



Instrument Science Report WFPC2 2008-02

Evolution of WFPC2 Superbiases

Deepashri Thatte and John Biretta
May 29, 2008

ABSTRACT

We examine the evolution of the WFPC2 superbias from 1996 to 2007. Relatively little change is seen, implying generally good stability of the readout electronics during the 14+ years of WFPC2 mission. Most of the observed change results from the evolution of the dark current contained in the bias frames. The 2007 superbias also shows reduced row-to-row fluctuations in the WF4 CCD, which is a side-effect of the software used to remove the horizontal streaks associated with the WF4 anomaly.

1. Introduction

WFPC2 superbias is a cosmic ray rejected and averaged combination of one hundred and twenty bias level subtracted frames that are free of severe bias jumps and visual anomalies. These biases are from the previous year(s) and are generated as part of regular WFPC2 calibration program. Superbias is used in the pipeline calibration of WFPC2 observations taken throughout the year. Two superbias are made each year, one with gain 7 biases and another with gain 15 biases. Evolution of superbias from 1996 to 2007 is discussed herein.

Superbias frames prior to 1996 are not considered here, as they were made with smaller numbers of input frames that were obtained over a shorter period. Here we only consider the superbias from 1996 and onwards, where 120 input bias frames are taken over a ~1

year period and combined.

1.1 Exposure time for WFPC2 biases

As one would expect, the WFPC2 bias frames are taken with the shutter closed, and therefore contain no light. They do contain, however, any electronic signatures related to the exposure. They also contain significant amounts of dark current, due to the way WFPC2 is operated. Major camera events are performed on one-minute “ticks” of the HST spacecraft clock. For example, the CCDs will be cleared (or “preped”) on one tick, while readout of the CCDs will not commence until the following tick – hence bias frames will contain approx. 1+ minutes of dark current.

The illustration below gives more detail of the camera timing and dark current. Assuming a bias frame is commanded to start at a one minute tick at time (t1), the first 16.4 seconds are used to clear the four CCDs. Readout can start only at the minute mark and therefore it happens at the next minute mark (t2). Therefore dark current collects on the CCD for 43.6 seconds. Readout of the CCDs is performed one after another, starting with PC1, and each chip requires 13.6 seconds. Hence the bias frames contain between $43.6 + 13.6 (n-1)$ seconds and $43.6 + 13.6 (n)$ seconds of dark current where n is the chip number.

		Readout			
Clear CCDs	Dark Current	PC1	WF2	WF3	WF4
<- 16.4 s --->	<----- 43.6 sec ----->	13.6s	13.6s	13.6s	13.6s
t1		t2			

1.2 Dark Current in WFPC2 CCDs

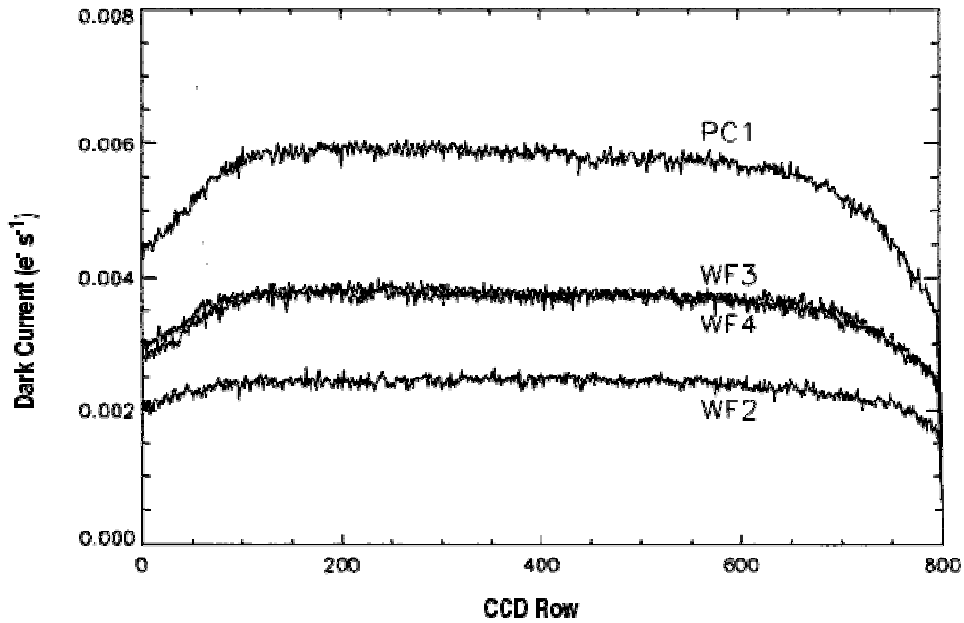
1.2.1 Sources of dark current

The dark current in WFPC2 has two components. One is from electronic sources in the CCDs and the other correlates with cosmic ray flux. The second component of dark current appears only on-orbit with its strength dropping towards the edges of each CCD. This second component is thought to be caused by scintillation within the field-flattener lens immediately in front of each CCD. The edge-drop is associated with the physical edge of the lens (edge of light source) near the edge of the CCD.

The dark current is known to be both chip and time dependent. Figure 1 shows average dark current as a function of CCD row. PC1 has the highest dark current, and WF2 has

the lowest. All CCDs show the edge-drop effect, which is attributed to scintillation. For more discussion on dark current please refer to WFPC2 Instrument handbook section 4.8.

Figure 1. Average dark rates vs. CCD row (Plots generated using darks from 1998).

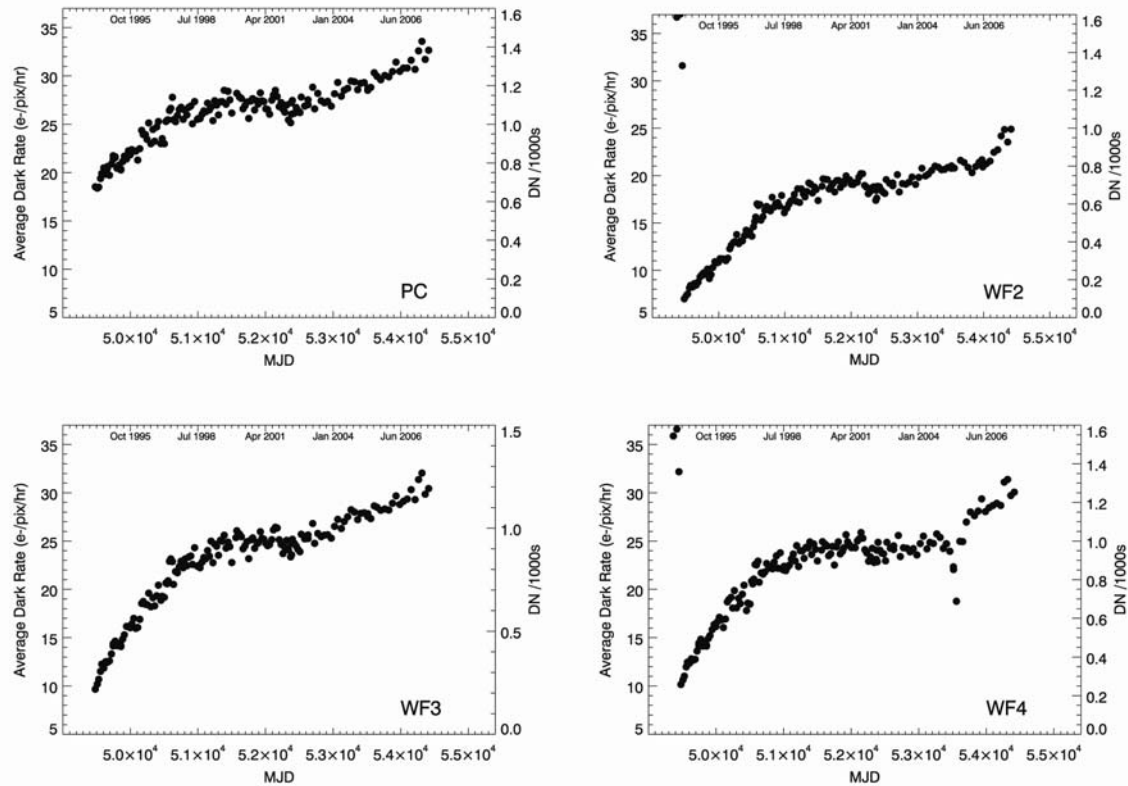


Adapted from WFPC2 instrument handbook

1.2.2 Dark current evolution

The dark current in WFPC2 has evolved over the lifetime of the instrument. Figure 2 shows the median dark current for the central 400x400 pixels of each CCD at gain7. Each data point represents the median of five raw 1800s dark frames taken just after decontamination. In all CCDs the dark current rises during the first few years of the mission, and then levels-off around year 2000 and begins to increase again after 2004. As already seen in Figure 1, PC1 shows the highest dark current, and WF2 shows the lowest.

