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STIS CCD Performance Monitor: Read Noise, Gain, and Consistency of Bias correction during June 1997 - June 1998

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ABSTRACT

We summarize the baseline performance of the STIS CCD during the period June 1997 - June 1998. Read-out noise and gain as a function of time are reported. These basic CCD parameters turn out to be generally consistent with those measured during Ground Calibration, and do not show any significant trend with time. The exception is the read-out noise in the high gain settings (`CCDGAIN`[1]`=2`, `4`, and `8`), which are higher in orbit than they were on the ground. This is due to electronic pick-up "pattern" noise which raises the effective read-out noise. Fortunately, data in the standard gain setting (`CCDGAIN=1`) are not affected by electronic pick-up noise. The current values for in-flight unbinned data taken in `CCDGAIN=1` are: Read-out noise = 4.02 +/- 0.08 electrons, and gain = 1.00 +/- 0.02 electrons per ADU. The current values for the `CCDGAIN=4` setting are: Read-out noise = 7.65 +/- 0.16 electrons, and gain = 4.08 +/- 0.05 electrons per ADU. The two-dimensional structure of bias frames is sufficiently stable to allow combinations of many of them, taken over a long period of time, to create high-signal-to-noise superbias images.

1. Introduction

We report on data collected from the STIS Cycle 7 calibration programs 7600 ("CCD Functional") and 8057 ("CCD Functional (continued)") to monitor the baseline performance of the CCD system on orbit. This currently comprises measurements made in three epochs: June 1997, December 1997, and June 1998. Measurements of the following quantities are reported here:

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[1] In this document, words in `COURIER` font denote keywords in the main FITS header of the images

1. The Read-out Noise (RON) in electrons, for all *available*[2] `CCDGAIN` settings;
2. The Gain, defined as the number of electrons per Analog-to-Digital Unit (ADU, this is always the measured unit, sometimes also called Data Number (DN)), for all *available* `CCDGAIN` settings;
3. The average level of the trailing parallel overscan region in ADU, its variation in time, and the global variation of the bias level over the CCD in time, for all *supported* `CCDGAIN` settings.

The evolution of the dark current and the Charge Transfer Efficiency of the STIS CCD in time will be reported on in separate, forthcoming ISRs.

2. Behavior of Gain and Read-out Noise over Time

During each of the CCD Functional tests, two flat field exposures (using an internal tungsten lamp) and two bias frames are taken at each available `CCDGAIN` setting (i.e., `CCDGAIN` = 1, 2, 4, and 8) to provide a rough confirmation of the gain values measured during ground calibration. Binned data were also taken for `CCDGAIN=1`. The gain and read-out noise values were determined using the IRAF CL script stisgain which derives these parameters from a pair of flat field frames and a pair of bias frames as follows:

1. Create a "difference flat" and a "difference bias" for each `CCDGAIN` setting, e.g.,

flatdiff = flat1 - flat2
biasdiff = bias1 - bias2

2. Then calculate the gain and read-out noise as follows:

$$\text{gain} = \frac{\text{mean(flat1)} + \text{mean(flat2)} - \text{mean(bias1)} - \text{mean(bias2)}}{(\text{sigma(flatdiff)})^2 - (\text{sigma(biasdiff)})^2}$$

$$\text{read-out noise} = \text{gain} * \text{sigma(biasdiff)} / \text{sqrt}(2)$$

where the gain is given in electrons per ADU and the read-out noise in electrons. Pairs of bias frames and flat field frames are used to render the effects of non-flat bias frames and/or flat field frames negligible. Statistics for the bias- and flat field frames were derived in regions where the bias-and flat field frames are reasonably flat and free of dust 'motes' (i.e., dust on the CCD window). There is no evidence of a variation of the gain values across the CCD to within 1 sigma of the gain measurements in the individual regions. The results of the gain measurements for each epoch are listed below in Table 1, and the read-out noise measurements are listed in Table 2.

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[2] The only two *supported* `CCDGAIN` settings are `1` and `4`. The `CCDGAIN=2` and `8` settings are only available after approval by a Contact Scientist, are not as well calibrated as the supported settings, and their use is discouraged.

Table 1. CCD Gain values as a function of time.

`CCDGAIN` setting	Binning	Gain measured on ground [a]	Gain [b] measured in Mar 1997	Gain measured in Jun 1997	Gain measured in Dec 1997	Gain measured in Jun 1998
1	1x1	0.994 +/- 0.008	0.97 +/- 0.02	0.98 +/- 0.02	0.99 +/- 0.02	1.00 +/- 0.02
1	1x2	0.995 +/- 0.005	0.98 +/- 0.02	0.96 +/- 0..02	0.99 +/- 0.02	1.01 +/- 0.02
1	2x1	0.995 +/- 0.013	1.00 +/- 0.01	1.01 +/- 0.02	1.03 +/- 0.02	0.99 +/- 0.02
1	2x2	1.001 +/- 0.010	1.00 +/- 0.01	1.00 +/- 0.02	1.01 +/- 0.03	1.00 +/- 0.02
1	4x1	0.984 +/- 0.024	---	0.96 +/- 0.03	0.97 +/- 0.03	0.99 +/- 0.03
1	4x2	1.008 +/- 0.013	---	---	0.97 +/- 0.03	1.01 +/- 0.03
2	1x1	2.008 +/- 0.006	2.06 +/- 0.03	2.01 +/- 0.02	---	2.02 +/- 0.02
4	1x1	4.096 +/- 0.009	---	4.00 +/- 0.05	4.07 +/- 0.05	4.08 +/- 0.05
8	1x1	8.323 +/- 0.027	---	8.07 +/- 0.10	---	8.05 +/- 0.10

