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WFC3 SMOV Proposal 11808: UVIS Bowtie Monitor

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ABSTRACT

This report summarizes the results obtained from the SMOV UVIS bowtie program, designed to monitor for detector hysteresis as well as to apply a QE 'pinning' exposure. Twice a day during SMOV, a triplet of internal flatfields was obtained: a short exposure before and after a deliberately saturated exposure. While no characteristic 'bowtie' features were found in the on-orbit data, a low level of hysteresis (~4%) does appear to be present immediately after the CCDs are cooled to operating temperature; in all cases, the saturated exposure successfully quenched the hysteresis. Any future UVIS detector cooldown should be followed immediately by at least one bowtie visit; the required frequency of bowtie visits between cooldowns is still to be determined though lab tests on a spare device indicate that once a week or less may be more than sufficient. Additional results, unrelated to the hysteresis issue, are: the tungsten lamp has a slightly longer warm up time than allotted by the commanding, the lamp output has declined by ~0.5% over the ~60 days in SMOV, the shutter blade B exhibits slight differences in its acceleration, manifested as striping at the ~0.5% peak to peak level in image ratios, and the F475X wheel exhibits a 1-step, or 0.5 degree, offset in positioning approximately 3% of the time. The wheel missteps are not an issue for external observations, as the internal calibration subsystem beam is significantly more collimated than the science beam.

Introduction

Every Hubble servicing mission is followed by a time period called SMOV (Servicing Mission Orbital Verification) during which the telescope and all its instruments undergo on-orbit calibration tests to commission them for science observing. The recent servicing

mission in May 2009, during which WFC3 (Wide Field Camera 3) was installed in HST, was no exception. One of the WFC3 SMOV tests performed during this commissioning was the UVIS Bowtie monitor, a program to detect quantum efficiency hysteresis (QEH) and provide a means of correcting the effect.

A low level of quantum efficiency hysteresis was found during instrument-level thermal vacuum ground tests. Dubbed the 'bowtie' effect due to the shape manifested in flatfield ratios - an hourglass shape turned on its side - it occurred sporadically during the ground tests. A systematic survey of UVIS images taken during all WFC3 ground-based tests helped to parameterize the behavior of the 'bowtie' effect (Baggett et al., 2008; Baggett et al., 2010) and guide further lab tests on flight-like devices. At nominal CCD operating temperatures during instrument-level ground tests, the effect occurred at a level of a few tenths of a percent up to a maximum of ~1%, lasting for timescales of hours to days. Subsequent lab tests on similar e2v devices at Goddard Space Flight Center's Dectector Characterization Lab (DCL) showed that the hysteresis 1) was present as a global change in quantum efficiency across the entire CCD, *without* any discernable pattern such as a 'bowtie' and 2), was at the level of ~5% at 230 and 600nm and ~2% at 900nm and 3) could be effectively neutralized using a visible light flatfield with a signal level several times full-well (Collins et al., 2009). The saturated exposure is thought to fill the charge traps which cause the QEH, thereby "pinning" the quantum efficiency to its optimum level.

This report summarizes the observing program and analysis results from the WFC3 SMOV UVIS bowtie proposal.

Data

Proposal Structure
A triplet of internal calsystem tungsten lamp F475X flatfields binned 3x3, in a single short uninterrupted visit, was taken approximately every 12 hours during SMOV, for a total of 100 visits. Each triplet consisted of one unsaturated, one saturated, and one unsaturated exposure, in that order. The first image provided a means of checking for the presence of any bowtie or global hysteresis features, while the second image was intended as a neutralizing exposure similar to the ones found to be effective in pinning the QE in the DCL tests of a spare detector. At an exposure level of ~10x full well, the neutralizing exposure should fill charge traps and quench any hysteresis. The third image was another unsaturated flatfield, to assess the efficacy of the QEH removal, if any was present.

The bowtie monitor internal flatfields were taken with the F475X filter, chosen for its high throughput, blue bandpass, and location in one of the less-used wheels in the WFC3

filter assembly. Exposure times were 1 sec and 200 sec, for the unsaturated and saturated (pinning) image, respectively; binning minimized the overhead times and data volume. Each visit required ~360 sec of observing time. All images taken are tabulated in Table 1 of Appendix A.

For this proposal, the channel select mechanism (CSM) was in the IR position; if the CSM was not in position at the start of the bowtie visit, nominal commanding moved it to the IR position before the UVIS internal flats were taken.

Analysis

Processing

The data were reduced using calwf3 and the appropriate ground-based reference files appropriate for 3x3 binned data. Steps performed included data quality initialization, bias overscan subtraction, bias image subtraction, and dark image subtraction. Although calwf3 was updated during SMOV, these changes did not affect UVIS processing so no bowtie data from earlier epochs were reprocessed. All images from the UVIS SMOV bowtie proposal are tabulated in Table 1 of Appendix A; listed are the image rootnames, exposure times, date and time of observation, and shutter blade in use. The calwf3 versions used to process the data are summarized in Table 2 of Appendix A.

Image Features

All images from this program were examined for evidence of any unexpected behavior. Experience with ground-based data showed that the bowtie feature occurred infrequently (about 30 times in 2200 full-frame images), and at very low levels (< 1%). To aid in detecting such faint features embedded in the normal internal flatfield structures, a variety of ratios were formed from the unsaturated images: an image 1 to image 3 ratio for each visit, an image 1 to a reference image 1 ratio, and an image 3 to a reference image 3 ratio. All ratios were examined both visually and via average column and line plots. Figure 1 shows a single unsaturated F475X flatfield on the left, and a ratio of the flatfields taken before and after the QE pinning exposure (image1/image3). The myriad of normal internal flatfield features, from large-scale gradients to smaller scale filter and CCD features, are stable and divide out.

