Instrument Science Report WFC3 2005-09

WFC3 Thermal Vacuum and Ambient Testing: Calibration Subsystem Performance

S.Baggett
March 2, 2005

ABSTRACT

This report summarizes the behavior of the calsystem in the UVIS and IR channels, based upon the recent thermal vacuum data as well as earlier ambient data. The UVIS tungsten flatfields technically meet the uniformity specification but show gradients of up to 1.5x across the field of view. There are prominent glints in two quadrants as well, ranging from 1.1x to 1.6x brighter than the surrounding area. The UVIS tungsten count rates in the subset of filters sampled during ambient testing were found to meet the flux requirement. The UVIS deuterium (D2) calsystem flatfields were found to meet the flux requirement as well (when measured in the midrange level of the flats) but they fail the uniformity requirement, showing gradients of 5 to 10x across the field of view. The IR calsystem flatfields fail to meet the uniformity requirement: they are highly vignetted, with large (>25x) gradients from center to corner across the field of view. Flux levels in the IR calsystem flatfields (taken in all IR filters except the two grisms), measured in the central bright region of the illuminated area, meet the flux requirement.

Introduction

The WFC3 calibration subsystem was designed to provide internal flatfields for both the UVIS and IR channels. The calsystem tungsten lamps supply the visible and infrared flux: there is one lamp plus one backup lamp per channel, for a total of four Tu lamps. The deuterium lamp (for which there is no backup) provides the UV flux. The resulting flatfields are not intended to be used directly in the calibration pipeline but are meant to allow monitoring of high-frequency changes in the flatfield structure over time without requiring external HST orbits. Calsystem flatfields acquired on the ground will provide the baseline calibration of the internal lamp illumination pattern. Changes between ground and on-orbit calsystem flatfields will be propagated into the official pipeline flatfields constructed from external observations taken with WFC3 and the CASTLE (optical stimulus) during ground testing.

The calsystem was integrated into WFC3 in the spring of 2004; first light was under ambient conditions in May, when a small set of UVIS tungsten and D2 calsystem flatfields were taken manually. An additional number of followup UVIS calsystem flatfields were taken via SMS UV23 in ambient in July 2004. Due to scheduling constraints, the planned UVIS calsystem check was not performed during TV though occasional UVIS calsystem flatfields were taken as part of the system and UV filter monitors (results for those tests are discussed in separate reports).

The first IR calsystem images were taken under thermal vacuum (TV) conditions with the WFC3 instrument in the GSFC SES (Goddard Space Flight Center Space Environment Simulator) in Sept 2004, when the IR detector could be cooled to operating temperature. The images were acquired via the calsystem check SMS IR15 (IR calsystem flatfields taken as part of the system monitor are discussed in the report for that test).

This report summarizes the illumination patterns and flux levels seen in the UVIS and IR channel calsystem data taken during ambient and TV conditions, respectively. The results are evaluated in light of the CEI uniformity and count rate specifications which require: illumination uniform to better than a factor of 2 across the field of view and count rates of at least ~17e^-/s/pix, in all filters.

Observations and Analysis

The tables in Appendix A summarize the UVIS and IR calsystem exposures examined. Prior to analysis, the UVIS exposures had the bias overscan correction performed and the IR exposures had the reference pixel correction and first read subtracted.

UVIS Tungsten Exposures

The illumination pattern of the UVIS tungsten calsystem images showed several distinctive features; Figure 1 presents a representative tungsten flatfield (other tungsten flatfields are shown Appendix B). Most prominent are ‘glints’ in quadrants B and C connected by a broad stripe of illumination; the glints are typically at levels 10-50% above the local background. There is also an overall gradient across the field of view from outer corner of quad A to the outer corner of quad D. These features appear regardless of the filter in use and are seen even with all wheels in the SOFA in the OPEN position. They do not appear in external flatfields taken using the CASTLE. Table 1 below lists the typical levels of the glints in B/C and the overall gradient.

The faint diamond shape extending across the field of view from upper left down to lower right appears to be related to the detector package as a whole rather than the calsystem, as the feature is seen in external flatfields as well as in the UVIS detector flatfields taken at Ball Aerospace (Pre-Ship Review slides 39-40, Sept 24,2003). The smaller, fainter arc-like glints in quads A and D are not seen in external flatfields but similar arc features have been seen in some external sources. There are also donut-like features likely due to particulates on the filter (e.g., in center of F350LP in the figure below; in quads A/B in F588N in Appendix B). Finally, two narrowband flatfields (and possibly F814W) show additional horizontal, vertical, and disk-shaped reflections not present in flatfields taken with the other filters (one of those narrowbands is shown in the figure below); later investigation has shown that these features are correlated with specific filters.

