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Results of WFC3 Thermal Vacuum Testing - IR Channel Throughput

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ABSTRACT

The throughput measurements for the WFC3 IR channel, taken during the Fall 2004 thermal-vacuum test, show that the IR throughput is approximately 15% lower than expected at all wavelengths. These measurements were obtained through all of the IR filters, scanning a monochromatic source through the central wavelengths of each filter, from 930 to 1670 nm. The source of this discrepancy is under investigation.

Throughput Tests

The Fall 2004 thermal vacuum test for WFC3 was the first to characterize the fully-assembled instrument, housing both the UVIS and IR channels. This report focuses on the results of the throughput measurements made on the IR channel through its entire set of filters. The results are compared to the expected throughput, which is based upon the product of all measured component throughputs (Brown, T.M. 2003, ISR WFC3-2003-13).

Settings for both the optical stimulus (CASTLE) and the WFC3 are summarized in Table 1. All tests were done with a 200 micron fiber on the optical stimulus, projecting a spot roughly 6 pixels wide on the WFC3 detector, thus averaging over pixel-to-pixel variations in response and allowing measurements with a high signal-to-noise ratio without approaching saturation. The standard tests of the IR channel were performed on the IR01 and IR11 field points, which fall in the lower left-hand corners of quadrants 3 and 1, respectively, using full-frame images. After finding anomalously low throughput in all filters, a cross check was done against the UVIS channel at the UV15 field point, which falls in quadrant 4 of the IR detector; the parameters for this cross check are given in the last two rows of Table 1. This cross-check test was performed twice; in the first run, CASTLE errors placed the wrong ND filter into the first image, while in the second run the CASTLE flux calibration was stale, such that slow drifts in the lamp introduced ~5% errors.

Table 1: Optical stimulus and WFC3 settings for IR throughput measurements

stimulus wavelength (nm)	WFC3 Filter	Bandpass (nm)	stimulus lamp	stimulus fiber	stimulus mono-chromator	stimulus ND	RAPID reads	exp. time (sec)
930	F093W	5	Tungsten	VISIR	Double IR	ND4	7	31.3
980	F098M	5	Tungsten	VISIR	Double IR	ND5	15	67.0
1050	F105W	5	Tungsten	VISIR	Double IR	ND5	13	58.1
1100	F110W	5	Tungsten	VISIR	Double IR	ND5	9	40.2
1250	F125W	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1260	F126N	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1270	F127M	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1280	F128N	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1300	F130N	5	Tungsten	VISIR	Double IR	ND5	6	26.8
1320	F132N	5	Tungsten	VISIR	Double IR	ND5	6	26.8
1390	F139M	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1530	F153M	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1600	F160W	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1640	F164N	5	Tungsten	VISIR	Double IR	ND5	7	31.3
1670	F167N	5	Tungsten	VISIR	Double IR	ND5	7	31.3
930	IR F093W	10	Tungsten	VISIR	Double IR	ND5	15	67.0
930	UVIS CLEAR	10	Tungsten	VISIR	Double IR	ND5	-	300

The throughput measurements in the standard test were taken as a pair of exposures at each wavelength, with an exposure through a filtered aperture and an exposure at the “blank” aperture to obtain a contemporaneous dark image. From the UVIS throughput tests (Brown & Reid 2005, ISR WFC3 2005-02), we know the CASTLE source is very stable on short timescales, with back-to-back measurements of the count rates in agreement to better than 1%. Neutral density filters were employed on the optical stimulus to keep the count rates well below saturation in the WFC3 exposures, but the total counts collected in the projected spot were of order 10^6 e^-, such that the Poisson uncertainties on the throughput measurements were of order 0.1%. The errors are thus dominated by systematics, such as the calibration of the optical stimulus. Calibrated images were created by subtracting the reference pixels, de-glitching (removing large jumps in signal from cosmic ray hits), and fitting the ramp in each pixel through the stack of multiple reads in each FITS file, using the software of Hilbert (2004, ISR WFC3 2004-10); this process was used to create a count-rate image of each throughput exposure and its contemporaneous dark exposure, and then the dark was subtracted from the throughput exposure.

In the cross check against the UVIS channel, a series of 5 images was taken, alternating IR-UVIS-IR-UVIS-IR, followed by an IR dark exposure. Calibrated IR images were created in the same manner as that in the standard tests. The UVIS images were analyzed in the same manner as described in Brown & Reid (2005, ISR WFC3 2005-02).

