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WFPC2 Clocks-ON Close Out

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ABSTRACT

We present results from an analysis of WFPC2 standard star observations and dark frames obtained with the serial clocks ON. The photometric calibration accuracy of WFPC2 is monitored by observing the white dwarf standard star GRW+70D5824 (HIC 66578; DA; V=12.77; B-V=-0.09) with serial clocks OFF. However, a few tests of the clocks ON mode have been performed, including a recent Cycle 10 calibration program (9252). A comparison of the clocks ON and OFF photometric observations show that there is no significant difference between the results of the two modes. A comparison of the dark frames taken with serial clocks ON and OFF does, however, reveals a small difference (a few %) in the dark current between the two modes.

1. Introduction

This report examines potential calibration changes when imaging with the Wide Field and Planetary Camera 2 (WFPC2) with the serial clocks on (CLOCKS=YES). This mode is not used as frequently as serial clocks OFF: 6% of all WFPC2 archival images were taken with the serial clocks ON. The WFPC2 Charge-Coupled Devices (CCDs) are front-illuminated, lumogen coated 800X800 pixel Loral CCD sensors with 15 μm pixel format. During readout, the CCDs are clocked vertically to shift charge packets through adjacent potential wells by changing the bias of each well. The charge packets are clocked vertically (parallel clocks) to the horizontal shift register. The output of the horizontal shift register (serial clocks) is connected to a pre-amplifier which converts the charge into a voltage signal. Clocks ON (CLOCKS=YES) in Phase II proposal mode is used for two purposes: (1) to minimize impact of charge bleeding on severely saturated images, and (2) to reduce the overhead time on exposures > 180 sec.

2. WFPC2 Commanding

WFPC2 CCDs are commanded to be in autoflush mode except during exposures, including South Atlantic Anomaly (SAA) passages. The continuous clocking of WFPC2 CCDs flushes charge from traps. The standard exposure sequence is to gate off the vertical and horizontal clocks before commanding the shutter to open. Upon completion of the exposure, the shutter is closed, the clocks are gated on, and all four CCDs are read out in sequence. The output from the CCD horizontal register is directed to an analog-to-digital converter (ADC) which is stored onboard the telescope for later down link to the ground. When the serial clocks are on during an observation, the output of the horizontal register is ignored by the ADC.

The overhead times of the WFPC2 are defined by major frame (MF) pulses which occur every minute. At most, only one command may be executed every major frame. In order to read out an exposure taken with clocks OFF (normal default mode), the clocks must be enabled requiring a major frame (or extra minute of time); this extra minute is not required for clocks ON exposures. A review of a Science Mission Specification (SMS) confirmed this; a 1800 sec. dark with the serial clocks ON executes in one minute less than with the clocks OFF. The dark exposure with the clocks OFF needs an extra minute to enable clocks as discussed above.

During each HST observing cycle, calibration programs are executed to monitor the photometric calibration of the WFPC2, the CTE effect, decontaminations, the UV throughput, and the health and stability of WFPC2. In addition, a series of 1800 sec. dark frames with clocks OFF, at gain 7, are obtained. Dark frames should not to be confused with bias frames which are read out in minimum time without an exposure. Dark frames are used to measure charge buildup caused by thermal generation of electrons in the bulk silicon as well as contributions from optical luminescence and hot pixels. At the normal CCD operating temperature (-88^{o} C), the normal dark rate with the serial clocks OFF has been determined to be less than 0.01 e^{-}/pixel/sec (see Instrument Handbook).

3. Photometric Data

The white dwarf standard star GRW+70D5824 (HIC 66578; DA; V=12.77; B-V=-0.09) is normally observed with clocks OFF, matching the majority of science exposures. However, a few tests of the clocks ON mode have been performed. An initial test of the clocks ON photometric mode was run in Dec. 1994; additional standard star observations using a small number of filters were taken and checked in Nov. 2000. The cycle 10 close-out proposal (9252) observed the standard star in many of the most frequently used filters and apertures not covered by prior observations. The results are compared with clocks OFF data, in order to determine whether any significant differences exist between the two modes, while no photometric changes are expected, it is crucial to verify this. The analysis

of these new images, along with previous clock ON images, will serve as a final verification of the calibration of this mode.