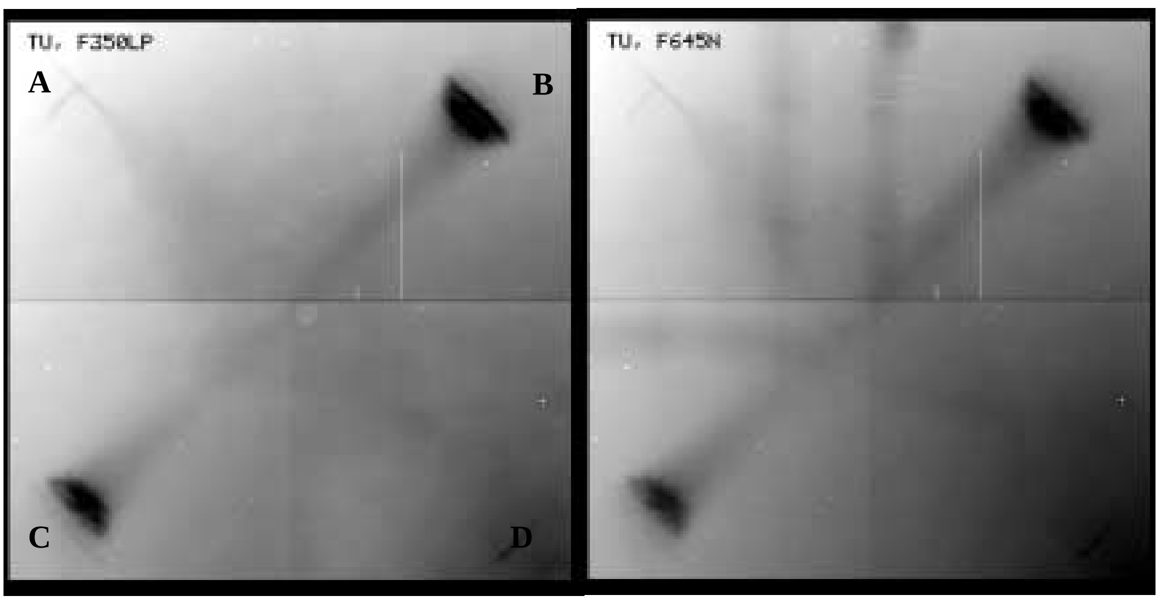


Figure 1: At left is a typical UVIS calsystem flatfield with the tungsten lamp, displayed with a hard inverted stretch to highlight features; quadrants are marked. At right is a tungsten calsystem flatfield through the f645n filter, showing additional vertical and horizontal reflections. Tungsten flatfields using other filters are shown in Appendix B.

The flux levels observed in high and low corners of the tungsten flatfields are listed in Table 1 below; all flatfields were taken with tungsten lamp 1. Regardless of location, the count rates easily meet the CEI specification of 16.6 e^-/s/pix: the lowest rate observed is still nearly a factor of 10 higher than the requirement. The F336W flatfield does not meet the CEI requirement with the tungsten bulb but does meet it with the D2 lamp (see next section). Only a subset of filters were observed with the calsystem during ambient in 2004; however, assuming the relative predicted exposure times are valid (Table in UVIS23 procedure), the remaining filters should have flux levels that satisfy the requirement.

Table 1. Exposure levels in the UVIS tungsten lamp1 flatfields along with gradient and glint levels.

filter	flux (low corner) e^-/s/pix	flux (high corner) e^-/s/pix	gradient	glint B	glint C
F336W	2.8	4.3	1.5-1.6	1.1	1.1
F350LP	24,350	35310	1.4-1.5	1.4	1.3
F475W	705	1050	1.5	1.2	1.2
F475X	1915	2845	1.5	1.2	1.2
F555W	2015	2985	1.5	1.2	1.2
F588N	155	225	1.4	1.3	1.2
F606W	5850	8660	1.5	1.3	1.2
F625W	5010	7390	1.5	1.3	1.2
F645N	295	440	1.5	1.3	1.3
F775W	9660	14200	1.5	1.4	1.3
F814W	15680	22770	1.4-1.5	1.4	1.4
F850LP	8320	11725	1.4	1.1	1.2
F953N	450	640	1.4-1.5	1.5	1.6
OPEN	28480	41830	1.4-1.5	1.4	1.3