[a] The Ground Calibration measurements (column 3) are taken from GSFC Pre-flight Report #90 (R.S. Hill, March 10, 1997)

[b] These first in-flight measurements (March 1997) are taken from STIS Instrument Science Report 97-10 (P. Goudfrooij et al., May 1997)

During the first on-orbit visit of the CCD Functional Monitor in March 1997, the gain for settings `CCDGAIN=4` and `CCDGAIN=8` could not be measured because of saturated flat fields (the flat field lamps turned out to have a higher output than expected). The exposure times for the subsequent visits of the Functional Monitor were adjusted accordingly.

The in-flight gain values tabulated in Table 1 should not be regarded as “very accurate” since they have been derived from only two flat field images (one intensity level) per gain setting, which were rather highly illuminated (in the upper ~30% of the dynamical range). However, the bulk of the measured gain values are consistent with the values measured on the ground. Furthermore, the STIS CCD Sensitivity Monitor (Cycle 7 calibration program 7672), which includes a spectroscopic (wide-slit) measurement of a spectrophotometric standard star in the `CCDGAIN=1` and `CCDGAIN=4` settings every four months, has shown that the gain ratio between the `CCDGAIN=1` and `CCDGAIN=4` settings is 4.034 +/- 0.010 and does not show any trend with time (STIS Instrument Science Report 98-27, Walborn & Bohlin 1998), which is consistent with the results listed in Table 5. The only slight deviation from the gain values measured during ground calibration is found for the `CCDGAIN=8` setting for which the in-flight gain value seems to be about 2.5 sigma lower than that measured on the ground. All measured in-flight gain values are within 2% of the nominal, commanded gain.

Table 2. Read-out noise values as a function of time. The uncertainties include those from the gain measurements in Table 1.

`CCDGAIN` setting	`Binning`	Read noise [e$^-$] measured on ground [a]	Read noise [e$^-$] measured in Mar 1997 [b]	Read noise [e$^-$] measured in Jun 1997	Read noise [e$^-$] measured in Dec 1997	Read noise [e$^-$] measured in Jun 1998
1	1x1	4.0	3.78 +/- 0.05	3.98 +/- 0.06	3.95 +/- 0.08	4.02 +/- 0.08
1	1x2		4.18 +/- 0.05	3.83 +/- 0.08	3.99 +/- 0.09	4.05 +/- 0.11
1	2x1		3.65 +/- 0.05	3.70 +/- 0.09	3.87 +/- 0.07	3.69 +/- 0.09
1	2x2		3.76 +/- 0.03	3.70 +/- 0.12	3.85 +/- 0.15	3.85 +/- 0.10
1	4x1		---	3.69 +/- 0.13	3.59 +/- 0.10	3.73 +/- 0.12
	4x2		---	---	3.66 +/- 0.09	3.84 +/- 0.20
2	1x1	4.8	5.32 +/- 0.10	5.75 +/- 0.10	---	5.79 +/- 0.12
4	1x1	6.4	---	7.50 +/- 0.21	7.22 +/- 0.11	7.65 +/- 0.16
8	1x1	10.4	---	11.87 +/- 0.21	---	12.24 +/- 0.30

