, if they exist, average out on a scale of 100 x 100 pixels.

On the other hand, there do appear to be differences in slope between the various visits. Some of the differences, namely those associated with Visit 02 (51,000 e) and Visit 05 (23,000 e) are surely due to the fact that the amount of persistence in these images is small or non-existent. Visit 01 is, as we have noted earlier, is anomalous for reasons not fully understoond and is disregarded. If the visits are sorted in order of increasing fluence, not only does the constant, C, increase, but the power law slope α decreases, a characteristic that could be attibuted either to the the amount of overexposure (i.e charge), or to the amount of time that the pixels were overexposed, since the way the fluence was obtained was to increase the exposure time.

Table 2 – Power law fits

Visit	Fluence (e-)	C	α
05	23,000	0.01	0.65
02	51,000	0.06	0.59
01	143,000	0.65	0.79
11	143,000	0.31	1.06
12	143,000	0.34	0.98
03	460,000	0.43	0.93
04	1,400,000	0.52	0.78

In an attempt to determine a nominal value of α to use, we rescaled the measured persistence in each of the observations to a common value of 1 at 1000 s, eliminating data values where the persistence was measured to be less than 0.05 e s^{-1}. We then fit the rescaled data to a power law. The results are shown in Figure 6. The fitted value of α was 0.88; the RMS error in the fit corresponds to 10% of the persistence signal at 1000 s, and is dominated by differences between the model and the data at short times.

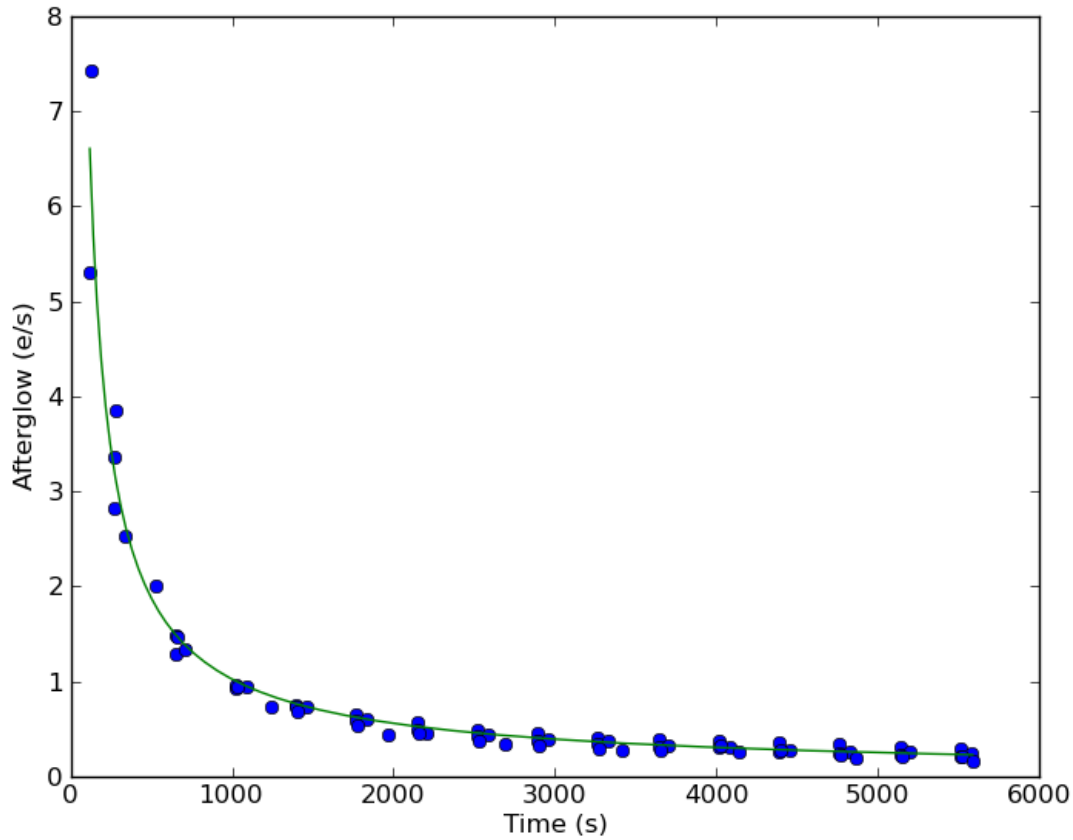

Figure 6 - A power law representation of the renormalized persistence as a function of time. The data points are plotted as filled blue circles and the model is the solid (green) curve, Unlike some of the earlier figures, here both the x and y scales are linear.

The power law slopes that we measure from the Cycle 17 data are slightly shallower than those measured from the ground tests ($\alpha \sim 1.0$ for flat fields and ~1.25-1.6 for small sources with FWHM~5.5 pixels); the values of the persistence at 1 hour for Visit 03 and 04 (0.13 and 0.19 e s-1, respectively) bracket the value predicted by McCullough & Deustua. Specific tests will be carried out in the Cycle 18 Persistence calibration program to check whether the persistence from stars decays at the same rate as the persistence in flat fields (Tungsten lamp exposures).

Conclusions

We have measured the persistence that results from illuminating the WFC3/IR detector with light from the internal Tungsten lamp at 5 different fluence levels ranging from 23,000 e to 1,400,000 e (0.3 – 20x saturation). Persistence is observed at all levels except at 23,000 e, where one would probably not have expected it to exist. At high fluence levels, persistence lasts to at least 5400 s after the end of the flat field exposure. At 1,000 s after saturation, the persistence ranges from

0.35 to 0.65 e s^{-1}, including data obtained from the anomalous Visit 01. Rescaling the persistence to 1 at 1,000 s, the persistence decays roughly as a power law with a slope α of about 0.9. But the slope of the power law decay appears to decrease with increasing fluence. There is not enough data to determine the root cause of the slope changes, particularly since one of the visits with a fluence level of 143,000 e showed a very different response than the other two at the same fluence level, though at a different epoch. The Cycle 18 Persistence calibration program will attempt to address this problem by increasing the number of levels at which the persistence will be measured from 4 to 10 and repeating the experiment 3 times.

Acknowledgments

References

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