WFC3 Thermal Vacuum Testing: UVIS Science Performance Monitor

H. Bushouse and O. Lupie

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ABSTRACT

During WFC3 thermal-vacuum testing in September and October 2004, the UVIS28 test procedure, “UVIS Science Performance Monitor”, was executed eight times; twice in ambient conditions and six times in thermal-vacuum. This procedure tests and monitors the stability of biases, darks, flats, and both unresolved and resolved sources. The results show very good repeatability of bias, dark, photometric, PSF, and flatfield measurements.

1. Introduction

The WFC3 UVIS camera must maintain high stability in its performance over month- and year-long time scales if it is to provide reliable scientific data. The UVIS28 test procedure provides monitoring of the scientific performance of the UVIS channel during ground testing. The basic science functions include biases, darks, internal and external flats at multiple wavelengths, resolved sources to measure photometric throughput and unresolved sources to monitor optical quality (see Reid et al. 2004). The data allow for the measurement of bias level, dark current, read noise, dead and hot/cold pixels, optical throughput, and PSF quality, as well as the stability and repeatability of all of these characteristics.

The UV28S01 SMS was executed a total of eight times during the course of thermal-vacuum testing of WFC3 in September and October 2004. Two iterations were performed under ambient conditions. The first was before chamber pump-down occurred and the second was after the chamber had been returned to ambient conditions following thermal-vacuum tests. Six iterations of the procedure were performed under thermal-vacuum con-
ditions, three times during each of the two phases of science calibration activities. Table 1 lists the dates and other pertinent information for each of the eight runs. The CCD temperature was about 12° C warmer during the test runs conducted in ambient than it was during thermal-vacuum tests. The optical bench temperatures were also significantly different in these two environments. In ambient, the optical bench temperatures are generally around 20° C, while under thermal-vacuum they are near 0° C.

Table 1. Test Run Information

<table>
<thead>
<tr>
<th>Run #</th>
<th>Date (UT)</th>
<th>Day of Year</th>
<th>SMS</th>
<th>Environment</th>
<th>CCD Temp (°C)</th>
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<td>UV28S01A</td>
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2. Test Contents

The UV28S01 SMS consists of a total of 22 exposures. The parameters for the exposures are listed in Table 2. All exposures were obtained using a commanded CCD gain setting of 1.5 and a commanded CCD bias offset value of 3. There is a combination of full-frame and 512x512 pixel subarray exposures, as well as unbinned and binned exposures. Matching biases and darks were obtained for each of the full-frame, subarray, unbinned, and binned modes, which were used to calibrate the science exposures for each of those modes. A combination of point source, extended source, and flatfield exposures were also obtained. The point source exposures are used to monitor optical quality and PSF characteristics. The extended source exposures were used in conjunction with flux calibration measurements performed by the CASTLE optical stimulus (OS) in order to monitor the absolute throughput of WFC3 at different wavelengths. Flatfields were obtained at different wavelengths, using both the internal WFC3 calibration subsystem lamps and the external OS lamps.
Table 2. UV28S01 Exposure Parameters

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<th>Image Size</th>
<th>Bin Size</th>
<th>Amps</th>
<th>Internal Lamp</th>
<th>OS Lamp</th>
<th>OS λ (nm)</th>
<th>OS BW (nm)</th>
<th>OS Img Pos</th>
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Column explanations:
(1) ObsID value for the corresponding STScI ground system IPPSSOOT-style image file name. (2) Type of image or source present. (3) Exposure time. (4) WFC3 filter. (5) Image size. Full, unbinned raw images are 4206x4140 pixels; Full, 3x3 binned raw images are 1402x1380 pixels. (6) On-chip binning factor: 1 = 1x1 binning; 3 = 3x3 binning. (7) CCD amplifier readout mode. (8) Internal cal system lamp. (9) Optical stimulus lamp. (10) OS monochromator central wavelength. (11) OS monochromator bandwidth. (12) OS image source position. (13) OS flux cal measurement obtained.
3. Data Reduction

