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WFC3 TV3 Testing: Quantum Yield in the UV

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ABSTRACT

The gain for the integrated WFC3 UVIS-1' flight detector has been computed using the mean-variance method on flatfields taken in a small set of UV filters. These gains are compared to the gain computed in the visible (F606W) in order to estimate the quantum yield for the UVIS-1' detector. The measured quantum yields are 1.07, 1.08, 1.03, and 1.00 e^-/photon, for F218W, F225W, F275W, and F336W, respectively, with errors of ~0.02 e^-/photon, except for F218W, where the error is ~0.06 e^-/photon due to some adverse effects attributed to the D2 lamp warm-up. The measured values are up to ~30% less than the predicted quantum yields (1.55, 1.45, 1.25, and 1.01e^-/photon).

Introduction

At optical wavelengths, an incoming photon generates a single electron within the silicon of a CCD, i.e., the quantum yield is 1. In devices like WFC3, which are directly sensitive to the UV (unlike WFPC2, which had a lumogen coating to down-convert UV photons to visible wavelengths), there is a finite probability that a UV photon will generate more than one electron, or a quantum yield >1. This behavior can be a benefit, for example, in detecting faint targets in the UV.

Quantum yield values are used in a variety of situations. Quantum efficiency (QE) curves are typically scaled downwards by the quantum yield, thereby avoiding QE values greater than 1 (Janesick 2001). Of course, applying a quantum yield correction that is too high can result in an underestimate of the actual QE of the device in the UV. An exposure time calculator (ETC) must account for quantum yields larger than 1 in order to provide correct predictions of the number of expected electrons in response to a particular input flux (e.g., when estimating exposure levels attainable without saturating the device), yet it must also provide correct S/N estimates (extra electrons cause the noise to deviate from a pure Poisson distribution based on the number of incoming photons). Both the WFC3 ETC (*http://www.stsci.edu/hst/wfc3/tools/etc*; see also Brown 2008) and the HST synthetic photometry package (*http://www.stsci.edu/resources/software_hardware/stsdas/synphot*; Laidler 2008) include the capability of specifying quantum yield terms.

For WFC3, the quantum yield was initially expected to be 1.7 e^-/photon at 200 nm, decreasing linearly to 1.0 at 340 nm; specifically, the factors were computed as λ_{crit} / λ, where the critical wavelength is 339.4 nm which corresponds to the wavelength of the photon with an energy (3.65 eV) sufficient to generate an electon/hole pair in silicon (Janesick 2001). However, there were indications during TV3 that the quantum yield in WFC3 was not as large as expected, thus a program was included to measure the values in the UVIS channel. This report presents the results of that test.

Observations and Analysis

The flatfields used in the quantum yield analysis are summarized in Table 1. The UV data were taken with four different filters using the deuterium (D2) lamp of the internal calibration subsystem, while the F606W data were taken using the ground system optical stimulus (CASTLE). All but one set were read out in subarray (1024x1024) format; the subarray was positioned in the outer corner of the C amp, including the overscan regions so that a bias level subtraction could be performed. The full-frame set was part of the standard gain program and has been included here as a control sample: the same subarray area was extracted from the full-frames and processed in the same manner as the data taken as subarrays. Each set contained at least six pairs of images with exposure times chosen to provide exposure levels of ~500-30,000 DN at the nominal gain of 1.5 e^-/DN.

Table 1. List of flatfields.

tvnum range	filter	observation date	illumination	data format
54142-54153	F218W	2008-03-27	D2 calsystem	subarray
54154-54165	F225W	2008-03-27	D2 calsystem	subarray
54166-54177	F275W	2008-03-27	D2 calsystem	subarray
54178-54189	F336W	2008-03-27	D2 calsystem	subarray
54190-54201	F606W	2008-03-27	CASTLE	subarray
50946-50970, 50997	F606W	2008-03-12	CASTLE	subsection of full-frame

All raw images were first processed through calwf3 version 1.0 in order to remove the bias level (blevcorr=perform). Each pair of images at a given exposure level was used to form an average and a difference image. While the calibration subsystem images show considerable structures, as is normal for the internal flatfields, the difference images are featureless, as expected, except for the occasional cosmic ray outlier. In terms of the average exposure levels, the first three image pairs in the F218W filter seemed to have anomalously low counts. The F218W set was the first in the UV observing sequence, so these low counts may be due to the D2 lamp not having warmed up sufficiently at the time the flatfields were acquired. The exposures were fast (subarrays with short exposure times) which could explain why more than 1-2 images were impacted. To avoid any possible negative effects on the results, only the last 3 image pairs from the F218W dataset are used here.

Following the mean-variance methodology used to compute the nominal instrument gain (Baggett 2008), the mean signal level is plotted versus the variance and the inverse of the resulting slope is the gain. The mean levels were measured on the average images while the variances were taken from the difference images (standard deviation squared divided by two). The statistics were measured in two ways: across the entire subarray as a whole, i.e., a single value at each exposure level in each filter; and in small 20x20 pixel subsections covering the subarray, providing a cloud of points at each exposure level. In all cases, the lower left corner of the subarrays was not included in the statistics, to avoid some vignetting in the CASTLE illumination pattern (conservatively, columns 1-200 and rows 1-200 were excluded). The mean-variance plot based for all five filters is shown in the left plot of Figure 1. As can be seen in the plot, there is a clear trend for steeper slopes, i.e., smaller gain values, at bluer wavelengths.

