

STIS CCD Anneals

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ABSTRACT

In this ISR we outline the comprehensive monitoring program that has been underway for the STIS CCD dark current since STIS was installed on HST (February 1997). This program consists of monitors of darks, biases, the growth of hot pixels, and the effect that annealing has on the elimination of these hot pixels. We outline in this ISR the outcome of the analysis of the utility of the anneal process for the STIS CCD. We find that the STIS CCD has grown a number of hot persistent pixels (i.e., hot pixels which do not anneal away). We also find that we continue to grow hot pixels at a constant rate. We also find that the STIS CCD does anneal new hot pixels at the ~80% rate which is comparable to that reported by the WFPC2 group, and that we see at brightness cuts greater than 1 e/sec a flattening of the growth rate of new hot pixels, though no flattening is seen at lower levels (e.g., > 0.1 e/sec). We also find that the average post-anneal dark count-rate is now 0.0068 e/sec.

1. Introduction

The STIS CCD is a SiTe 1024 by 1024 back-illuminated thinned CCD. The pixels are 21 microns square, and the CCD is optimised to give a maximum quantum efficiency in the near-UV and visible. This particular CCD was chosen in order to: allow first-order visible spectroscopy; target acquisitions; imaging; and partial backup for the near-UV MAMA. The readout noise is quite low (3.78 e), and there is a low dark current (≈ 0.015 e/sec at -83C), Goudfrooij et al. (1997). The quantum efficiency is quite good (> 60% at 5000 Å with decreases to ~20% at 3000 Å and 9000 Å respectively). The full range of spectral response for the CCD is from 2000 Å to 11000 Å (Baum et al. 1996).

However, like all CCDs, the detector is subject to cosmetic defects, of which the most serious are: charged particle hits (cosmic rays); hot pixels (pixels that retain and gain charge); and bad rows and columns. All of these problems will appear on all calibration and science data taken, and can change with time. It is for this reason that the STIS CCD is monitored on a series of differing timescales in order to accurately track the variations on the dark and bias levels of the CCD at the two routinely used GAIN settings (1 and 4), to

track the cosmic ray rate and hot pixel growth, and to monitor the utility of the monthly anneals for the removal of hot pixels.

2. The Anneal Program

Currently, STIS CCD anneals occur monthly and are a way of minimising (by heating the CCD from -83C to +5C, as measured by engineering telemetry) the number of hot pixels from the CCD. To monitor the usefulness of the anneal, we regularly obtain pre- and post-anneal biases, darks and flats. We have re-analysed the SMOV anneals (program 7107) and analysed the Cycle 7 anneals to date (program 7635) in a uniform way. The SMOV and Cycle 7 programs required that a bias, and a series of darks and flats be taken. We have found that 5 separate integrations (i.e., a CR-SPLIT=5) are needed to allow for the best detection and elimination of cosmic rays in the individual darks and flats, but for the July, August and November anneals, a CR-SPLIT = 3 was used by mistake. These biases, darks and flats are obtained immediately before and immediately after the anneal has taken place.

The anneal process itself is on the order of 16 hours long: sufficient time to allow the CCD to warm up from its operating temperature of -83C to the ambient telescope temperature of roughly +5C. Once the data are obtained and retrieved from the archive, the darks are recalibrated using the latest versions of calstis and co-added in order to form pre- and post-anneal superdarks. We have used both the contemporaneous biases and the “pipeline” reference biases in the re-analysis and found a very small (< 2% change) between mean superdark levels. For all the analyses reported in this ISR, we have used the pipeline reference biases. A similar procedure is used to form pre- and post-anneal superflats. The superflats are used to monitor, at a gross level, the effect the anneal has had on the quantum efficiency of the CCD and will be discussed in a further ISR.

The overall purpose is to allow one to:

1. compare the pre- and post-anneal bias levels and darks;
2. compare the numbers of hot pixels before and after the anneal to see if the numbers of hot pixels decrease;
3. determine whether the pre-anneal hot pixels actually anneal out or just become weaker; and
4. to check that there is no loss in the quantum efficiency of the CCD during the anneal process.

In Table 1 we show an example of the observations occurring either before or after an anneal.

Table 1. Structure of STIS CCD Anneals

Target Name	Aperture	Optical Element	CR-SPLIT	Integration Time
Bias	50CCD	Mirror	3	0s
Dark	50CCD	Mirror	5	1200s
Imaging flat	50CCD	Mirror	3	0.6s
Spectral flat	52x2	G750M at $\lambda = 6768\text{\AA}$	3	0.1s

3. Analysis

In order to insure a uniform and straight-forward process in the analysis of the efficiency of the anneals, Hayes has written and delivered to the `xstis` package a new STS-DAS task called `anneal_darks`. This task is for the use of the STScI STIS team only, or under the guidance of one of the STScI Instrument Scientists, as the task will not be exported to the GO community since a typical GO has no need of its functionality.