Results

To measure the count rate incident on the WFC3 detector, aperture photometry was performed on the calibrated images with a local background subtraction. The aperture radius was 20 pixels, with a background annulus of radii 30 to 40 pixels. The sizes of the aperture and background annulus ensured that they enclosed nearly all of the incident flux in the projected spot from the optical stimulus. Increasing or decreasing these sizes by 5 pixels had negligible effects on the calculated throughput (1% or less).

The optical stimulus calibrates the photon flux incident on the WFC3 pickoff mirror via a flux measurement on its own detectors: a Si photodiode for wavelengths of 1000 nm or less, and an InGaAs photodiode for longer wavelengths. This information is recorded in the WFC3 FITS header under the keyword "OSFLUX." The throughput, then, is just a simple ratio of the count rate (e^-/s) measured by the WFC3 CCD detector to the photon rate (photons/s) incident on the WFC3 pickoff mirror. This throughput is the desired quantity for calibrating the instrument, because it allows the observer to calculate the incident photon flux for a given count rate on the detector.

The expected throughput is a product of the individual WFC3 component throughputs, as measured prior to WFC3 assembly. Those components are (Figure 1): the pick-off mirror (POM), IR fold mirror (IRFOLD), channel select mechanism (CSM), IR mirror 1 (IRM1), IR mirror 2 (IRM2), refractive corrector plate (RCP), IR window (IRWIN), IR cold mask (IRCM), detector quantum efficiency (QE; quadrant-dependent), and the filter transmission (F110W shown here). Although the Detector Characterization Lab (DCL) measured the QE in each detector quadrant to vary by a few percent, the differences are a combination of variations in absolute gain and true spatial variations in the QE; it is difficult to separate the two effects in laboratory measurements, and the gain in these data is assumed to be a constant 2.5 in all quadrants.

Tests were repeated several times throughout the thermal vacuum program, giving a sense of the repeatability of the measurements, and also accounting for loss of data due to test anomalies. These were usually due to hardware and software errors associated with the optical stimulus, which would put the stimulus in the incorrect state (ND filter, lamp settings, etc.), although there were also occasions when a test was aborted after the first few measurements, for troubleshooting. Tables 3 gives the results of the standard throughput tests; when data were not available at a given wavelength, either due to problems with the optical stimulus or aborting the test, the entry "NA" appears. Table 4 gives the results of the throughput tests cross-checking the IR against the UVIS channel, averaging the throughputs calculated from the individual IR and UVIS images in each test (which agreed at the 1% level).

Using the data from Table 3, Figure 2 gives the WFC3 absolute throughput in the IR, while Figure 3 gives the ratio of the observed throughput to the throughput expected from the product of the component measurements. The throughputs are generally ~15% lower than expected at all wavelengths. A small part of this is due to the fact that the DCL measurements of the detector QE were taken at normal incidence, instead of the non-normal incidence (24^o) of the beam hitting the detector when integrated into WFC3, but recent DCL tests imply that this should be a small effect (0-2%). Given that the loss of throughput is fairly independent of wavelength, it could be due to a geometric effect. Alternatively, there could be a systematic problem with the CASTLE calibration (implying the WFC3 IR sensitivity is better than that portrayed in Figure 2) or with the component measurements, such as the detector QE (implying that the WFC3 IR sensitivity shown in Figure 2 is accurate).