Figure 2. Dark current evolution



Adapted from WFPC2 instrument handbook

2. Data

Table 1 shows the list of superbias frames that were used to analyze the evolution of the superbias at gain 7 and gain 15. Superbias frames were made every year for each gain setting from 1996 to 2004. No superbias was made in 2005 or 2006, hence there is no data for these years. The final WFPC2 superbias was made in 2007 and is included in the analyses.

Table 1

Gain 7		Gain 15	
Rootname	Dates	Rootname	Dates
h161240au	05/12/95 - 30/07/96	h1612404u	05/12/95 - 30/07/96
i2h10231u	31/07/96 - 30/11/97	i2h1025iu	22/08/96 - 30/11/97
j6e16008u	01/12/97 - 13/08/98	j3f1747qu	01/12/97 - 13/08/98
j9a1612mu	29/08/98 - 21/08/99	j9a1612nu	29/08/98 - 21/08/99
kcd1557lu	26/08/99 - 29/08/00	kci1424gu	26/08/99 - 29/08/00
l9i12088u	06/09/00 - 27/08/01	l9i12087u	06/09/00 - 27/08/01
m8r1536ou	01/08/01 - 05/08/02	m8r1536pu	04/09/01 - 19/08/02
n9p0938nu	05/08/02 - 25/08/03	n9p0938ou	05/08/02 - 25/08/03
p1p1510lu	18/08/03 - 23/08/04	p1p1510ku	18/08/03 - 23/08/04
r6c1454eu	21/02/06 - 14/05/07	r6s1735mu	21/02/06 - 14/05/07

3. Evolution of WFPC2 Superbiases

We begin by looking at the evolution of bright pixels (or hotpixels) in the bias frames. Figure 3 shows the number of pixels above 5 DN in the gain 7 and gain 15 superbiases. Since bias frames have $43.6 + 13.6(n-1)$ seconds of dark current, these are effectively the number of hot pixels in 43.6, 57.2, 70.8 and 84.4 sec for PC1, WF2, WF3, and WF4, respectively. The number of hot pixels above 5 DN increases from PC1 to WF4, and this is due to the extra dark time for the CCDs occurring later in the readout sequence.

The trend of evolution in gain 7 and gain 15 superbiases is slightly different due to the difference in gain and read noise and hence the conversion factor from detected electrons to data numbers (DN). Refer to section 4.13 of the instrument handbook for read noise and gain settings of WFPC2 chips. However both the plots for pixels above 5 DN show increase in the number of hot pixels in later years, and approximately mirrors the behavior in Figure 2.

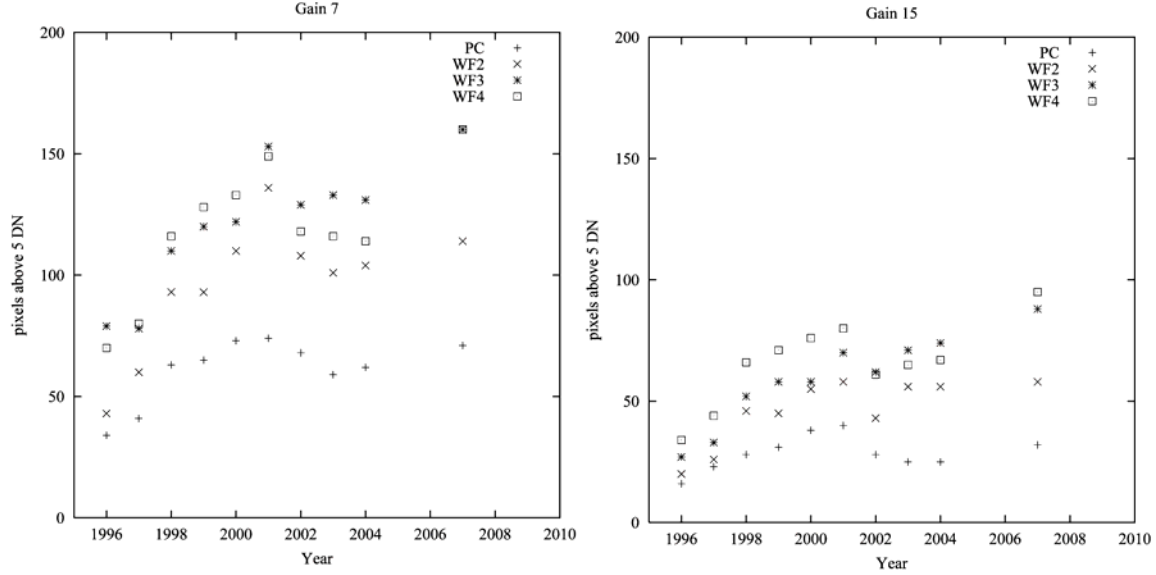
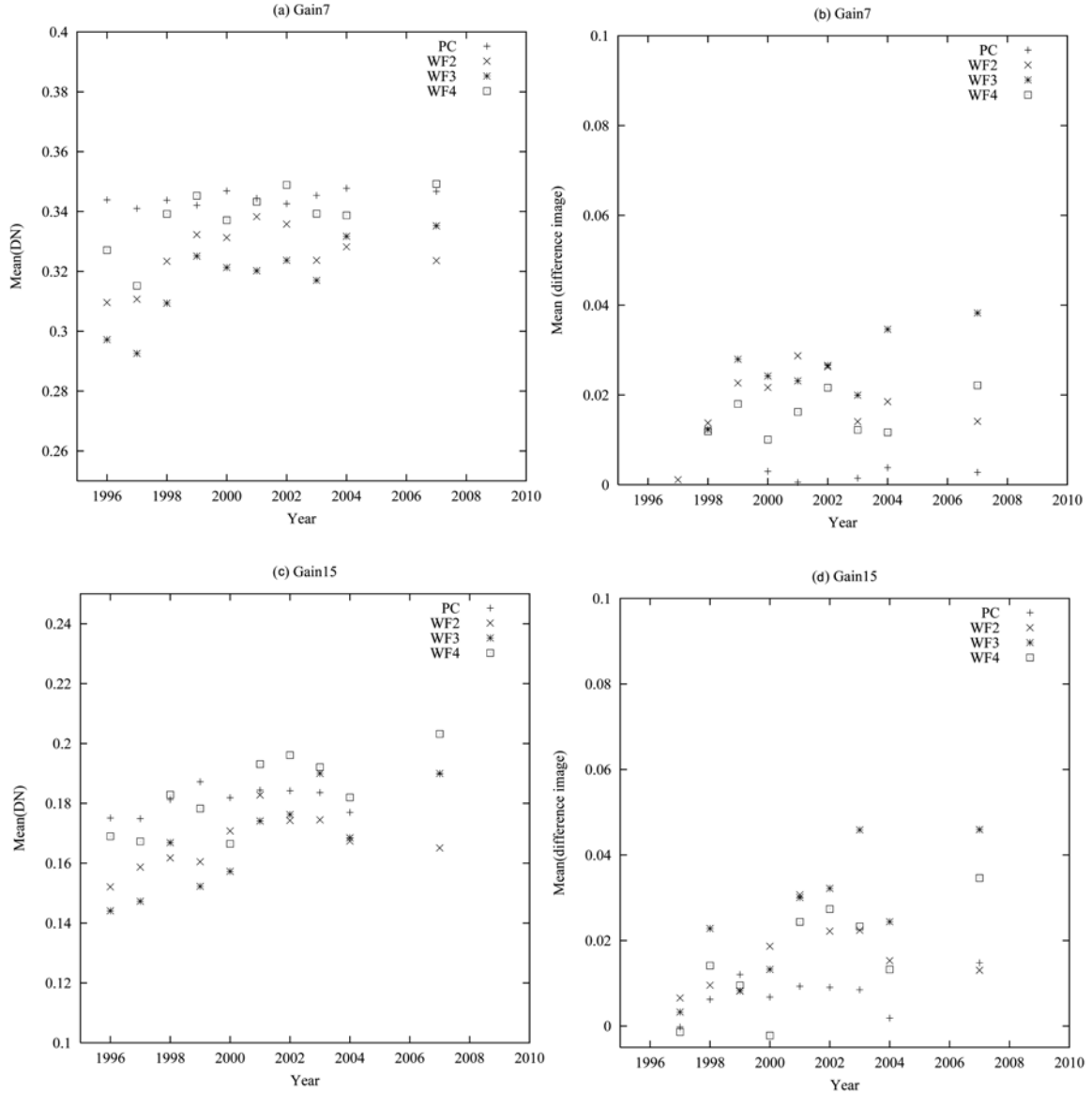
Figure 3. Number of pixels above 5 DN in gain 7 and gain 15 superbias.