The task presumes that one has run `calstis` on the pre- and post-anneal darks and created a CRJ file. These CRJ files we call *superdarks* for the sake of this paper. `anneal_darks` will, when given the pre- and post-anneal superdarks, automatically generate a pair of re-normalised superdarks (i.e., normalize the superdarks to 1 sec), histograms of these re-normalised superdarks, statistics on the mean and standard deviation of the re-normalised superdarks, and find the brightness, the number and the positions of the hot pixels in common between the pre- and post-anneal superdarks (i.e., which pixels do not anneal out). We have chosen to re-normalise the superdarks by their total integration times in order to allow the analysis to be conducted directly in electron/sec/pixel. The task is written to facilitate the tracking of hot pixels that do not anneal out so that the STIS group can, when needed, post advisories to the community as to which pixels are chronically hot.

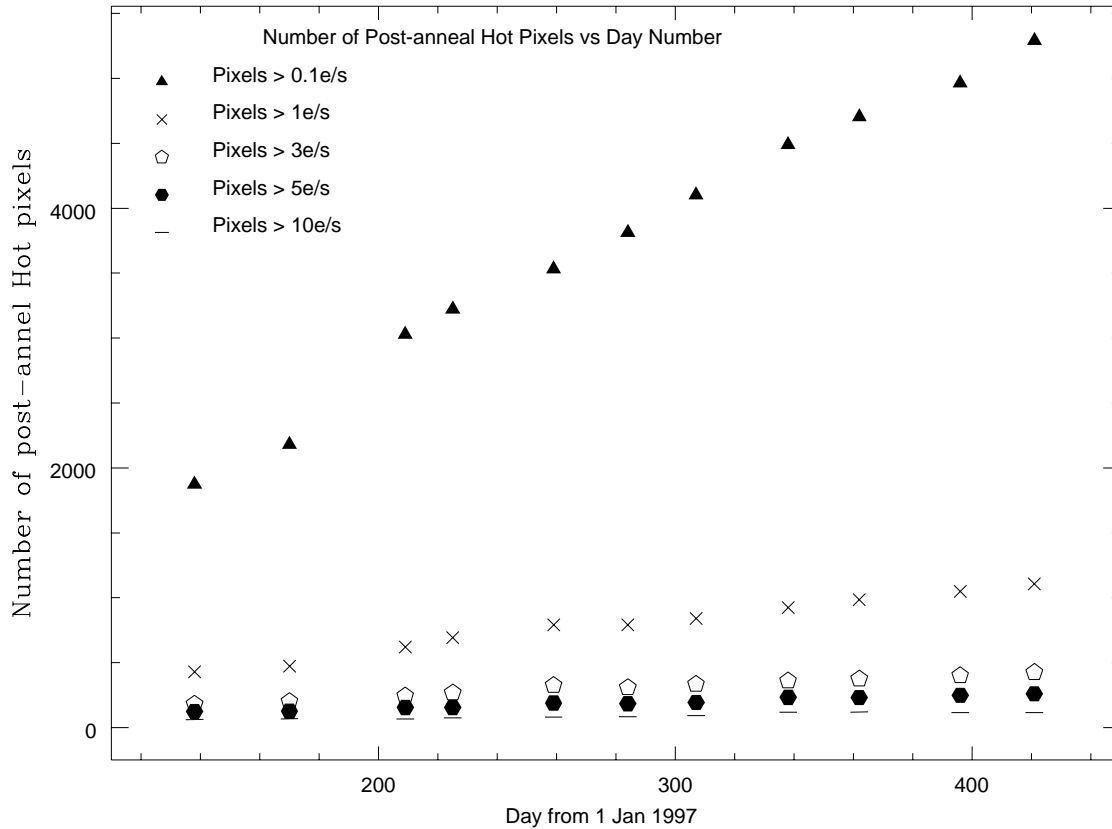
4. Discussion

We present the overall results of the combined SMOV-Cycle 7 analysis in Tables 2 and 3, and Figure 1. One can clearly see that the STIS CCD grows hot pixels at all cuts of brightness quite rapidly. We see that the growth rate has been at a steady linear rate (more on this in the Conclusions below). We note that the STIS CCD seems to have two effects that partly mask each other, but which it is important to disentangle. We have hot persistent pixels that last for a number of anneal cycles; and new transient pixels, most of which are annealed away every month. We will discuss both of these classes in more depth later.

