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WFC3 TV2 Testing: UVIS-2 Gain Results

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ABSTRACT

Thermal-vacuum (TV) level tests using the integrated WFC3 instrument, with the UVIS-2 detector in place, were performed at Goddard Space Flight Center (GSFC) during the summer of 2007. Data were acquired to allow an absolute gain measurement using the mean-variance method at the nominal gain 1.5 setting, with a CCD operating temperature of -78^{o} C, for both unbinned and binned modes. In addition, data were taken to allow a check of the gain ratios between the standard 1.5 setting and the other three available settings (nominally 1.0, 2.0, and 4.0 e^{-}/DN), at two different temperatures. For unbinned images, taken with the CCD at -78^{o} C, the gains were measured at 1.57, 1.54, 1.63, 1.59 e^{-}/DN, for quadrants A, B, C, and D, respectively, with errors ~0.01 e^{-}/DN. These values are 1-2% lower than the gains measured with the CCD at -54^{o} C during ambient testing (Baggett, 2007). TV gain values for the binned modes were generally within 1% of the unbinned mode gain, though systematically slightly lower than the unbinned mode gain. Finally, the gains for the other three settings, at -78^{o} C and assuming 1.5 e^{-}/DN for the default gain, were found to be, on average, 1.03, 2.11, and 4.30 e^{-}/DN. Within the errors, the relative gains measured at the cooler temperature (-81.5^{o} C) were the same as those at the warmer temperature.

Introduction

The integrated WFC3, with the UVIS-2 detector in place, recently underwent thermal-vacuum level testing in the GSFC Space Environment Simulator chamber. External light sources were provided by the WFC3 optical stimulus (CASTLE), which simulates the HST OTA including the major aberrations. For the flatfields used in the gain measurements, the CASTLE tungsten lamp and integrating sphere were used to provide the required flat illumination.

Data for the gain determinations were taken at various gain settings, binning modes, and CCD temperatures. In terms of gain, there are four possible settings for the WFC3 UVIS channel, nominally 1.0, 1.5, 2.0, and 4.0 e^-/DN. The gain 1.5 setting has been chosen as the default, as it is expected to provide the best sampling of the entire full-well of the detector given the 16-bit A to D converter. As of this writing, the other three settings have been implemented but designated as restricted modes and are not expected to be available to observers. For this reason, the ground tests consisted of an absolute gain check at the default 1.5 setting; gains for the other three settings were measured relative to that of the 1.5 setting.

WFC3 UVIS data may also be taken in binned mode, where multiple pixels (either 2x2 or 3x3) are binned into a single pixel during readout. Binning improves the signal-to-noise in an image by minimizing readout noise (each binned pixel has the same amount of noise as an unbinned pixel), so it can be useful for observing very faint targets; however, it does of course also reduce spatial resolution. The default observing mode is full resolution, no binning, though the binned modes will be available to observers and are expected to be fully supported; the TV ground tests provided a check of the unbinned as well as the two binned modes.

Finally, most of the gain tests were performed with the UVIS detector at an operating temperature of -78^o C. The default UVIS operating temperature is nominally -83^o C; however, due to a lien against the detector in place for the TV2 tests (UVIS-2, the flight spare), most operations were kept ~ -78^o C. The relative gain checks were performed at both -78^o C and -81.5^o C.

This report presents the details of the gain analyses and the results for the various modes.

Absolute Gain

The mean-variance method was used to compute the absolute gain; that is, in a plot of the mean signal level versus the variance, the gain is the inverse slope. This relationship is derived from the noise equation, i.e., the total noise, or observed variance, in an image can

be written as $(N/g)^2=(p/g)^2+(R/g)^2$, where N is the total noise, g is the gain conversion in units of e^-/DN and the noise terms (photon, p, and readnoise, R) are in units of in e^-. Since photon noise is the square root of g*signal when the mean signal μ is in DN, the observed variance σ^2 can be rewritten as $\sigma^2 = (1/g) *\mu + (R/g)^2$, i.e., the inverse slope provides the gain.

To maximize efficient use of TV test time, there are no specific absolute gain SMS's but rather, a subset of the flatfields taken for linearity checks (UV05 SMSs) are used. During the 2007 TV2 tests, both the unbinned and binned versions of the linearity proposals were executed, with CCD temperature of -78^o C; the flatfields used for absolute gain measurement are listed in Table 3, Appendix A.

