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WFC3 TV3 Testing: System Throughput on the UVIS Build 1' Detector

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ABSTRACT
The UVIS flight detector (UVIS build 1') was installed in WFC3 prior to its third and final campaign of thermal vacuum ground testing. We performed testing of the end-to-end system throughput on the UVIS channel, and found that it performs near or better than expectations at most wavelengths. However, the measured throughput is significantly different than that measured for this detector in the first campaign of thermal vacuum testing. This is due to two systematic changes that generally work in opposite directions. First, the sensitivity of the ground reference detector was revised downward in the UV, which produces a corresponding change in sensitivity for the WFC3 detector. Second, the quantum yield correction (accounting for the fact that there is a finite chance of producing two electrons from a single incoming UV photon) was found to be very small for this detector, meaning that the true UV sensitivity of this detector is nearly as high as the raw sensitivity.

Background

In the spring of 2008, the Wide Field Camera 3 (WFC3) was subjected to its third and final campaign of thermal vacuum (TV) tests. For these tests, the UVIS flight detector (UVIS build 1') was in the instrument, replacing the spare detector (UVIS build 2) in place for the second TV campaign. The UVIS-1' detector is the same detector installed during the first TV campaign of 2004, but it was subsequently reworked to replace its thermo-electric cooler (TEC) and to mask a baffle that was producing optical glints; it was subsequently renamed UVIS-1' from the original UVIS-1. The TEC and mask work on this detector was not expected to change the sensitivity of the channel, given the CCD chip and optics are all the same.

However, in the years since the original tests of this channel (Brown & Reid 2005, WFC3 ISR 2005-02), the reference detectors of the optical stimulus (CASTLE) were recalibrated, with a significant change in sensitivity for the photomultiplier tube (PMT) that handles wavelengths of 200 to 600 nm. Furthermore, a test of the quantum yield effect showed the effect to be small for this detector (< 10%; Baggett 2008, ISR WFC3 2008-47). There is a finite chance for a CCD to produce two electrons for a single incoming UV photon, which causes a "raw" measurement of the quantum efficiency to be artificially higher than it really is. To correct for the quantum yield effect, we have previously scaled the throughput by the factor λ/λ_{crit} for $\lambda<\lambda_{crit}$, where λ_{crit}=339.6 nm. Since the correction has been measured as smaller than this factor, the quantum efficiency in the UV is nearly as high as the raw throughput measurements imply.

Among the tests performed in TV is a measurement of the end-to-end system throughput (i.e., the throughput of the entire instrument excluding the filter and the HST optical telescope assembly). These tests are performed at NASA/GSFC using an optical stimulus (called "CASTLE") that can deliver flux-calibrated monochromatic light to the WFC3 focal plane with a variety of source sizes. The end-to-end system throughput tests are performed with a 200 micron fiber, producing a spot approximately 20 pixels across on the WFC3 CCD. This large spot allows the throughput to be measured more accurately, because it averages over pixel-to-pixel variation in response and allows a large number of counts in the measurement (generally >> 10,000 electrons) without approaching the saturation limit of the CCD (70,000 electrons per pixel). The current tests are very similar to the tests performed during the first TV campaign (see Brown & Reid 2005, ISR WFC3 2005-02 for details) and the second TV campaign (see Brown 2007, ISR WFC3 2007-07 for details).

Each UVIS detector consists of two chips. There are various ways the detectors and their chips can be identified, so I summarize this information here. Confusingly, the FITS files for images obtained on the UVIS channel put chip 2 in extension [SCI,1] and chip 1 in extension [SCI,2]. On UVIS build 1', chip 1 is #178 and chip 2 is #18, where these numbers refer to identification numbers used by the GSFC Detector Characterization Lab (DCL). On UVIS build 2, chip 1 is #50 and chip 2 is #40. These chip identifications have been verified by comparing DCL images of the detector (B. Hill, private communication) against flat-field images taken during the ambient campaign.