Table 2. Results of STIS CCD Anneals

Month (1997)	Int. Time (sec)	> 0.1e/sec (number)	> 1e/sec (number)	> 3e/sec (number)	> 5e/sec (number)	> 10e/sec (number)
May (pre)	6000	3301	725	317	210	107
May (post)	(CR-SPLIT=5)	1875	430	182	125	62
No. common		1624	363	149	99	45
Creation rate (Pix/day)		117.3	25.5	11.1	7.3	3.8
June (pre)	6000	3758	759	333	221	106
June (post)	(CR-SPLIT=5)	2181	473	202	126	68
No. common		1877	407	158	97	46
Creation rate (Pix/day)		58.8	10.3	4.7	3.0	1.4
July (pre)	2400	4271	820	332	221	113
July (post)	(CR-SPLIT=3)	3029	620	244	155	67
No. common		2290	498	192	115	47
Creation rate (Pix/day)		115.4	9.4	3.5	2.6	1.2
August (pre)	2400	4148	836	326	206	97
August (post)	(CR-SPLIT=3)	3222	694	269	155	76
No. common		2702	612	222	133	63
Creation rate (Pix/day)		74.6	14.4	5.5	3.4	2.0
Sept (pre)	6000	5119	1084	454	281	151
Sept (post)	(CR-SPLIT=5)	3533	791	326	189	82
No. common		3156	693	284	159	68
Creation rate (Pix/day)		57.5	11.8	5.6	3.8	2.3
Oct (pre)	6000	4773	925	389	233	100
Oct (post)	(CR-SPLIT=5)	3814	790	309	184	83
No. common		3364	707	276	158	64
Creation rate (Pix/day)		49.6	5.4	1.6	1.8	0.8
Nov (pre)	2400	5776	1078	425	256	119
Nov (post)	(CR-SPLIT=3)	4102	840	334	194	93
No. common		3577	733	289	163	70
Creation rate (Pix/day)		93.4	13.7	5.5	3.4	1.7
Dec (pre)	6000	5770	1051	424	251	118
Dec (post)	(CR-SPLIT=5)	4491	925	361	233	118
No. common		3991	808	312	190	93
Creation rate (Pix/day)		53.8	6.8	2.9	1.8	0.8
Jan/98 (pre)	6000	5895	1076	415	268	129
Jan/98 (post)	(CR-SPLIT=5)	4703	985	376	231	120
No. common		4200	846	317	191	100
Creation rate (Pix/day)		66.8	7.2	2.6	1.7	0.5
Feb/98 (pre)	6000	6210	1128	415	259	130
Feb/98 (post)	(CR-SPLIT=5)	4964	1049	402	249	115
No. common		4434	908	402	206	94
Creation rate (Pix/day)		45.7	4.3	1.2	0.8	0.3
Mar(1)/98 (pre)	6000	6273	1202	462	293	127
Mar(1)/98 (post)	(CR-SPLIT=5)	5291	1108	426	260	115
No. common		4742	957	368	221	96
Creation rate (Pix/day)		52.4	6.1	2.4	1.8	0.5

Figure 1: Plot of the total number of post-anneal hot pixels vs. day number for the STIS CCD. The plot shows the total number of pixels at different brightness cuts.