Bias and dark images in unbinned, full-frame mode were obtained as part of the UV28S01 science monitor program, which can, in principle, be used to construct bias and dark calibration reference files to be used to reduce the remaining exposures. However, because there were only six iterations of the science monitor performed under thermal-vacuum conditions, and the fact that the longest darks were only 1000 seconds, it was decided to use biases and darks obtained from the UV01S03 program to construct reference files. UV01S03 was executed five times, producing a total of ten full-frame, unbinned bias images, and also ten full-frame, unbinned, 3000 second darks. The larger number of images and the longer exposure times for the darks yield higher quality bias and dark reference images to use for processing the UV28S01 program data and also allow an independent comparison with the bias and dark data obtained from UV28S01.

The ten raw biases from UV01S03 were processed with calwf3, measuring and subtracting the row-by-row bias levels from the serial and parallel virtual overscan regions and then trimming the overscan regions. The trimmed bias images were then combined, using the IRAF imcombine task. The resulting bias reference image was then used to process the darks from UV01S03. The 10 raw darks were processed with calwf3 to first subtract the row-by-row bias from the overscan regions and then the reference bias image was subtracted. The 10 bias-subtracted and trimmed darks were then combined to form a dark reference image.

For the 3x3 binned datasets, the six binned bias (ObsID 0S) and dark (ObsID 0Q) images obtained during thermal-vac executions of UV28S01 were used to form bias and dark reference files. The data processing procedures were the same as for the unbinned images described above.

All of the exposures from all eight runs of UV28S01 were then processed with calwf3, using the appropriate reference files to perform bias and dark subtraction, as needed.

4. Results

4.1. Bias Images

Three different types of bias images are included in the UVIS science monitor procedure: a full-frame, unbinned bias (ObsID 01), a 512x512 pixel subarray bias (ObsID 02), and a full-frame, 3x3 binned bias (ObsID 0S). The only processing performed by calwf3 on these images is the row-by-row bias level subtraction (the “blevcorr” calibration step). The bias value for each row is determined using the pixel values in the serial and parallel virtual overscan regions of the raw images.
4.1.1. ObsID 01: Full-frame, Unbinned Bias

The mean and rms scatter of the overscan bias levels measured by calwf3 for the four image quadrants corresponding to each readout amplifier are listed in Table 3. The bias levels show good repeatability amongst the eight repetitions of the test. The rms scatter amongst images is less than 1 DN and in some cases as low as a few tenths of a DN. There are systematic bias level offsets associated with each of the four CCD amplifiers, which is not unexpected. The offsets are 100 DN or less. There is also a systematic offset in bias level for the images taken in ambient conditions, as compared to those taken in thermal-vacuum. These offsets have a range of 2-6 DN for the different amplifiers.

The mean residual signal in the overscan-subtracted images was measured, in order to test the reliability of using the overscan regions to estimate the bias level in the active image areas. The mean residuals were generally less than 0.1 DN (0.15 e⁻) for each amp, although for amp-A there is one image with a mean residual of 0.18 DN (0.28 e⁻). This level of repeatability easily meets CEI specification 4.6.14, which requires bias levels correctable to 1 e⁻ rms. The rms pixel-to-pixel scatter within the overscan-subtracted images is 2.2 DN (3.4 e⁻), which is consistent with the level of read noise in the CCD’s.

Table 3. Bias Levels in ObsID 01 and 0S Images

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<th>ObsID 01</th>
<th>ObsID 0S</th>
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<td>Thermal-Vac</td>
<td>Ambient</td>
</tr>
<tr>
<td></td>
<td>Mean (DN)</td>
<td>σ (DN)</td>
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<td>B</td>
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<tr>
<td>D</td>
<td>2606.2</td>
<td>0.8</td>
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4.1.2. ObsID 0S: Full-frame, Binned Bias

The mean and rms scatter of the overscan bias levels measured by calwf3 for the four image quadrants corresponding to each readout amplifier are listed in Table 3. As with the unbinned bias images from ObsID 01, the scatter in mean bias level for a given image quadrant is less than 1 DN throughout the six test runs performed in thermal-vac. We also again see systematic offsets in bias level amongst the quadrants, as well as between the ambient and thermal-vac environments. The sense of the offsets between quadrants is the same as for the unbinned bias images, although the overall bias levels are lower by ~40 DN.