Calibration

The standard star data were calibrated using the On-The-Fly-Reprocessing (OTFR) option within StarView upon retrieval from the HST Archive. No additional calibration steps were performed.The IRAF/STSDAS task **imedit** was used to manually remove cosmic ray hits from the individual frames. The exposures were relatively short so typically only ~5-20 CRs required removal. Photometry was extracted from the cr-cleaned data using the same technique and IRAF/STADAS software tools as for the WFPC2/CAL photometric monitor programs (Gonzaga, S. 2001). An aperture radius of 11 pixels (radius=0.5”) was used for the PC1 observations and an aperture radius of 5 pixels (radius=0.5”) was used for the WF3 observations. A listing of the clocks ON and OFF photometric observations and count rates are presented in Appendix I.

Photometric Results

For each filter, the corrected count rates (corrected for shutter timing) obtained for the standard star with the serial clocks ON were ratioed with the corresponding count rates obtained for the star with the serial clocks OFF (i.e., ON/OFF). Tables 1 & 2 list the ratios of the data between the clocks on and clocks off photometry obtained for the apertures PC1 and WF3, respectively. The data are plotted in Figure 1. Information about the individual observations used in this study is presented in Appendix I.

The clocks OFF measurements were obtained from the photometric monitor programs or from the observations following a WFPC2 DECON. Observations closest in time to the corresponding clocks ON measurements were used for the comparison. The respective dates of the observations are given in the corresponding tables in Appendix I.

All clocks ON exposures are shortened by either 0.125 or 0.250 seconds due to special shutter commanding used for clocks ON. The decrease in exptime is not reflected in the header exptime keyword but must be corrected after calibration; the amount depends upon which shutter blade was in place at exposure start. The decrease in exposure time is due to the manner in which the application processor (AP17) in the spacecraft computer operates the shutter blades: when clocks are OFF, the WFPC2 microprocessor opens the shutter, the AP17 closes the shutter, and the exposure time is as requested. However, with clocks ON, the AP17 opens the shutter, first blade A, then blade B. When blade A is closed at the start of the exposure, the actual exposure begins 0.125 seconds late (after the AP17 issues the blade command). When blade B is closed at the exposure start, the exposure starts 0.250 seconds late (after the AP17 sends the open-A command followed by open-B). The shutter in place at exposure start is given in the SHUTTER keyword in the c0h file; note that the EXPTIME keyword will not reflect the 0.125 or 0.250 decrease in exposure time. The

photometry for clocks ON data presented in this ISR has been corrected for these shutter timing effects.

Table 1. Count rate ratio (clocks ON/clocks OFF), aperture = PC1. The quoted errors are only those due to photon noise.

wavelength	ratio	error	filter
1666.0	1.010262	0.00553	F170W
2117.0	0.990909	0.00681	F218W
2545.0	0.985449	0.00612	F255W
3317.0	1.022794	0.00553	F336W
4283.0	0.992376	0.00667	F439W
5012.0	0.980571	0.00653	F502N
5202.0	1.022677	0.00633	F555W
5446.0	1.014937	0.00355	F547M
5767.0	1.019725	0.00346	F606W
6564.0	0.973372	0.00937	F656N
6591.0	0.980739	0.00752	F658N
6714.0	1.014826	0.00687	F675W
7969.0	1.010707	0.00306	F791W
8203.0	1.005137	0.00289	F814W
9650.0	1.001665	0.00409	F850LP

Table 2. Count rate ratio (clocks ON/clocks OFF), aperture = WF3. The quoted errors are only those due to photon noise.

wavelength	ratio	error	filter
1666.0	1.014408	0.00539	F170W
2117.0	0.999569	0.00628	F218W
2545.0	0.986763	0.00537	F255W
3317.0	1.010274	0.00490	F336W
4283.0	1.013433	0.00593	F439W
5202.0	1.019511	0.00561	F555W
5767.0	1.023360	0.0039	F606W
6564.0	0.981203	0.00776	F656N

wavelength	ratio	error	filter
6714.0	1.037597	0.00628	F675W
6732.0	0.985732	0.00623	F673N
6940.0	1.010249	0.00364	F702W
8203.0	1.003215	0.00393	F814W
9283.0	0.982478	0.00370	F785LP