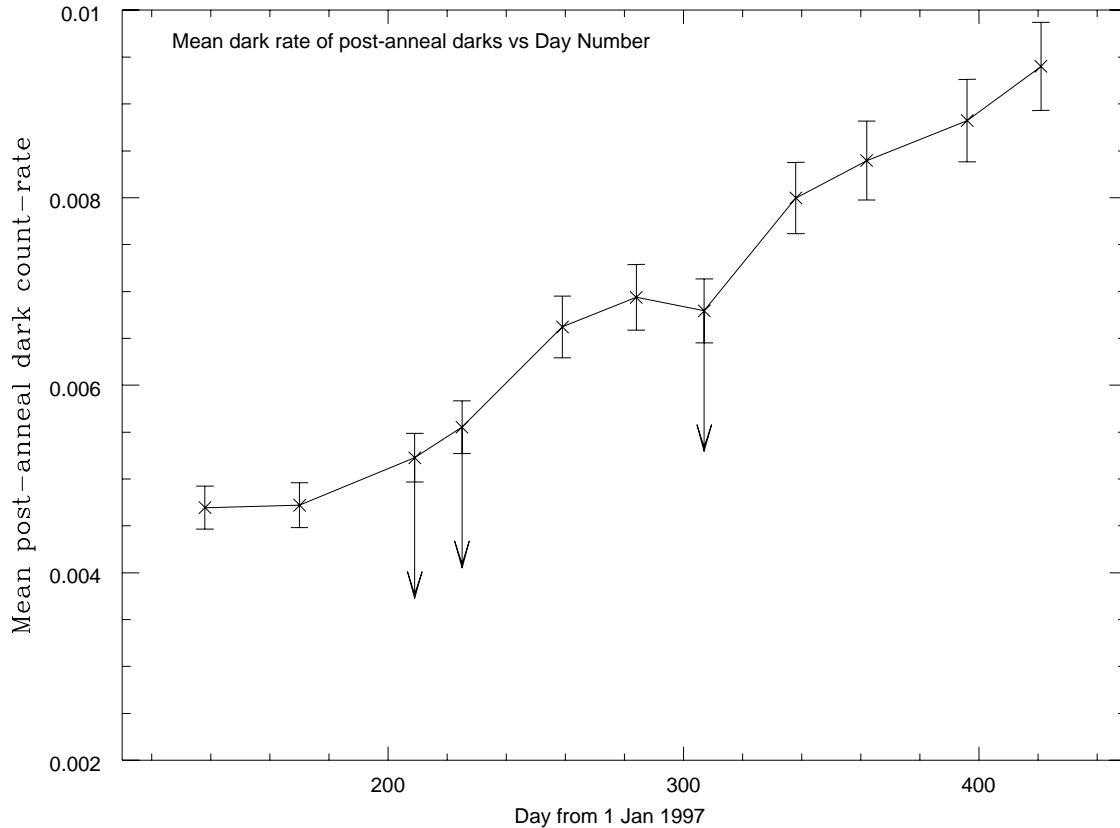


In Figure 2, we plot the mean post-anneal dark countrate (which omits points 5σ away from the overall mean) versus day number for 1997, and the standard deviations on those numbers as calculated by the STSDAS task `imstat`. The plot clearly shows a rising trend in the dark countrate well outside the standard deviations, implying that one has still not reached an equilibrium, even though there is a very slight roll-over after the Day 97.285 (9 October 1997). What is noticeable is that the rate at which the increase of the dark countrate is growing is much less since Day 97.259 (the 16 September 1997) anneal.