The tungsten calsystem has four lamps, two for each channel (nominally, lamps 1 and 2 are the primary and backup for the UVIS channel and lamps 3 and 4 are the primary and backup for the IR channel). Flatfields in F814W were taken with each of the four lamps, to check for changes in illumination patterns and total output. The illumination pattern of all lamps was found to be very similar. The glints relative to the surrounding areas are the same for each lamp to within <0.5%. There is a small dip in the ratio images, about 1%, in quad D (lamps 2,3,and 4 are dimmer in that region than lamp1). There is also a slight gradient from lower left to upper right, at the level of 2-4% (lamps 2,3, and 4 are dimmer in the lower left than lamp1). The overall output of the lamps was found to vary more significantly: based upon the median count rate within the entire field of view, lamp 1 is faintest, with lamps 2,3,4 being 10%, 20%, and 27% brighter, respectively. This may be a sign of aging, as lamp 1 has seen the most use to date.

To investigate the two bright glints in quadrants B and C, all wheels were set to OPEN and flatfields were taken at the nominal position and with the OPEN slot in wheel 1 manually stepped by +/-10degrees from nominal. The glint in C was found to nearly disappear in the -10deg image while it remained effectively unchanged in the +10deg image (viewing the filter wheel from the OTA towards the CCD, positive steps move the filter wheel clockwise). Figure 2 shows the images from this test as well as cuts taken through the glint area in these images after each image scaled was scaled to its median. Note also that the ratio image of the OPEN flatfield to the OPEN-10deg flatfield shows residual vertical and horizontal glints reminiscent of those seen in the two narrowband flatfields (F645N, F588N) though the features are not obvious in the individual OPEN flatfields.

