*The 2005 HST Calibration Workshop*
*Space Telescope Science Institute, 2005*
*A. M. Koekemoer, P. Goudfrooij, and L. L. Dressel, eds.*

# WFC3 Calibration and Data Processing

H. Bushouse, S. Baggett, T. Brown, G. Hartig, B. Hilbert, J. Kim Quijano, J. MacKenty, I. N. Reid and M. Robberto

*Space Telescope Science Institute*

B. Hill, R. Kimble and O. Lupie

*NASA/Goddard Space Flight Center*

## 1. Introduction

Wide Field Camera 3 (WFC3), a panchromatic imager being developed for the Hubble Space Telescope (HST), is now fully integrated and over the past year has completed first rounds of extensive ground testing at Goddard Space Flight Center (GSFC), in both ambient and thermal-vacuum test environments. This report summarizes the results of those tests and describes the pipeline processing methods that will be used to calibrate WFC3 data.

WFC3 is designed to ensure that the superb imaging performance of HST is maintained through the end of the mission and takes advantage of recent developments in detector technology to provide new and unique capabilities for HST. WFC3 contains ultraviolet/visible (UVIS) and near-infrared (IR) imaging channels, offering high sensitivity and wide field of view over the broadest wavelength range of any HST instrument. It is slated to replace the current Wide Field and Planetary Camera 2 during Servicing Mission 4.

The WFC3 UVIS channel is based on elements from the Advanced Camera for Surveys (ACS) Wide Field Camera (WFC), with a 4096x4096 pixel Marconi CCD covering a 160x160 arcsecond field of view. The WFC3 UVIS channel is optimized for maximum sensitivity in the near-UV and contains a complement of 48 spectral filters and a grism. The WFC3 IR channel uses a 1024x1024 pixel HgCdTe Hawaii-1R detector array covering a 135x135 arcsecond field of view. The array sensitivity is optimized in the 0.8—1.7$\mu$m spectral range. The IR channel accomodates 15 filters and 2 grisms for slitless spectroscopy.

## 2. Test Setup and Procedures

WFC3 is designed to have its UVIS and IR detectors cooled to flight temperatures of $-83°$C and $-123°$C, respectively, to minimize dark current and thermal background. The IR detector can only be cooled sufficiently close to this flight temperature when it is in a thermal-vacuum environment, while the UVIS detector can be tested in both ambient and thermal-vacuum conditions. To date, the WFC3 UVIS channel has undergone two episodes of ambient testing, in January and June–July 2004. The UVIS and IR channels have together undergone thermal-vacuum testing during September–October 2004.

In both environments, the WFC3 is mounted to the Radial Instrument Alignment Facility (RIAF), which provides a reference to the HST latch plane. An optical stimulus apparatus, known as "CASTLE", is also mounted to the RIAF and is used to provide external sources to WFC3 for testing. The CASTLE is capable of providing point and extended targets, as well as flat-field illumination, over the entire wavelength range of WFC3. Single- and double-mode monochromators in CASTLE can be used to control the bandwidth of all sources. The CASTLE also includes NIST-calibrated detectors to measure absolute flux levels of incident sources, which are used to measure the absolute throughput and sensitivity of WFC3.

During routine data taking episodes, WFC3 test exposures are commanded via an HST-style SMS that is run on the instrument. Complementary scripts are used to control the CASTLE optical stimulus, to provide the desired source for each exposure, resulting in a highly automated process. All exposures are processed, previewed, and archived locally, and are also automatically sent to the STScI pipeline (OPUS) system to be converted to FITS files and stored in the long-term HST archive.

## 3. Ground Tests Performed

The goals of the ground tests performed to date were to:

- characterize the thermal performance of WFC3
- demonstrate flight-like operations of the UVIS and IR channels
- verify and characterize the science capabilities of WFC3

The types of tests that have been performed during the ambient and thermal-vacuum testing campaigns include detector alignment, encircled energy, read noise, dark current, flat field uniformity, detector gain, detector linearity, detector crosstalk, image stability, grism dispersion, filter ghosts, system and filter throughputs, internal calibration system flux level and uniformity, and IR thermal background measurements.

## 4. Testing Results

The high-level results of these tests include: 1) the first integrated operation of the IR channel; 2) the same good performance of the UVIS and IR detectors seen in previous unit tests before integration into the instrument; 3) the demonstration of routine science operations in flight-like conditions; 4) good margins on the achievable UVIS and IR detector temperatures; 5) lower than expected IR thermal background, based on previous subsystem tests; and 6) excellent optical performance, with UVIS and IR image quality at or near specifications at all wavelengths.