Figure 1: The image at left is an unsaturated internal flatfield from Visit 5, with a stretch of +/-20%; quadrants have been labeled. At right is the ratio of the two unsaturated flatfields (image1/image3) from Visit 5, stretched to +/-3%.
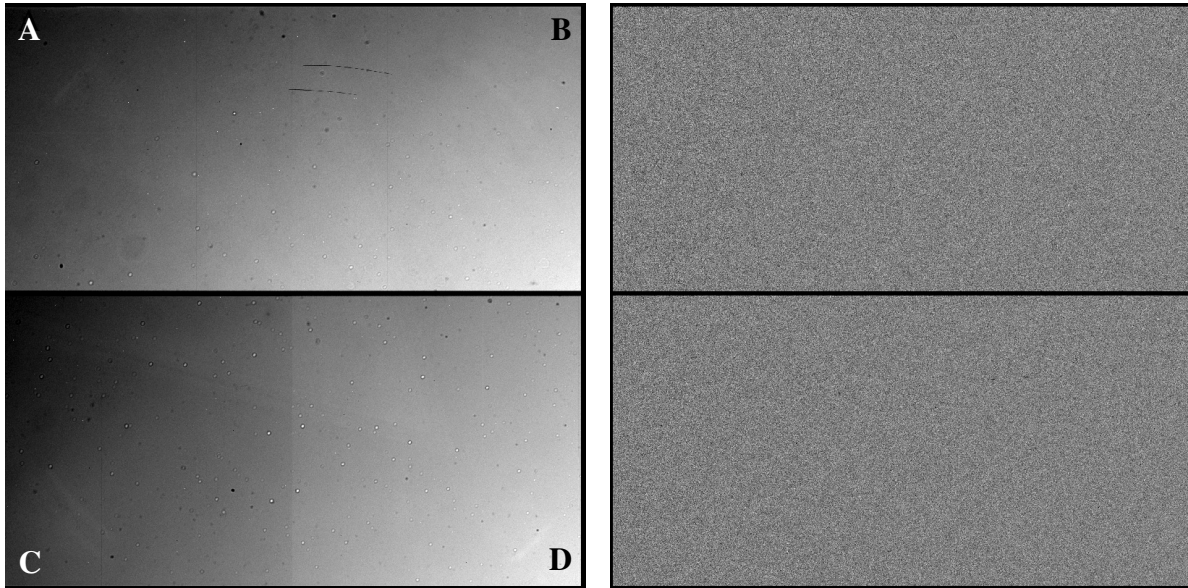

Of the 100 SMOV bowtie visits, only three show QE structures; these are shown in Figure 2. The most prominent feature is the large enhanced spot in quadrant D but there is also the slight deficit in quadrant C as well as the striping in quadrants A and B. Each of these three visits occurred immediately after the CCDs had been cooled down: Visit 1 were the first images taken on-orbit after the detectors were cooled to their nominal operating temperature, Visit 8 occurred after the first anneal[1] on June 23,2009, and Visit 62 occurred after the second anneal on July 20,2009 . Each post-cooldown bowtie visit shows the same pattern: features in the first image of the first visit are gone by the third image of the first visit; images in visits after the post-cooldown visit show no QE structures. Though the post-cooldown visit image ratios did not show the characteristic 'bowtie' shape as observed in TV3 data, the appearance of these QE structures in the flatfield preceding the pinning flatfield and the disappearance of the structures in the flatfield following the pinning flatfield strongly suggest that hysteresis was present. As a precaution, any future cooldown of the CCDs, such as during the anneal procedures, should be followed by at least 1 bowtie visit. There is no evidence that more than one visit is

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1. Anneals are planned procedures during which the CCDs are warmed in order to repair a fraction of the pixels damaged by the on-orbit radiation environment, then subsequently cooled back to nominal operating temperature.

required but more anneals and bowtie visits should be acquired before reducing the number of bowtie visits.

Figure 2: Ratios of the two unsaturated internal flatfields (image1/image3) taken as part of Visit 1 (left), immediately after the CCDs had been cooled for the first time in orbit, as part of Visit 8 (middle) and as part of Visit 62 (right), immediately after the CCDs were cooled after the SMOV anneal procedures. Greyscale stretch is +/-4%.
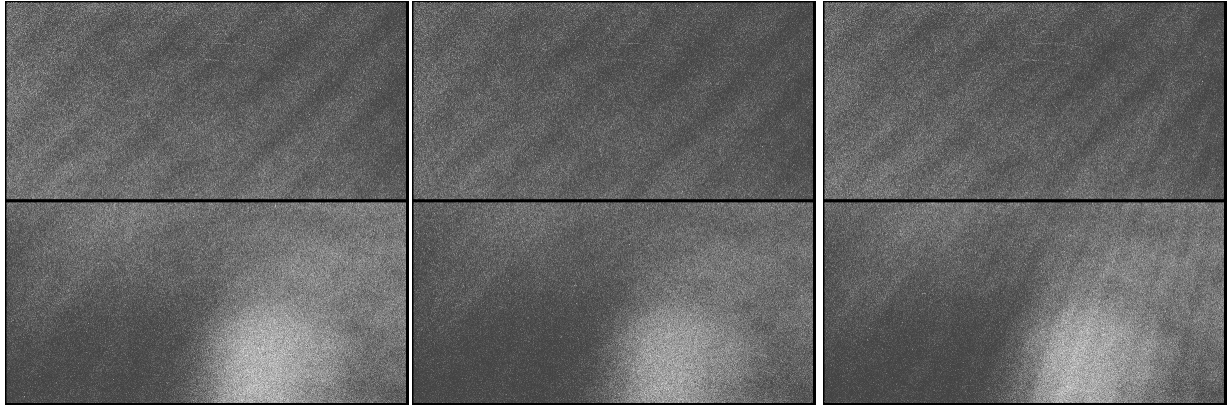

Other Results

Two minor effects unrelated to hysteresis are also noted in the image ratios. The first one is illustrated in the left image of Figure 3: faint stripes running approximately across the diagonal from upper right to lower left, at levels of about ~0.5% peak to peak. This effect was seen in ground test image ratios and is attributed to variations in the WFC3 shutter blade travel speed. All on-orbit image1/image3 ratios taken in the blade B configuration - a total of 52 of the 100 visits - show these stripes, while all but two of the blade A ratios were flat to better than 0.1% (the exceptions showed faint stripes at <0.2% peak to peak). SMOV proposal #11427 was executed to investigate the shutter effects on photometry of external point sources; those results have been reported elsewhere (Hilbert, 2009).