All images were processed through calwf3, performing the overscan correction only, using the versions of CCDTAB and OSCNTAB in place during 2007 (q911321ni_ccd.fits and q911321oi_osc.fits, respectively). Average and difference images were formed for each available pair of flatfields at a given exposure level and the mean-variance plot constructed from the means of the average images and the variances of the difference images (standard deviation squared and divided by two).

For the unbinned data, statistics were measured in twenty-six 400x400 pixel regions per quad; no pixels were masked. Figure 1 shows the quad C results; there are no obvious outliers though there is a hint of non-linearity at the highest exposure level (~38K DN), somewhat worse in the other quads. Restricting the fit for each quad out to only the second-highest level (26K DN) lowered the resulting gains by ~1-1.5%; rather than basing the measurements on such a relatively small range however, the final results, listed in Table 1, are based upon fits across the entire range (up to 38K DN). Allowing for masking of some pixels (3 iterations of 3 sigma clipping of statistics, prior to mean-variance fit) was found to increase the gain systematically by 2-3%; however, given the lack of obvious outliers in the mean-variance plot based on unmasked data, the results shown in Table 1 have not had any pixels clipped. The final TV2 gains for UVIS-2, at -78^o C, were 1-2% lower than those measured during ambient-2 testing for UVIS-2, at -54 C (1.58, 1.55, 1.65, and 1.61 e^-/DN; Baggett, 2007).

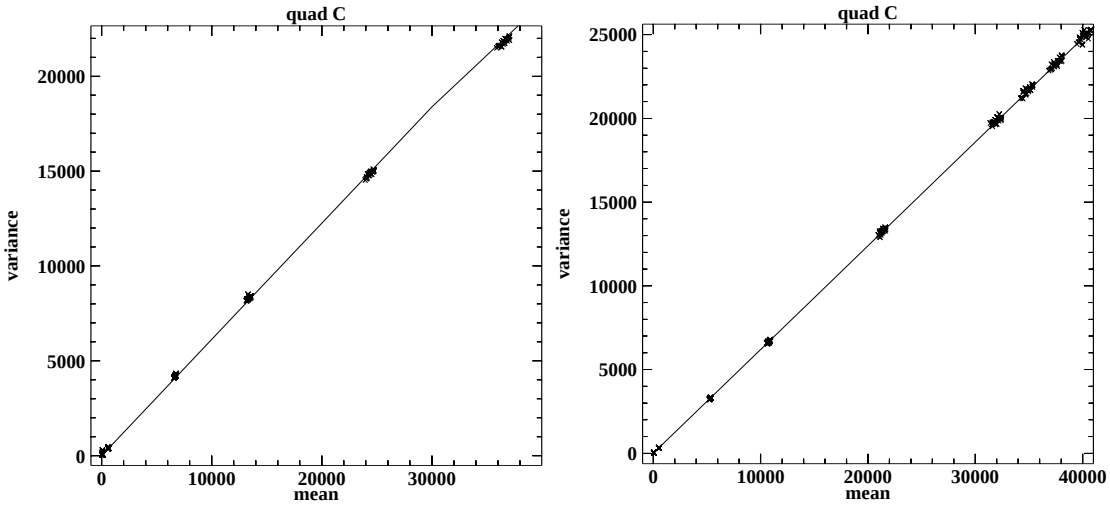
For the binned data, statistics were computed in twenty-six 200x200 pixel regions (2x2 binned images) and twenty-six 133x133 pixel regions (3x3 binned images). In the initial mean-variance plots, there were obvious outliers, found to be due to the influence of e.g. bad columns on the now-smaller image sections being used. For this reason, some masking of pixels was done during computation of the statistics of the binned images (3 iterations of 3 sigma clipping). One of the resulting mean-variance plots is show in Figure 1 (quadrant C, 2x2 binned mode). All quadrants showed excellent mean-variance behavior out to the limit of the data (~52K DN) except for quadrant B, where the variances dropped sharply beyond 40K DN. This non-linearity issue with quad B was characterized further

during TV2 (Baggett et al., 2007), with a fix identified and confirmed successful. To avoid the non-linear regime in the amp B data and treat all quads equally, gains were measured out to only 38K DN; values are tabulated in Table 1. The binned mode gains were found to be within 1-1.5% of the unbinned mode gains.