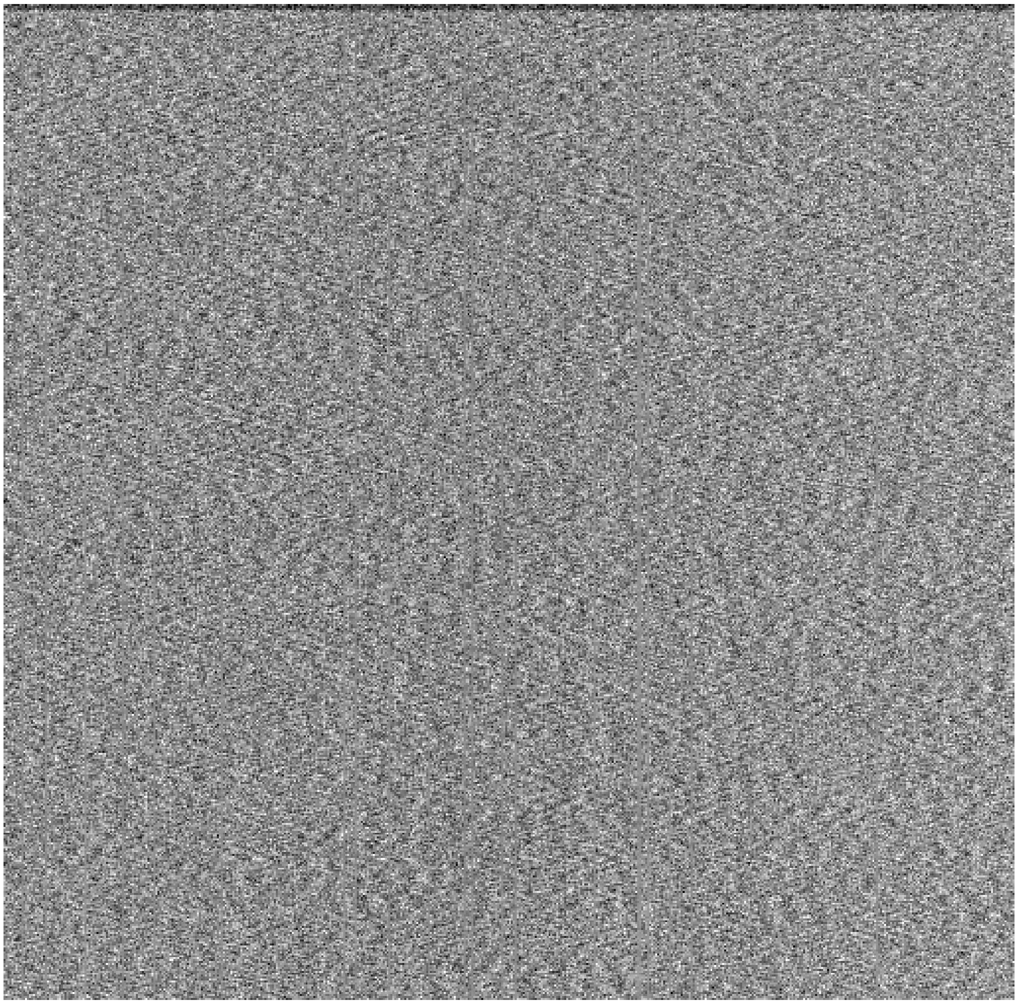
[a] These ground measurements are taken from GSFC Pre-flight Report #64 (R. Kimble, July 1996).

[b] As in Table 1, the March 1997 measurements are taken from STIS Instrument Science Report 97-10 (P. Goudfrooij et al., May 1997)

Electronic Pick-up Noise in the CCDGAIN=2, 4, and 8 Settings

As Table 2 shows, the read-out noise in the `CCDGAIN=2`, `4`, and `8` settings is higher in orbit than the ground measurements indicated. The main cause of these higher noise values is electronic pick-up “pattern” noise; as an example, Fig. 1 depicts the structure in an unbinned superbias frame taken in `CCDGAIN=4`. Although the pattern noise is present in all `CCDGAIN=4` images to some extent, its exact structure is not stable enough to subtract out using a reference superbias. Fortunately, the read-out noise in the `CCDGAIN=1` setting [which has the lowest read-out noise and is the nominal gain setting for scientific exposures with STIS] does not show the pattern noise; its effective read-out noise has remained constant in time.

Figure 1: Portion of an (unbinned) superbias frame taken in `CCDGAIN=4.` Notice the "fishbone" pattern (due to electronic pick-up noise), raising the effective read noise.



3. Stability of Bias Level Subtraction

3.1. Superbias Frames

To construct "superbias" frames and test the stability of STIS bias frames, 31 bias frames are taken each six months (during the "CCD Functional" monitor proposals, cf. Section 1) for the following gain & binning combinations:

1. `CCDGAIN=1`, no binning
2. `CCDGAIN=2`, no binning
3. `CCDGAIN=4`, no binning
4. `CCDGAIN=8`, no binning

5. `CCDGAIN=1, BINAXIS1=1, BINAXIS2=2` (i.e., 1x2 binning)
6. `CCDGAIN=1, BINAXIS1=2, BINAXIS2=1` (i.e., 2x1 binning)
7. `CCDGAIN=1, BINAXIS1=2, BINAXIS2=2` (i.e., 2x2 binning)
8. `CCDGAIN=1, BINAXIS1=4, BINAXIS2=1` (i.e., 4x1 binning)
9. `CCDGAIN=1, BINAXIS1=4, BINAXIS2=2` (i.e., 4x2 binning)
10. `CCDGAIN=4, BINAXIS1=1, BINAXIS2=1`, 100x100 pixel subarray
11. `CCDGAIN=4, BINAXIS1=1, BINAXIS2=1`, 100x1024 pixel subarray

The last two combinations were specifically chosen to test the stability of the bias level in subarray read-outs which is important for, e.g., target acquisitions during which a fixed bias level is subtracted prior to acquisition measurements (see STIS ISR 97-03B, R. Downes et al., May 1997).

In addition to these 6-monthly functional monitors, Cycle 7 calibration proposals 7601 and 7926 ("Dark and Bias Monitor") have been taking weekly biases in the `CCDGAIN=1` and `CCDGAIN=4`, unbinned settings which are used below to test the stability of the bias level subtraction.