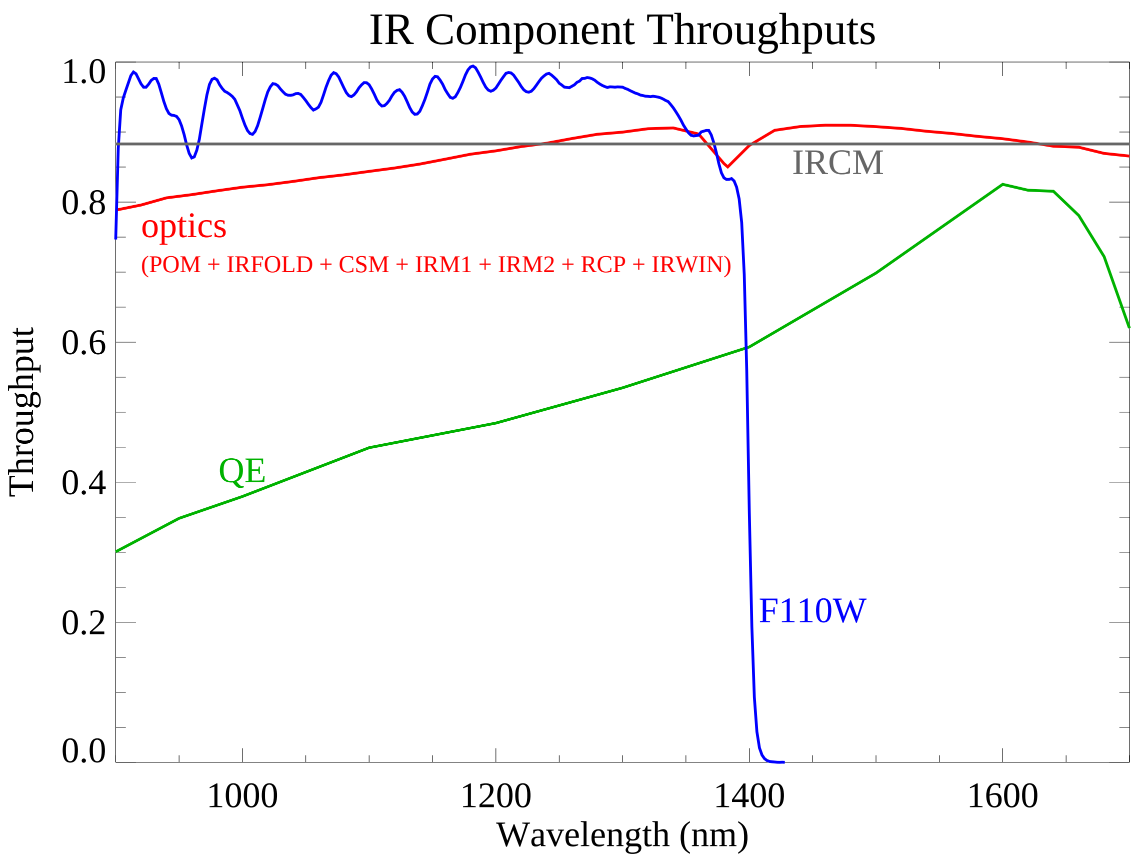

Figure 1: The component throughputs for the IR channel, along with the filter transmission of the F110W filter.

Table 3: WFC3 IR throughput

wavelength (nm)	Quadrant 3 throughput 19 Sep 2004	Quadrant 3 throughput 22 Sep 2004	Quadrant 3 throughput 29 Sep 2004	Quadrant 1 throughput 3 Oct 2004	Quadrant 3 throughput 3 Oct 2004	Quadrant 1 expected throughput	Quadrant 3 expected throughput
930	NA	0.18	0.18	0.18	0.16	0.22	0.20
980	0.19	0.19	0.19	0.21	0.19	0.25	0.24
1050	0.23	0.23	0.24	0.25	NA	0.30	0.28
1100	0.25	0.25	0.26	0.27	NA	0.33	0.31
1250	0.30	0.30	0.32	0.33	NA	0.38	0.37
1260	0.28	NA	0.31	0.31	NA	0.36	0.35
1270	0.30	NA	0.32	0.33	NA	0.38	0.37
1280	0.29	NA	0.30	0.32	NA	0.39	0.37
1300	0.32	NA	0.34	0.36	NA	0.41	0.40
1320	0.32	NA	0.33	0.35	NA	0.40	0.39
1390	0.35	NA	0.37	0.39	NA	0.43	0.42
1530	0.45	NA	0.48	0.49	NA	0.57	0.54
1600	0.51	0.50	0.52	0.53	NA	0.64	0.62
1640	0.46	NA	0.46	NA	NA	0.59	0.58
1670	0.54	NA	0.54	0.57	NA	0.55	0.56

Table 4: WFC3 IR-UVIS cross check

wavelength (nm)	Test 1: IR Quad 4 throughput 16 Oct 2004	Test 1: UVIS Chip 1 throughput 16 Oct 2004	Test 2: IR Quad 4 throughput 16 Oct 2004	Test 2: UVIS Chip 1 throughput 16 Oct 2004	expected IR Quad 4 throughput	expected UVIS Chip 1 throughput
930	0.16	0.11	0.15	0.10	0.20	0.13

The cross check of the IR channel against the UVIS channel (Table 4) at 930 nm supports the conclusion that the IR throughput is systematically low, although it is worth stressing that, at this wavelength, we are working at the limits of each detector where they overlap in coverage. Without any reliance upon the CASTLE flux calibration, we can see that the IR throughput is ~5% low relative to the UV throughput at 930 nm: the ratio of the observed IR throughput to the observed UVIS throughput is 1.45 in the first test, and 1.50 in the second test, while from the components one would expect this ratio to be 1.54. Relying upon the CASTLE calibration, we know the UVIS channel throughput is lower than expected near this wavelength. From the first test (which has a contemporaneous flux calibration from CASTLE), the UVIS throughput is about 15% lower than its expected value at 930 nm, which is fairly consistent with the 9% deficiency at 950 nm in the standard UVIS throughput measurements (Table 3 of Brown & Reid 2005, ISR WFC3-2005-02).