The preliminary analysis of the TV3 throughput data showed a significant decrease in the absolute raw throughput in the UV compared to that measured in TV1. However, an investigation demonstrated that the CASTLE PMT had a significantly different calibration in TV3 than it did in TV1, and that the change in the PMT calibration could account for the difference in measured throughput. The PMT was thus recalibrated over the summer of 2008 by R. Telfer at GSFC, with the new calibration roughly falling between the original TV1 calibration and the preliminary TV3 calibration. The analysis also demonstrated that the response of the PMT is very sensitive to where it is illuminated by the CASTLE fiber. In the recalibration effort, there was an attempt to ensure that the calibration accounted for the illumination positioning that occurred in TV3, but there is no way to recover this information for the TV1 campaign. Thus, the original TV1 calibration of the UVIS throughput has significant (~20%) uncertainties in the UV, and we cannot infer any trends in the UVIS throughput by comparing the best calibration of the TV3 data to the TV1 data.

The calibration here accounts for other calibration efforts such as those involving the gain and flat-field. For the purposes of the current calibration, we assumed the gain values of Baggett (2008, ISR WFC3 2008-13). In previous throughput campaigns, we checked the position of the source against flat-field images, to make sure that the detector locations used for throughput measurements were representative of the detector as a whole. In the current analysis, we performed the measurements on both raw images and flat-fielded images (Sabbi 2008, ISR WFC3 2008-17). The flat-field correction used a filter flat that was closest in wavelength to the CASTLE monochromator setting for these unfiltered throughput measurements. The filter flats can have a median value in each chip that is significantly distinct from unity, because they are normalized to a clean area in a single quadrant, and the two chips have significantly different QE, especially in the UV. Thus, the normalization for each chip in the flat-field was reset to unity so that the throughput measurements did not lose the distinction in QE between the two chips. From 200 to 800 nm, there was little difference (1-2%) between the measured throughputs obtained using raw or flat-fielded images, because these detectors are fairly flat and the location of the throughput measurements is representative of the chip as a whole. However, beyond 800 nm, flat-fielding makes a significant (5-10%) difference in the measurement, due to CCD fringing. Unfortunately, at this time we do not have monochromatic flats that match the wavelengths used in the throughput test, so there are no appropriate flats to apply on the red end of the UVIS range. Given the lack of true monochromatic flats for any wavelength, the raw images have been used to construct the throughput, as done for previous calibrations in TV1 and TV2. The comparison of flat-fielded results to raw results shows that this assumption only matters on the red end of the UVIS range, so this will need to be corrected at a later date once appropriate fringe flats are available.

Results

The results of the TV3 tests on UVIS build 1' are given in Table 1 and Figures 1 through 3. Figure 1 shows the absolute throughput of the WFC3 UVIS channel on each chip (excluding filter transmission or the HST optical telescope assembly). As explained above, the throughputs have been corrected to account for the absolute gain on each amp. The throughputs do not include a quantum yield correction. Figure 2 shows the throughputs relative to expectations, based on component measurements in the lab. Figure 3 shows the comparison of the UVIS channel throughput as measured in TV1, as measured in the preliminary TV3 analysis, and as measured here (after the CASTLE PMT recalibration). Note that all three of these analyses were delivered to the database of calibration files that drives the IRAF synphot package and the exposure time calculators (ETCs). The initial release of the IRAF synphot package and ETCs assumed the TV1 results. The results of the preliminary TV3 analysis were implemented in the synphot package and ETCs in early May 2008, with the knowledge that the PMT was being recalibrated, because the analysis at face value implied a significant change in instrument sensitivity. With the current revisions to the PMT calibration and the effect on the throughput analysis, the synphot files and

ETC have been updated yet again. The relevant files for each analysis are the CCD QE tables, which are FITS files called wfc3_uvis_ccdX_00Y_syn.fits where "X" is the chip number (i.e., 1 or 2) and "Y" is the revision (1 = TV1, 2 = preliminary TV3, and 3 = post PMT recalibration). Users can determine if their synphot database has been updated by using the "showfiles" routine; for example, if specifying the obsmode "wfc3,uvis1,f606w" gives the CCD QE file as "wfc3_uvis_ccd1_003_syn.fits" then the database includes the update discussed here, but if it shows "wfc3_uvis_ccd1_002_syn.fits" then the database does not include this update.