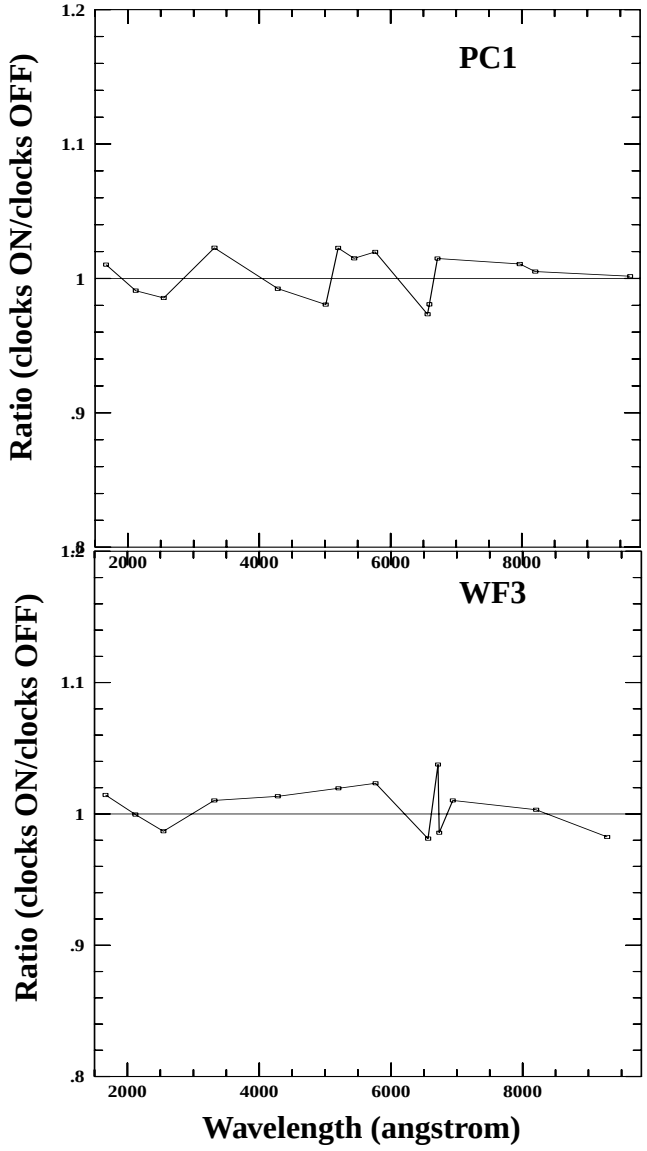

Figure 1: Comparison of standard star count rates obtained with clocks ON (CLOCKS=YES) and clocks OFF (CLOCKS=NO) as a function of wavelength.

Pipeline calibrated data (c0h) are in units of Data Numbers (DN); the photometric calibration is provided in the calibrated science header (.c0h) keywords. The WPFC2 photometric calibration uncertainties are typically +/- 2% and worse in the UV (see HST Data Handbook). The comparison between count rates obtained with clocks ON and OFF are generally within 2% (0.02 mag) peak to peak of each other with the associated errors being quite small. Clocks ON does not appear to cause any significant changes in photometric calibration. The standard photometric calibration appears to be sufficient for observations obtained with the serial clocks ON or OFF at least for the relatively short exposures tested here.

4. Dark Data

A series of 50 dark frames (exp=1800s; CR-SPLIT=NO, CLOCKS=YES, ATD-GAIN=7) were obtained during the two weeks of July 17-24, 2001 (WFPC2/CAL program ID: 9252). They are compared to normal darks (exp=1800s; CR-SPLIT=NO, CLOCKS=NO, ATD-GAIN=7) taken close in time to the clocks ON darks. The results of this comparison will serve as a final verification of the calibration of this mode.

Calibration

The dark frames were processed via OTFR with the normal calibration steps (MASK, ATOD, BLEV, and BIAS corrections).The darks were manually inspected for residual images and /or CTE trails from previous exposures; those frames affected by residual images were rejected. The IRAF/STSDAS task **crrej** was used to combine the data in groups of 10 images. Ten images were used in order to have the ON and OFF dark stack from the same 2 weeks (to remove any possible time dependent effects). The **crrej** parameters are listed below.

```
PACKAGE = wfpc
   TASK = crrej

input   = @clocks_on_10_c0h.lis Input images
output  =         clocks_on_10  Output image name
masks   = @clocks_on_10_c1h.lis  Input/output masks (optional)
sigmas  =              4,4,3,2  Rejections levels in each iteration
(radius =                  1.5) CR expansion radius in pixels
(pfactor=                  0.5) CR expansion discriminator reduction fac-
tor
(initial=                  min) Initial value estimate scheme (min or med)
(lower  =                 -99.) Lower limit of usable data
(upper  =                4096.) Upper limit of usable data
(sky    =                 none) How to compute the sky
(expname=              exptime) Exposure time keyword name
(readnoi=                 0.72) Read noise(s) (in DN) of the detector(s)
(atodgai=                    7) Detector gain(s) in electrons/DN
(scaleno=                  3,1) Multiplicative term (in PERCENT) from
noise mode
(dq     =                      ) Data quality filter pset
(skyname=            BACKGRND) Name of the group parameter to be updated
with t
```

```
(crdqval=                  128) Data quality value for pixels flagged as
cosmic
(fillval=                   0.) Fill value for pixels having no good val-
ues in a
(verbose=                  yes) Print out verbose messages?
(mode   =                   al)
```