For the construction of the superbiases, we used the IRAF CL script refbias (available at STScI only) which is based on the STIS pipeline routine calstis (modules basic2d and ocrreject, cf., STIS ISR 98-14, Katsanis et al., April 1998). The exact way in which the script refbias works will be described in a separate ISR.

3.2. Time Evolution of Overscan Level

Using the bias frames taken during Cycle 7 calibration proposals 7601 and 7926 ("Dark and Bias Monitor"), the stability of the level of the trailing serial overscan region with time has been studied during the time interval August 1997 - June 1998. An IRAF CL script getblev was written for this purpose, which eliminates hot pixels or cosmic ray hits in the image statistics. The results are depicted in Figures 2 and 3. For both `CCDGAIN` settings, the overscan level turns out to slowly increase with time by about 0.03 electrons per day. In addition, there is an intrinsic scatter of about 8 electrons (peak-to-peak) at any given date. These changes are likely related to (small) variations in CCD temperature (of order 0.1 - 0.2 degrees), or to intrinsic variations (probably also of thermal nature) in the Aspect Bias Board of the CCD Electronics Box. Unfortunately however, the accuracy of STIS CCD chip temperatures is only about 0.75 degrees per increment (and 0.51 degrees per increment for the Aspect Bias Board temperature sensor), so that we cannot thoroughly test this hypothesis at this time. Incidentally, the CCD temperature of the WFPC2 chips *has* shown a long-term increase by about 0.15 degrees since WFPC2 was installed [which was during December 1993] (S. Balleza & M.R. Jones, private communication).

Figure 2: Overscan level vs. Modified Julian Date for Bias frames taken in `CCDGAIN=1` during Cycle 7 proposals 7601 and 7926 between August 1, 1997, and June 30, 1998.

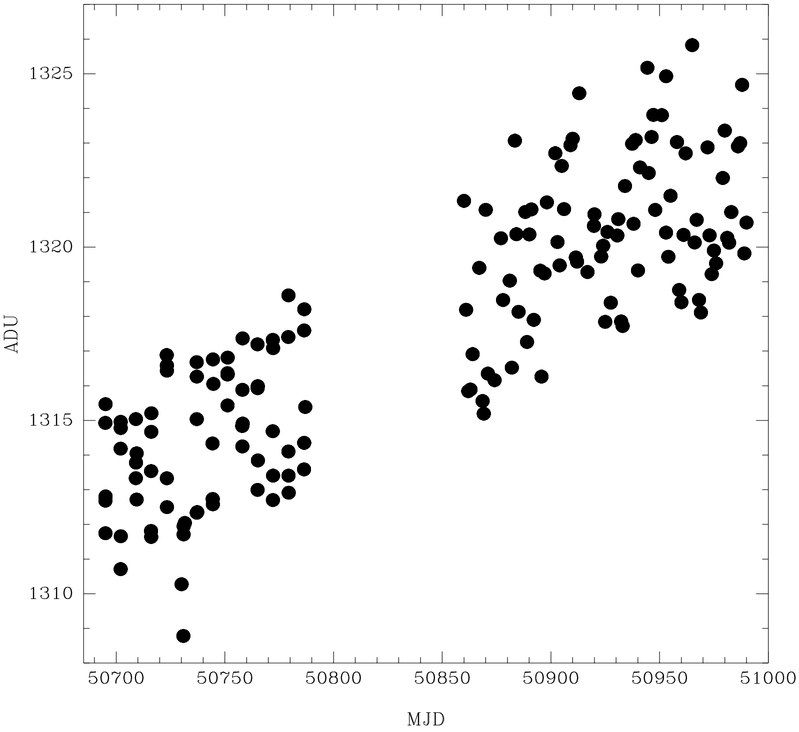
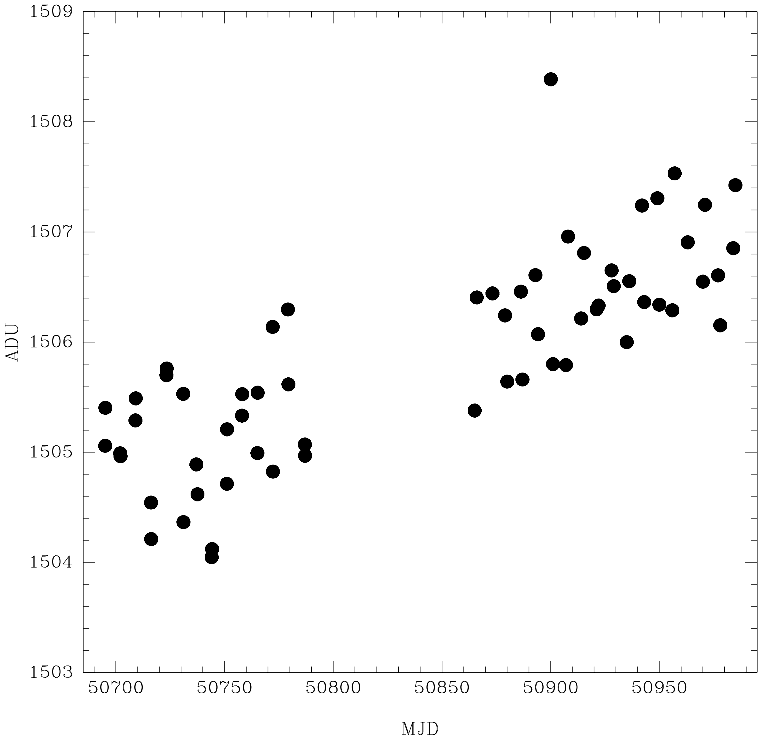


Figure 3: As Figure 2, but now for bias frames taken in `CCDGAIN=4`.