Table 3. Mean dark countrates for STIS CCD anneals

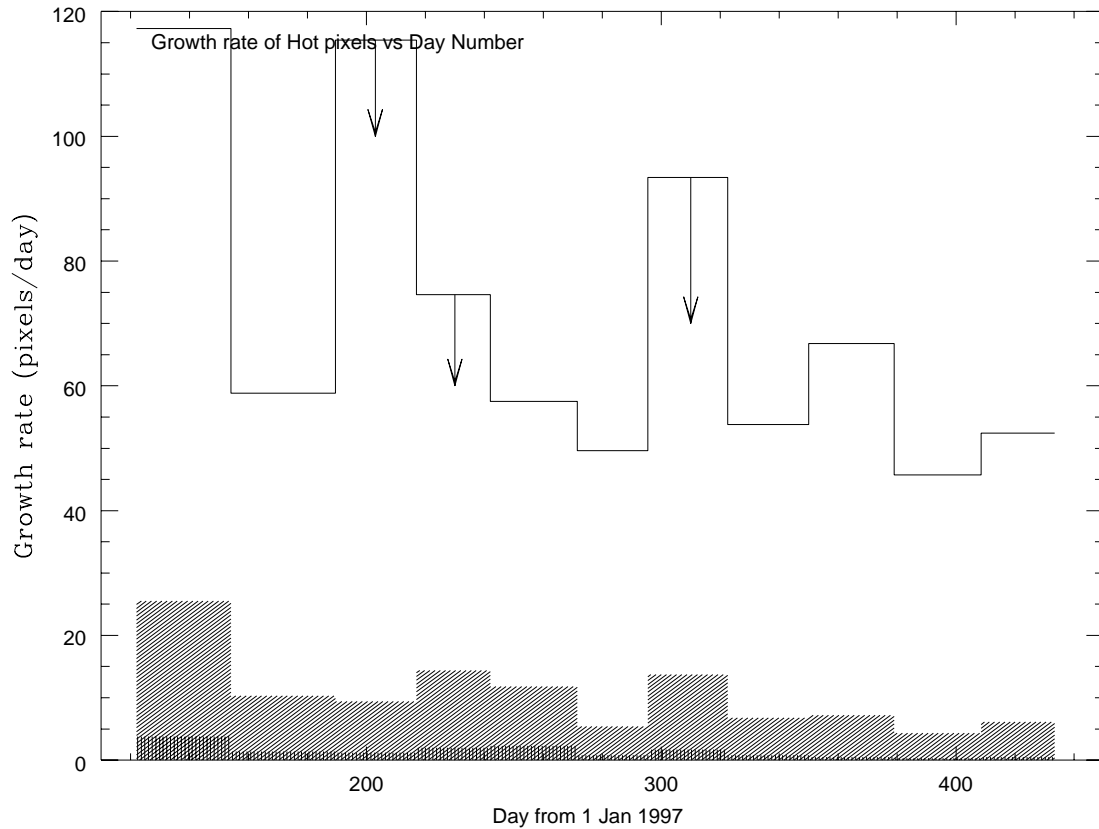
Month	Date	mean	Std. Dev.
May (pre)	17 May 1997	0.006765	0.00034
May (post)		0.004695	0.00023
June (pre)	20 June 1997	0.007134	0.00036
June (post)		0.004721	0.00024
July (pre)	22 July 1997	0.007375	0.00037
July (post)		0.005227	0.00026
August (pre)	12 August 1997	0.006954	0.00034
August (post)		0.005553	0.00028
Sept (pre)	16 September 1997	0.009521	0.00048
Sept (post)		0.006622	0.00033
Oct (pre)	9 October 1997	0.008065	0.00041
Oct (post)		0.006938	0.00035
Nov (pre)	3 November 1997	0.009124	0.00046
Nov (post)		0.006794	0.00034
Dec (pre)	4 December 1997	0.009353	0.00045
Dec (post)		0.007997	0.00038
Jan/98 (pre)	29 December 1997	0.009463	0.00047
Jan/98 (post)		0.008396	0.00042
Feb/98 (pre)	31 January 1998	0.009974	0.00049
Feb/98 (post)		0.008822	0.00044
Mar(1)/98 (pre)	25 February 1998	0.01043	0.00052
Mar(1)/98 (post)		0.009401	0.00047

Figure 2: Plot of the post-anneal dark countrate vs. day number for the STIS CCD. The means plotted omit points that fall outside of 5σ away from the means of the superdarks. The arrows indicate that the values for the 3 months indicated (June, July, November) should be viewed as upper limites, as the pre-and post-anneal darks were obtained with a CR-SPLIT=3 instead of the usual 5.



In Figure 3, the rate of growth of pixels hotter than 0.1 e/sec are plotted as a function of day number for 1997. There are variations of up to 100 in the growth rate of pixels hotter than 0.1 e/sec. We also note that for pixels at higher cuts (1.0 and 10 e/sec), that the variations in the rates of growth are much smaller, and show evidence of flattening out. The possibility of cosmic-ray contamination has been looked into, and we find that there are elevated creation rates at all cuts for the months of July, August, and November (the months when a CR-SPLIT=3 was used). It is obvious that we have not effectively eliminated all the cosmic rays from the darks in these 3 months, and so our numbers for those three months should be taken as upper limits. We have plotted the locations of the individual darks with their location on-orbit (via `hstpos`), and see no correlation with geomagnetic position on-orbit and the variation in the growth rate of the hot pixels on the CCD.

Figure 3: Histogram of the total growth rate of hot pixels vs. day number for the STIS CCD. The line histogram is for pixels hotter than 0.1 e/sec; the light shaded histogram is for pixels hotter than 1.0 e/sec; and the dark shaded histogram is for pixels hotter than 10 e/sec. The arrows indicate that the values for the 3 months indicated should be viewed as upper limites because the pre-and post-anneal darks were obtained with a CR-SPLIT=3 instead of the usual 5.