The clocks ON and OFF images (generated from a stack of 10 individual dark frames) appear to be very similar; Fig 2 shows the clocks ON and OFF images for PC1. There are no obvious significant distinguishing characteristics between the images in the two modes. There are a small number of pixels, in the first row of each chip, that possess a consistently-higher dark current rate in the clocks ON darks than they do in the clocks OFF darks. The effect, however, is limited to the first row; a check of some of the individual pixels in the rest of the imaging area show that the clocks ON and OFF modes do not appear to be significantly different. That these differences appear only in the first row might be expected since it is adjacent to the serial register. Figures 3 and 5 in Appendix II show plots of regions from row 1 for all 50 individual dark frames in the clocks ON mode and the 50 individual dark frames taken with clocks OFF (each line represents one image). There appears to be two flavors to these row 1 “hot” pixels in the clocks ON mode: the first type sometimes appear hot in the clocks OFF mode as well (though not as frequently) while the second type never appear hot in the clocks OFF mode.

Dark Statistics

Both ON and OFF combined dark images are relatively flat across the central region of each CCD and drop OFF in counts toward the edges. The central 400x400 pixel region was used to determine the median count value. The IRAF/STSDAS task **wstatistics** was used to perform 3 times 3 σ-clipping to obtain the image statistics (lower=mean-3σ and upper=mean+3σ). Table 3 presents the 3 σ-clipping statistics for each combined dark image (clocks ON and OFF) which were each created from 10 images. Slight differences in counts are evident for the clocks ON data.

Table 3. CCD statistics (not normalized) for 1800 sec (commanded) darks. Statistics are for combined images, and a 400x400 pixel area in the center of each chip was used.

	Clocks ON			**Clocks OFF**		
CCD	**Mean**	**STDDEV**	**Median**	**Mean**	**STDDEV**	**Median**
PC1	18.9506	4.7455	18.75	18.5178	4.6799	18.271
WF2	11.976	4.2504	11.704	12.2728	4.3339	11.968
WF3	17.2658	4.7966	16.936	17.853	4.839	17.678
WF4	16.7927	4.3485	16.537	16.6533	4.3207	16.375

Individual Dark Frames

The 3 σ-clipping statistics for the specific 10 dark images chosen for this study are presented in Table 4. Each value in Table 4 represents the mean (and median) of 10 individual 1800 sec. dark frames. The statistics of the individual dark frames in Table 4 confirm what was seen in the combined image results in Table 3: there is a slight difference in counts between the clocks ON (CLOCKS=YES) and clocks OFF (CLOCKS=NO) dark frames.

Table 4. CCD statistics for 1800 sec (commanded) darks. Each value represents the mean, and median, of the measurements of the mean and median from the 10 individual 1800 sec dark frames. The STDDEV is the standard deviation of the mean values for the 10 individual darks. A 400x400 pixel area in the center of each chip was used.The measurements are a factor of ~10 smaller than in Table 3 because we are looking at individual frames.

	Clocks ON			**Clocks OFF**		
CCD	**Mean**	**STDDEV**	**Median**	**Mean**	**STDDEV**	**Median**
PC1	2.0593779	0.320927	2.14575	1.9953829	0.232825	2.03602
WF2	1.3426677	0.176489	1.37809	1.3776498	0.190689	1.40559
WF3	1.8762527	0.2829	1.93881	1.9515174	0.287806	1.96011
WF4	1.8438485	0.301365	1.85933	1.8167337	0.217119	1.8749

Dark Results

The darks for ON and OFF modes appear qualitatively similar (Figure 2 in Appendix II), and only small differences are seen in the statistics. The clocks ON dark count levels for PC1 and WF4 appear to be a few percent higher than the clocks OFF darks, while the count levels for WF2 and WF3 appear to be low. This does not include the difference in exposure time (the clocks ON darks are 1 minute shorter than the clocks OFF darks). Including the exposure time difference (1 minute is 1/30 = 3%), the clocks ON darks counts are a few % higher than for the clocks OFF darks.