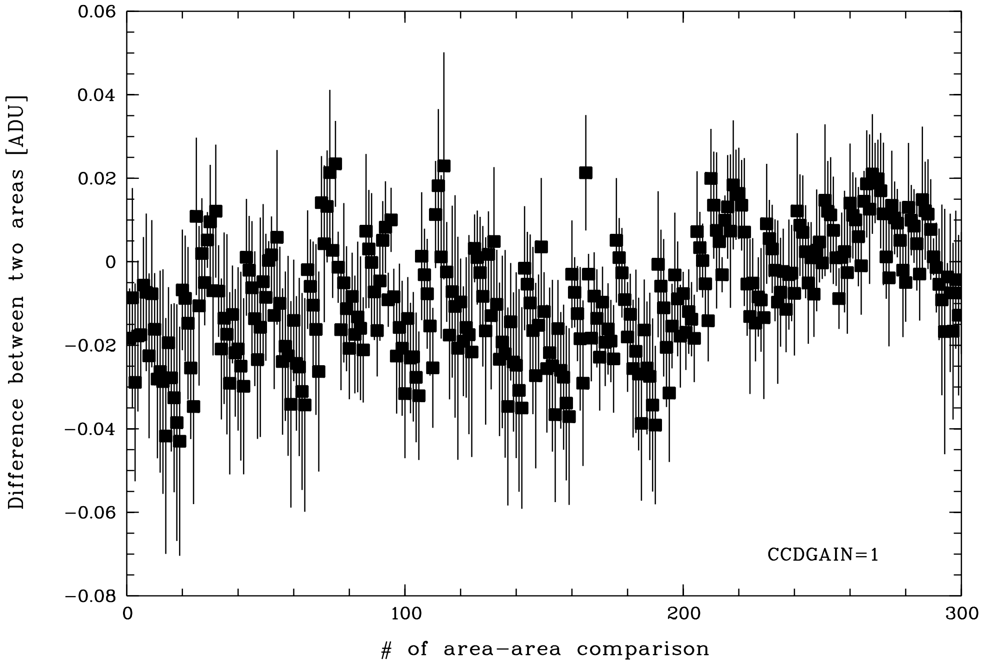


3.3. Stability of Bias Pattern over Time

3.3.1. Stability of Global Two-dimensional Bias Pattern

We have studied the stability of the global , 2-dimensional pattern of the bias level over time as follows. From all bias frames taken in `CCDGAIN=1` during the period September 1997 - June 1998, we created "monthly" superbiases using the script refbias (cf. Section 2.2.1). These monthly superbiases are combinations of typically 25 (unbinned) bias frames. After that, one monthly superbias was assigned as "reference" and subtracted from the other superbiases. In the resulting "residual" images, we determined the level in 25 sub-areas of 100 x 100 pixels, uniformly distributed over the CCD. Linear regressions were subsequently performed between the levels of the sub-areas, to test the stability of the superbiases (as created by script refbias) over time. Figure 4 depicts the intensity offsets found between the different sub-areas of the CCD, along with their 1-sigma error bars (the mean RMS of the regressions is 0.015 ADU). As Figure 4 shows, any residual change of bias pattern over the CCD chip stays within about 0.04 ADU (peak-to-peak), which represents a mere 2.5 sigma change. The mean of the area-area offsets is (-0.008 +/- 0.015) ADU, i.e., insignificant. As a final sanity check, we repeated the experiment using two other monthly superbiases as "reference"; the results were the same within the uncertainty.

Figure 4: Differences between pairs of residual bias levels in different areas on the CCD among monthly `CCDGAIN=1` superbiases, after subtraction of one "reference" superbias. The data cover the period September 1997 - June 1998. The mean RMS of the measurements is 0.015 ADU.



3.3.2. Stability of Structure of Bias Pattern along Columns and Rows

For each of the monthly superbiases mentioned above, we created column-averaged and row-averaged one-dimensional ‘traces’. The column-averaged traces are plotted in Figure 5, and the row-averaged traces are plotted in Figure 6. Appropriate shifts (in intensity level) between the individual traces were applied for ease of visualization.