With the delivery of UVIS flat field files, changes were required in synphot to handle both raw and flat-fielded data. Up to now, the synphot files have always assumed that one was interested in detected counts, because these are the counts that affect signal-to-noise ratio and saturation of the detector. This is the correct behavior for the ETCs (which calls synphot routines) or observers using synphot directly to plan their observations. However, observers also use synphot to interpret their data after the fact, and in this case they will be analyzing flat-fielded data. As mentioned earlier, the flat-field files delivered to the calibration database impose a renormalization on the data by chip; to provide a "flat" image, the flat-field file corrects for the differences in QE between the chips, along with flat-field structure on smaller scales. To account for this renormalization between chips, a new "cal" keyword has been provided for WFC3 modes. For example, if observers want to predict the signal-to-noise for a star observed in the F218W filter on chip 2, they should specify "wfc3,uvis2,f218w" as the synphot obsmode. If, however, observers want to compare the countrate in flat-fielded data to a model that is folded through synphot, they should specify a synphot obsmode of "wfc3,uvis2,f218w,cal" although the "cal" keyword only works if the synphot database includes the updates discussed in this report.

It is also worth noting that since May 2008, the ETCs have not assumed a quantum yield correction for UV data, given that it is currently thought to be less than a 10% effect. Before the synphot/ETC updates of May 2008, the ETCs did assume a quantum yield correction. This decision may be revisited in the future. Adding a "qyc" keyword to the synphot obsmode will still apply the theoretical quantum yield correction; that correction factor is λ/λ_{crit} for $\lambda<\lambda_{crit}$, where λ_{crit}=339.6 nm.

Table 1: TV3 Throughput Results

wavelength (nm)	absolute CLEAR chip 1 throughput	chip 1 relative to expectations	absolute CLEAR chip 2 throughput	chip 2 relative to expecations
200	0.1768	1.2215	0.2263	1.3722
205	0.2135	0.9430	0.2802	1.0735
210	0.2572	1.0342	0.3445	1.1768
215	0.2977	1.0975	0.4005	1.2328
220	0.3297	1.1125	0.4402	1.2240
225	0.3665	1.1120	0.4780	1.1885
230	0.4008	1.1070	0.5098	1.1540
235	0.4338	1.0985	0.5380	1.1258
240	0.4425	1.0477	0.5360	1.0602
245	0.4412	1.0345	0.5162	1.0272
250	0.4350	1.0287	0.4958	1.0128
255	0.4225	1.0120	0.4675	0.9865
260	0.4042	0.9822	0.4327	0.9480
270	0.3577	0.9022	0.3680	0.8792
280	0.3505	0.8503	0.3557	0.8565
290	0.3578	0.8082	0.3652	0.8402
300	0.3790	0.8237	0.3898	0.8653
320	0.3765	0.8627	0.3855	0.8975
340	0.3628	0.8950	0.3732	0.9280
360	0.3143	0.8700	0.3217	0.9012
380	0.3238	0.9180	0.3313	0.9415
400	0.3560	0.9258	0.3595	0.9335
450	0.3840	0.9293	0.3815	0.9158
500	0.3922	0.9210	0.3912	0.9007
550	0.3892	0.9055	0.3885	0.8895
600	0.3845	0.8978	0.3818	0.8748
650	0.3918	0.9457	0.3922	0.9323
700	0.3630	0.9720	0.3598	0.9427
725	0.3375	0.9690	0.3320	0.9580
750	0.3090	0.9582	0.3138	1.0095
775	0.2800	0.9435	0.2830	1.0190
800	0.2500	0.9175	0.2480	1.0050
825	0.2200	0.9145	0.2185	0.9905
850	0.1955	0.9100	0.1940	0.9695
875	0.1740	0.9245	0.1730	0.9600
900	0.1532	0.9507	0.1475	0.9168
925	0.1260	0.9250	0.1210	0.9010
950	0.0896	0.8362	0.0913	0.8835
975	0.0675	0.8490	0.0632	0.8315
1000	0.0398	0.7893	0.0364	0.7613
1050	0.0061	0.2410	0.0057	0.2240
1100	0.0011	0.1485	0.0010	0.1415