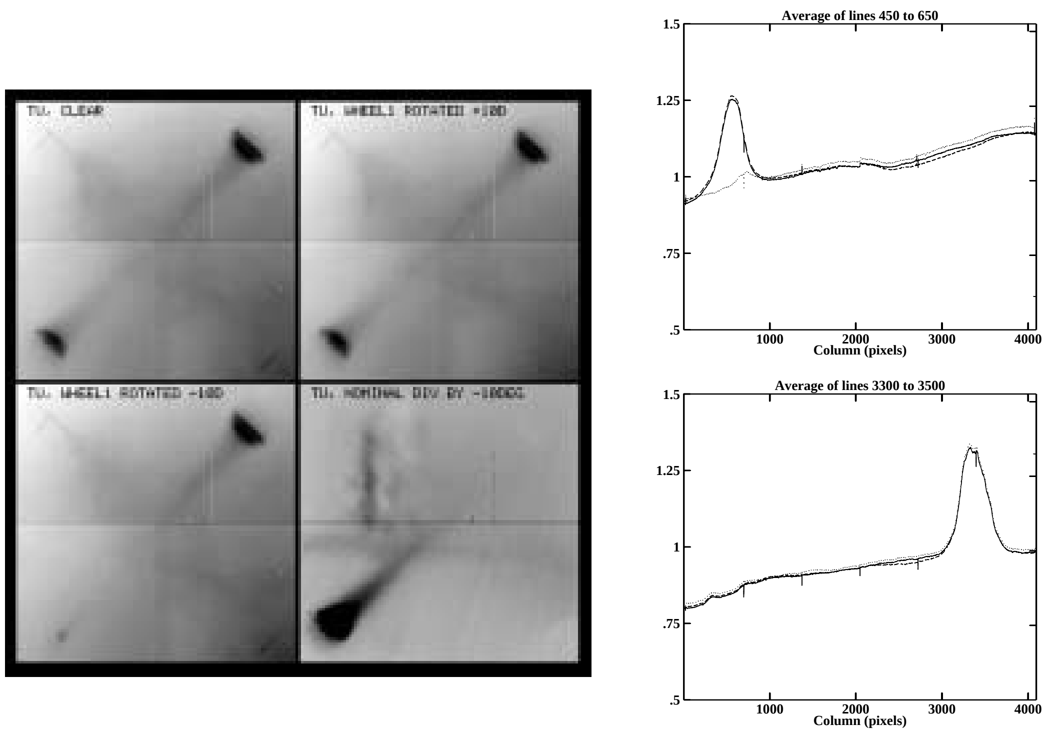


Figure 2: Change in illumination pattern due to filter stepping. Image mosaic shows the full-frame flatfield with all slots open and in the nominal position (upper left), all slots open and wheel 1 open rotated +10^{o} from nominal (upper right), all slots open and wheel 1 open rotated -10^{o} (lower left), and a ratio of the nominal to -10^{o} images (lower right). Plots at right show cuts through the glints in C and B quadrants, respectively; cuts from nominal, +10^{o} and -10^{o} images are overplotted.

UVIS Deuterium Exposures

The lower right image in Figure 3 shows a typical calsystem flatfield with the deuterium lamp in its current position. The most prominent feature is the strong gradient running from lower left to upper right. The gradient ranges from about a factor of 5 in F218W and F225W, to a factor of 7 in F275W and F300X, up to a factor of 8 in F336W (see plot in Figure 3) and F395N. The background cross-hatch pattern is part of the normal UVIS flat-field and also seen in external flatfields; the white spots are the painted pinholes. There is some hint that the quad B/C glints seen in the tungsten flatfields are present in the D2 flats.

Although access to the D2 lamp while the calsystem is integrated in WFC3 is difficult and quite limited due to the calsystem's compact design, an attempt was made to realign the lamp in-situ to correct the strong gradient in the D2 flats (GSFC optics branch and WFC3 team, Eichhorn et al.). The realignment did change the illumination pattern, reversing the bright and dim areas, effectively rotating the pattern by approximately 140^{o} counter-clock-wise relative to the original pattern (see Figure 3); the pattern of painted pinholes shifted somewhat as well. The gradient remained at effectively the same level as before (see F336W flux levels Table 2).

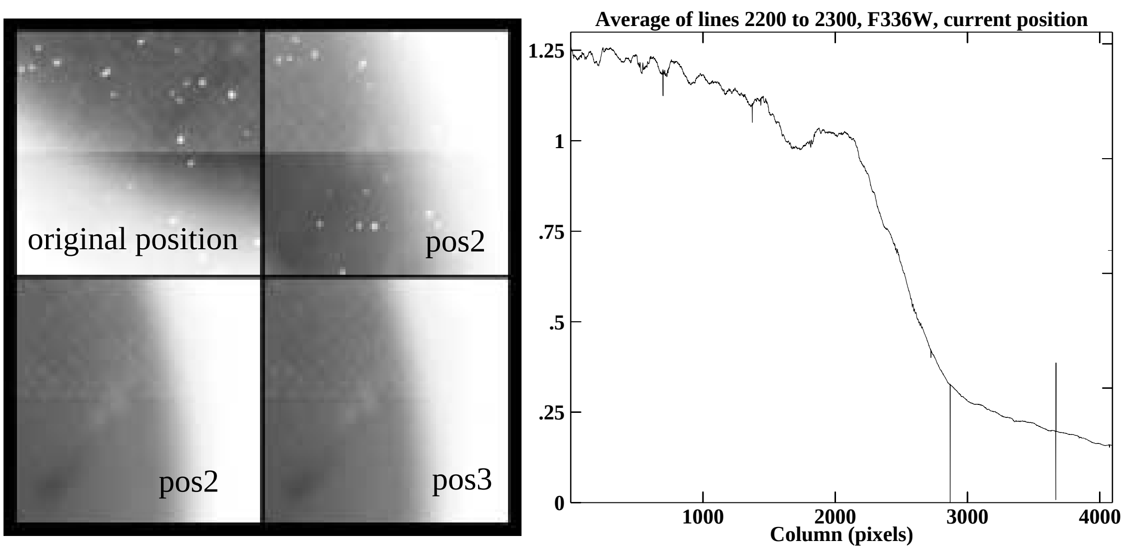


Figure 3: Mosaic of four full-frame D2 calsystem flatfields, shown in an inverted stretch. The two upper images are F225W: left is from May 2004 with the D2 lamp in its original position, right is the result of the first realignment. Bottom images are F336W: left is after the first realignment, right is after the second realignment (the current position). The plot at right shows a 100-row wide cut through the current position flatfield.