The mean residual signal in the bias-subtracted images produced by calwf3 has a range of 0.5-1.0 DN. This is significantly larger than the ~0.1 DN residual measured in the unbinned bias images from ObsID 01. This residual appears to be due to a real offset in
pixel values between the overscan and active image areas of the binned raw images. The mean signal in the serial virtual overscan area is systematically ~0.7 DN lower than that in the active image area (see Figure 1). Thus the bias levels measured and subtracted by calwf3 are systematically low and leave a residual signal in the active image area.

A closer look at the signal levels in the active and overscan areas of the unbinned raw bias images in ObsID 01 indicates that the same effect is present in those images, although at a much reduced level. These images show a systematic offset in bias signal of ~0.08 DN between the active and overscan regions, which is consistent with a factor of 9 difference due to the 3x3 binning in the ObsID 0S images (see Figure 1).

If this offset is stable, it should be removed during calwf3 processing of science images via the subtraction of a bias reference image (the “biascorr” calibration step), because the bias reference images will contain the same residual signal.

4.1.3. ObsID 02: Subarray Bias

These subarray images do not contain any overscan area, therefore it is not possible to directly measure the bias level in each image. In this case, calwf3 subtracts a constant bias value from each raw subarray image, where the bias value comes from a calibration reference table and is the mean bias value, per amplifier quadrant, previously computed from a large number of full-frame bias images. The mean residual signal measured in the processed, bias-subtracted images ranges from 0.5 to 1.5 DN, with an rms scatter within each image of 2.2 DN. This indicates that the accuracy of bias subtraction that we can expect for subarray images containing no overscan is on the order of 1 DN.

4.2. Dark Images

Three different types of dark images are included in the UVIS science monitor procedure: a full-frame, unbinned, 1000 second dark (ObsID 0C), a 512x512 pixel subarray, 300 second dark (ObsID 03), and a full-frame, 3x3 binned, 300 second dark (ObsID 0Q). The raw darks were processed with calwf3 to remove row-by-row bias levels (“blevcorr”) and to subtract a bias reference image (“biascorr”).

4.2.1. ObsID 0C: Full-frame, Unbinned Dark

The dark signal was measured in the processed images by computing the sigma-clipped mean of a 1000x1000 pixel area within each CCD quadrant. These measurements were then converted to units of e-/pix/hour using the CCD gain values from Baggett (2005a). The results are shown in Figure 2. A combined dark image was also created from the six images obtained in thermal-vac, using the IRAF imcombine task. The standard deviation for a given pixel within the stack of six images is 2.2 DN (3.4 e-), which is consistent with the expected level of read noise. The six thermal-vac images yield a mean dark cur-
rent, averaged over the entire detector, of 0.37 e⁻/pix/hour, which is in good agreement with the results of Hilbert & Baggett (2005). The two images taken in ambient conditions, at a warmer CCD temperature, have a mean dark current of 2.87 e⁻/pix/hour. The dark current appears to be relatively stable throughout the thermal-vac tests, with the scatter amongst the six runs being ~0.2 e⁻/pix/hour.