5. Conclusions

The normal WFPC2 photometric calibration appears to be sufficient for observations obtained with the serial clocks ON or OFF. The comparison between count rates of the standard star for different filters obtained with clocks On and OFF are generally within 2% (0.02 mag) peak to peak of each other with the associated errors quite small.

Analysis of the 1800 sec (commanded) darks (serial clocks ON and OFF) indicate that the count levels for the clocks ON darks are similar to those for the clocks OFF darks. When the 1 minute difference in exposure time between an 1800 sec. clocks ON and OFF dark is taken into account as well, the clocks ON dark current is found to be a few % higher than the clocks OFF dark current. Since the pipeline dark reference files for clocks ON mode have always been generated from clocks OFF darks (minimizing the number of calibration observations required), the difference in dark current may affect the calibration of some clocks ON observations. It will not be a problem in majority of clocks ON exposures, as this mode is normally used on very bright targets (i.e., exposure times are very short). However, for longer exposures, the difference may be more noticeable.

Acknowledgements

The authors would like to thank Dr. Vicki Balzano and Dr. Wayne Baggett (FSET) for discussions on WFPC2 commanding and Alan Welty (FSET) for verifying WFPC2 overhead times for observations obtained with the serial clocks ON and OFF.

References

Baggett, S., McMaster, M., et al. 2002, HST Data Handbook, Version 4.0, (Baltimore:STScI).

Biretta. J., et al. 2001, WFPC2 Instrument Handbook, Version 6.1, (Baltimore:STScI).

Gonzaga, S. 2001, “Standard Star Monitoring Memo”, http://www.stsci.edu/instruments/wfpc2/Wfpc2_memos/wfpc2_stdstar_phot3.html

6. Appendix I - Photometric Data

The data used for the photometric comparison between standard star observations with the serial clocks ON (CLOCKS=YES) and clocks OFF (CLOCKS=NO) are presented in this section. Table columns are observation date, observation ipppssoot, filter, clocks (clks), shutter for the clocks ON observations, exposure time (exptime), count rate, and count rate uncertainty.

Table 5. Shutter Timing Corrected Count Rates. Standard star GRW+70D5824 observed with the serial clocks ON, aperture = PC1.

Date	Observation	Filter	Clks	Shutter	Exptime (sec.)	[corrected] count rate	uncertainty
1994-12-20	u2a71x0ft	F170W	ON	B	30	148.605	0.673
1994-12-19	u2eg0z01t		OFF	N/A	60	147.095	0.453
1994-12-20	u2a71x0dt	F218W	ON	B	30	134.658	0.652
1994-11-22	u2a71r0dt		OFF	N/A	30	135.893	0.663
1994-12- 20	u2a71x0bt	F255W	ON	B	30	157.483	0.690
1994-11-22	u2a71r0bt		OFF	N/A	30	159.808	0.703
1994-12-20	u2a71x09t	F336W	ON	B	8	767.340	2.899
1994-11-21	u2a71r09t		OFF	N/A	8	750.239	2.909
1994-12-20	u2a71x07t	F439W	ON	B	5	868.313	4.091
1994-11-21	u2a71r07t		OFF	N/A	5	874.983	4.195
2001-07-23	u6i05108r	F502N	ON	A	80	55.651	0.263
1994-09-22	u2eo050lt		OFF	N/A	80	56.754	0.266
1994-12-20	u2a71x05t	F555W	ON	B	1	3796.109	18.158
994-11-21	u2a71r05t		OFF	N/A	1.6	3711.932	14.634
2001-07-23	u6i05104r	F547M	ON	A	8	1629.444	4.031
2001-03-25	u69p0105r		OFF	N/.A	8	1605.462	3.986
2001-07-23	u6i05102r	F606W	ON	A	3	4907.761	11.199
2001-03-25	u69p0107r		OFF	N/A	2.6	4812.824	12.120
2001-07-23	u6i05106r	F656N	ON	A	80	31.584	0.217
1994-09-22	u2eo050nt		OFF	N/A	80	32.448	0.218
2001-07-23	u6i05107r	F658N	ON	B	70	48.479	0.267
1994-09-22	u2eo050zt		OFF	N/A	70	49.431	0.263
1994-12-20	u2a1x03t	F675W	ON	B	2	2096.969	9.772
1994-11-21	u2a71r03t		OFF	N/A	2	2066.332	10.168
2001-07-23	u6i05105r	F791W	ON	B	14	1210.669	2.583
2001-03-25	u69p010br		OFF	N/A	14	1197.843	2.581
2001-07-23	u6i05101r	F814W	ON	B	14	1337.289	2.705
2001-07-14	u6945801r		OFF	N/A	14	1330.454	2.719
2001-07-23	u6i05103r	F850LP	ON	B	40	250.220	0.721
2001-03-25	u69p010M		OFF	N/A	40	249.804	0.723

Table 6. Shutter Timing Corrected Count Rates. Standard star GRW+70D5824 observed with the serial clocks ON, aperture = WF3.