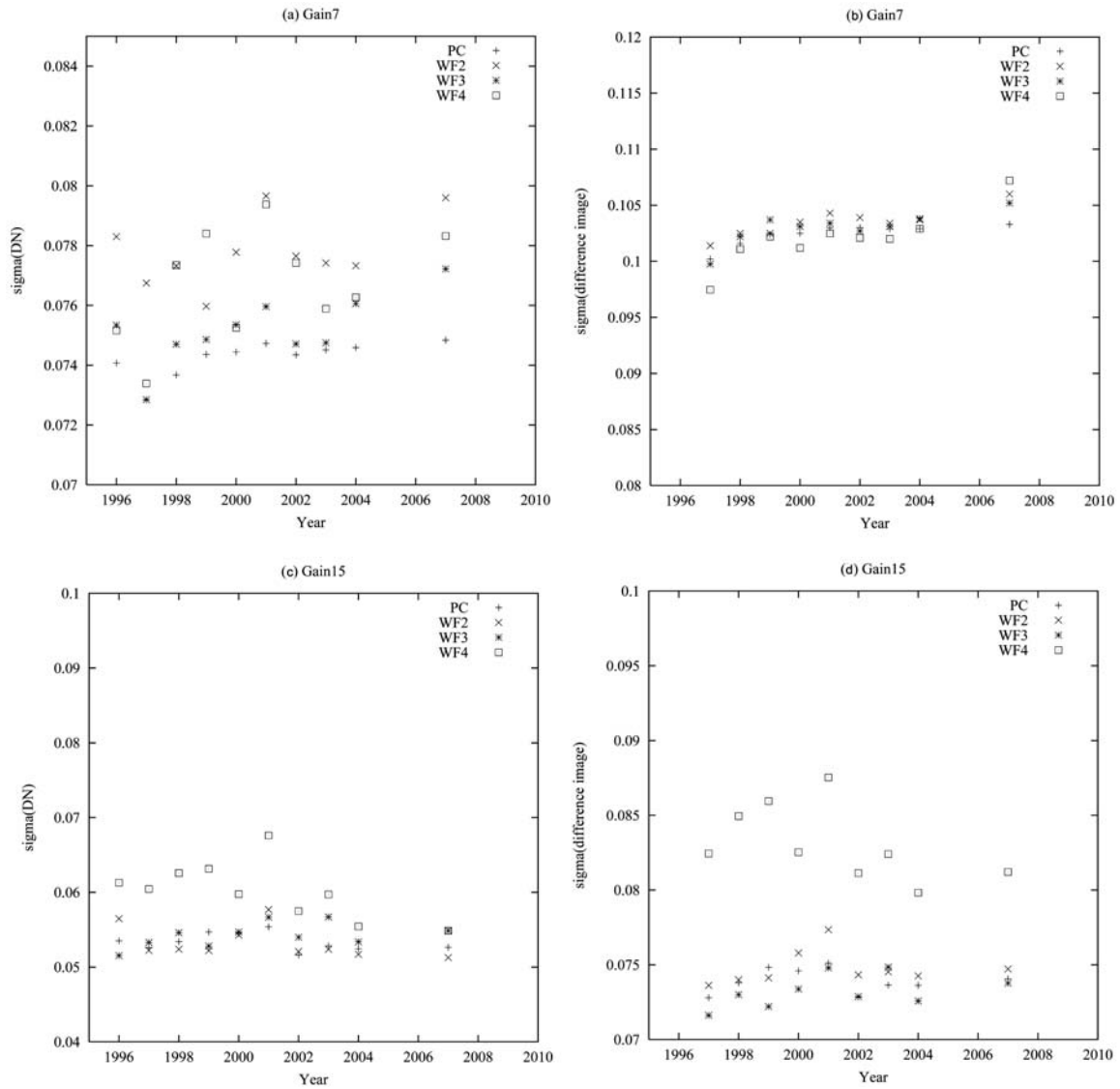
Figure 4(a) and 4(c) show the mean pixel value for the gain 7 and gain 15 superbias vs. year. Figure 4(b) and 4(d) are plotted after taking the difference between each superbias and the 1996 superbias. In all four panels 5-sigma iterative clipping was used to exclude highly discrepant pixels from the mean. The trends are generally consistent with the evolution of dark current evolution shown in Figure 2. PC1 is more stable, while the other CCDs show a modest increase between 1996 and 2000. The size of the increase is roughly consistent with the expected dark current increase (e.g. ~ 0.035 DN increase at gain 7 for dark time ~ 70 s).

Figure 4. Mean pixel values in gain 7 and gain 15 superbias.

Figures 5 (a) and (c) show the standard deviations for each gain 7 and gain 15 superbias. Again, 5-sigma iterative clipping has been applied to remove highly discrepant pixels. The measured sigmas are roughly consistent with the expected read noise in the average of 120 bias frames. For gain 7, the read noise in 120 exposures is $(\text{read noise for each chip}) / (\text{gain for each chip} * \sqrt{120})$. Using the Table 2, the read noise is 0.068 DN for PC1, 0.070 DN for WF2, 0.069 DN for WF3 and 0.067 DN for WF4. For gain 15, the read noise is 0.046 DN for PC1, 0.049 DN for WF2, 0.046 DN for WF3, and 0.054 for WF4. These values of the read noise essentially determine the lower limit or “floor” of the sigma values in Figure 5. The actual measured sigmas are slightly

higher than the read noise due to warm pixels scattered throughout the images, and a small amount of “photon” noise from the uniform component of the dark current. The higher read noise in WF4 at gain 15 is also apparent in panel (c).

Figure 5. Standard deviation in gain 7 and gain 15 superbias.