The second anomaly is that on three separate occasions, filter wheel 10, containing F475X, did not move to precisely the same position. The behavior is apparent in the flatfield ratios where filter features have shifted (Figure 3, right image); levels are +/-1% or less over the local surrounding flatfield level. The offset, 30 to 60 pixels depending upon location in the field of view, is consistent with a mis-step of 1 wheel step, or 0.5 degrees, from the nominal position. This mis-step is seen in images iac735*, iac736*, iac737*, iac742*, iac796*, and iac797* (listed in Table 1 in Appendix A). While a total of six visits were affected, based on the WFC3 activities at the time they are the result of only three wheel mispositionings. That is, when a UVIS filter is selected for use, it stays in place until another UVIS exposure requires a different filter. There were no other UVIS expo-

sures between the image sets of iac735*, iac736*, and iac737*, so the wheel was never moved and remained in its offset state. Likewise, there were no filter wheel motions between iac796* and iac797*, so both those visits show the offset positioning. Ground tests and engineering analyses performed at Goddard Space Flight Center have determined that the mis-steps pose no mechanical risk to the filter mechanism. External science observations will not be affected by a 1-step offset; the internal calibration subsystem has significantly more collimated beam which accentuates features due to dust and other particles on the filter or CCD windows. The offsets are taken into account when using the internal flatfields for monitoring purposes.

Figure 3: At left is the ratio of two unsaturated internal flatfields (image1/image3) from a visit taken with the B shutter blade configuration. At right is the ratio of two unsaturated internal flatfields from different visits (image3,visit35/image3,visit2), the round filter features illustrating the slight difference in wheel positioning between the two visits. Both images are stretched to +/-3%.
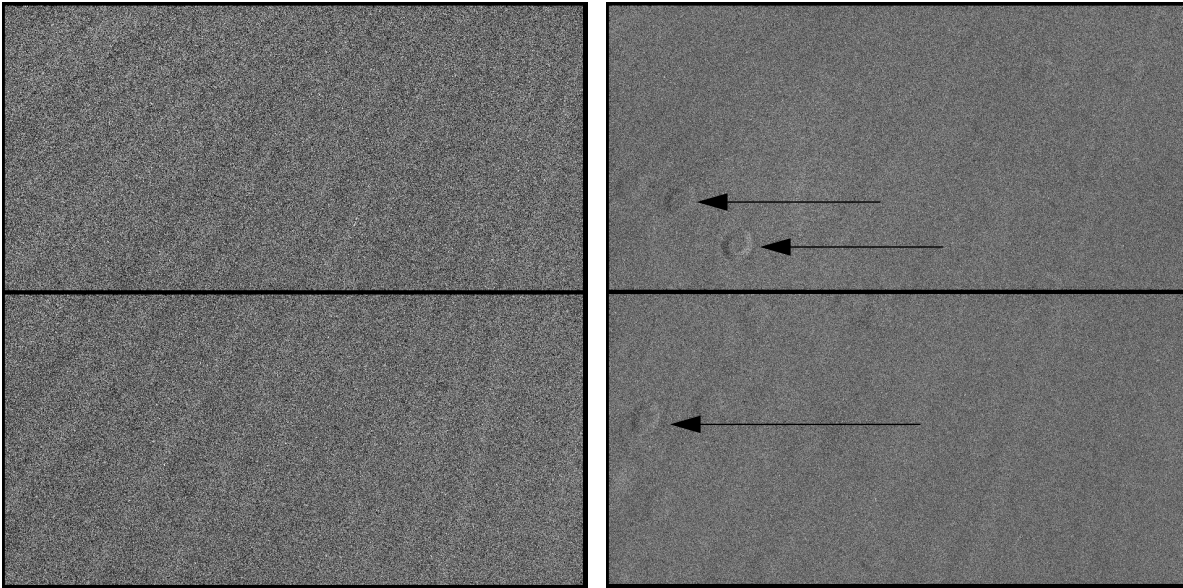
Line and column averages were taken across each chip (2000 lines and 4000 columns) to search for any features not visually apparent in the image ratios; typical examples are shown in Figure 4. Ratios for most visits showed that the averages are flat to <0.1% in both the x and y directions in both chips (left plots; the departure of the absolute level from 1.0 is discussed in the next section). The plots in the right column are based on images from a visit immediately after a cooldown: there is a decrease in absolute level in both chips, with a slight gradient in amps A/B and an extended peak in amps C/D corresponding to the large spot seen in the post-cooldown visit image ratios (see Figure 2). A bowtie feature in the on-orbit data would have appeared as a plateau in the column averages (top row of plots); no bowtie features were seen in any of the on-orbit data.