Date	Observation	Filter	Clks	Shutter	Exptime (sec.)	[Corrected] Count rate	uncertainty
1994-12-20	u2a71x0gt	F170W	ON	A	30	159.592	0.643
1994-12-19	u2eo0z02t		OFF	N/A	30	157.325	0.546
1994-12-20	u2a71x0et	F218W	ON	A	30	133.602	0.595
1994-11-22	u2a71u0et		OFF	N/A	30	133.659	0.592
1994-12-20	u2a71x0ct	F255W	ON	A	30	171.322	0.659
1994-11-22	u2a71r0ct		OFF	N/A	30	173.620	0.669
1994-12-20	u2a71x0at	F336W	ON	A	8	808.424	2.758
1994-11-21	u2a71r0at		OFF	N/A	8	800.202	2.767
1994-12-20	u2a71x08t	F439W	ON	A	5	899.073	3.666
1994-11-21	u2a71r08t		OFF	N/A	5	887.156	3.727
1994-12-20	u2a71x06t	F555W	ON	A	1	3868.939	16.299
1994-11-21	u2a71r06t		OFF	N/A	1.6	3794.897	13.475
2001-07-23	u6i0510ar	F606W	ON	A	2	4975.408	13.153
2001-03-25	u69p0207r		OFF	N/A	2	4861.833	13.412
2001-07-23	u6i0510dr	F656N	ON	B	80	31.489	0.177
1994-09-22	u2eo051zt		OFF	N/A	80	32.092	0.178
1994-12-20	u2a71x04t	F675W	ON	A	2	2118.501	8.871
1994-11-21	u2a71r04t		OFF	N/A	2	2041.738	8.922
2001-07-23	u6i0510cr	F673N	ON	A	40	96.329	0.433
1994-09-22	u2eo0521t		OFF	N/A	40	98.537	0.433
2001-07-23	u6i0510br	F702W	ON	B	4	2962.297	7.157
2001-03-25	u69p0209r		OFF	N/A	3.5	2932.243	7.870
2001-07-23	u6i0510er	F785LP	ON	A	20	515.137	1.375
2001-03-25	u69p020ar		OFF	N/A	20	524.324	1.392
2001-07-23	u6i05109r	F814W	ON	B	7	1353.300	3.716
2001-05-17	u69q3806r		OFF	N/A	7	1348.963	3.777

7. Appendix II - Image Analysis

Figure 2 shows the stacked clocks ON and OFF images for PC1. There are no obvious significant distinguishing characteristics between the images in the two modes.