Panels (b) and (d) show sigma of the difference image, where each difference image is obtained by subtracting the 1996 superbias. Since it's the difference between two images, the noise sigma is effectively multiplied by $\sqrt{2}$ compared to panels (a) and (c). The different CCDs tend to give more similar results in these plots, as the sigma contributed

by persistent warm/hotpixels are reduced or eliminated. The elevated sigma for WF4 at gain 15 in panel (d) is somewhat surprising, but may be attributed to a combination of higher read noise, higher numbers of bias jumps, and higher bias jump amplitude in WF4 at gain 15. O'Dea, et al., 1997 have previously reported elevated bias jump amplitudes for WF4 at gain 15. In general, the WF4 CCD bias levels have always been less stable than the other CCDs.

Table 2. Read noise and other CCD parameters.

Parameter	Gain	PC1	WF2	WF3	WF4
Read Noise (e ⁻)	"7"	5.24 ± 0.30	5.51 ± 0.37	5.22 ± 0.28	5.19 ± 0.36
	"15"	7.02 ± 0.41	7.84 ± 0.46	6.99 ± 0.38	8.32 ± 0.46
Gain (e ⁻ /DN)	"7"	7.12 ± 0.41	7.12 ± 0.41	6.90 ± 0.32	7.10 ± 0.39
	"15"	13.99 ± 0.63	14.50 ± 0.77	13.95 ± 0.63	13.95 ± 0.70
Gamma	"7"	1.0015 ± 0.0006	1.0015 ± 0.0006	1.0020 ± 0.0006	1.0038 ± 0.0007
	"15"	1.0004 ± 0.0001	1.0023 ± 0.0004	1.0032 ± 0.0006	1.0018 ± 0.0012
14/7	ratio	1.987 ± 0.02	2.003 ± 0.02	2.006 ± 0.02	1.955 ± 0.02

Adapted from WFPC2 instrument handbook

Most of the sigma in panels (b) and (d) is due to the read noise, which apparently is constant with time. The small long-term increase in the sigma can be attributed to the added noise from the dark current, which is accumulated in 43.6, 57.2, 70.8 and 84.4 seconds for PC1, WF2, WF3, and WF4 in each bias frame. This long-term increase is consistent with the evolution of dark current shown in Figure 2.

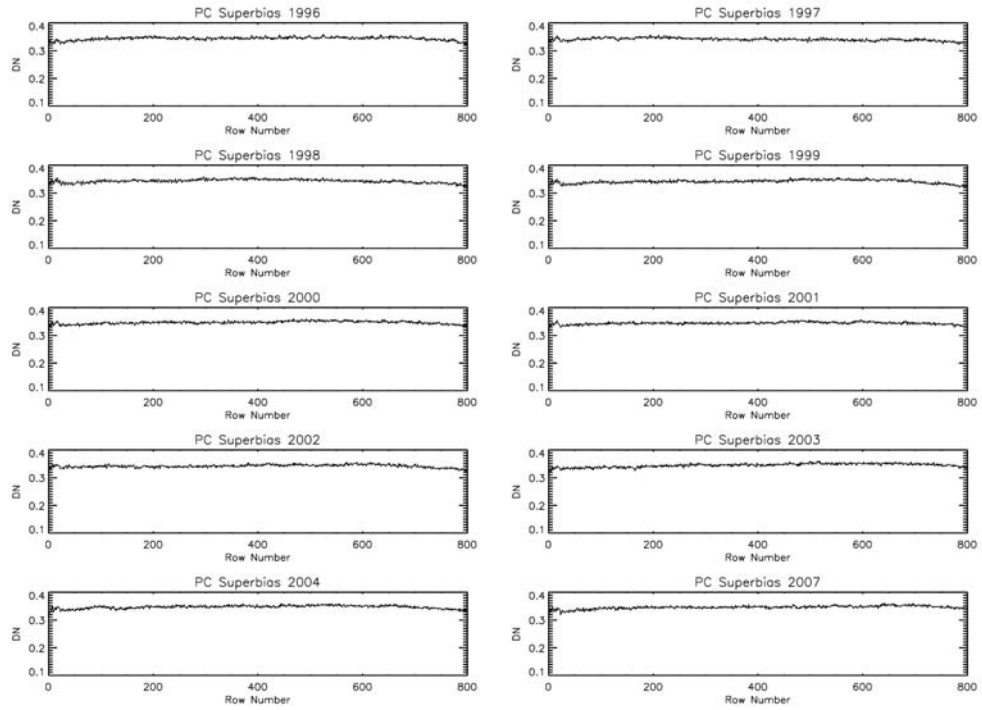
Figures 6 to 9 show the column-averaged superbias plotted as a function of CCD row. As explained in section 1.2.1 all chips except for WF4 in 2007 show dark current dropping towards the edges; this is due to the scintillation component of the dark current. For 2007 a horizontal streak removal algorithm was applied to the WF4 (due to WF4 CCD anomaly; Biretta and Gonzaga 2005) which has a side-effect of removing any row-dependent structure from the images. (This makes some small error in the superbias images of ~0.03 DN near the top and bottom of the CCD, but the error is felt to be unimportant for the vast majority of observers.)

Figures 10 to 13 show the row-averaged superbias plotted as a function of CCD column. Many positive or negative spikes are apparent in these plots, and are due to the presence

of bad columns (blocked columns, deferred charge columns, etc.; e.g. Whitmore and Wiggs 1995) in each WFPC2 chip.

Figure 6. Average of superbias for PC1 vs. CCD row.

(a) Gain 7



(b) Gain 15

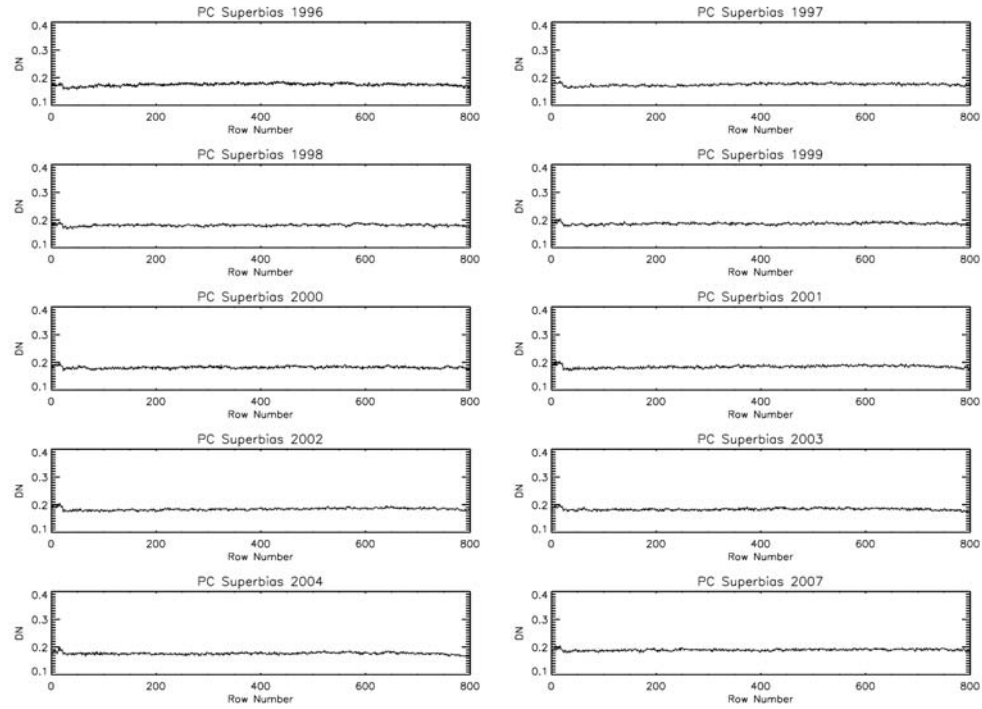


Figure 7. Average of superbias for WF2 vs. CCD row.