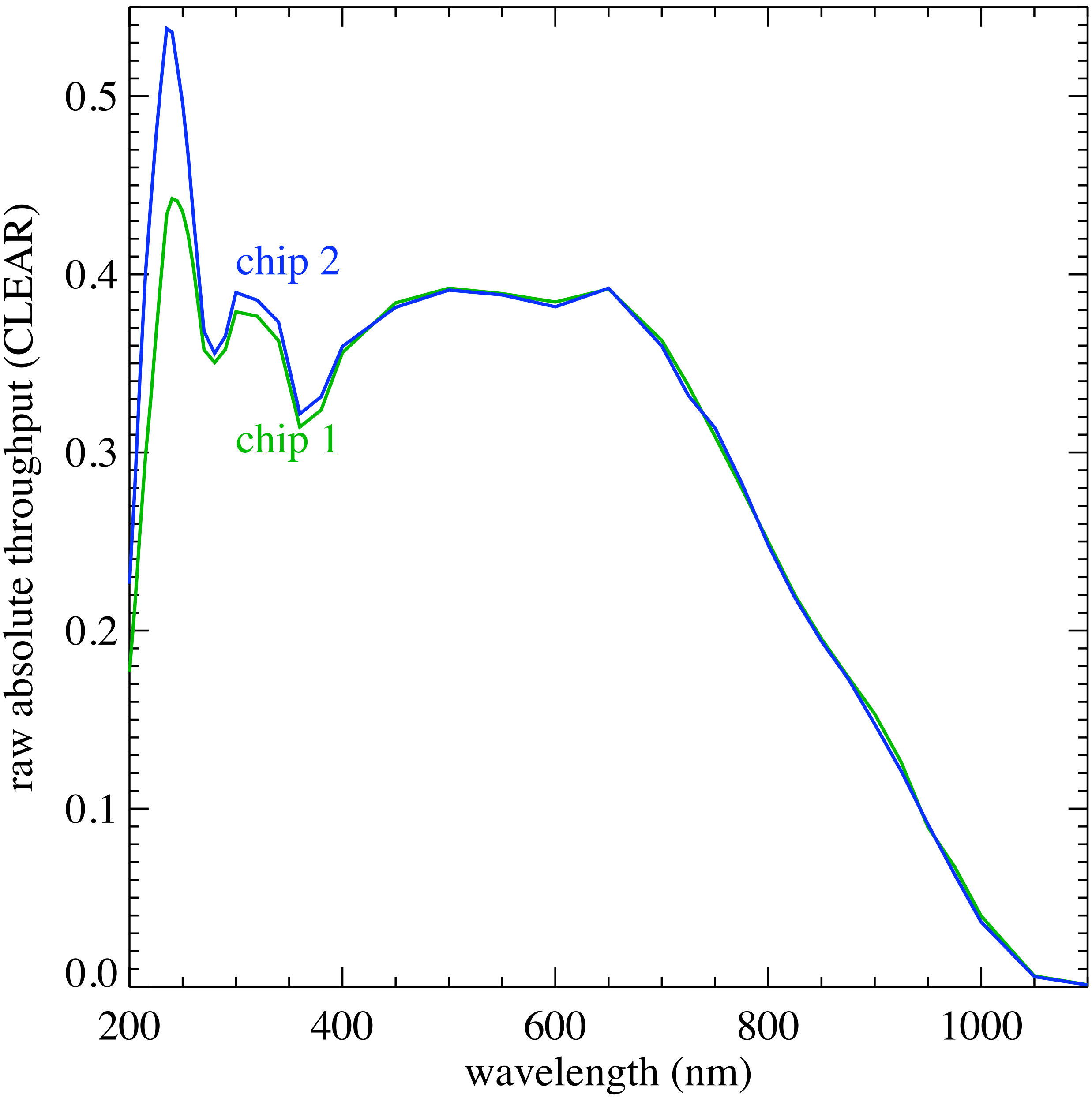

Figure 1: Absolute throughput on the two UVIS channel chips for the “CLEAR” (unfiltered) mode, without a quantum yield correction.