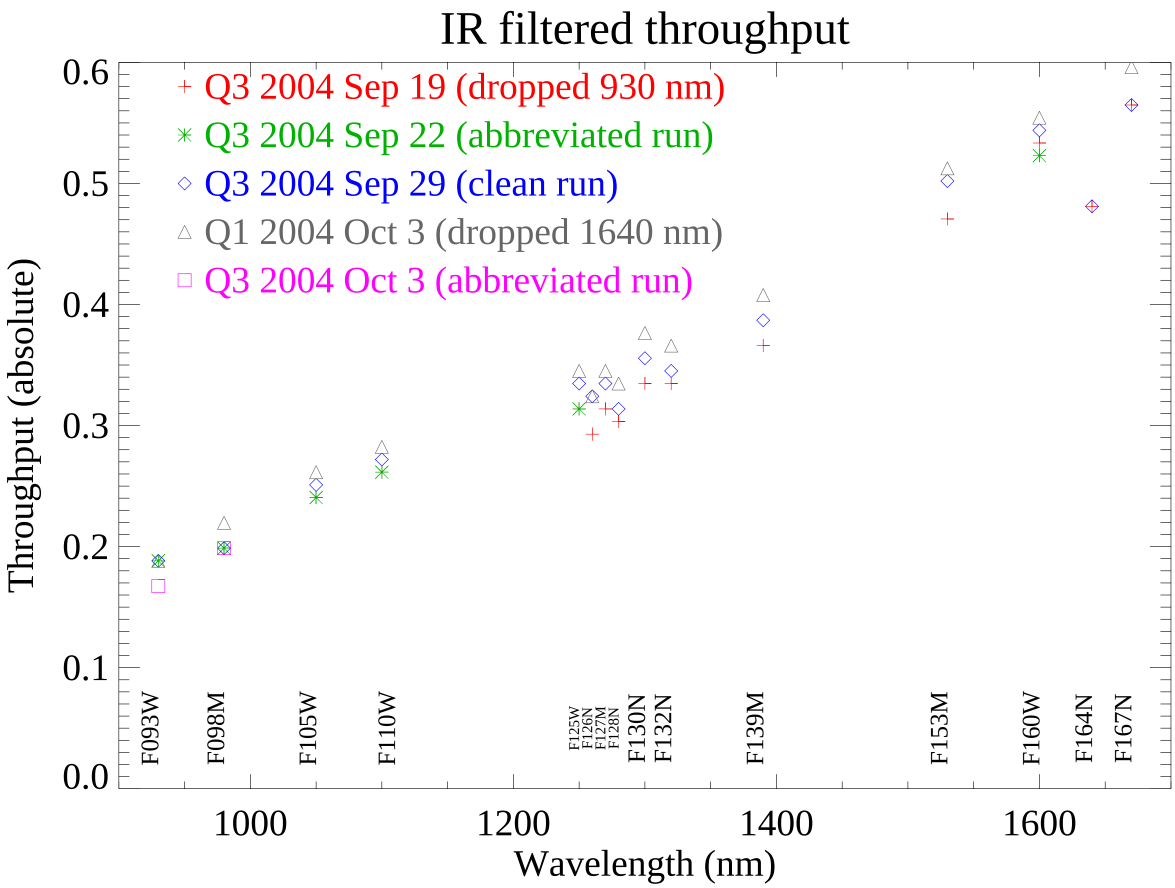

Figure 2: The absolute throughput of WFC3 IR channel through each of its filters, as observed in tests on detector quadrants 1 and 3.

Discussion

The WFC3 IR channel shows lower throughput than expected across a wide wavelength range, through all of its filters. Because this ~15% deficiency is independent of wavelength, it may be due to some geometric factor, a miscalibration of the CASTLE, or an overestimate of the detector QE by the DCL.