Table 1. UVIS-2 gain results for the commanded gain 1.5 setting.

	unbinned		2x2 binning		3x3 binning	
quadrant	**gain**	**fit error**	**gain**	**fit error**	**gain**	**fiterror**
A	1.57	<0.01	1.56	<0.01	1.55	<0.01
B	1.54	<0.01	1.52	<0.01	1.52	<0.01
C	1.63	<0.01	1.61	<0.01	1.61	<0.01
D	1.58	<0.01	1.57	<0.01	1.56	<0.01

Figure 1: Mean-variance plots for quad C, for unbinned mode (left) and 2x2 binned mode (right).



Relative Gain

The relative gain measurements for UVIS-2 were made from UV03S01 SMS data: 40-second F606W flatfields taken on June 28, 2007, two flatfields at each gain (1.0, 1.5, 2.0, and 4.0) ending with an additional pair taken at gain=1.0 to verify the stability of the CASTLE stimulus. Each pair of flatfields were preceded and followed by a biasfile taken at the same gain setting. The images were full-frame, unbinned, four-amp readouts taken at the nominal bias offset level of 3 (images are listed in Table 2, Appendix A). During the first run of

UV03S01, the UVIS-2 detector temperature was -78^{o} C. The entire set was repeated later that same day, with the UVIS-2 detector temperature set to -81.5^{o} C.

All images were processed through the STSDAS calwf3, performing the overscan correction (BLEVCORR) and using versions of CCDTAB and OSCNTAB in place during 2007 (q911321ni_ccd.fits and q911321oi_osc.fits, respectively). Each pair of flatfields at a given gain was averaged, the result ratioed to the average gain 1.5 image, and scaled by 1.5, the nominal gain. Pixel statistics were measured across each quadrant of the ratio images; no pixels were masked but there were no significant differences between the average and median. The results are listed in Table 1. The two sets of gain=1.0 data were analyzed separately but the gains were found to be the same within the errors. Application of a biasfile, generated from data taken close in time to the flatfields, had no significant effect on the results. The gain ratios were also computed using sigma-clipped image statistics (3 iterations of 3 sigma clipping), once again with no significant change in the results.

Table 2. Gains for off-nominal settings based upon ratios for the four quadrants of UVIS-2 relative to gain 1.5. Gain values assumed for gain 1.5 setting are noted in the table; there are no associated absolute measurements of the gain 1.5 setting values at the colder temperature, so off-nominal gain values were derived assuming 1.50 for all amps only.

quad	gain 1.0	stddev	gain 2.0	stddev	gain 4.0	stddev
CCD -78^{o} C						
Values assuming 1.50 for all amps at gain 1.5 setting						
A	1.02	<0.01	2.09	0.01	4.27	0.02
B	1.04	<0.01	2.15	0.01	4.38	0.02
C	1.02	<0.01	2.10	0.01	4.27	0.02
D	1.02	<0.01	2.10	0.01	4.30	0.02
Values assuming Table 1, column 2 (this ISR) values for amps at gain 1.5 setting						
A	1.07	0.01	2.18	0.01	4.46	0.02
B	1.07	0.01	2.20	0.01	4.49	0.02
C	1.11	0.01	2.29	0.01	4.65	0.02
D	1.08	0.01	2.22	0.01	4.54	0.02
CCD -81.5^{o} C						
Values assuming 1.50 for all amps at gain 1.5 setting						
A	1.02	<0.01	2.09	0.01	4.25	0.02
B	1.04	<0.01	2.15	0.01	4.36	0.02
C	1.02	<0.01	2.10	0.01	4.25	0.02
D	1.02	<0.01	2.10	0.01	4.28	0.02

Summary

The absolute gains have been measured for the default gain1.5 setting at -78^{o} C, for both unbinned and binned modes, and are summarized in Table 1. The gains for the other three settings have been measured relative to the gain 1.5 setting, at two different temperatures, and are summarized in Table 2.

Acknowledgements

Thanks are due to all the WFC3 team members, at GSFC and STScI, who made the thermal vacuum tests possible.

References

Baggett, S., “WFC3 Ambient-2 Testing: UVIS Gain Results,” ISR 2007-11.

Baggett, S., et al., “WFC3 UVIS-2 Amp B Anomaly,”, in progress.

Appendix A.