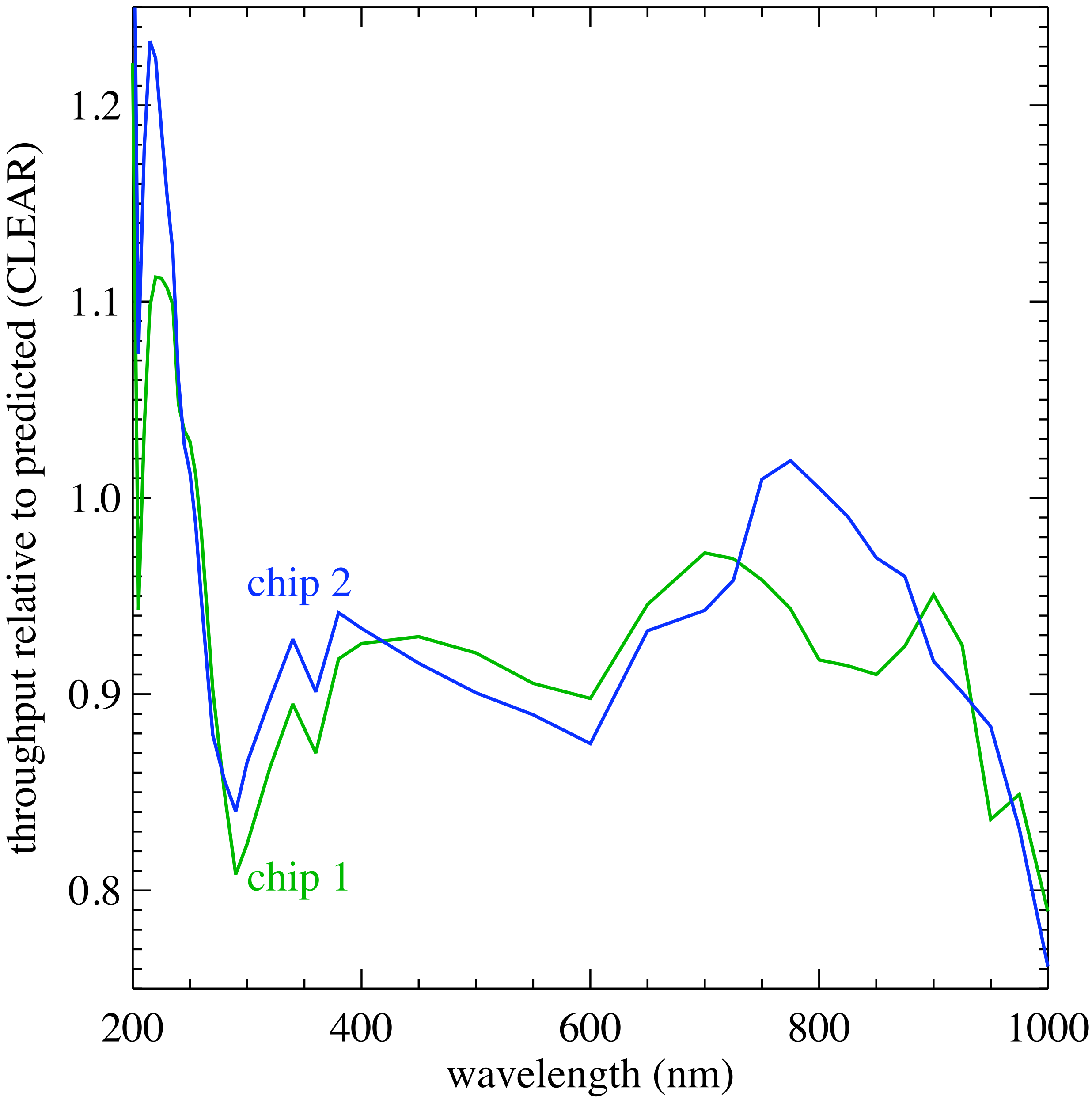

Figure 2: The throughput in the CLEAR (unfiltered) mode on each UVIS channel chip, relative to the expectations (product of component throughputs).