The gain values as a function of filter are tabulated in Table 2. Results for several different methods are shown: no clipping and with clipping (3 iterations of 3-sigma clipping) of the entire subarray statistics, as well as using small 20x20 subsections covering the subarray, removing individual obvious outliers (typically <5, out of 8000 total points per plot). The quantum yield parameter is the ratio of the gain in the visible to the gain in the UV (Janesick 2001). Although the absolute values of the gain can change slightly, depending upon the method used to determine the statistics, they do so across all wavelengths such that the resulting quantum yield values remain the same. The graph at right in Figure 1 shows the quantum yields plotted as a function of pivot wavelength of the filter; a linear fit (dashed line) to the measured UV quantum yielded a slope of -6.44e-04 with intercept of 1.22.

Figure 1: At left are the mean-variance plots based on the full subarray statistics showing the fits for F218W (crosses), F225W (circle), F275W (plus), F336W (box), and F606W (diamond). At right are the resulting quantum yields plotted as a function of pivot wavelength; the dashed line is a linear fit to the UV points.

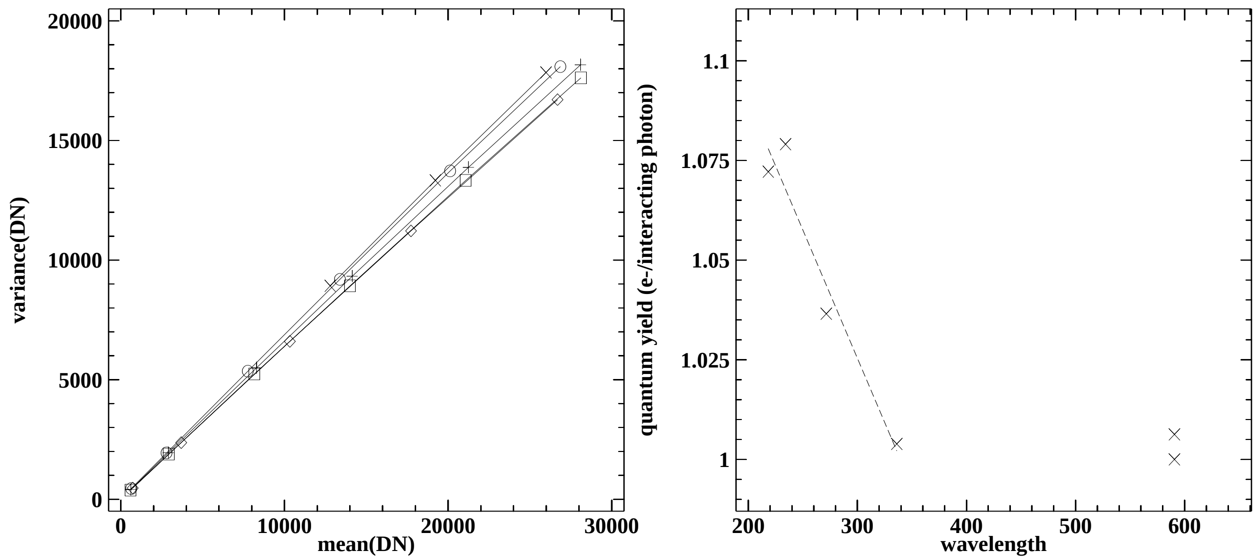

Table 2. Gain and quantum yield as a function of wavelength. Quantum yields are in units of e^-/interacting photon, with errors of ~0.02 except for F218W, where they are ~0.06.

filter	pivot wavelength (nm)	no clipping, entire subarray			clipping, entire subarray			20x20 pixel regions, outliers removed		
		gain	error	quantum yield	gain	error	quantum yield	gain	error	quantum yield
F218W	218.3	1.47	0.09	1.07	1.52	0.05	1.07	1.48	<0.01	1.07
F225W	234.1	1.47	0.02	1.08	1.51	0.01	1.08	1.47	<0.01	1.08
F275W	271.5	1.53	0.03	1.04	1.58	0.01	1.03	1.53	<0.01	1.04
F336W	336.1	1.58	0.02	1.00	1.63	0.01	1.00	1.58	<0.01	1.00
F606W	590.7	1.58	0.01	1.00	1.63	0.01	1.00	1.58	<0.01	1.00
F606W (full)	590.7	1.57	0.01	1.01	1.62	0.01	1.00	1.57	<0.01	1.01

Conclusions

The quantum yields have been measured in a subset of filters in the UV to be 1.07, 1.08, 1.03, and 1.00 e^-/photon, for F218W, F225W, F275W, and F336W, respectively, with errors of ~0.02 e^-/photon (error in F218W is ~0.06); the values are up to 30% less than originally predicted. These values will be incorporated into the WFC3 ETC and synphot tables.

Acknowledgments

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References

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