Figure 4: Average column and line plots across image ratios (image1/image3) from Visit 7 (left), just prior to the June 2009 anneal, and from Visit 8 (right) just after the June 2009 anneal. The top row of plots show a column average taken across the entire chip 1 (amps A and B) while the second row shows a line average taken across chip 2 (amps C and D).
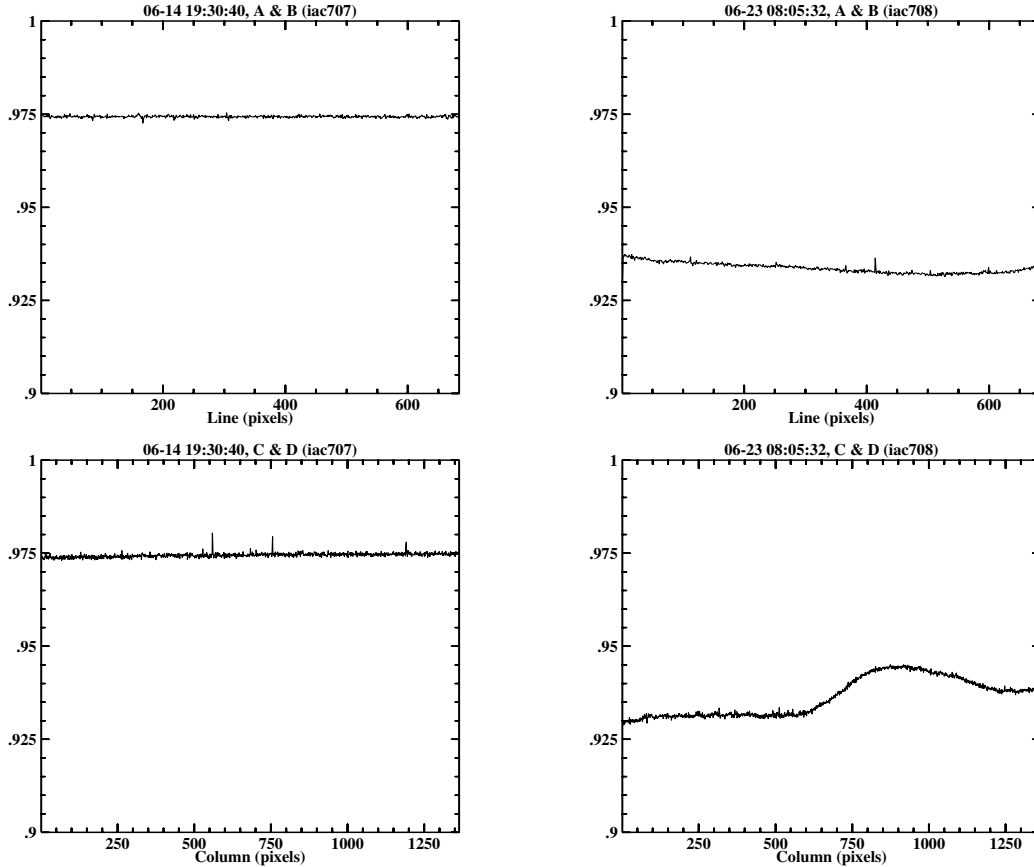
Longterm trends

Median levels of the image ratios were monitored as a function of time; the left plot in Figure 5 presents the results for the image1/image3 ratios. The median was computed using three iterations of three sigma clipping to exclude cosmic ray effects. The x-axis is date of the bowtie visit, in units of days since June 11,2009 (the date of the first WFC3 cold on-orbit images). The anneal procedures are marked with vertical lines. The gap in the observing program between days ~4-12 is due to the SIC&DH electronic malfunction, during which time the Hubble telescope was not taking observations. The right plot in Figure 5 shows histograms for a subset of the image1/image3 ratios: the three post-cooldown visits and every 10th normal visit during SMOV. The plots illustrate what had been detected visually in the image ratios: the first visit after each cooldown of the detectors to nominal operating temperature are out-of-family, that is, the levels of the ratios from the visits on day 1, 11, and 40 are about 4% lower than the majority of the ratio lev-

els. This deficit is larger than what was seen in the bowtie during the ground tests but is of the same order as that observed by the DCL during lab tests of the spare device. By the second visit after each cooldown, the image ratio levels are back to normal. The levels in each chip are in good agreement with each other, with the exception of the three post-cooldown visits. These results imply that less frequent bowtie monitors should suffice during on-orbit operations, a conclusion supported by DCL tests which indicated that on the spare part, the effects of the pinning exposure were long-lived, with <0.1% decrease in sensitivity after one week (Collins et al., 2009). Finally, we note that from visit to visit, the levels in the nominal data fluctuate about +/-1% peak to peak and the ratios show less scatter after day 40 than before; this is likely due to lamp variations.

Figure 5: At left, median flatfield (image1/image3) ratio levels as a function of day since June 11, 2009; crosses are for chip 1 and circles are for chip 2. Solid vertical lines mark the dates of the detector cooldowns. The first and second visits after each cooldowns are labeled with '1' and '2', respectively. At right are histograms of the three post-cooldown ratios and the ratios of every tenth normal visit.
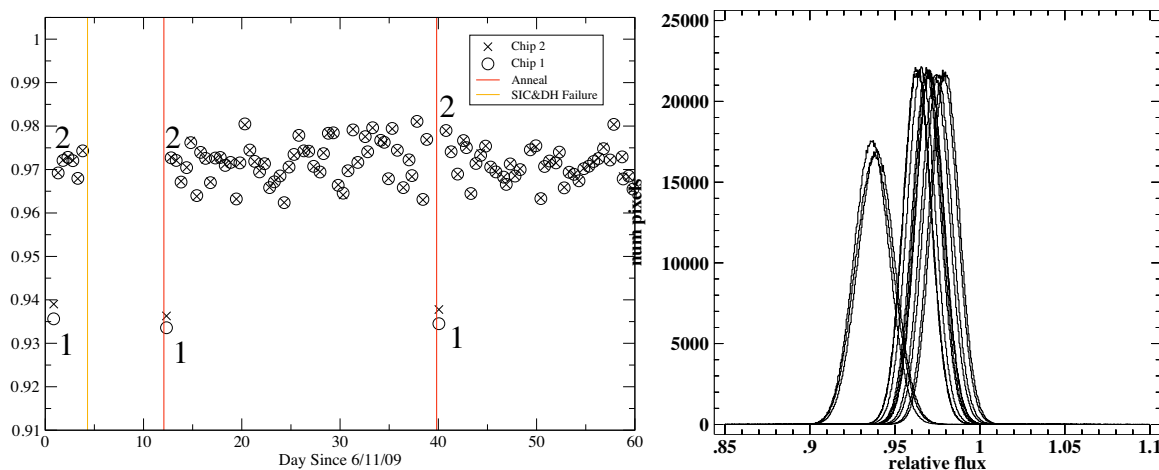
The median levels of the *nominal* ratios plotted in Figure 5 are systematically ~3% low, attributed to the time required for the tungsten lamp to warm up[1]. If the lamp wasn't completely warmed up before the first short image was acquired but had reached at its final operating temperature by the time of the third image, the image1/image3 ratios would be systematically low. Additional data will be required to determine how much extra lamp warmup time would be needed to avoid this effect. As shown in Figure 6, ratios of the first images to the first image in Visit 2 (visit 1 was not used as the reference due to the QE structures present) are around unity, with a handful of 1-2% high outliers