Table 3. Files used for absolute gain determinations. Images were all full-frame, four-amp readouts, with offset=3, WFC3 side 2 (MEB2), CCD temperature -78^{o} C (IUVDETMP), and gain 1.5 setting. Flats were taken with F606W, using CASTLE tungsten lamp with OSFILT0=LP340. Shown are the imagenames, tv number, observation date and time, exposure time, CASTLE OSFILT1/2, bin mode, and median level (in DN).

imagename	tvnum	date-obs	exptim	OSFILT1, OSFILT2	bin	median DN level
iu051b01r_07182154431	32278	2007-07-01 15:37:24.04	0.0	--	1	0.17
iu051b02r_07182154431	32279	2007-07-01 15:40:25.06	100.0	ND3,OPEN	1	70.88
iu051b04r_07182160435	32280	2007-07-01 15:56:04.04	100.0	ND3,OPEN	1	71.06
iu051b05r_07182160435	32281	2007-07-01 16:00:29.06	100.0	ND3,OPEN	1	71.09
iu051b07r_07182162439	32282	2007-07-01 16:16:08.04	100.0	ND3,OPEN	1	71.19
iu051b08r_07182162439	32283	2007-07-01 16:20:33.06	100.0	ND3,OPEN	1	71.175
iu051b0ar_07182164443	32284	2007-07-01 16:36:12.04	100.0	ND3,OPEN	1	70.91
iu051b0br_07182164443	32285	2007-07-01 16:40:37.06	100.0	ND3,OPEN	1	71.32

imagename	tvnum	date-obs	exptim	OSFILT1, OSFILT2	bin	median DN level
iu051b0dr_07182170447	32286	2007-07-01 16:56:16.04	100.0	ND3,OPEN	1	71.28
iu051b0er_07182170447	32287	2007-07-01 17:00:41.06	100.0	ND3,OPEN	1	71.22
iu051b0gr_07182172441	32288	2007-07-01 17:16:20.06	100.0	ND3,OPEN	1	71.105
iu051b0mr_07182180242	32292	2007-07-01 17:54:43.06	100.0	ND2,OPEN	1	632.4
iu051b0nr_07182180242	32293	2007-07-01 17:58:36.05	100.0	ND2,OPEN	1	632.45
iu051b0pr_07182182142	32294	2007-07-01 18:13:43.06	100.0	ND2,OPEN	1	631.8
iu051b0qr_07182182142	32295	2007-07-01 18:17:36.05	100.0	ND2,OPEN	1	632.3
iu051b0sr_07182184042	32296	2007-07-01 18:32:43.06	100.0	ND2,OPEN	1	633.5
iu051b0tr_07182184042	32297	2007-07-01 18:36:36.05	100.0	ND2,OPEN	1	632.9
iu051b0vr_07182185946	32298	2007-07-01 18:51:43.06	100.0	ND2,OPEN	1	632.65
iu051b0wr_07182185946	32299	2007-07-01 18:55:36.05	100.0	ND2,OPEN	1	633.1
iu051b11r_07182193626	32302	2007-07-01 19:28:27.06	100.0	ND1,OPEN	1	6977.5
iu051b12r_07182193626	32303	2007-07-01 19:32:20.05	100.0	ND1,OPEN	1	6987.
iu051b15r_07182195838	32305	2007-07-01 19:52:54.07	200.0	ND1,OPEN	1	13998.
iu051b17r_07182201936	32306	2007-07-01 20:09:37.04	200.0	ND1,OPEN	1	14003.5
iu051b1br_07182203636	32309	2007-07-01 20:33:30.06	40.0	OPEN,OPEN	1	25483.5
iu051b1dr_07182205356	32310	2007-07-01 20:47:37.04	40.0	OPEN,OPEN	1	25507.5
iu051b1gr_07182211136	32312	2007-07-01 21:04:57.04	60.0	OPEN,OPEN	1	38163.5
iu051b1hr_07182211136	32313	2007-07-01 21:08:10.06	60.0	OPEN,OPEN	1	38161.5
iu051b2ar_07183001348	32332	2007-07-02 00:07:01.04	0.0	--	1	0.26
iu050201r_07221050852	41603	2007-08-09 05:02:23.04	0.0	--	2	0.04
iu050202r_07221050852	41604	2007-08-09 05:04:31.04	23.0	ND3,OPEN	2	53.84
iu050203r_07221051400	41605	2007-08-09 05:06:46.05	23.0	ND3,OPEN	2	54.095
iu050204r_07221051400	41606	2007-08-09 05:08:27.04	232.0	ND3,OPEN	2	541.7
iu050206r_07221052237	41607	2007-08-09 05:13:35.04	232.0	ND3,OPEN	2	541.95
iu050209r_07221052820	41609	2007-08-09 05:22:12.06	267.0	ND2,OPEN	2	5562.5
iu05020br_07221054739	41610	2007-08-09 05:27:55.04	267.0	ND2,OPEN	2	5560.
iu05020er_07221055509	41612	2007-08-09 05:37:06.05	49.0	ND1,OPEN	2	11257.5
iu05020fr_07221055907	41613	2007-08-09 05:39:14.05	49.0	ND1,OPEN	2	11263.
iu05020gr_07221060304	41614	2007-08-09 05:41:22.05	97.0	ND1,OPEN	2	22343.
iu05020hr_07221060713	41615	2007-08-09 05:44:18.05	97.0	ND1,OPEN	2	22339.5
iu05020ir_07221061122	41616	2007-08-09 05:47:14.05	145.0	ND1,OPEN	2	33444.5