It seems unlikely that this deficiency is due to the CASTLE calibration. The CASTLE detectors are calibrated against NIST diodes, and are supposedly accurate to ~5%. The IR channel is systematically lower than expected at all wavelengths, and thus utilizes a variety of parameters on the CASTLE (two different CASTLE detectors and two different ND filters). The range of signals observed on both WFC3 and the CASTLE detectors argues against a nonlinearity problem. Also, the throughput of the WFC3 IR channel, relative to the WFC3 UVIS channel, is ~5% lower than expected, where they overlap in wavelength coverage. The UVIS channel is itself lower-than-expected at these wavelengths, but the the measured throughput of the UVIS channel varies smoothly with wavelength, showing no abrupt variations as CASTLE filters and detectors are changed (Brown & Reid 2005, ISR WFC3-2005-002). Thus, although the CASTLE cannot be ruled out, it does not seem a likely source of the throughput discrepancy. An overestimate of the QE by the DCL appears to be the most likely explanation, but the IR throughput discrepancy remains under investigation.

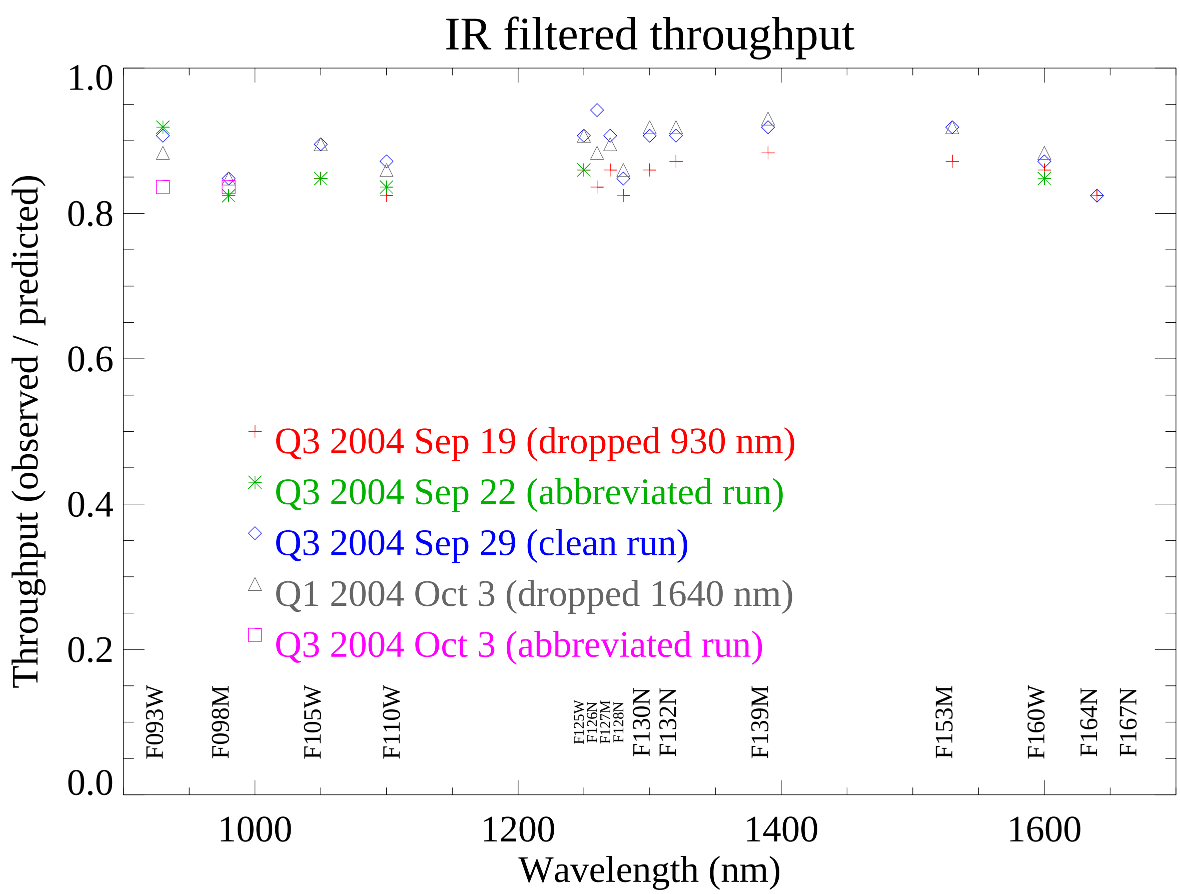

Figure 3: The observed throughput of the WFC3 IR channel through all of its filters, relative to the throughput expected from the product of the individual component throughputs (Figure 1). The IR channel is systematically lower than expectations by ~15%.