As Figure 5 reveals, there is a slope in the structure of the superbiases along columns. This is due to cumulative *spurious charge* (cf. STIS ISR 97-09, Goudfrooij & Walsh, 1997) which starts to accumulate at row #512 (in unbinned images). In describing the stability of the structure of the bias frames along columns, we therefore discriminate between the *overall intensity level* of the frames, which is measured in the upper 512 rows (i.e., out of the region in which spurious charge builds up), and the *slope of the structure in the lower 512 rows*. The results on the stability of these two parameters are listed in Table 3. We find that both the intensity level and the slope of the structure in the upper 512 rows are stable in time to within about 5% and 3% RMS, respectively. There is no significant trend of either parameter with time, allowing one to combine many bias frames taken over a long period of time to prepare high signal-to-noise superbiases.

As to the structure along rows, Figure 6 and Table 3 reveal that there is no significant scatter in the “global” slope (the reason why the relative scatter among the slopes [cf., third column of Table 3] *seems* large is that the error of the individual slopes is comparable to or larger than the slopes themselves), or in the behavior of the “roll-over” at columns 950 to 1024. The main change in structure is the increasing number of “hot” columns with time. While the refbias procedure which is used to create STIS superbiases does detect hot columns at a level of 5 sigma above local median values of the superbias image and replaces them by the columns in a median-filtered version of the superbias (a forthcoming ISR will explain in detail how the refbias procedure works), this growing number of hot columns might have an impact on the quality of the basic CCD reduction[3]. As another illustration of the growing number of hot columns, Figures 5 and 6 depict the 2-D structure of reference superbiases made in August 1997 and September 1998, respectively (both are combinations of several months worth of bias frames). We are currently considering a new procedure for bias correction: creating “weekly superbias” reference files (from about 15-20 weekly bias frames) from which one would extract the ‘hot’ columns every week and place them in the current, high-signal-to-noise reference superbias (from which all hot columns are removed, as currently done). The “weekly bias” reference files would then be used as `BIASFILE` in calstis. We expect to test this procedure this winter

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[3] Currently, hot pixels and columns are corrected for in the Dark Correction step (`DARKCORR` in calstis) by creating weekly (and, optionally, daily) superdarks in which the hot pixels that are at least 5 sigma above the median dark are updated. However, this process currently does not provide a very accurate correction of all hot columns, which is most probably partly due to insufficient signal-to-noise in the weekly/daily darks, especially for the columns that are only 3-10 sigma ‘hotter’ than the median.

(1998-99), and we will report the results in the next edition of the CCD Performance Monitor ISR.

Table 3. Stability of structure of bias pattern along columns and rows, over the time period September 1997 - June 1998. All results have been obtained by excluding pixels having intensities exceeding 5 sigma above the local median bias level. The quoted uncertainties are mean errors of the mean.

Median Intensity level of upper 512 rows	**Slope along lower 512 rows ("*spurious charge*" region)**	**Slope along first 900 columns**
0.22 +/- 0.01	(-7.10 +/- 0.21) 10^{-4}	(-1.49 +/- 3.00) 10^{-5}

Figure 5: Stability of structure in superbias frames along columns on timescales of about a month, between September 1997 and June 1998. The structure plotted at the bottom is the September 97 monthly superbias, and the structures of subsequent superbiases are overplotted after applying offsets of 0.15 ADU between the different structures (for ease of visualization).