All data analysis results to date have been documented in a series of over thirty Instrument Science Reports (ISRs), which are available for viewing and downloading from the HST WFC3 web site at http://www.stsci.edu/hst/wfc3/documents/ISRs.

### 4.1. Detector Characteristics

The results of specific tests of detector characteristics are shown in Table 1 and Table 2 for the UVIS and IR channels, respectively. Included in these tables is the Contract End Item (CEI) specification for each characteristic. As can be seen from the tables, the only detector characteristic that does not currently meet the specifications is the IR read noise (note that the values quoted are for a subtracted pair of non-destructive readouts).

Table 1: UVIS Detector Characteristics

| Item | Measured Value | CEI Specification |
|---|---:|---:|
| Dark current | 0.3 $e^-$/pix/hour | <20 $e^-$/pix/hour |
| Read noise | 3.0 $e^-$/pix | <4 $e^-$/pix |
| Linearity | 5% deviation at 67,000 $e^-$/pix | <5% up to 50,000 $e^-$/pix |
| Full well | ~70,000 $e^-$/pix | >50,000 $e^-$/pix |

Table 2: IR Detector Characteristics

| Item | Measured Value | CEI Specification |
|---|---:|---:|
| Dark current | 0.15 $e^-$/pix/sec | <0.4 $e^-$/pix/sec |
| Read noise | ∼22 $e^-$/pix rms | 15 $e^-$/pix rms |
| Linearity | 5% deviation at 93,000 $e^-$/pix | <5% up to 70,000 $e^-$/pix |
| Full well | ∼105,000 $e^-$/pix | >100,000 $e^-$/pix |

### 4.2. Optical Characteristics

The results of encircled energy measurements are shown in Table 3.

Table 3: Encircled Energy

| Channel | Wavelength | Encircled Energy |
|---|---:|---:|
| UVIS | 250 nm | 72% in 0.20 arcsecond radius |
| | 633 nm | 79% in 0.25 arcsecond radius |
| IR | 1.0 $\mu$m | 60% in 0.25 arcsecond radius |
| | | 75% in 0.37 arcsecond radius |
| IR | 1.6 $\mu$m | 46% in 0.25 arcsecond radius |
| | | 80% in 0.60 arcsecond radius |

The blue-optimized CCD's of the WFC3 UVIS channel result in system throughputs that are below that of ACS/WFC at the red end of the optical range, yet far exceed that of WFPC-2 at near-UV wavelengths. Figure 1 shows the througput of the UVIS channel (optics+detector) without filters in place.

WFC3 IR channel throughputs are 50% or more higher than that of the HST NICMOS cameras over the 0.9—1.7$\mu$m wavelength range. Figure 2 shows the throughput of the entire IR channel as seen through each IR filter.

## 5. Pipeline Processing

The `calwf3` pipeline that will be used in the STScI OPUS system to calibrate WFC3 data will be very similar to the `calacs` pipeline in high-level structure (see Hack 1999a). There will be two main branches: one for UVIS channel images and another for IR images. The steps applied on the UVIS branch will be the same as what's used for ACS/WFC images and the IR steps will be similar to NICMOS processing (Hack 1999b; Bushouse, Skinner & MacKenty 1997). Figure 3 shows the high-level data flow through `calwf3` processing.

Basic calibration will include the usual necessary steps such as bias and dark subtraction, flat fielding, and saturation and bad pixel flagging. UVIS images will also have shutter shading and post-flash corrections, as necessary. IR exposures will receive a non-linearity correction and "up the ramp" fitting, which includes CR rejection. Scientific operations of the instrument will allow for subarray readouts in both the UVIS and IR channels, as well as on-chip binning, by factors of 2 and 3, in the UVIS channel. The calibration pipeline will accomodate all of these modes, using subarray extractions of reference images and binned reference images. A major new feature of the WFC3 IR channel detector is the inclusion of a set of "reference" pixels around the perimeter of the the detector array, which are not sensitive to light but are otherwise included in the remaining electronic readout chain.