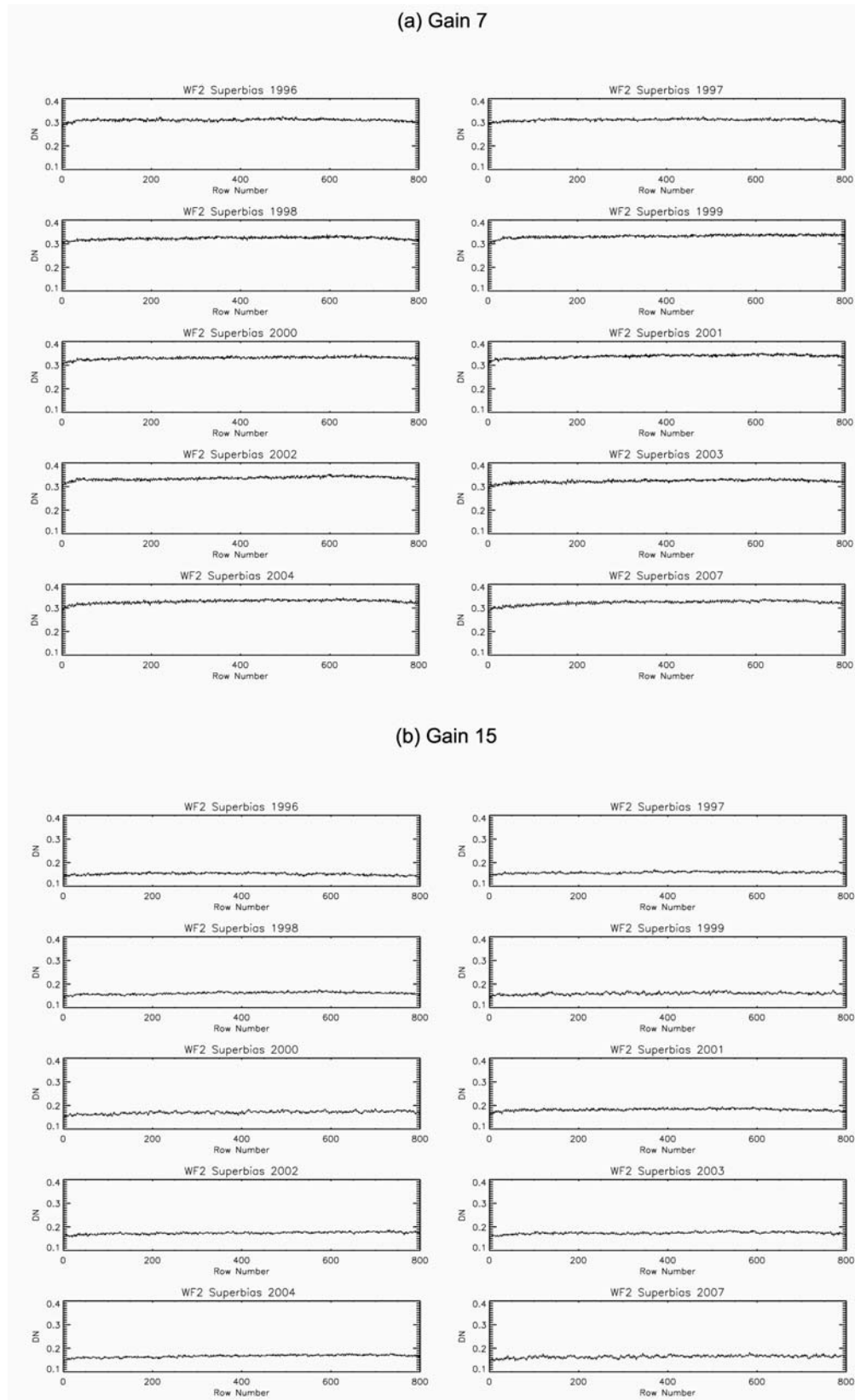
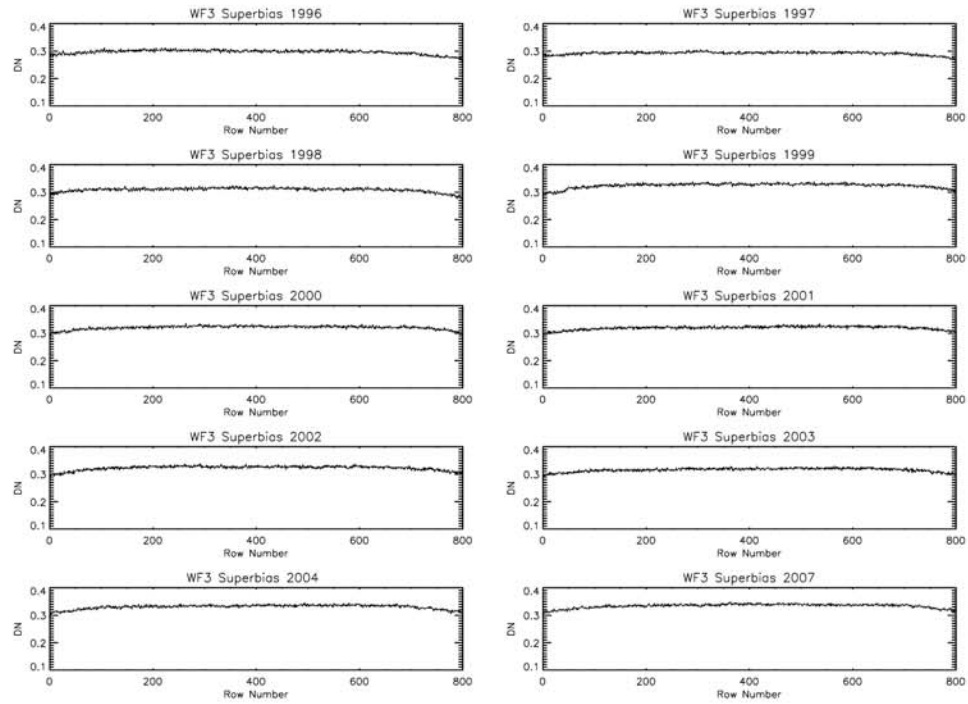


Figure 8. Average of superbias for WF3 vs. CCD row.