### 4.2.2. ObsID 0Q: Full-frame, Binned Dark

The six binned images obtained in thermal-vac conditions were combined to form a mean binned dark. The mean signal in the combined dark is ~0.19 DN/pix. After accounting for binning, gain, and integration time, this translates to a dark rate of ~0.39 e⁻/hour per unbinned pixel, which is in good agreement with the value derived from the unbinned images in ObsID 0C. The two images taken in ambient conditions have a dark rate of ~1.7 DN/pix (~3.6 e⁻/pix/hour). The dark rates derived from individual images are plotted in Figure 2. The scatter from image to image is similar to that in the ObsID 0C unbinned images and is on the order of ~0.2 e⁻/pix/hour (in units of unbinned pixels).

### 4.2.3. ObsID 03: Subarray Dark

The mean residual signal in the bias-subtracted images for these subarray darks is 0.7 DN/pix. If this residual signal is all due to dark current, it translates into a dark rate of ~13 e⁻/pix/hour, which is a factor of ~35 higher than the dark current measured from the ObsID 0C data (see above). The most likely cause of this discrepancy is inaccurate bias subtraction, due to the fact that these subarray images contain no overscan region from which to accurately measure the bias. Analysis of the ObsID 02 subarray bias images showed that residual bias levels of ~1 DN are typical in subarray images.

### 4.2.4. ObsIDs 0T and 0V: Special Mode Darks

These exposures are taken using a special CCD readout mode in which the charge in the CCD pixels is clocked in the direction of one of the readout amps on each chip while data values are read through the opposite amp. This mode of readout will be used for ground and on-orbit checks of the CCD detector when it is in an uncooled state. For all executions of the UV28S01 procedure that we are concerned with here, the CCD was cooled and therefore these exposures look very much like a bias image. They are included in the procedure to simply verify the functionality of the special readout mode. We will not deal with them further in this report.

### 4.3. Photometric Monitoring Measurements

There are five exposures in the UV28S01 procedure that can be used to monitor the photometric performance and stability of the WFC3 UVIS channel. All of these exposures use
the OS 200µm source fiber, which results in an extended source of ~40 pixels in diameter in UVIS images. OS flux calibration measurements were obtained for these exposures, in order to measure the incident source flux. Aperture photometry was performed on the processed images using the IRAF phot routine, with a source aperture of 45 pixels in radius, and a background annulus 60 pixels in radius and 10 pixels in width. The measured counts were normalized by the OS flux calibration measurement for each image to track and remove variations in OS source flux.

4.3.1. ObsIDs 04 and 05: F218W Extended Source at UV16 and UV13

These exposures use a source located at the UV16 (ObsID 04) and UV13 (ObsID 05) field positions, with a narrowband (13 nm) OS monochromator setting, at the central wavelength of the F218W filter. The peak signal levels range from 10k to 25k DN, which is well below saturation. The photometry results are shown in Figure 3. The values plotted are the result of dividing the measured counts in each image by the incident source flux (as measured by the OS flux detector), and then normalizing by the mean of these measurements.

As can be seen from both figures, the relative photometry for the exposures taken under ambient conditions (observation numbers 1 and 8 in the figures) is systematically higher, by ~10%, compared to the observations taken in thermal-vac. It is unlikely that this difference is due to either changes in bias or dark current for the ambient images. The exposure times are so short (4.0 sec) that dark current is not a factor. Furthermore, any changes in bias or dark level should be compensated for by the background subtraction process used in making the photometric measurements. Total system throughput measurements for the UVIS channel have been taken in both ambient and thermal-vac environments (see Brown & Reid 2005) and these measurements, taken without a filter in the optical path, show no change in UVIS channel throughput between ambient and thermal-vac conditions. The only thing that is different in the observations in the science monitor program is the inclusion of a filter in the path. This suggests that the change in filter temperature between ambient and thermal-vac environments is responsible for the observed change in throughput and may be associated with slight shifts in the filter bandpass as a function of temperature.

Because of this offset for the ambient results, the mean and rms scatter shown in Figure 3 have been computed using only the six data points obtained during thermal-vac (observation numbers 2-7). The rms scatter amongst these observations is ~2% for the ObsID 04 exposures, but only 0.9% for ObsID 05. It is not clear why the ObsID 04 data show a factor of two more scatter.