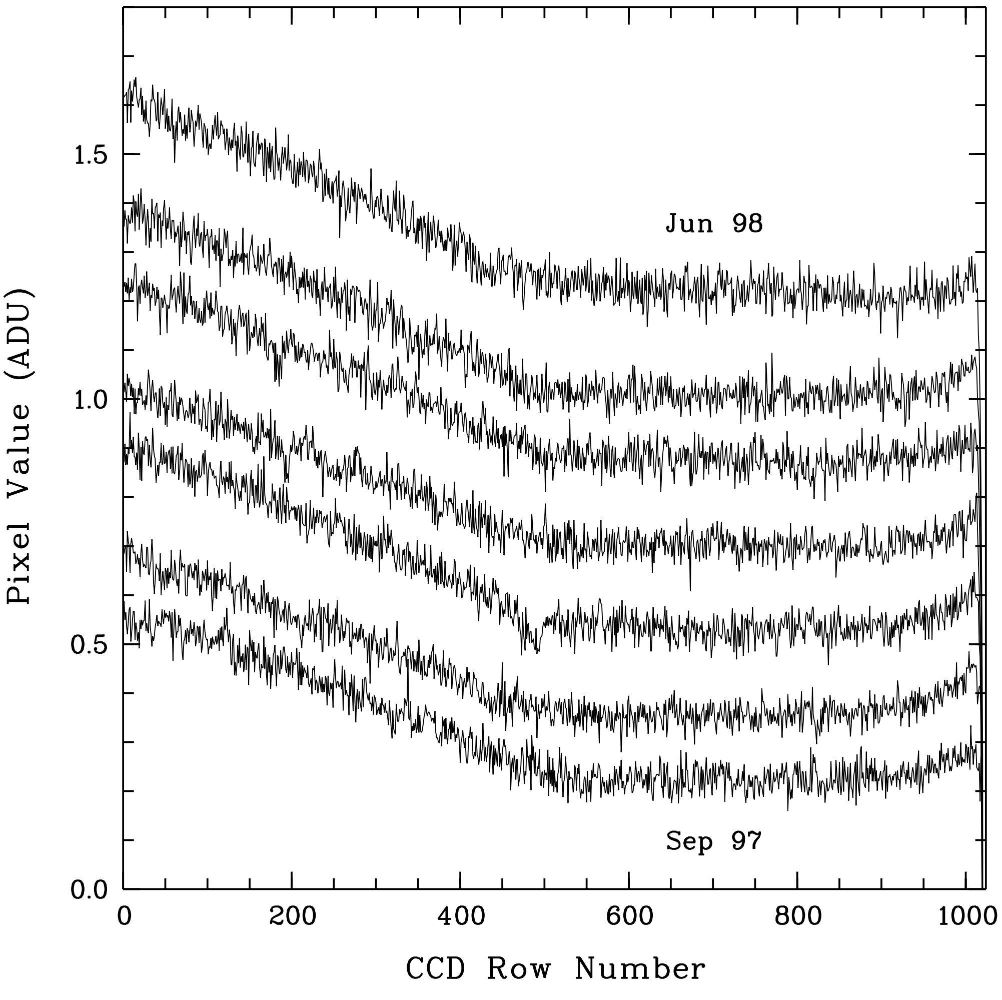
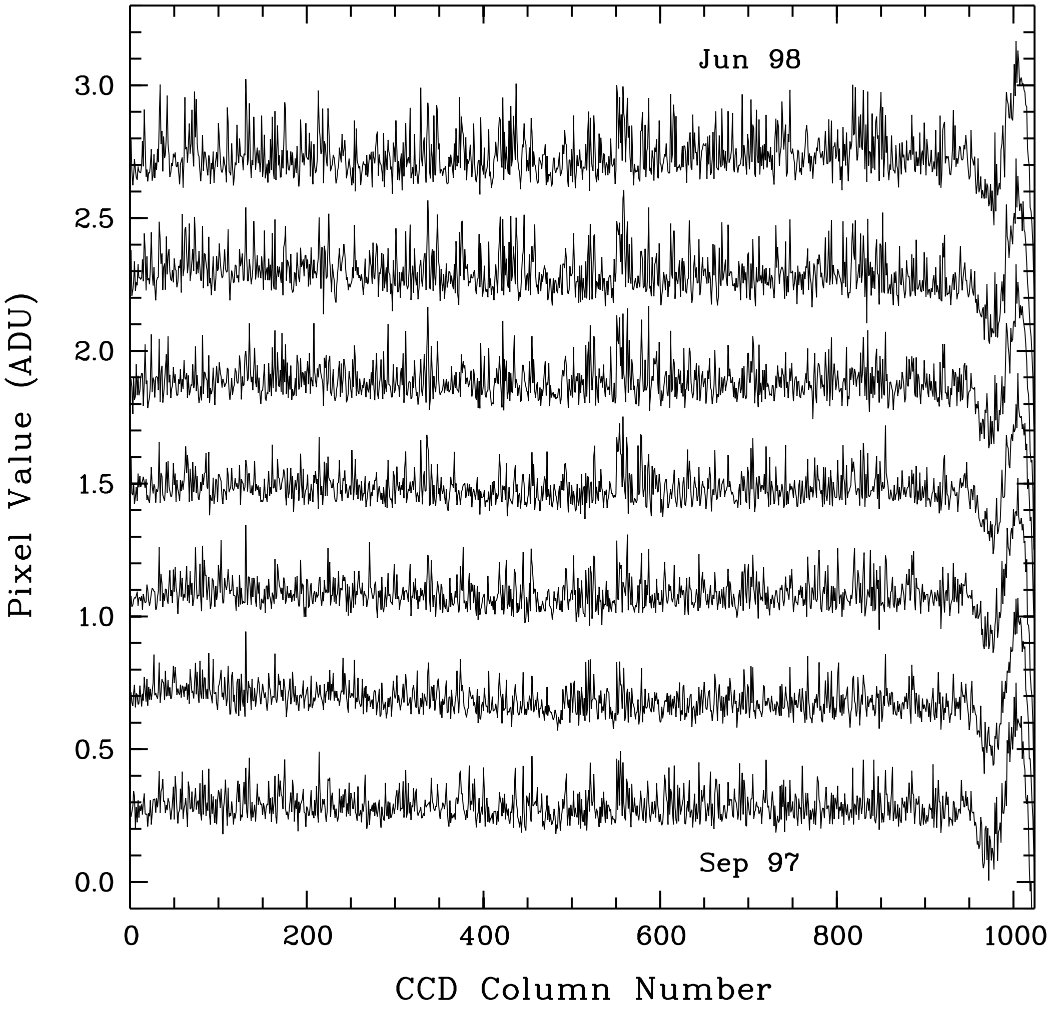


Figure 6: As Figure 5, but now structures of monthly superbiases along rows. The vertical offset applied between the subsequent structures is 0.4 ADU.