The absolute flux level of the D2 lamp is difficult to estimate due to the gradient; Table 2 shows two conservative measures: an average of the high and low areas and the median of the entire field of view. These should be underestimates, assuming that a fix to the D2 channel provides more uniform flux at a level brighter on average, not dimmer, than that currently seen in the flatfields. Under these conditions, the flux requirement is met in all filters used to date. Note that due to scheduling constraints, D2 flatfields have not been taken in all UV filters; however, based upon the observed count rates and the predicted exposure times from procedure UV23, the D2 flatfields in the remaining filters should meet the flux requirement.

Table 2. Exposure levels in the deuterium flatfields.

filter	ave of high+low e^{-}/s/pix	entire FOV e^{-}/s/pix	current setting	D2 lamp position
F218W	692.	906.5	medium	original (position1)
F218W	833.2	872.7	medium	position 2
F225W	825.	1085.7	medium	original
F225W	2388.4	2446.2	high	position 2
F275W	566.1	789.3	medium	original
F300X	973.3	1389.	medium	original
F336W	320.8	468.4	medium	original
F336W	362.4	485.6	medium	position 2
F336W	342.4	446.7	medium	poition 3
F395N	28.8	42.7	medium	original

IR Tungsten Exposures

The primary feature of the IR tungsten flatfield illumination pattern is the strong vignetting. Figure 4 presents a greyscale image of a typical flatfield as well as a diagonal cut through the flat, showing the dramatic reduction in illumination at the corners of the field of view. Flats from all filters show the same vignetting problem, with ratios of 25x to 50x across the field of view. Note: the vignetting problem may be due to an incorrectly-sized lens in the IR tungsten light path (J.Turner-Valle, priv.comm.).

Count rates were measured in a 30x30 pixel region near the center of the IR illumination pattern. To avoid possible saturation or non-linearity effects, measurements were taken from the frames with median counts <30k DN in that subsection. The results have been tabulated in Table 4 below. Assuming the light level in the center of the current illumination pattern represents the light level that will be obtained after any fixes to the IR calsystem, the flux levels in all filters easily meet the CEI requirement of ~17 e^{-}/s/pix.

Figure 4: IR tungsten flatfields. At left is an image of a typical flatfield (F110W). At right is a cut through the F110W flat, taken diagonally through the image, from lower right to upper left, through the center of the illumination.

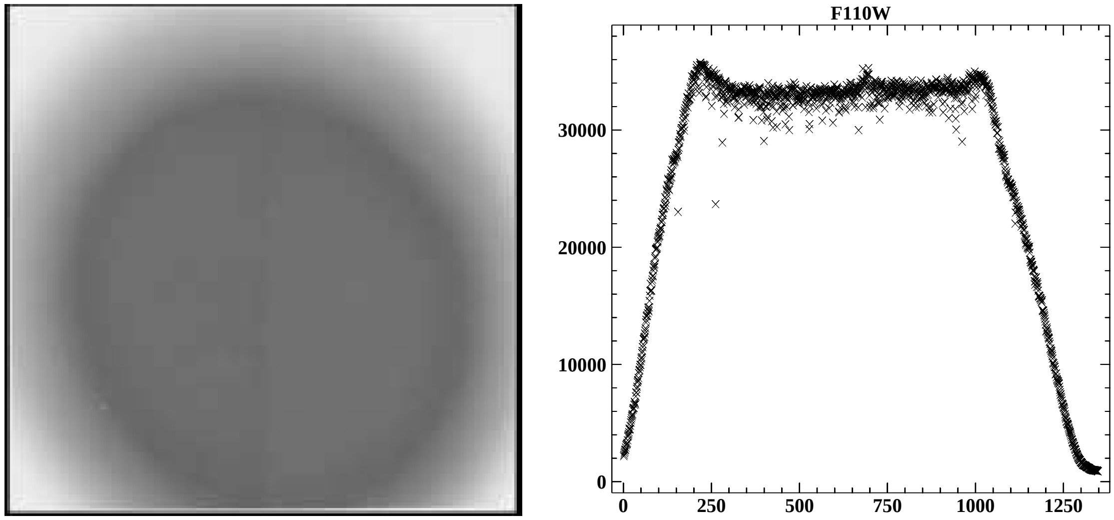


Table 3. IR tungsten exposures. Listed is the filter name, filename, exposure time and read number of the frame used to measure the count rate, total counts in the central bright region of the frame, and resulting count rate converted to e^-/s/pix assuming gain 2.5.