(a) gain 7



(b) gain 15

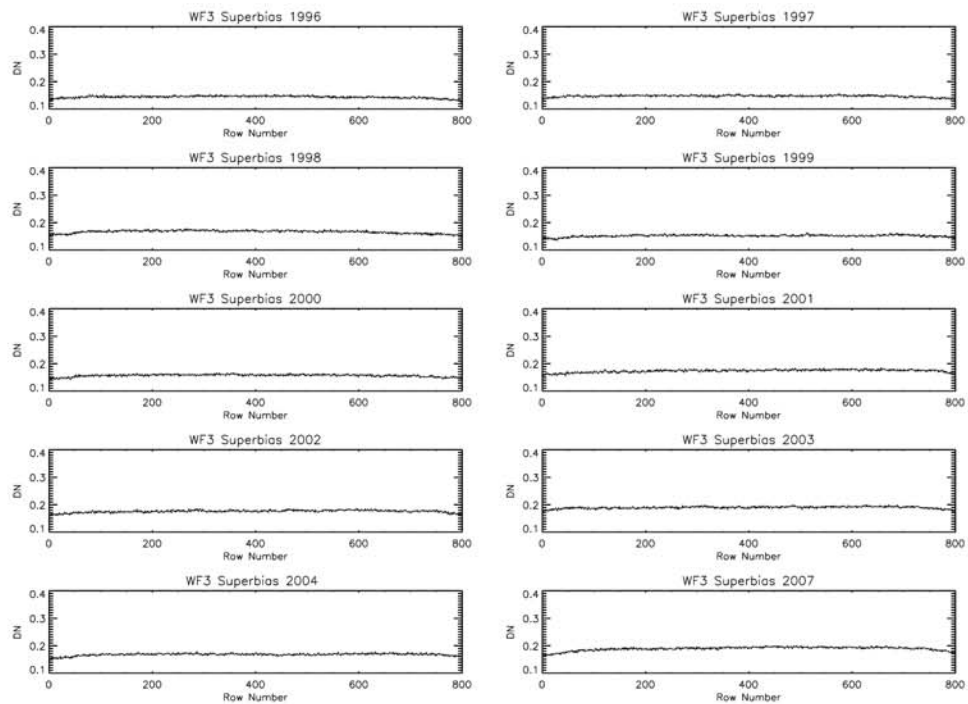
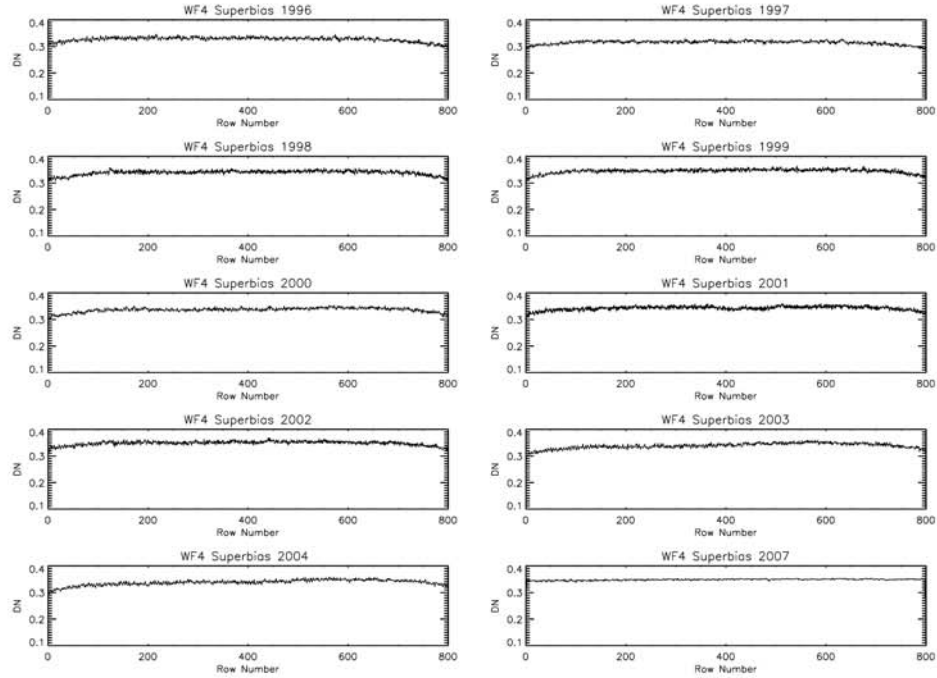


Figure 9. Average of superbias for WF4 vs. CCD row.

(a) Gain 7



(b) Gain 15

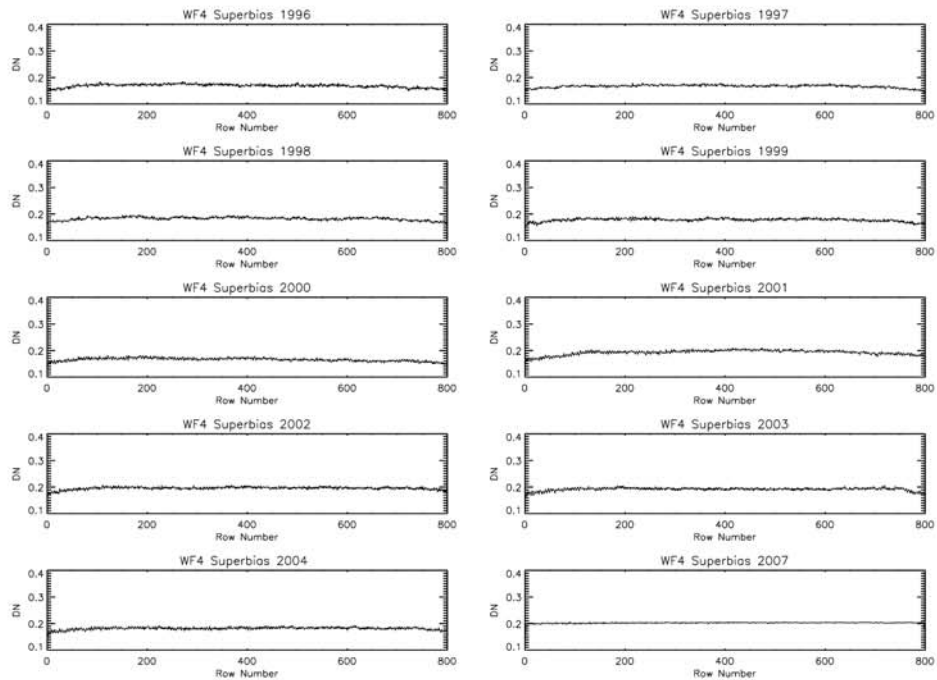
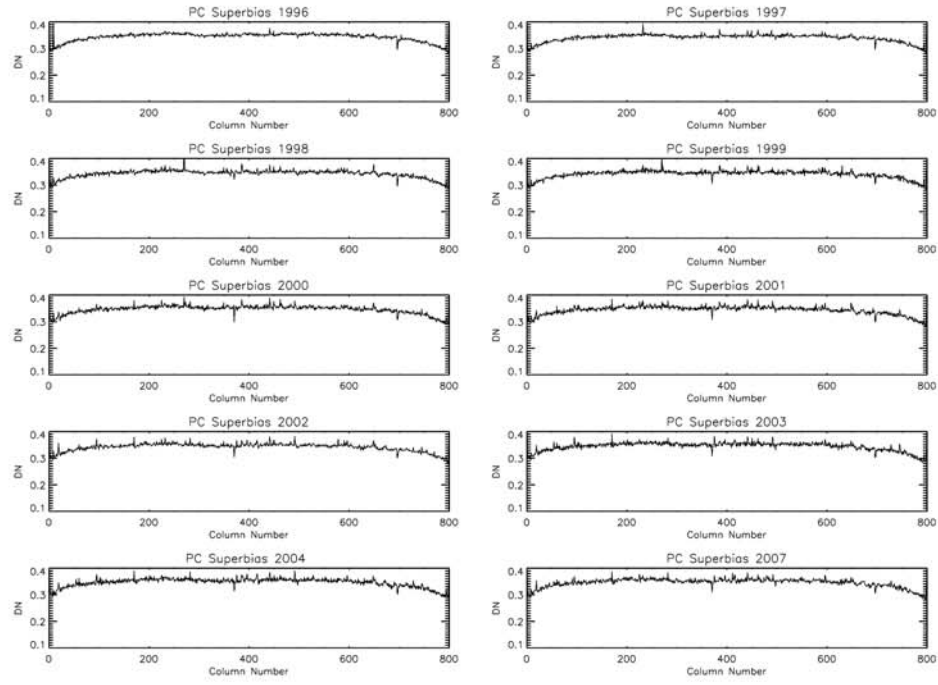


Figure 10. Average of superbias for PC1 vs. CCD column.