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1.   The total lamp warmup time before a tungsten flatfield exposure begins is a minimum of 75 sec. The warm up time specifically allocated for the tungsten lamps is 30 sec, followed by an additional 40 sec to transition WFC3 to the tungsten flatfield state, plus an additional few sec during which various image setup commands occur, such as filter selection and setting of the gain.

between days 20-40. Generally, the time it takes for the lamp to warm up is repeatable. Ratios of the third images to the third image in Visit 2 , shown at right in Figure 6, are also at unity. The medians in all cases are based on sigma-clipped statistics of image ratios and are shown as a function of date of the bowtie visit, in units of days since June 11,2009 (the first cold image). The average median is 1.00 for both sets of ratios, with standard deviations of 0.006 for the image1 ratios and 0.005 for the image3 ratios. For unknown reasons, the scatter of the data is higher between days 28-38 (July 9-19,2009): the average median before day 40 is 1.00 for both sets of ratios, with standard deviations of 0.006 and 0.004 for the image1 and image3 ratios, respectively. After day 40, the average median is 0.995 and 0.994 for the image1 and image3 ratios, respectively, and the standard deviation is 0.003 for both sets of ratios. By the end of the SMOV bowtie monitor proposal, after two months of use, the overall lamp output has dropped by 0.5%, not unusual behavior for this type of lamp. Currently, there is no concern for the lifetime of the bulbs: they are rated for a minimum of 5000 cycles and there is a primary and a spare for each WFC3 channel, i.e., a total of 4 bulbs, any of which can be used for either channel.

Figure 6: Medians of the ratios plotted as a function of the date of the bowtie visit in days since June 11,2009, the date of the first cold on-orbit WFC3 images. At left are image1 unsaturated flatfields from each visit ratioed to image1 from Visit 2; crosses are for chip 1 and circles are for chip 2. Anneals are marked with vertical lines. At right are the image 3 unsaturated flatfields from each visit ratioed to image 3 from Visit 2.
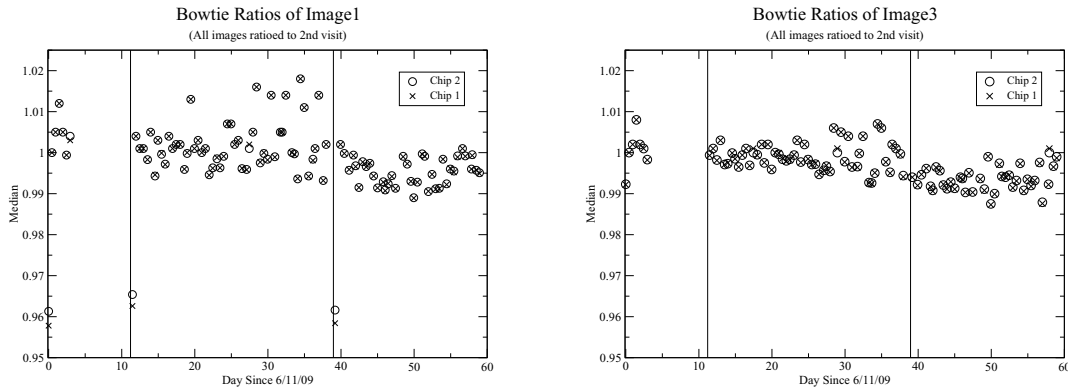
Conclusions

This report has summarized the SMOV UVIS bowtie monitor proposal and the data analysis results. While no 'bowtie' features were found in the on-orbit data, there is evidence for a global quantum efficiency deficit, or hysteresis, at the ~4% level immediately after the CCDs are cooled to operating temperature. As seen in the ground tests of the spare device, a single 10x full-well flatfield is sufficient to quench the hysteresis. For this

reason, a minimum of one bowtie visit should be included after every cooldown of the WFC3 UVIS detectors to effectively 'pin' the CCD QE. Based on the DCL lab tests, the QE remains pinned to better than 0.1% for at least one week; thus, expectations are that the bowtie visit frequency can be reduced in the future. The current plan for Cycle 17, which follows SMOV, is to reduce the bowtie visit frequency from two visits per day down to one per day, then one every other day. On-orbit monitoring will verify that the reduction in frequency has no ill effects. Other effects noted in the data include 1) the tungsten lamp output has declined 0.5% over the ~60 day SMOV time period, 2) the tungsten lamp has a slightly longer warmup time than is currently allotted which would warrant further study, 3) shutter blade B exhibits small differences in its travel time, at <0.5% in the flatfield ratio, and 4) the filter wheel containing F475X (#10) shows a benign misstep in its positioning.

Acknowledgements

References

Baggett, S., Martel, A., Sabbi, E., Deustua, S., and Kim-Quijano, J., "WFC3 Bowties in Groundbased TV3 data," WFC3 Instrument Science Report, in draft, 2010.

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Hilbert, B., "WFC3 SMOV Program 11427: UVIS Channel Shutter Shading,", WFC3 Instrument Science Report 2009-25, Nov 2009.

Appendix A.

Table 1. List of observations: rootname, exposure time (in sec), date and time of observation and shutter blade used. All images were 3x3 binned full-frame, four-amp readouts, taken with F475X. Dates of interest include June 11, the first on-orbit cooldown of the CCDs; June 23, the first CCD anneal procedure; and July 20, the second CCD anneal procedure. See Table 2 for a list of the software versions used to calibrate the data.