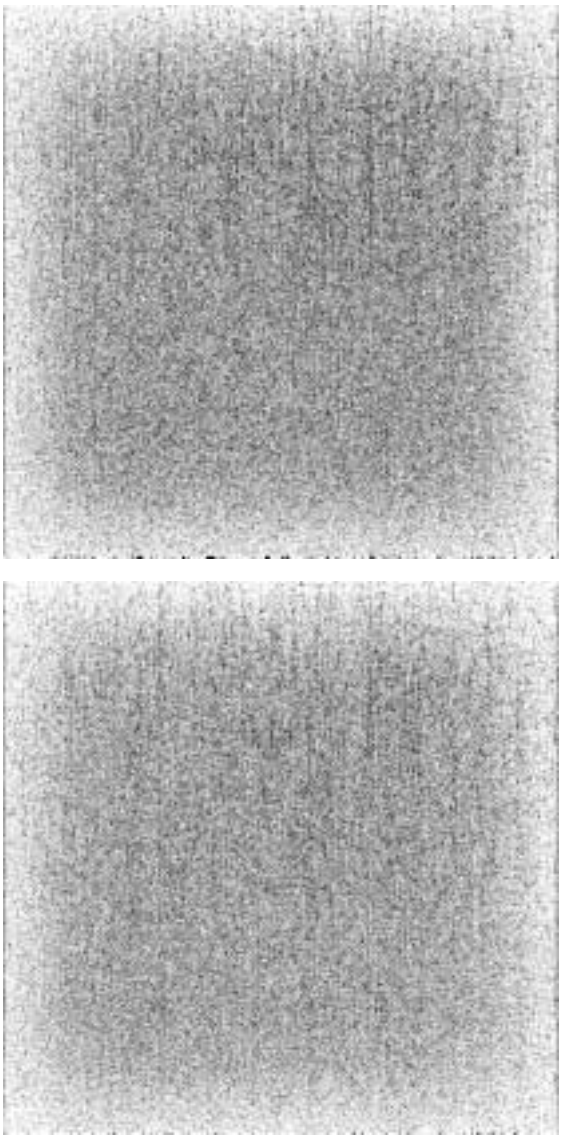

Figure 2: Clocks ON and OFF dark frames (negative images displayed). Upper clocks ON and lower clocks OFF PC1 images. Each image was generated from a stack of 10 individual dark frames taken during the same 2 week time period.

Figures 3 and 5 show plots of regions from row 1 for all 50 individual dark frames in the clocks ON and clocks OFF mode (each line represents one image). There appear to be two flavors to these persistent row 1 “hot” pixels in the clocks ON mode: the first type sometimes appear hot in the clocks OFF mode as well (though not as frequently) while the second type never appear hot in the clocks OFF mode. The effect appears limited to row 1. For example, Figure 4 shows similar plots for PC1 row 2 hot pixels. There is also a redundant serial register adjacent to row 800 which is active during clocks ON, but no additional hot pixels were seen in row 800.

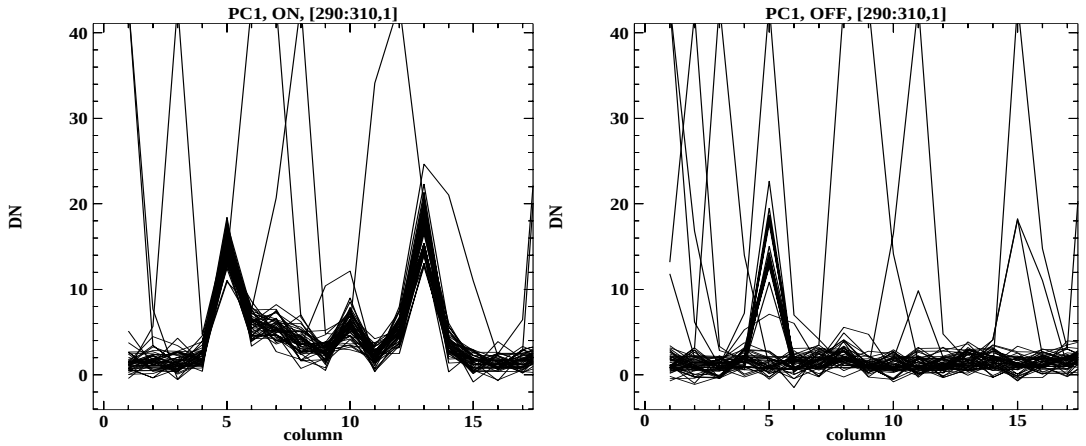

Figure 3: Row 1 hot pixels for PC1. Figure shows 50 individual clocks ON (left) and clocks OFF (right) dark frames stacked.

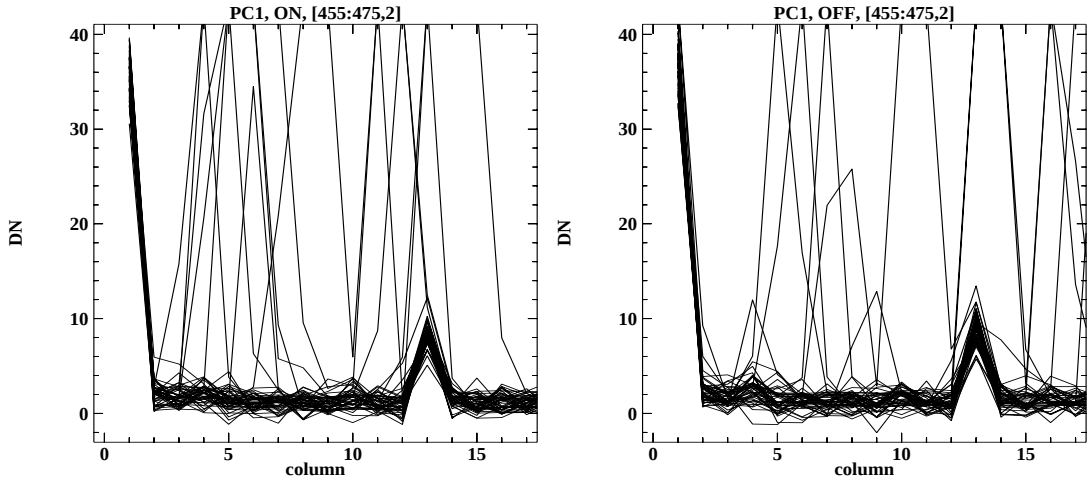

Figure 4: Row 2 hot pixels for PC1. Figure shows 50 individual clocks ON (left) and clocks OFF (right) dark frames stacked.