filter	filename	exptime	read number	total (DN/pix)	countrate e^-/s/pix
F098M	ii150105r_04265053612	129.76	9	27813.9	535.9
F105W	ii150107r_04265054918	29.65	5	17335.6	1461.8
F125W	ii150108r_04265054918	26.82	6	28232.9	2631.8
F126N	ii150109r_04265061203	604.64	7	27062.7	111.9
F127M	ii15010br_04265061203	104.73	8	26367.7	629.4
F128N	ii15010dr_04265063827	504.61	6	26436.5	131.0
F130N	ii15010er_04265065402	504.61	6	28729.5	142.3
F132N	ii15010gr_04265071445	504.61	6	28670.7	142.0
F139M	ii15010ir_04265071445	104.73	8	26295.7	627.7
F110W	ii15010jr_04265071445	17.88	4	24941.6	3487.6
F153M	ii15010lr_04265073054	79.71	7	29900.7	937.8
F160W	ii15010mr_04265073054	17.88	4	26863.5	3756.3
F164N	ii15010nr_04265073949	204.53	3	22557.2	275.7
F167N	ii15010pr_04265075049	204.53	3	23883.3	291.9

Conclusions

The WFC3 calsystem flatfields from ambient and TV testing last year have been examined and details of the illumination patterns discussed. Those results, along with the performance compared to the CEI specifications, can be summarized as follows.

1) The UVIS tungsten flatfields barely meet the uniformity requirement; the (subset of) filters observed do meet the flux requirement. There are significant glints in quadrants B/C, seen in all filters observed as well as in exposures taken without any filter in place. All four lamps produce similar glints. There are some additional horizontal and vertical reflections seen in only two, possibly three, filters. The absolute output of the four tungsten lamps varies somewhat, with lamp1 currently the dimmest; lamps 2,3,4 are 10%, 20%, and ~30%, brighter, respectively, than lamp1.

2) The UVIS D2 flatfields do not meet the uniformity requirement; the (subset of) filters observed appear to meet the flux requirement. The remaining filters are estimated to also meet the flux requirement. An attempt to realign the lamp in-situ resulted in a change to the illumination pattern but the overall gradient remains.

3) The IR tungsten flatfields do not meet the uniformity requirement. The IR flatfields do meet the flux requirement, based upon the count rates observed in the center of the illuminated area.

Acknowledgements

Thanks are due to the optics team for the attempts at correcting the D2 lamp illumination and the WFC3 team members who made the ambient and TV testing possible as well as S.Rose for help with the appendix figures.

Appendix A

Table 4. UVIS calsystem images taken during ambient testing. Listed are the database entry number, rootname, filename, camera, lamp, filter, exposure date (2004) and comment.