rootname	expt(s)	date-obs	time-obs	shut	rootname	expt(s)	date-obs	time-obs	shut
iac701i3q	1	2009-06-11	20:45:50	A	iac750wvq	1	2009-07-15	03:21:53	A
iac701i4q	200	2009-06-11	20:46:37	B	iac750wwq	200	2009-07-15	03:22:40	B
iac701i5q	1	2009-06-11	20:50:43	A	iac750wxq	1	2009-07-15	03:26:46	A
iac702kkq	1	2009-06-12	07:30:40	B	iac751yqq	1	2009-07-15	11:59:53	A
iac702klq	200	2009-06-12	07:31:27	A	iac751yrq	200	2009-07-15	12:00:40	B
iac702kmq	1	2009-06-12	07:35:33	B	iac751ysq	1	2009-07-15	12:04:46	A
iac703lcq	1	2009-06-12	19:30:41	A	iac752anq	1	2009-07-15	22:21:09	B
iac703ldq	200	2009-06-12	19:31:28	B	iac752aoq	200	2009-07-15	22:21:56	A
iac703leq	1	2009-06-12	19:35:34	A	iac752apq	1	2009-07-15	22:26:02	B
iac704p5q	1	2009-06-13	07:30:40	B	iac753dmq	1	2009-07-16	07:30:42	A
iac704p6q	200	2009-06-13	07:31:27	A	iac753dnq	200	2009-07-16	07:31:29	B
iac704p7q	1	2009-06-13	07:35:33	B	iac753doq	1	2009-07-16	07:35:35	A
iac705r2q	1	2009-06-13	19:30:41	A	iac754g1q	1	2009-07-16	19:59:25	B
iac705r3q	200	2009-06-13	19:31:28	B	iac754g2q	200	2009-07-16	20:00:12	A
iac705r4q	1	2009-06-13	19:35:34	A	iac754g3q	1	2009-07-16	20:04:18	B
iac706tdq	1	2009-06-14	07:30:40	B	iac755iyq	1	2009-07-17	10:32:08	A
iac706teq	200	2009-06-14	07:31:27	A	iac755izq	200	2009-07-17	10:32:55	B
iac706tfq	1	2009-06-14	07:35:33	B	iac755j0q	1	2009-07-17	10:37:01	A
iac707tsq	1	2009-06-14	19:30:40	A	iac756lxq	1	2009-07-18	00:30:49	B
iac707ttq	200	2009-06-14	19:31:27	B	iac756lyq	200	2009-07-18	00:31:36	A
iac707tuq	1	2009-06-14	19:35:33	A	iac756lzq	1	2009-07-18	00:35:42	B
iac708a1q	1	2009-06-23	08:05:32	A	iac757ncq	1	2009-07-18	07:30:41	B
iac708a2q	200	2009-06-23	08:06:19	B	iac757ndq	200	2009-07-18	07:31:28	A
iac708a3q	1	2009-06-23	08:10:25	A	iac757neq	1	2009-07-18	07:35:34	B
iac709alq	1	2009-06-23	19:30:41	B	iac758ppq	1	2009-07-18	19:54:23	B
iac709amq	200	2009-06-23	19:31:28	A	iac758pqq	200	2009-07-18	19:55:10	A
iac709anq	1	2009-06-23	19:35:34	B	iac758prq	1	2009-07-18	19:59:16	B

rootname	expt(s)	date-obs	time-obs	shut	rootname	expt(s)	date-obs	time-obs	shut
iac70addq	1	2009-06-24	07:56:58	A	iac759t1q	1	2009-07-19	10:25:39	A
iac70adeq	200	2009-06-24	07:57:45	B	iac759t2q	200	2009-07-19	10:26:26	B
iac70adfq	1	2009-06-24	08:01:51	A	iac759t3q	1	2009-07-19	10:30:32	A
iac710gfq	1	2009-06-24	19:43:09	B	iac760v2q	1	2009-07-19	19:51:53	A
iac710ggq	200	2009-06-24	19:43:56	A	iac760v3q	200	2009-07-19	19:52:40	B
iac710ghq	1	2009-06-24	19:48:02	B	iac760v4q	1	2009-07-19	19:56:46	A
iac711jaq	1	2009-06-25	09:30:10	A	iac761dgq	1	2009-07-21	01:25:08	B
iac711jbq	200	2009-06-25	09:30:57	B	iac761dhq	200	2009-07-21	01:25:55	A
iac711jcq	1	2009-06-25	09:35:03	A	iac761diq	1	2009-07-21	01:30:01	B
iac712jeq	1	2009-06-25	19:30:42	B	iac762lbq	1	2009-07-21	19:00:56	A
iac712jfq	200	2009-06-25	19:31:29	A	iac762lcq	200	2009-07-21	19:01:43	B
iac712jgq	1	2009-06-25	19:35:35	B	iac762ldq	1	2009-07-21	19:05:49	A
iac713nfq	1	2009-06-26	10:09:21	B	iac763mnq	1	2009-07-22	07:30:41	B
iac713ngq	200	2009-06-26	10:10:08	A	iac763moq	200	2009-07-22	07:31:28	A
iac713nhq	1	2009-06-26	10:14:14	B	iac763mpq	1	2009-07-22	07:35:34	B
iac714plq	1	2009-06-26	19:30:43	A	iac764sxq	1	2009-07-22	23:19:29	B
iac714pmq	200	2009-06-26	19:31:30	B	iac764syq	200	2009-07-22	23:20:16	A
iac714pnq	1	2009-06-26	19:35:36	A	iac764szq	1	2009-07-22	23:24:22	B
iac715tuq	1	2009-06-27	07:30:43	B	iac765cdq	1	2009-07-23	13:36:39	A
iac715tvq	200	2009-06-27	07:31:30	A	iac765ceq	200	2009-07-23	13:37:26	B
iac715twq	1	2009-06-27	07:35:36	B	iac765cfq	1	2009-07-23	13:41:32	A
iac716x7q	1	2009-06-27	19:30:43	A	iac766fpq	1	2009-07-23	20:42:07	B
iac716x8q	200	2009-06-27	19:31:30	B	iac766fqq	200	2009-07-23	20:42:54	A
iac716x9q	1	2009-06-27	19:35:36	A	iac766frq	1	2009-07-23	20:47:00	B
iac717ynq	1	2009-06-28	07:30:43	B	iac767inq	1	2009-07-24	07:30:41	A
iac717yoq	200	2009-06-28	07:31:30	A	iac767ioq	200	2009-07-24	07:31:28	B
iac717ypq	1	2009-06-28	07:35:36	B	iac767ipq	1	2009-07-24	07:35:34	A
iac718a2q	1	2009-06-28	19:30:44	A	iac768n9q	1	2009-07-24	20:04:34	A
iac718a3q	200	2009-06-28	19:31:31	B	iac768naq	200	2009-07-24	20:05:21	B
iac718a4q	1	2009-06-28	19:35:37	A	iac768nbq	1	2009-07-24	20:09:27	A
iac719ayq	1	2009-06-29	07:30:43	B	iac769t3q	1	2009-07-25	07:30:41	B
iac719azq	200	2009-06-29	07:31:30	A	iac769t4q	200	2009-07-25	07:31:28	A