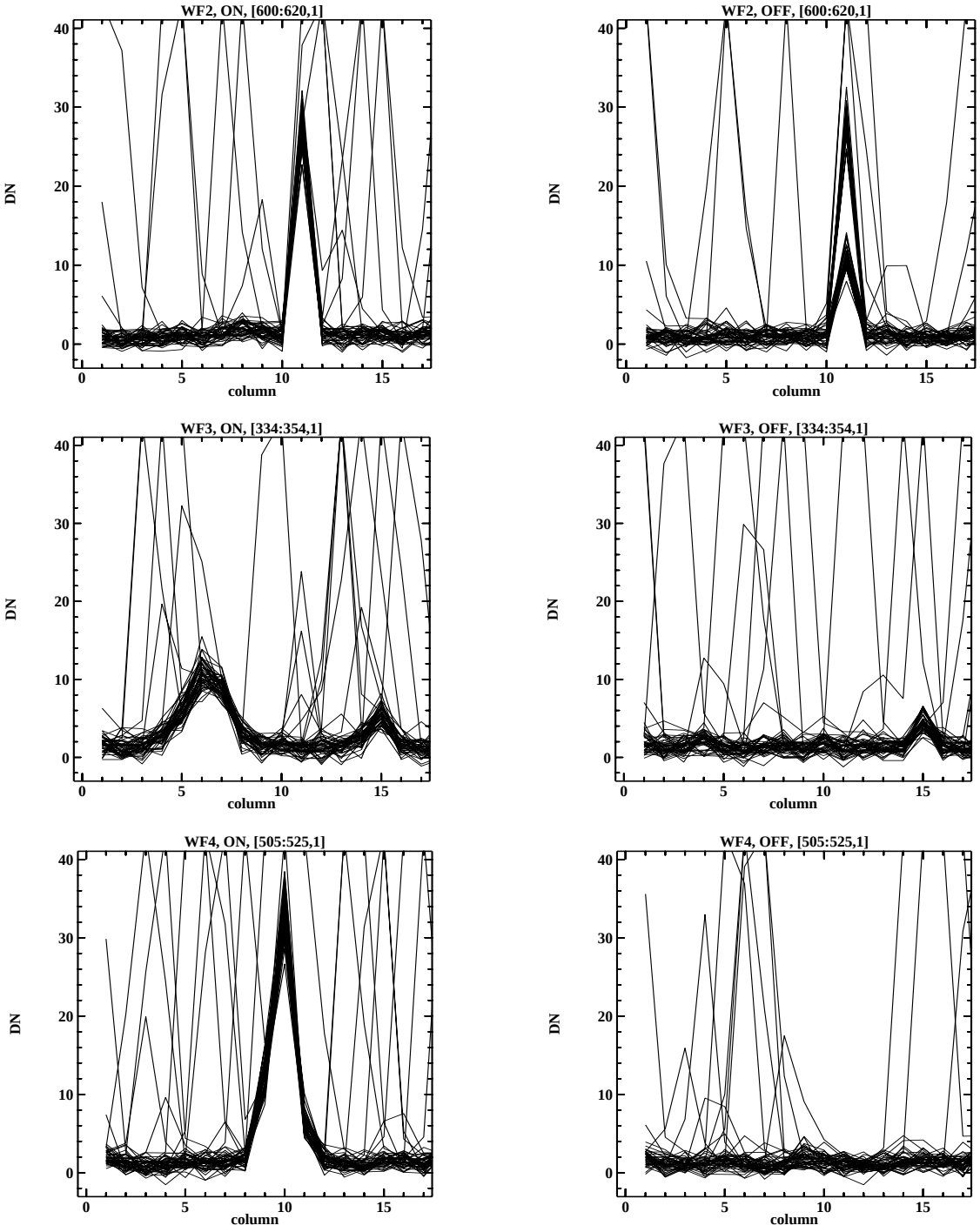

Figure 5: Row 1 hot pixels for WF CCDs. Figure shows 50 individual clocks ON (left) and clocks OFF (right) dark frames stacked.