entry	rootname	filename	camera	lamp	filter	exptime	date	comment
5227	IVA00201	CSII04128131744_1	UVIS	Tu1	F814W	0.5	05-07	
5228	IVA00202	CSII04128133644_1	UVIS	Tu1	F953N	54.3	05-07	
5229	IVA00203	CSII04128135633_1	UVIS	Tu1	F336W	520.0	05-07	
5234	IVA00208	CSII04128154512_1	UVIS	Tu2	F814W	0.5	05-07	
5235	IVA00209	CSII04128155631_1	UVIS	Tu2	F953N	54.3	05-07	
5236	IVA0020A	CSII04128161532_1	UVIS	Tu2	F336W	520.0	05-07	
5243	IVA0020H	CSII04128182723_1	UVIS	Tu3	NONE?	0.5	05-07	
5244	IVA0020I	CSII04128183704_1	UVIS	Tu3	F814W	1.5	05-07	
5245	IVA0020J	CSII04128184742_1	UVIS	Tu3	F953N	54.3	05-07	
5246	IVA0020K	CSII04128185954_1	UVIS	Tu1	F555W	2.0	05-07	
5247	IVA0020L	CSII04128191034_1	UVIS	Tu1	NONE	0.5	05-07	
5248	IVA0020M	CSII04128192042_1	UVIS	Tu4	NONE	0.5	05-07	
5249	IVA0020N	CSII04128193103_1	UVIS	Tu4	F814W	1.5	05-07	
5251	IVA0020O	CSII04128195402_1	UVIS	Tu1	OPEN1	0.7	05-07	wheel1 rotated $+10^{o}$ 2x2 bin
5252	IVA0020P	CSII04128200514_1	UVIS	Tu1	OPEN1	0.7	05-07	wheel1 rotated $+10^{o}$;
5253	IVA0020Q	CSII04128202305_1	UVIS	Tu1	OPEN1	0.7	05-07	wheel1 rotated -10^{o}
5254	IVA0020R	CSII04128203412_1	UVIS	Tu1	OPEN1	0.7	05-07	wheel1 nominal; 2x2 bin
5255	IVA0020S	CSII04128204803_1	UVIS	Tu1	OPEN1	0.5	05-07	wheel1 nominal; 2x2 bin
7617	IU230202	CSII04189164435_2	UVIS	Tu1	F350LP	0.8	07-07	
7618	IU230204	CSII04189171732_1	UVIS	Tu1	F336W	1000.0	07-07	
7619	IU230205	CSII04189171732_2	UVIS	Tu1	F475X	10.0	07-07	
7620	IU230207	CSII04189173712_1	UVIS	Tu1	F588N	200.0	07-07	
7621	IU230208	CSII04189173712_2	UVIS	Tu1	F606W	6.3	07-07	
7622	IU23020A	CSII04189175335_1	UVIS	Tu1	F625W	7.3	07-07	
7623	IU23020B	CSII04189175335_2	UVIS	Tu1	F775W	4.3	07-07	
7624	IU23020D	CSII04189181055_1	UVIS	Tu1	F850LP	6.8	07-07	
7625	IU23020E	CSII04189181055_2	UVIS	Tu1	F475W	30.0	07-07	
7626	IU23020G	CSII04189182833_1	UVIS	Tu1	F645N	100.0	07-07	