We have also used these data to compute the total throughput of the UVIS channel in the F218W filter, using the same methods as Brown & Reid (2005) and comparing with their
results. The six ObsID 05 exposures taken in thermal-vac, with the source located on CCD chip 2, give a mean throughput of 0.15, which agrees exactly with the chip 2 values of Brown & Reid (2005). The ObsID 04 exposures, which have the source on CCD chip 1, give a mean filtered throughput of 0.10. This decrease is consistent with the lower QE of chip 1 at this wavelength and also with the lower total throughput for chip 1 reported by Brown & Reid (2005).

4.3.2. ObsID 08: F225W Extended Source at UV16

These exposures are identical to those of ObsIDs 04 and 05, except in this case the source is imaged through the F225W filter. The peak signals range from 12k to 19k DN. The photometry results are shown in Figure 4. Here again the two ambient exposures are ~10% high relative to the six thermal-vac exposures. For this ObsID the rms scatter in photometry for the six thermal-vac images is 1.1%.

Computation of total F225W throughput gives a mean value of 0.10 from the six thermal-vac exposures. Brown & Reid (2005) report F225W filtered throughput of 0.14, but their value is for a source on chip 2, which is known to have 35-40% higher throughput at this wavelength.

4.3.3. ObsIDs 0A and 0B: F555W Extended Source at UV16 and UV13

These exposures image a source at the UV16 and UV13 field positions, using a wideband (128 nm) OS continuum source in the F555W filter. The peak signal levels are 14-15k DN. The results of the photometric measurements are shown in Figure 5. We note that the observation-to-observation variations in photometric measurements are highly correlated between the ObsID 0A and 0B exposures, suggesting that this is not random scatter, but is likely due to real systematic changes from one test run to the next. We also see that the data from the first exposures taken in ambient conditions matches those from thermal-vac very well, while the last exposures taken in ambient (observation number 8) are both 3-4% low. This offset is well outside the range of statistical uncertainty in the photometric measurements, which is ~0.2%, and also well outside the rms scatter of the other seven measurements. The rms scatter of the first seven measurements in both ObsIDs is ~0.6%, which shows excellent photometric repeatability. The fact that the final observation is low for both ObsID’s suggests that a real, but as yet unknown, change occured somewhere within the overall test system.

4.4. PSF Monitoring Images

Point-source images were obtained at two different wavelengths at the UV16 field position. ObsID 06 images used a narrow-band (13 nm) point source centered at a wavelength of 225 nm. ObsID 09 images used the OS HeNe laser diode source, which has an effective
wavelength of 633 nm. Encircled energy measurements were made with the same analysis routine used for the routine alignment and focus procedures for WFC3 (see, for example, Hartig 2005 for more details on the analysis procedures). Measurements were made within apertures of 0.15” and 0.25” diameter at each wavelength. The results are shown in Figure 6.

For the ObsID 06 images, at 225 nm, the mean encircled energies of the six observations taken in thermal-vac are 0.70 ($\sigma=0.009$) and 0.87 ($\sigma=0.006$) for the 0.15” and 0.25” diameter apertures, respectively. For the ObsID 09 images, at 633 nm, the corresponding mean values are 0.56 ($\sigma=0.005$) and 0.80 ($\sigma=0.002$). These values are all in excellent agreement with those derived from the UVIS11 PSF evaluation program that was executed during thermal-vac testing (Hartig 2005) and show little scatter throughout the course of testing (less than 1%). The data obtained in ambient conditions show some indication of having mean values that are 1-2% different than the thermal-vac measurements.

4.5. Flatfield Images

The UV28S01 procedure includes three flats taken using the WFC3 internal calibration subsystem for illumination and four flats using the external OS sources for illumination. All of the flats are obtained in full-frame mode, with two of the external flats obtained using 3x3 on-chip binning. All of the raw flatfield images were processed with calwif3, performing row-by-row bias subtraction (“blevcorr”), bias reference image subtraction (“biascorr”), and dark reference image subtraction (“darkcorr”).