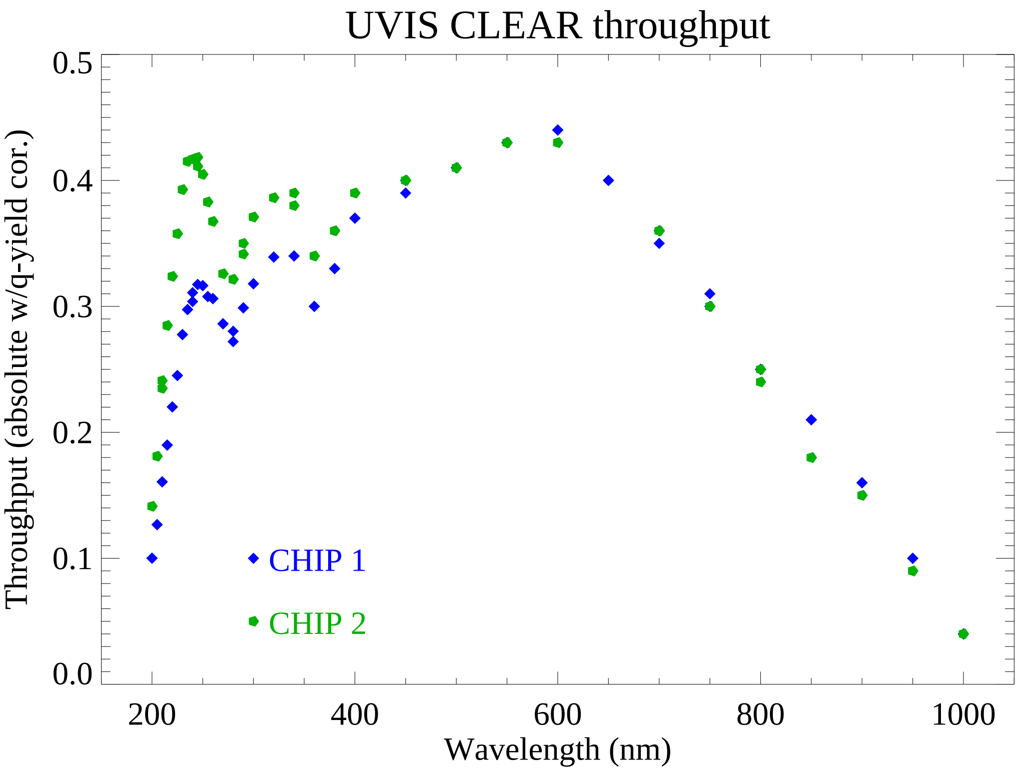

Figure 1: UVIS channel clear throughput

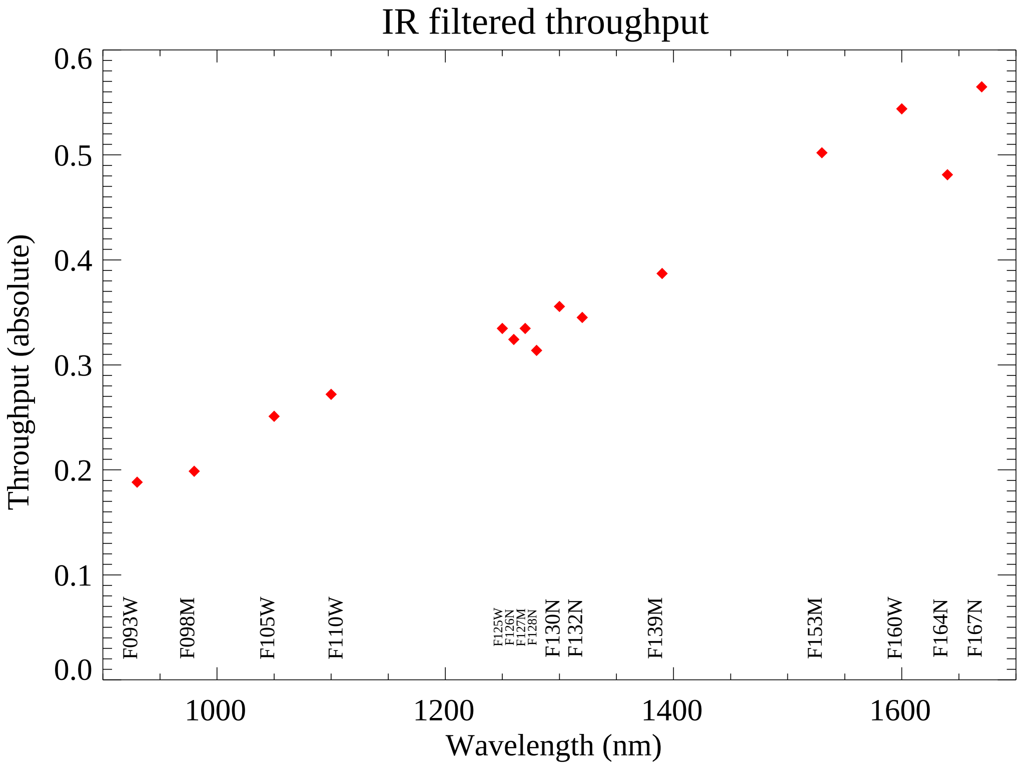

Figure 2: IR channel filtered throughput

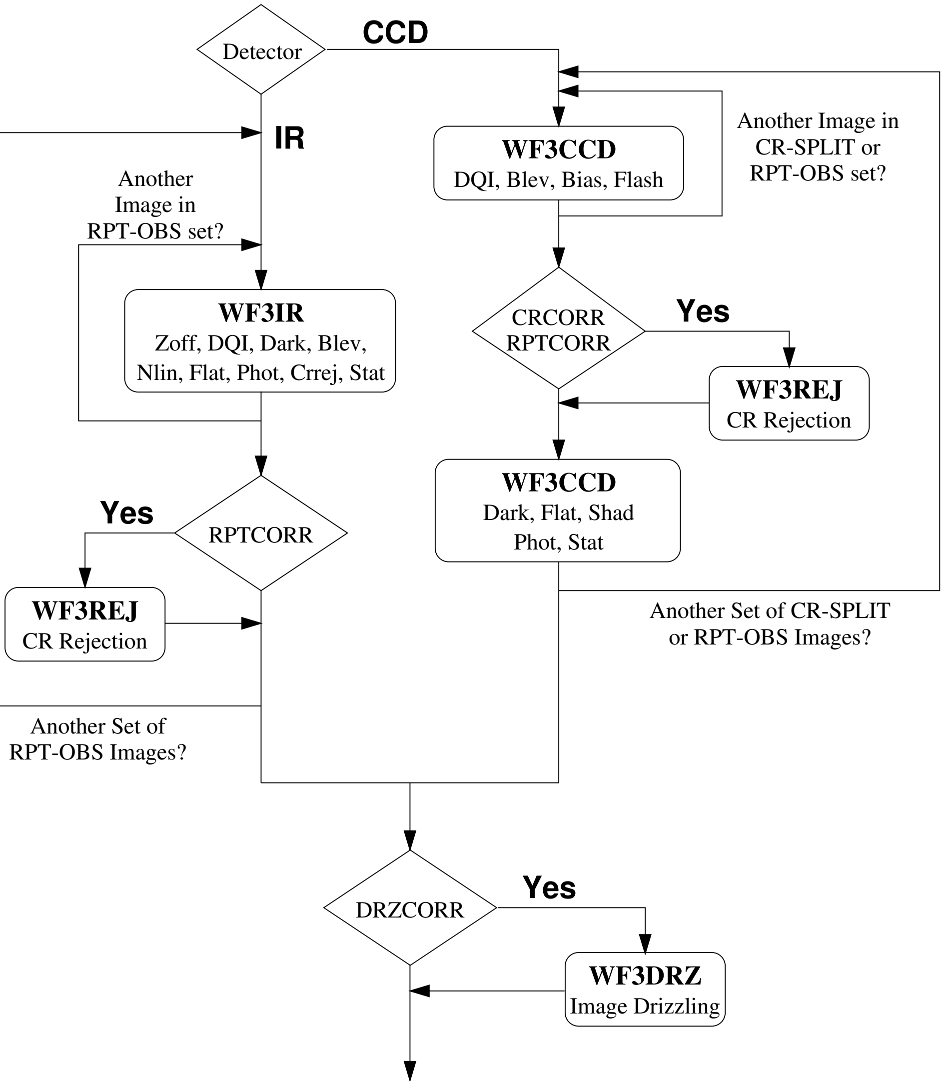

Figure 3: CALWF3 high-level flow

These pixels will be used by the IR branch of `calwf3` to track and remove drifts in the detector bias level from readout to readout within a given exposure.

The ground system will allow observers to obtain multiple exposures on a target, in either CR-SPLIT or REPEAT-OBS modes. These multiple images will be associated and combined during `calwf3` processing. Both UVIS and IR calibrated images will receive drizzle processing, either as individual images or as associated sets (e.g. for dithered patterns). Drizzle processing is necessary, even for individual images, in order to remove geometric distortions and to correct for distortion-induced photometric errors.

## References

Bushouse, H., Skinner, C., & MacKenty, J. 1997, *Instrument Science Report* NICMOS 97-28, (Baltimore: STScI)

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