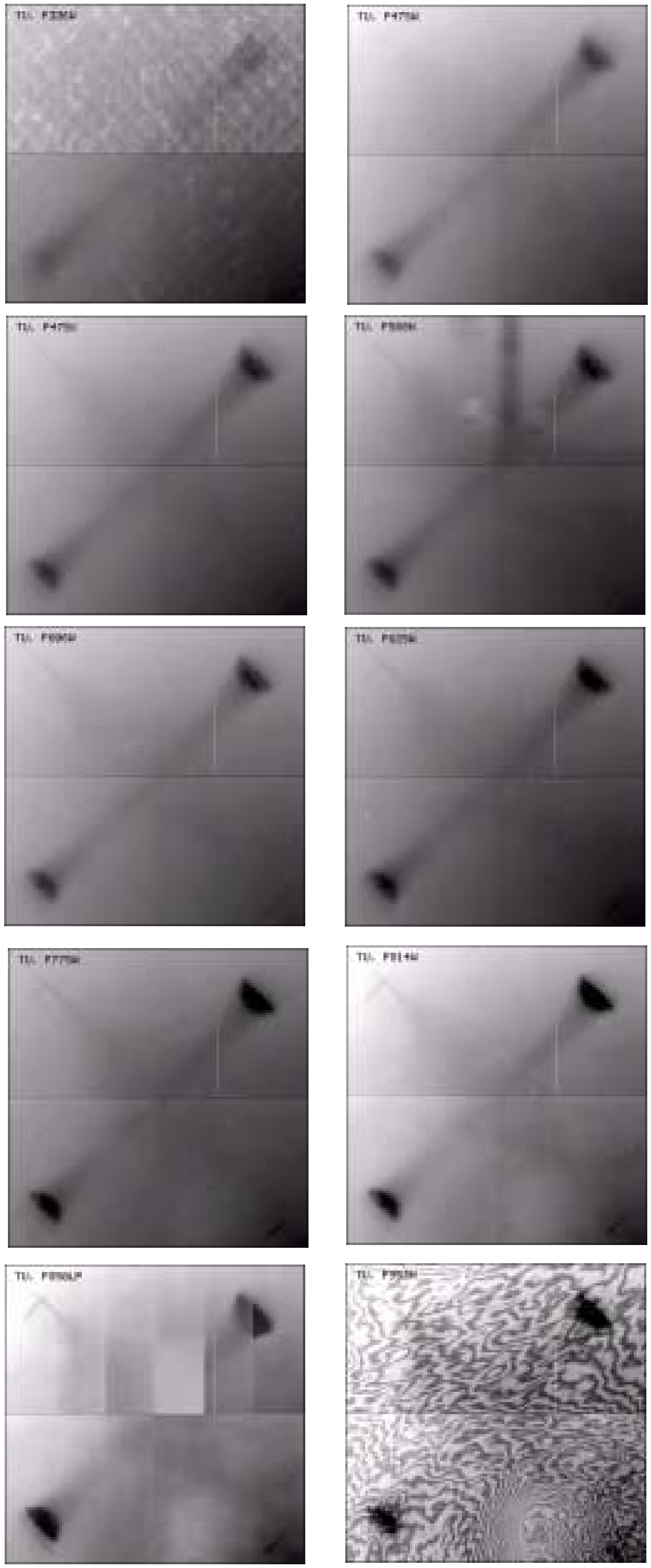
entry	rootname	filename	camera	lamp	filter	exptime	date	comment
5231	IVA00205	CSII04128142802_1	UVIS	D2	F300X	13.8	05-07	high current
5232	IVA00206	CSII04128144042_1	UVIS	D2	F218W	45.3	05-07	high current
5233	IVA00207	CSII04128150451_1	UVIS	D2	F218W	30.0	05-07	high current
5237	IVA0020B	CSII04128163404_1	UVIS	D2	F300X	25.0	05-07	medium current
5238	IVA0020C	CSII04128164344_1	UVIS	D2	F218W	24.0	05-07	medium current
5239	IVA0020D	CSII04128165335_1	UVIS	D2	F225W	15.0	05-07	medium current
5240	IVA0020E	CSII04128170503_1	UVIS	D2	F336W	40.0	05-07	medium current
5241	IVA0020F	CSII04128171454_1	UVIS	D2	F275W	45.0	05-07	medium current
5242	IVA0020G	CSII04128173412_1	UVIS	D2	F395N	500.0	05-07	medium current
5256	IVA0020T	CSII04147162923_1	UVIS	D2	F225W	15.0	05-26	high current, lamp pos2
5257	IVA0020U	CSII04147165122_1	UVIS	D2	F218W	24.0	05-26	med current, lamp pos2
5258	IVA0020V	CSII04147170202_1	UVIS	D2	F336W	40.0	05-26	med current, lamp pos2
5259	IVA0020W	CSII04147175143_1	UVIS	D2	F336W	40.0	05-26	med current, lamp pos3

Table 5. IR calsystem images taken during thermal vac testing. Listed are the database entry number, rootname, filename, camera, lamp, filter, exposure date (2004) and comment.

entry	rootname	filename	camera	lamp	filter	exptime	date
13788	II150105	CSII04265053612_2	IR	Tu3	F098M	179.8	09-21
13789	II150107	CSII04265054918_1	IR	Tu3	F105W	79.7	09-21
13790	II150108	CSII04265054918_2	IR	Tu3	F125W	49.2	09-21
13791	II150109	CSII04265061203_1	IR	Tu3	F126N	1104.8	09-21
13792	II15010B	CSII04265061203_2	IR	Tu3	F127M	204.8	09-21
13793	II15010D	CSII04265063827_1	IR	Tu3	F128N	1004.8	09-21
13794	II15010E	CSII04265065402_1	IR	Tu3	F130N	904.7	09-21
13795	II15010G	CSII04265071445_1	IR	Tu3	F132N	904.7	09-21
13796	II15010I	CSII04265071445_2	IR	Tu3	F139M	204.8	09-21
13797	II15010J	CSII04265071445_3	IR	Tu3	F110W	40.2	09-21
13798	II15010L	CSII04265073054_1	IR	Tu3	F153M	154.8	09-21
13799	II15010M	CSII04265073054_2	IR	Tu3	F160W	35.7	09-21
13800	II15010N	CSII04265073949_1	IR	Tu3	F164N	504.6	09-21
13801	II15010P	CSII04265075049_1	IR	Tu3	F167N	504.6	09-21

Appendix B

Figure 5: UVIS calsystem tungsten flatfields taken during ambient testing in 2004.



F336W F475W

F475X F588N

F606W F625W

F775W F814W

F850LP F953N