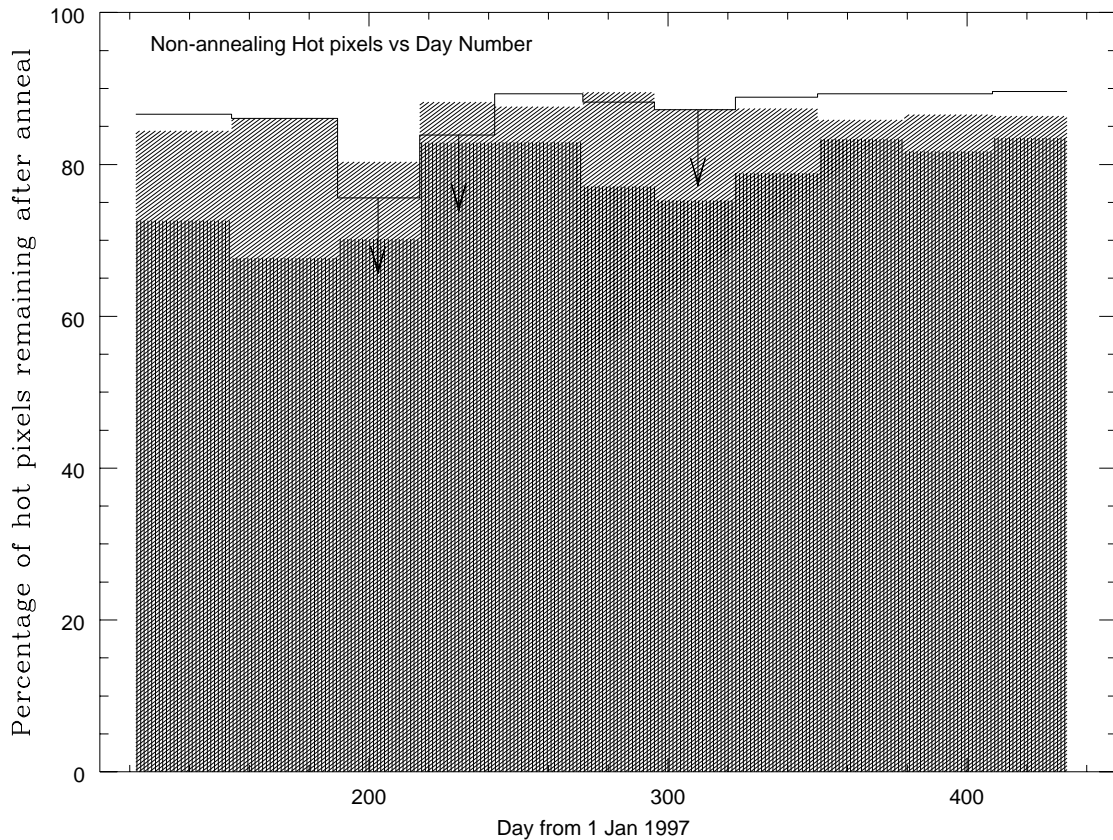
Persistent pixels

We find that on the STIS CCD 83% of pixels hotter than 0.1 e/sec after the May 1997 anneal are still at least that hot after the December 1997 anneal. While the numbers of pixels involved are small, we find that they anneal away very slowly; e.g., for post-May 1997 we had 1410 pixels hotter than 0.1 e/sec, while in post-December 1997 we had 1181 of the *same* pixels at least that hot—a decrease rate of just over 1 pixel/day. The other point to bear in mind is that for each month, we obtain new hot pixels in addition to the ones which already exist, and that the decline rate is roughly the same (i.e., 1 pixel/day). The net effect is to drive the numbers of long-term hot pixels up, but only by a few tens of pixels every month.

In Figure 4, we plot a histogram of the number of hot pixels that persist after the anneal process. We see that, on average, roughly 85% of pixels that were hotter than 0.1 e/sec before the anneal are still *at least* that bright after that anneal (i.e., *the same pixels*). In

addition, while the percentage of persistent hot pixels decline depends on the brightness cut used (for pixels brighter than 10 e/sec, only about 75 of the pixels persist), the trend is the same: the numbers of persisting hot pixels remains the same from anneal to anneal. It would seem that our anneals are of only limited effectiveness in removing these very hot persistent pixels.