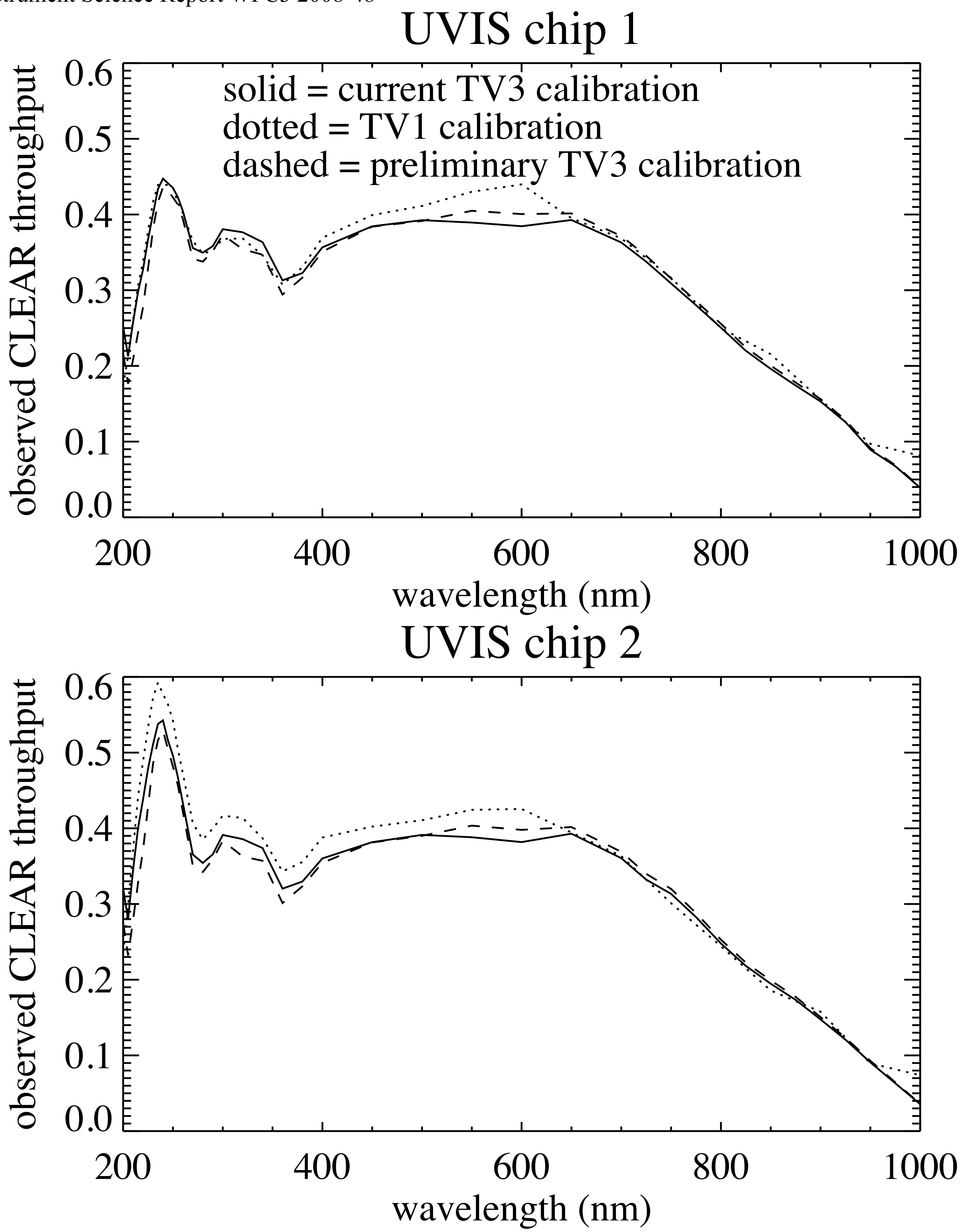

Figure 3: A comparison of the CLEAR (unfiltered) UVIS channel throughput on the flight detector as of TV1, the preliminary TV3 calibration, and the current TV3 calibration (post PMT re-calibration). The results of TV2 are not shown because the flight spare detector was installed in the instrument at the time of the TV2 campaign.