rootname	expt(s)	date-obs	time-obs	shut	rootname	expt(s)	date-obs	time-obs	shut
iac719b0q	1	2009-06-29	07:35:36	B	iac769t5q	1	2009-07-25	07:35:34	B
iac720bvq	1	2009-06-29	20:31:42	A	iac770urq	1	2009-07-25	19:35:09	B
iac720bwq	200	2009-06-29	20:32:29	B	iac770usq	200	2009-07-25	19:35:56	A
iac720bxq	1	2009-06-29	20:36:35	A	iac770utq	1	2009-07-25	19:40:02	B
iac721kjq	1	2009-06-30	10:47:00	B	iac771x3q	1	2009-07-26	07:47:59	B
iac721kkq	200	2009-06-30	10:47:47	A	iac771x4q	200	2009-07-26	07:48:46	A
iac721klq	1	2009-06-30	10:51:53	B	iac771x5q	1	2009-07-26	07:52:52	B
iac722msq	1	2009-06-30	19:30:43	B	iac772aaq	1	2009-07-26	20:42:46	B
iac722mtq	200	2009-06-30	19:31:30	A	iac772abq	200	2009-07-26	20:43:33	A
iac722muq	1	2009-06-30	19:35:36	B	iac772acq	1	2009-07-26	20:47:39	B
iac723beq	1	2009-07-01	07:30:44	A	iac773dhq	1	2009-07-27	15:36:05	A
iac723bfq	200	2009-07-01	07:31:31	B	iac773diq	200	2009-07-27	15:36:52	B
iac723bgq	1	2009-07-01	07:35:37	A	iac773djq	1	2009-07-27	15:40:58	A
iac724egq	1	2009-07-01	19:38:22	A	iac774f8q	1	2009-07-27	21:54:38	A
iac724ehq	200	2009-07-01	19:39:09	B	iac774f9q	200	2009-07-27	21:55:25	B
iac724eiq	1	2009-07-01	19:43:15	A	iac774faq	1	2009-07-27	21:59:31	A
iac725nrq	1	2009-07-02	07:30:44	A	iac775j3q	1	2009-07-28	07:46:10	B
iac725nsq	200	2009-07-02	07:31:31	B	iac775j4q	200	2009-07-28	07:46:57	A
iac725ntq	1	2009-07-02	07:35:37	A	iac775j5q	1	2009-07-28	07:51:03	B
iac726t4q	1	2009-07-02	19:30:44	B	iac776ovq	1	2009-07-28	19:30:42	A
iac726t5q	200	2009-07-02	19:31:31	A	iac776owq	200	2009-07-28	19:31:29	B
iac726t6q	1	2009-07-02	19:35:37	B	iac776oxq	1	2009-07-28	19:35:35	A
iac727tuq	1	2009-07-03	07:30:44	B	iac777rdq	1	2009-07-29	07:44:37	B
iac727tvq	200	2009-07-03	07:31:31	A	iac777req	200	2009-07-29	07:45:24	A
iac727twq	1	2009-07-03	07:35:37	B	iac777rfq	1	2009-07-29	07:49:30	B
iac728apq	1	2009-07-03	19:56:32	A	iac778yuq	1	2009-07-30	08:44:44	A
iac728aqq	200	2009-07-03	19:57:19	B	iac778yvq	200	2009-07-30	08:45:31	B
iac728arq	1	2009-07-03	20:01:25	A	iac778ywq	1	2009-07-30	08:49:37	A
iac729i5q	1	2009-07-04	07:30:44	A	iac779cfq	1	2009-07-30	22:09:42	B
iac729i6q	200	2009-07-04	07:31:31	B	iac779cgq	200	2009-07-30	22:10:29	A
iac729i7q	1	2009-07-04	07:35:37	A	iac779chq	1	2009-07-30	22:14:35	B
iac730n4q	1	2009-07-04	21:23:19	B	iac780dnq	1	2009-07-31	10:19:25	B