The same analysis procedure was followed for each set of flats. A mean flat was formed by combining the processed images taken under thermal-vac conditions, and then each of the individual processed flats was divided by the mean flat. Statistics for the mean flat and the individually flatfielded frames were measured and are presented in the following sections. Many of the individual flats were also ratioed to one another, in order to assess the stability and repeatability of the flatfield structure over time.

A peculiar anomaly is present in all of the flats taken during repetitions one and six of the science monitor. Repetition one was taken under ambient conditions, while number six was in thermal-vac. The feature is shown in Figures 7 and 8, and appears as horizontal bands along the top and bottom edges of both CCD chips, where the signal is depressed relative to the rest of the image area. Due to its shape, this feature has come to be known as the “bowtie” effect. The feature appears at a level of 0.5-0.8% in the ObsID 0F images for repetitions one and six, and gradually decreases in level through the remaining flats taken in ObsIDs 0G through 0M. In ObsID 0L images it is reduced to a level of 0.1% and in ObsID 0M it is essentially gone. Due to this “contamination” of images taken in repetition six, these images were not included when constructing a mean flat for each of the ObsIDs. Only the remaining five good images taken under thermal-vac were used.
4.5.1. ObsIDs 0F and 0G: Internal F555W and F814W Flats

These images were obtained using one of the internal cal system’s tungsten lamps and have exposure levels of 17k to 21k DN. The mean flat constructed from the five good F555W thermal-vac images is shown in Figure 9, where the overall field gradient and bright “glints” previously discovered in cal system tungsten flats are seen (see Baggett 2005b). For both the F555W and F814W images, the rms scatter in values for an individual pixel within the stack of five thermal-vac images used to construct the mean flats is ~0.6%, which is exactly the level of Poisson noise expected from a signal of ~20k DN (~31k e−). The pixel-to-pixel scatter in individual images, after division by the mean flat, is also ~0.5%. There are no significant features present in the ratios of individual flats, indicating good stability of the flatfield structure over the seventeen day baseline of the thermal-vac tests. The only feature that appears in the ratios of ambient and thermal-vac flats is a slight change in the pattern of the scattered light glints.

4.5.2. ObsID 0I: Internal F218W Flats

These images were obtained using the internal cal system’s deuterium lamp and have exposure levels of 8k to 14k DN. The mean flat constructed from the five good thermal-vac images is shown in Figure 10, where the rather severe overall field gradient and slightly out-of-focus paint spots previously discovered in cal system deuterium flats are seen (see Baggett 2005b). The rms scatter in values for an individual pixel in the stack of five images used to construct the mean flat ranges from 0.6% to 1.1% over the field, depending on the local signal level. The pixel-to-pixel scatter in individual images, after division by the mean flat, also ranges from ~0.5% in high signal areas, to 2-3% in the lowest signal areas. Ratios of individual flats to one another sometimes show changes in the large-scale field gradient up to 3-4%, as well as some residuals from the paint spots at a level of 0.5-1.0%. The 3-4% large-scale changes seen in the ratio images are associated with slight changes in the overall slope of the very large (factor of five) illumination gradient currently supplied by the cal system D2 lamp.

4.5.3. ObsIDs 0J and 0L: External F555W and F814W Flats

These images were obtained using the tungsten lamp in the external OS and have exposure levels of 13k to 15k DN. The mean F555W flat is shown in Figure 11. The rms scatter in values for an individual pixel within the stack of five images used to create each of the mean flats is ~0.6%, as is the pixel-to-pixel scatter in individual frames after division by the mean flat. Ratios of individual flats have been created, using data from the beginning and end of the thermal-vac testing (a period of seventeen days), from the first and last ambient episodes (a period of fifty-one days), as well a combination of thermal-vac and ambient images. None of these ratios shows evidence for any large-scale changes in the flatfield structure and all have pixel-to-pixel rms scatter of 0.6-1.0%. This indicates very
good flatfield stability over periods of up to fifty-one days and also indicates that there is no significant change in flatfield structure between ambient and thermal-vac conditions.