imagename	tvnum	date-obs	exptim	OSFILT1, OSFILT2	bin	median DN level
iu05020kr_07221061543	41617	2007-08-09 05:50:59.04	145.0	ND1,OPEN	2	33451.5
iu05020mr_07221062004	41618	2007-08-09 05:54:44.06	158.0	ND1,OPEN	2	36421.
iu05020or_07221062438	41619	2007-08-09 05:58:42.05	158.0	ND1,OPEN	2	36444.5
iu05020qr_07221062910	41620	2007-08-09 06:02:39.04	170.0	ND1,OPEN	2	39231.5
iu05020sr_07221062910	41621	2007-08-09 06:06:48.06	170.0	ND1,OPEN	2	39268.
iu05021cr_07221071749	41632	2007-08-09 06:52:28.06	0.0	--	3	0.58
iu05021dr_07221072233	41633	2007-08-09 06:54:07.04	135.0	ND4,OPEN	3	55.495
iu05021fr_07221072233	41634	2007-08-09 06:57:45.06	135.0	ND4,OPEN	3	55.495
iu05021ir_07221072233	41636	2007-08-09 07:03:44.06	103.0	ND3,OPEN	3	542.
iu05021jr_07221072233	41637	2007-08-09 07:06:18.05	103.0	ND3,OPEN	3	542.15
iu05021lr_07221074734	41639	2007-08-09 07:11:48.06	119.0	ND2,OPEN	3	5579.5
iu05021mr_07221074946	41640	2007-08-09 07:14:37.06	119.0	ND2,OPEN	3	5578.5
iu05021nr_07221075203	41641	2007-08-09 07:17:24.06	238.0	ND2,OPEN	3	11180.5
iu05021pr_07221075420	41642	2007-08-09 07:22:08.06	238.0	ND2,OPEN	3	11186.
iu05021sr_07221075905	41644	2007-08-09 07:29:49.06	43.0	ND1,OPEN	3	22298.5
iu05021tr_07221080132	41645	2007-08-09 07:31:22.05	43.0	ND1,OPEN	3	22281.5
iu05021ur_07221081012	41646	2007-08-09 07:32:55.04	65.0	ND1,OPEN	3	33746.
iu05021vr_07221081012	41647	2007-08-09 07:34:50.05	65.0	ND1,OPEN	3	33719.5
iu05021wr_07221081012	41648	2007-08-09 07:36:45.06	70.0	ND1,OPEN	3	36320.5
iu05021xr_07221081012	41649	2007-08-09 07:38:45.06	70.0	ND1,OPEN	3	36335.
iu05021yr_07221081012	41650	2007-08-09 07:40:45.06	75.5	ND1,OPEN	3	39169.5
iu05021zr_07221081012	41651	2007-08-09 07:42:51.04	75.5	ND1,OPEN	3	39190.5
iu05022gr_07221081012	41660	2007-08-09 08:03:43.04	0.0	--	3	0.46
iu05022hr_07221081012	41661	2007-08-09 08:04:24.06	0.0	--	3	0.62

Table 4. Files used for relative gain determination. Images were all full-frame, four-amp unbinned readouts, offset=3 and WFC3 side 2 (MEB2). Flats were 40 sec exposures taken with F606W, CASTLE tungsten lamp with OSFILT0=LP340, and OSFILT1, OSFILT2 both open. Listed are imagenames, tv number, observation date and time, CCD temperature (^{o} C, from UVDETMP), commanded gain, and median level (in DN).