(a) Gain 7



(b) Gain 15

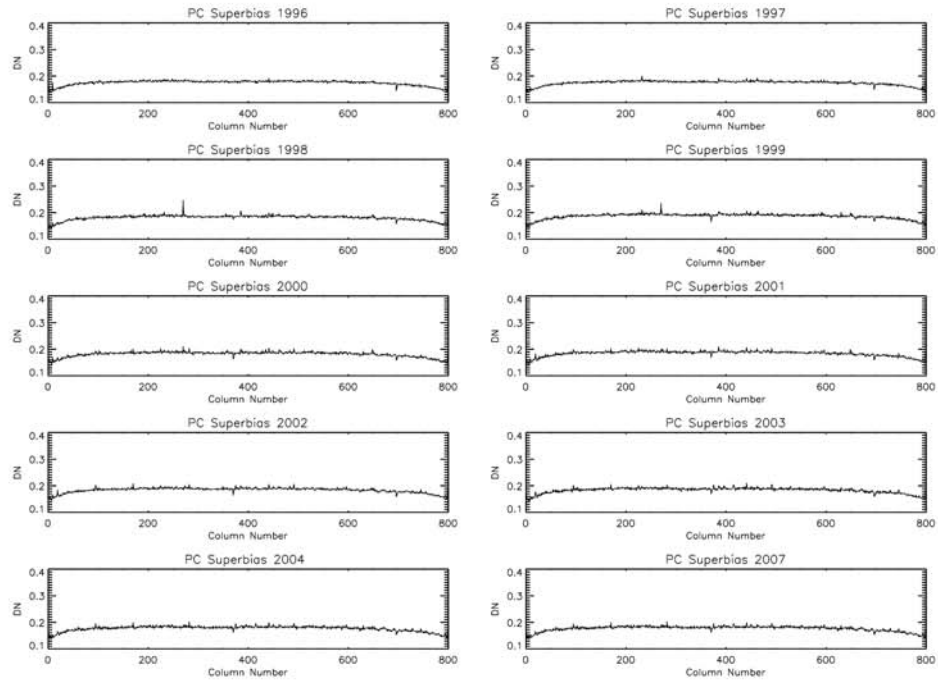
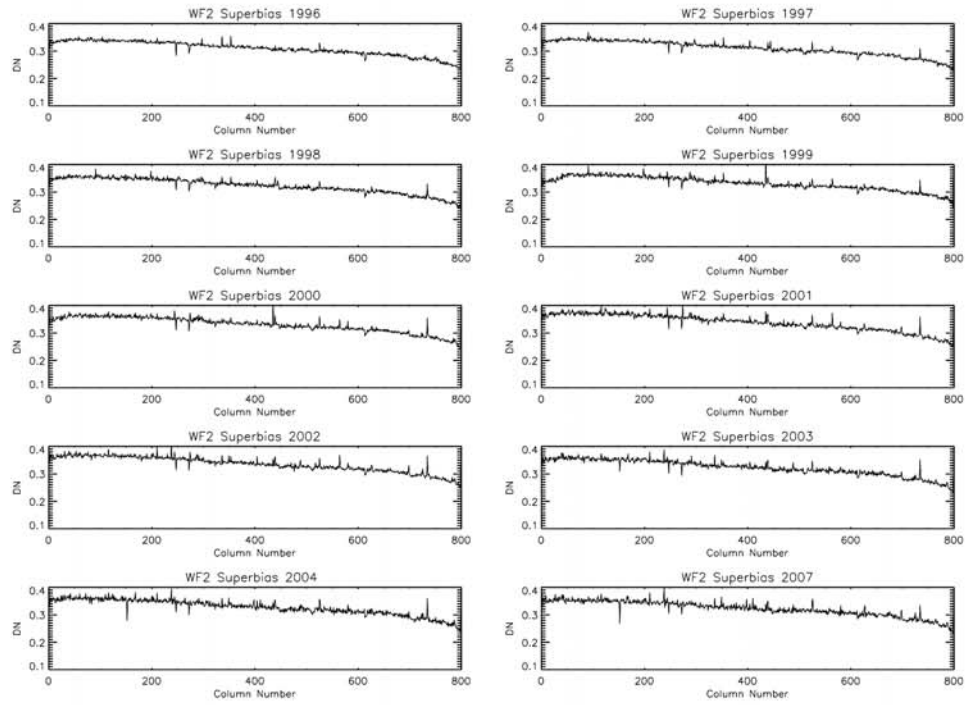


Figure 11. Average of superbias for WF2 vs. CCD column.

(a) Gain 7



(b) Gain 15

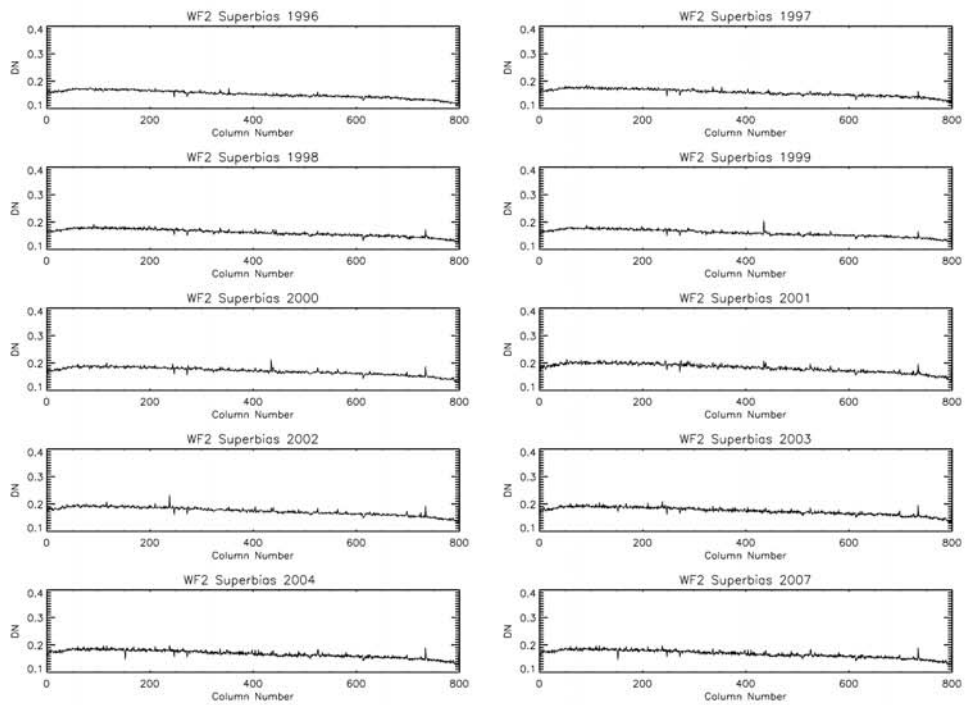
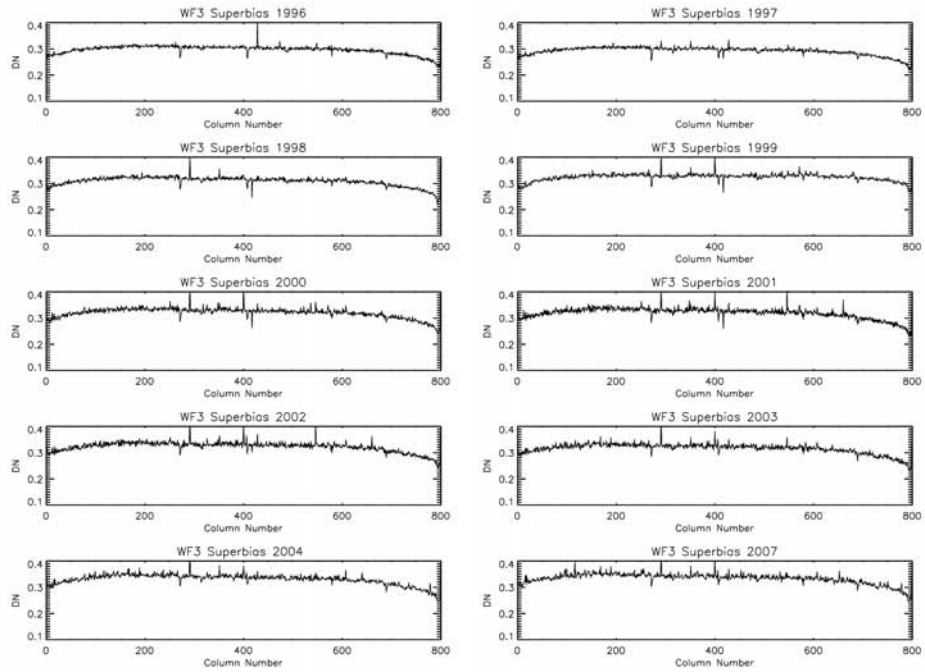


Figure 12. Average of superbias for WF3 vs. CCD column.