4.5.4. ObsIDs 0M and 0O: External, Binned F225W and F218W Flats

These images were obtained using the Xenon lamp in the external OS, using 3x3 on-chip binning, and have exposure levels of ~3.6k DN in the F225W images and ~12k DN in the F218W images. The mean F225W flat is shown in Figure 12. The rms scatter in values for an individual pixel within the stack of images used to create the mean flats is ~1.4% for the F225W images and ~0.8% for the F218W images. These values are exactly what is to be expected from Poisson noise in the signal levels of the individual images. The same values are obtained for the pixel-to-pixel scatter within individual frames after dividing them by the mean flats. The noise levels in the ratios of individual images taken over the seventeen day thermal-vac period are ~1.9% and ~1.1% for the F225W and F218W images, respectively. There is also no structure seen above a level of ~1.5% in ratios of the first and last ambient images (covering a fifty-one day span) or in the ratio of ambient and thermal-vac images.

5. Summary

The eight repititions of the UV28S01 SMS that were executed on WFC3 during the thermal-vacuum testing performed in September-October 2004 show that the UVIS channel performs well and is quite stable. This holds true in spite of the fact that on several occasions throughout the course of testing the instrument safed and was restarted, the detector packages temporarily lost vacuum, and the detectors were warmed and recooled.

Bias levels are repeatable to sub-DN levels, dark current is stable to ~0.2 e⁻/pix/hour or better, encircled energy is repeatable to less than 1%, photometric stability is on the order of 0.5-1.0%, and flatfielding accuracy and stability is also at a level of 0.5-1.0%.

6. References


Figure 1: Plots of the average column values in individual raw unbinned and binned bias images from ObsIDs 01 and 05. Between the active and overscan image areas there is a systematic offset of ~0.08 DN in the unbinned images and ~0.7 DN in the binned images.
Figure 2: Dark current measurements from ObsID 0C and 0Q images. Observations 1 and 8 were taken in ambient conditions.
Figure 3: Photometry results for ObsID 04 and 05 images. Data taken in ambient are shown as open circles, while thermal-vac data are filled circles. Errorbars due to statistical uncertainty in the measurements are about the size of the symbols. The values plotted are the measured WFC3 counts, divided by the OS incident source flux, and then normalized to the mean of the six thermal-vac results (observation numbers 2-7). The quoted rms scatter is for the six thermal-vac data values only.
Figure 4: Photometry results for ObsID 08 data, normalized to the mean of the six thermal-vac measurements.
Figure 5: Photometry results for ObsID 0A and 0B data, normalized to the mean of the six thermal-vac measurements.
Figure 6: Encircled energy measurements from ObsID 06 and 09 data. Results for 0.15” and 0.25” diameter apertures are shown. Observation numbers 1 and 8 were taken in ambient conditions.
Figure 7: ObsID 0F flatfield observation number 6, after dividing by the mean flat formed from the other images in the same ObsID. The horizontal, hourglass-like (a.k.a. “bowtie”) pattern appears in both CCD chips at a level of ~0.8%.
Figure 8: Cross-cut of pixel values in CCD chip 1 for flatfielded ObsID 0F observation number 6. This corresponds to the chip in the upper half of Figure 7.
Figure 9: Mean ObsID 0F F555W internal tungsten flatfield image.
Figure 10: Mean ObsID 01 F218W internal deuterium flatfield image. The dark spots are the result of painting pin holes on the filter.
Figure 11: Mean ObsID 0J F555W external flatfield image. The vignetting in the lower-left and upper-right corners is due to the optical stimulus.
Figure 12: Mean ObsID 0M F225W external flatfield image, using 3x3 on-chip binning.