imagename	tvnum	date-obs	CCD temperature	gain	median DN level
iu031b01r_07179075936	31895	2007-06-28 07:53:29.04	-78.2791	1.0	0.04 (bias)
iu031b02r_07179075936	31896	2007-06-28 07:56:30.06	-77.9070	1.0	40135.
iu031b04r_07179081634	31897	2007-06-28 08:11:09.04	-77.9070	1.0	40137.5
iu031b05r_07179081634	31898	2007-06-28 08:14:11.06	-78.0930	1.0	0.08 (bias)
iu031b07r_07179083332	31899	2007-06-28 08:27:29.04	-77.9070	1.5	0.19 (bias)
iu031b08r_07179083332	31900	2007-06-28 08:30:26.06	-77.9070	1.5	27507.5
iu031b0ar_07179085030	31901	2007-06-28 08:45:05.04	-77.9070	1.5	27484.
iu031b0br_07179085030	31902	2007-06-28 08:48:07.06	-78.2791	1.5	0.02 (bias)
iu031b0dr_07179090728	31903	2007-06-28 09:01:25.04	-78.2791	2.0	0.02 (bias)
iu031b0er_07179090728	31904	2007-06-28 09:04:22.06	-78.2791	2.0	19544.
iu031b0gr_07179092426	31905	2007-06-28 09:19:01.04	-78.0930	2.0	19528.5
iu031b0hr_07179092426	31906	2007-06-28 09:22:03.06	-78.0930	2.0	0.02 (bias)
iu031b0jr_07179094124	31907	2007-06-28 09:35:21.04	-77.9070	4.0	-0.04 (bias)
iu031b0kr_07179094124	31908	2007-06-28 09:38:18.06	-77.9070	4.0	9583.
iu031b0mr_07179095822	31909	2007-06-28 09:52:57.04	-77.9070	4.0	9554.5
iu031b0nr_07179095822	31910	2007-06-28 09:55:59.06	-78.0930	4.0	0.04 (bias)
iu031b0pr_07179101520	31911	2007-06-28 10:09:17.04	-78.0930	1.0	0.09 (bias)
iu031b0qr_07179101520	31912	2007-06-28 10:12:14.06	-78.0930	1.0	40157.5
iu031b0sr_07179103307	31913	2007-06-28 10:26:53.04	-78.0930	1.0	40137.5
iu031b0tr_07179103307	31914	2007-06-28 10:29:55.06	-78.2791	1.0	0.07 (bias)
iu031b01r_07179131435	31921	2007-06-28 13:08:28.04	-81.6279	1.0	0.08 (bias)
iu031b02r_07179131435	31922	2007-06-28 13:11:29.06	-81.6279	1.0	40254.
iu031b04r_07179133133	31923	2007-06-28 13:26:08.04	-81.6279	1.0	40188.5
iu031b05r_07179133133	31924	2007-06-28 13:29:10.06	-81.6279	1.0	-0.11 (bias)
iu031b07r_07179134831	31925	2007-06-28 13:42:28.04	-81.4419	1.5	-0.06 (bias)
iu031b08r_07179134831	31926	2007-06-28 13:45:25.06	-81.2558	1.5	27498.
iu031b0ar_07179140529	31927	2007-06-28 14:00:04.04	-81.2558	1.5	27538.
iu031b0br_07179140529	31928	2007-06-28 14:03:06.06	-81.6279	1.5	0.06 (bias)

imagename	tvnum	date-obs	CCD temperature	gain	median DN level
iu031b0dr_07179142227	31929	2007-06-28 14:16:24.04	-81.6279	2.0	-0.07 (bias)
iu031b0er_07179142227	31930	2007-06-28 14:19:21.06	-81.6279	2.0	19553.5
iu031b0gr_07179143925	31931	2007-06-28 14:34:00.04	-81.4419	2.0	19561.5
iu031b0hr_07179143925	31932	2007-06-28 14:37:02.06	-81.6279	2.0	-0.05 (bias)
iu031b0jr_07179145623	31933	2007-06-28 14:50:20.04	-81.8140	4.0	-0.00 (bias)
iu031b0kr_07179145623	31934	2007-06-28 14:53:17.06	-81.6279	4.0	9634.
iu031b0mr_07179151321	31935	2007-06-28 15:07:56.04	-81.8140	4.0	9602.
iu031b0nr_07179151321	31936	2007-06-28 15:10:58.06	-81.4419	4.0	0.09 (bias)
iu031b0pr_07179153019	31937	2007-06-28 15:24:16.04	-81.4419	1.0	0.03 (bias)
iu031b0qr_07179153019	31938	2007-06-28 15:27:13.06	-81.4419	1.0	40294.5
iu031b0sr_07179154806	31939	2007-06-28 15:41:52.04	-81.4419	1.0	40270.
iu031b0tr_07179154806	31940	2007-06-28 15:44:54.06	-81.4419	1.0	0.26 (bias)