(a) Gain 7



(b) Gain 15

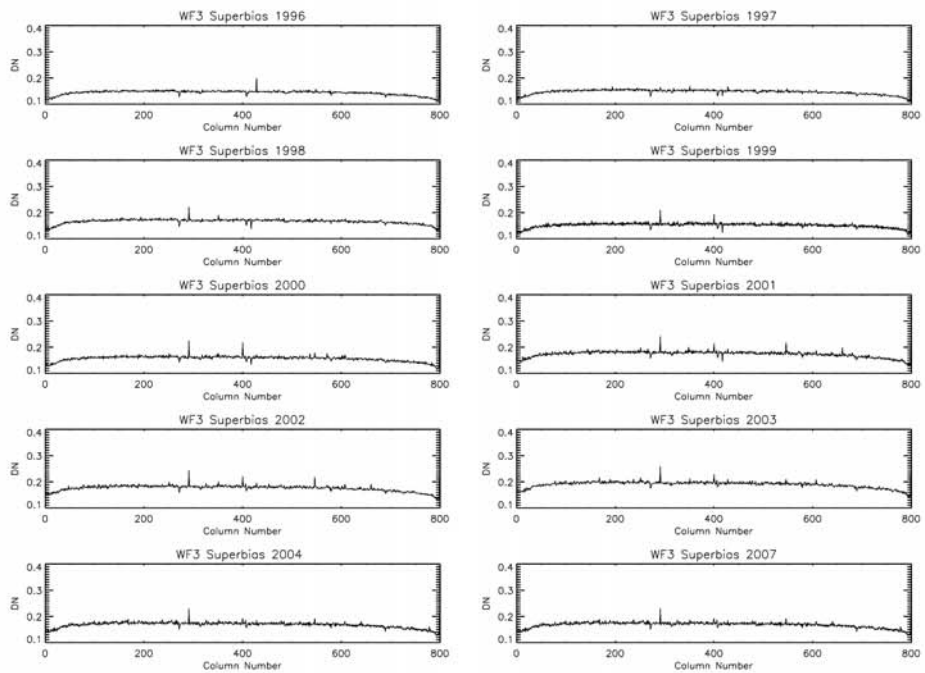
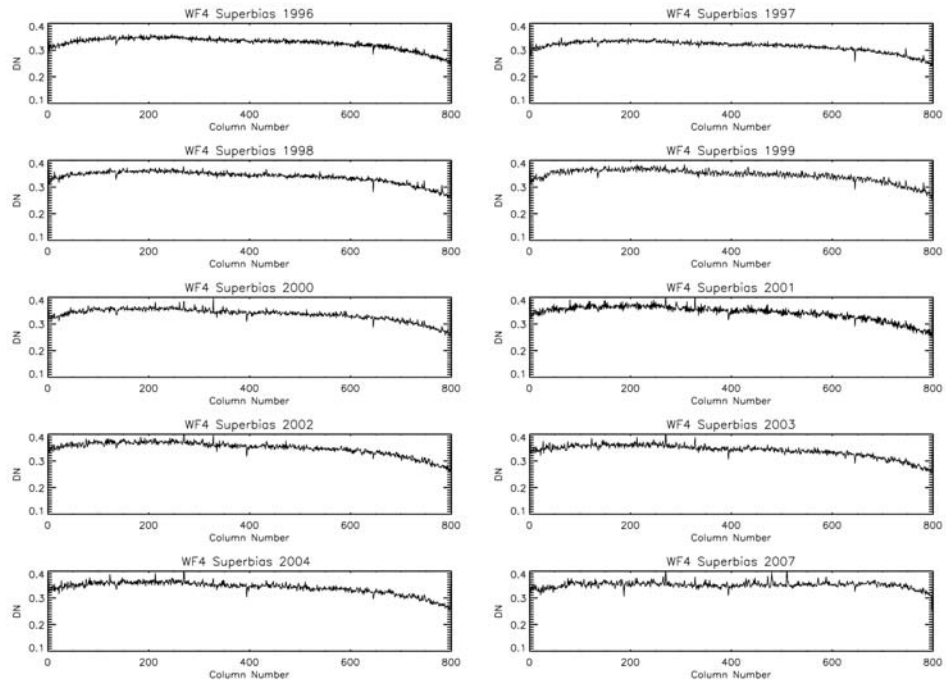
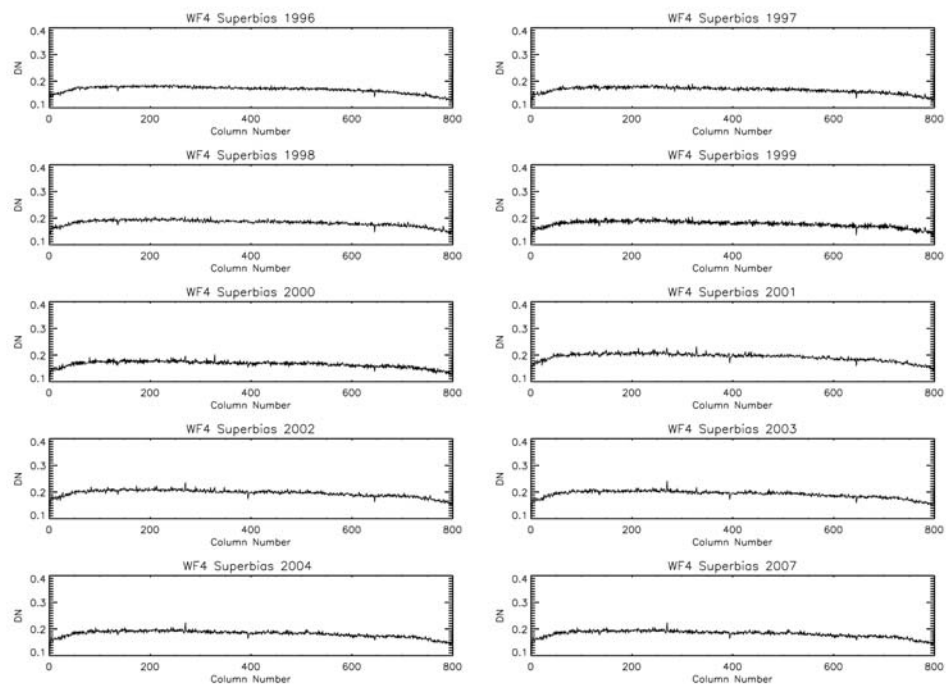


Figure 13. Average of superbias for WF4 vs. CCD column.

(a) Gain 7



(b) Gain 15



References

- Biretta, J. and Gonzaga, S., “Early Assessment of the WF4 Anomaly,”
WFPC2 ISR 2005-02.
- McMaster, M. and Biretta, J., “WFPC2 Instrument Handbook for Cycle 17, Version 10.0,
March 2008.
- O’Dea, C., Gonzaga, S., McMaster, M., Heyer, I., Hsu, J., Baggett, S., and Rudloff, K.,
“Properties of WFPC2 Bias Frames,” WFPC2 ISR 1997-04.
- Whitmore, B. and Wiggs, M., “Charge Transfer Traps in the WFPC2,”
WFPC2 ISR 1995-03.