4. Conclusions

The STIS SITe CCD is (still) performing very well in orbit. Gain and read-out noise in the nominal gain setting (`CCDGAIN=1`) are entirely according to specifications, and remain so with time. Electronic pattern noise is increasing the noise for `CCDGAIN` settings 2, 4, and 8 to values that are above those measured on the ground. The global pattern of the bias image is very stable with time, allowing one to combine many bias frames together to construct high-signal-to-noise superbias images. In Table 4 below we summarize the current values for gain and read-out noise.

Figure 7: 2-D structure of `CCDGAIN=1` superbias image produced from bias frames taken during April - August 1997. The grey-scale stretch is +/- 5 sigma from the mean.

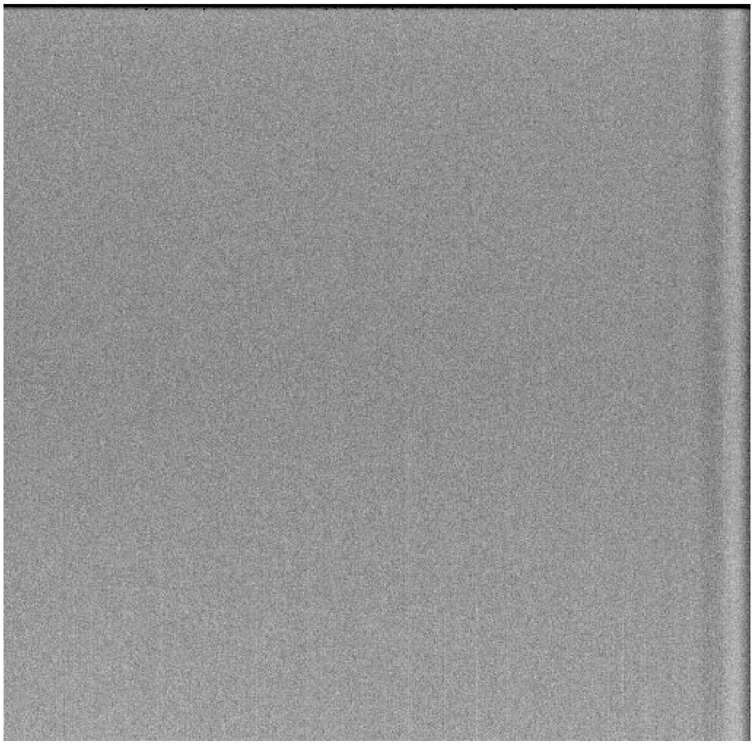


Figure 8: Same as Figure 7, but now for a superbias image produced from bias frames taken during June - September 1998.

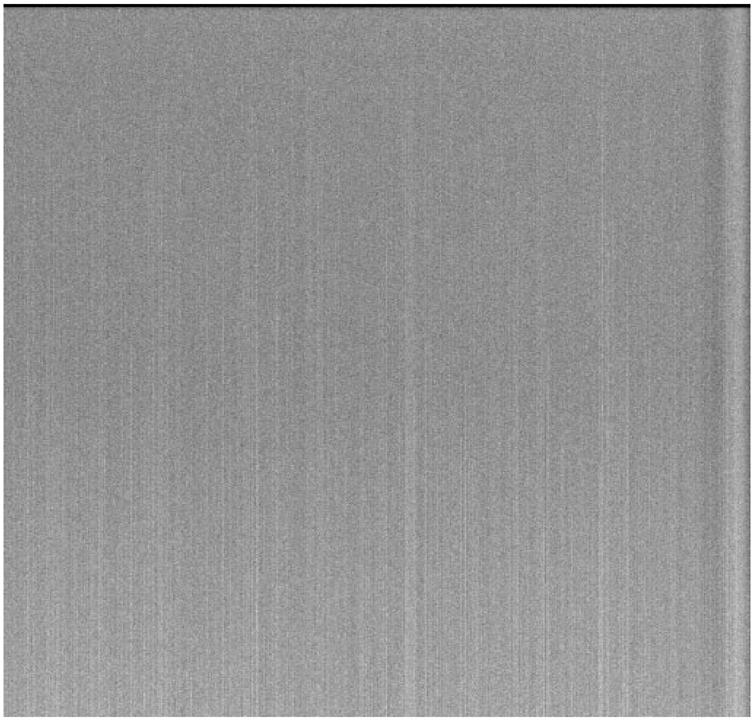


Table 4. July 1998 values for Gain and Read-out Noise of the STIS CCD.

`CCDGAIN` setting	`Binning`	Gain measured	Read-out Noise [electrons]
1	1x1	1.00 +/- 0.02	4.02 +/- 0.08
1	1x2	1.01 +/- 0.02	4.05 +/- 0.11
1	2x1	0.99 +/- 0.01	3.69 +/- 0.09
1	2x2	1.00 +/- 0.01	3.85 +/- 0.10
1	4x1	0.99 +/- 0.03	3.73 +/- 0.12
1	4x2	1.01 +/- 0.03	3.84 +/- 0.20
2	1x1	2.02 +/- 0.02	5.79 +/- 0.12
4	1x1	4.08 +/- 0.05	7.65 +/- 0.16
8	1x1	8.05 +/- 0.10-	12.24 +/- 0.30

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