rootname	expt(s)	date-obs	time-obs	shut	rootname	expt(s)	date-obs	time-obs	shut
iac730n5q	200	2009-07-04	21:24:06	A	iac780doq	200	2009-07-31	10:20:12	A
iac730n6q	1	2009-07-04	21:28:12	B	iac780dpq	1	2009-07-31	10:24:18	B
iac731ndq	1	2009-07-05	07:30:44	B	iac781frq	1	2009-07-31	19:30:41	A
iac731neq	200	2009-07-05	07:31:31	A	iac781fsq	200	2009-07-31	19:31:28	B
iac731nfq	1	2009-07-05	07:35:37	B	iac781ftq	1	2009-07-31	19:35:34	A
iac732p5q	1	2009-07-05	19:30:43	A	iac782h4q	1	2009-08-01	07:38:40	B
iac732p6q	200	2009-07-05	19:31:30	B	iac782h5q	200	2009-08-01	07:39:27	A
iac732p7q	1	2009-07-05	19:35:36	A	iac782h6q	1	2009-08-01	07:43:33	B
iac733ciq	1	2009-07-06	07:30:44	A	iac783l9q	1	2009-08-01	23:26:03	A
iac733cjq	200	2009-07-06	07:31:31	B	iac783laq	200	2009-08-01	23:26:50	B
iac733ckq	1	2009-07-06	07:35:37	A	iac783lbq	1	2009-08-01	23:30:56	A
iac734fyq	1	2009-07-06	19:30:43	B	iac784mpq	1	2009-08-02	07:36:27	B
iac734fzq	200	2009-07-06	19:31:30	A	iac784mqq	200	2009-08-02	07:37:14	A
iac734g0q	1	2009-07-06	19:35:36	B	iac784mrq	1	2009-08-02	07:41:20	B
iac735i7q	1	2009-07-07	07:30:43	A	iac785pqq	1	2009-08-02	19:30:43	B
iac735i8q	200	2009-07-07	07:31:30	B	iac785prq	200	2009-08-02	19:31:30	A
iac735i9q	1	2009-07-07	07:35:36	A	iac785psq	1	2009-08-02	19:35:36	B
iac736lhq	1	2009-07-07	19:30:43	B	iac786cjq	1	2009-08-03	07:34:12	B
iac736liq	200	2009-07-07	19:31:30	A	iac786ckq	200	2009-08-03	07:34:59	A
iac736ljq	1	2009-07-07	19:35:36	B	iac786clq	1	2009-08-03	07:39:05	B
iac737ojq	1	2009-07-08	07:30:43	A	iac787fxq	1	2009-08-03	19:30:42	A
iac737okq	200	2009-07-08	07:31:30	B	iac787fyq	200	2009-08-03	19:31:29	B
iac737olq	1	2009-07-08	07:35:36	A	iac787fzq	1	2009-08-03	19:35:35	A
iac738usq	1	2009-07-08	23:00:20	A	iac788joq	1	2009-08-04	07:31:53	B
iac738utq	200	2009-07-08	23:01:07	B	iac788jpq	200	2009-08-04	07:32:40	A
iac738uuq	1	2009-07-08	23:05:13	A	iac788jqq	1	2009-08-04	07:36:46	B
iac739weq	1	2009-07-09	07:30:43	B	iac789m2q	1	2009-08-04	19:33:26	B
iac739wfq	200	2009-07-09	07:31:30	A	iac789m3q	200	2009-08-04	19:34:13	A
iac739wgq	1	2009-07-09	07:35:36	B	iac789m4q	1	2009-08-04	19:38:19	B
iac740a1q	200	2009-07-09	19:31:30	B	iac790txq	1	2009-08-05	07:30:42	A
iac740a2q	1	2009-07-09	19:35:36	A	iac790tyq	200	2009-08-05	07:31:29	B
iac740zzq	1	2009-07-09	19:30:43	A	iac790tzq	1	2009-08-05	07:35:35	A

rootname	expt(s)	date-obs	time-obs	shut	rootname	expt(s)	date-obs	time-obs	shut
iac741ckq	1	2009-07-10	07:30:43	A	iac791c9q	1	2009-08-05	19:30:42	B
iac741clq	200	2009-07-10	07:31:30	B	iac791caq	200	2009-08-05	19:31:29	A
iac741cmq	1	2009-07-10	07:35:36	A	iac791cbq	1	2009-08-05	19:35:35	B
iac742fiq	1	2009-07-10	19:30:43	B	iac792hhq	1	2009-08-06	07:30:42	A
iac742fjq	200	2009-07-10	19:31:30	A	iac792hiq	200	2009-08-06	07:31:29	B
iac742fkq	1	2009-07-10	19:35:36	B	iac792hjq	1	2009-08-06	07:35:35	A
iac743g0q	1	2009-07-11	07:30:43	B	iac793jrq	1	2009-08-06	19:30:42	B
iac743g1q	200	2009-07-11	07:31:30	A	iac793jsq	200	2009-08-06	19:31:29	A
iac743g2q	1	2009-07-11	07:35:36	B	iac793jtq	1	2009-08-06	19:35:35	B
iac744g9q	1	2009-07-11	19:30:42	A	iac794raq	1	2009-08-07	11:32:59	B
iac744gaq	200	2009-07-11	19:31:29	B	iac794rbq	200	2009-08-07	11:33:46	A
iac744gbq	1	2009-07-11	19:35:35	A	iac794rcq	1	2009-08-07	11:37:52	B
iac745hgq	1	2009-07-12	07:33:00	B	iac795upq	1	2009-08-07	20:40:30	A
iac745hhq	200	2009-07-12	07:33:47	A	iac795uqq	200	2009-08-07	20:41:17	B
iac745hiq	1	2009-07-12	07:37:53	B	iac795urq	1	2009-08-07	20:45:23	A
iac746juq	1	2009-07-12	19:30:42	B	iac796d6q	1	2009-08-08	16:56:02	A
iac746jvq	200	2009-07-12	19:31:29	A	iac796d7q	200	2009-08-08	16:56:49	B
iac746jwq	1	2009-07-12	19:35:35	B	iac796d8q	1	2009-08-08	17:00:55	A
iac747gqq	1	2009-07-13	13:28:40	A	iac797f9q	1	2009-08-08	19:30:42	B
iac747grq	200	2009-07-13	13:29:27	B	iac797faq	200	2009-08-08	19:31:29	A
iac747gsq	1	2009-07-13	13:33:33	A	iac797fbq	1	2009-08-08	19:35:35	B
iac748j5q	1	2009-07-13	19:30:42	B	iac798ijq	1	2009-08-09	09:00:08	B
iac748j6q	200	2009-07-13	19:31:29	A	iac798ikq	200	2009-08-09	09:00:55	A
iac748j7q	1	2009-07-13	19:35:35	B	iac798ilq	1	2009-08-09	09:05:01	B
iac749mvq	1	2009-07-14	07:30:43	A	iac799klq	1	2009-08-09	19:30:41	A
iac749mwq	200	2009-07-14	07:31:30	B	iac799kmq	200	2009-08-09	19:31:28	B
iac749mxq	1	2009-07-14	07:35:36	A	iac799knq	1	2009-08-09	19:35:34	A

Table 2. Calwf3 versions used to process the Bowtie Monitor data; see previous table in this Appendix for a full list of images.

images	date	opus version	calwf3 version	comment
iac701i3q through iac707tuq	June 11 - June 14	2009_2c	1.3 (13 Mar 2009)	
iac708a1q through iac712jgq	June 23 - June 25	2009_2d	1.3 (13 Mar 2009)	gap between June 14-23 due to SIC&DH anomaly
iac713nfq - iac740zzq	June 26 - July 9	2009_2d	1.5 (24 June 2009)	calwf3 version changed to 1.5
iac741ckq through iac764szq	July 10 - July 22	2009_2f	1.5 (24 June 2009)	OPUS version changed to _2f
iac765cdq through iac799knq	July 23 - Aug 9	2009_2g	1.5 (24 June 2009)	