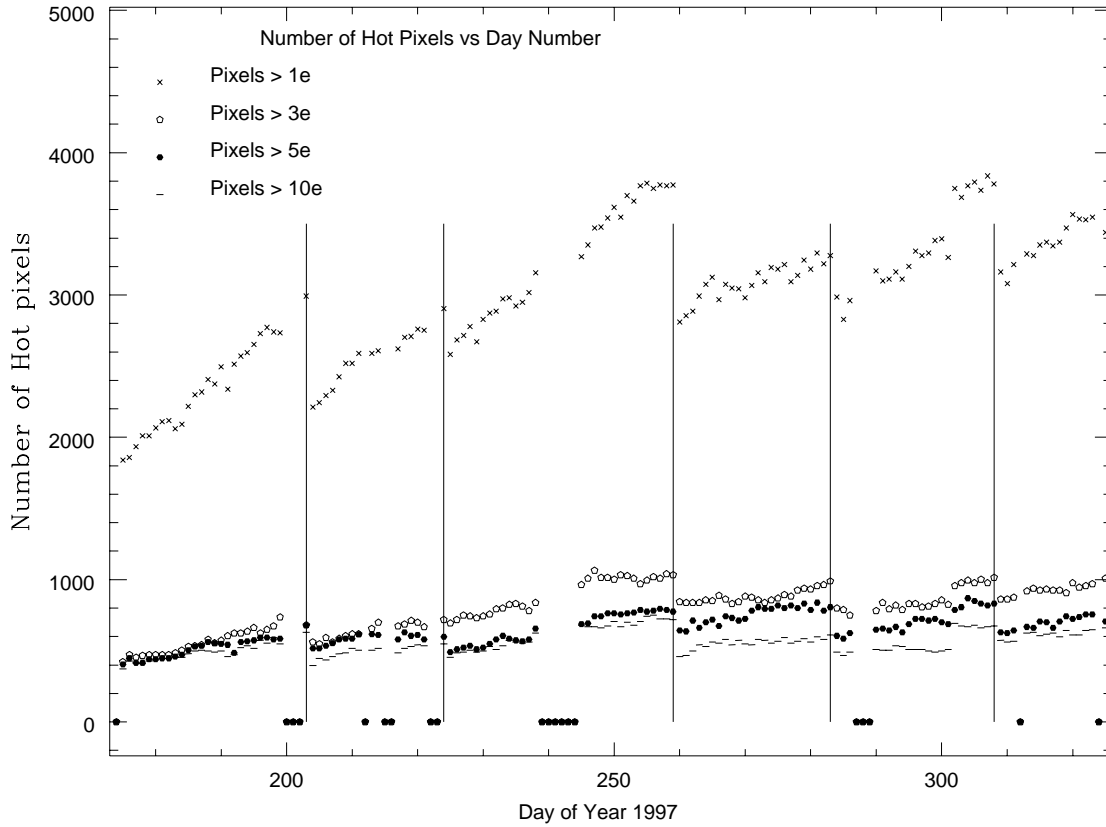
Figure 4: Histogram of the percentage of all hot pixels that persist after each anneal vs. the day number. We plot the percentage of pixels hotter than 0.1e/sec in the line histogram, the percentage brighter than 1 e/sec (in the shaded histogram at 45°), and the percentage brighter than 10 e/sec (in the darkest shaded histogram). Note that for the April-May period there were no common pixels brighter than 10 e/sec. We also note that, on average, the percentage of persistent hot pixels stays roughly constant from anneal to anneal independent of the brightness cut. The arrows indicate that the values for the 3 months indicated should be viewed as upper limits, as the pre- and post-anneal darks were obtained with a CR-SPLIT=3 instead of the usual 5.



As a further comparison, the STIS group has been producing hot pixel tables on a daily basis since 20 June 1997. This monitor, which was initiated to check for the growth of hot pixels in the target acquisition positions on the CCD, serve as an extremely useful secondary monitor on just how well the anneals work. As can be seen by inspecting Figure 5, the trend in both the growth rate of hot pixels, and the continuing rise in the absolute numbers

of these hot pixels is very evident, and confirms what has been found from the anneal monitor program.

Figure 5: Plot of the total number of hot pixels vs. the day number based on data from the daily dark programs for producing hot pixel tables. Note the trends found in Figure 1 are well reproduced for all the brightness cuts in this plot. The vertical bars indicate the dates on which anneals occurred.



Transient pixels

On the other hand, we do anneal new hot pixels away at a rate comparable to that seen by the WFPC2 group. We define the percentage of new hot pixels which anneal to be:

$$R_{CCD} = \frac{\eta_{pre} - \eta_{post}}{\eta_{pre} - \eta_{post, prev}}$$

where:

η_{pre} = number of hot pixels pre-anneal for a given month

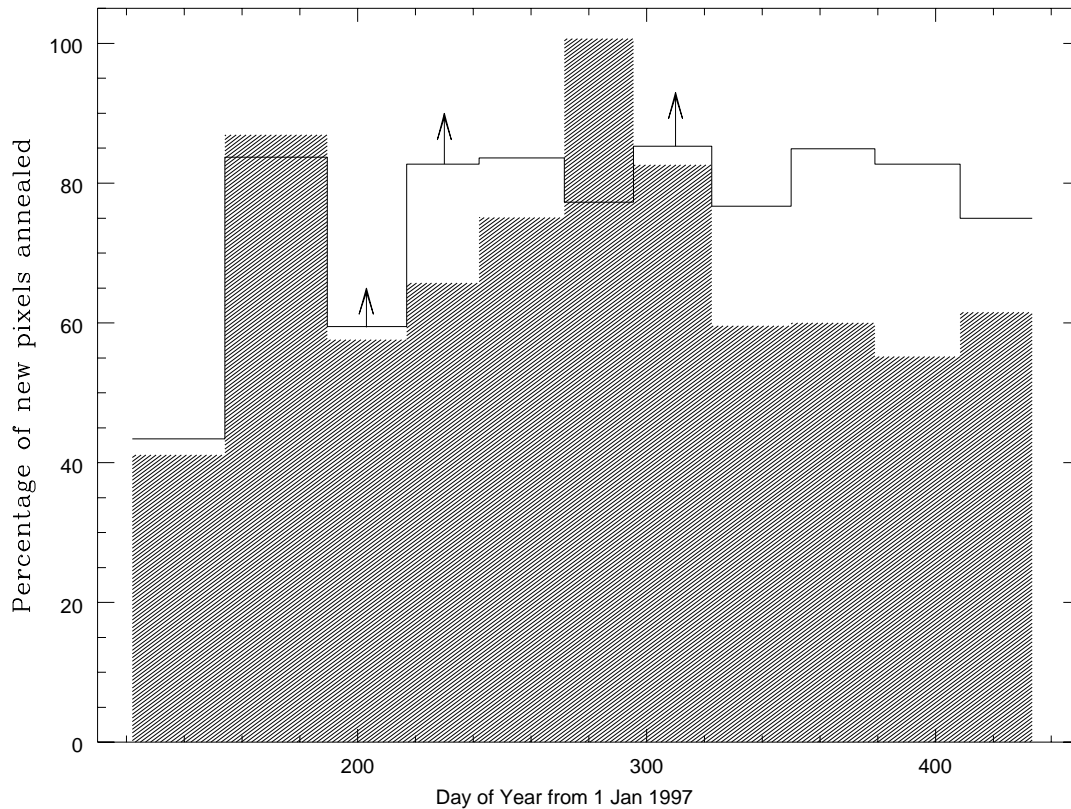
η_{post} = number of hot pixels post-anneal for a given month

$\eta_{post, prev}$ = number of hot pixels post-anneal for the previous month.

The above expression can be translated into “the number of hot pixels that annealed away in a given month divided by the number of new hot pixels that grew in that month.”

We find that the anneal rate on the STIS CCD matches that of WFPC2 quite well. Using the data presented in Table 2, we plot the anneal rate as calculated via the above equation in Figure 6. We see that the annealing rate is typically at the 80% level for 0.1 e/sec pixels for most months, and that at times we seem to even anneal away 100 of our new hot pixels. This latter is of course, an over-simplification. In cases like this, we can have new hot pixels persisting, while we have annealed away some of our persistent pixels.

Figure 6: Histogram of the percentage of new hot pixels annealed in a given month vs. the day number for each anneal cycle. The line histogram is for all pixels brighter than 0.1 e/sec, while the shaded histogram is for pixels brighter than 1 e/sec. We have lower limits for the 3 months in which the dark data were constructed using a CR-SPLIT=3 instead of the usual 5, as one would anticipate that the anneal rate would be better for darks having better cosmic ray rejection (i.e., less confusion between cosmic rays and real hot pixels).



As a comparison, we have looked at the reported creation and destruction rates of hot pixels on the WFPC2 CCDs (Biretta et al. 1996). The WFPC2 group report that they find 80% of their new pixels will be eliminated after each of their monthly decontaminations, and that the creation rate of hot pixels brighter than 0.02 e/sec (roughly 5σ for both the STIS CCD and WFPC2) is 33 pixels/day for one of the 800 x 800 CCDs. The rate that the STIS CCD exhibits for a brightness cut of 0.02 e/sec is 85.9 pixels/day. However, when one factors into account that the STIS CCD is 1024 x 1024, and that the STIS CCD pixels are a factor of 1.4 larger than those on the WFC CCDs, the “STIS normalised” creation rate for a WFPC2 CCD is 75.7 pixels/day—comparable to what the STIS CCD detects. In terms of gross numbers of hot pixels that remain after an anneal, we find that about 6100 remain on the STIS CCD (about 0.5% for the total). For WFPC2 at the same brightness cut (0.02 e/sec), we find that about 4200 hot pixels remain per chip after their anneals (about 0.6% of the total numbers of their pixels). Therefore we have roughly the same growth rates for both CCDs (Casertano 1998).

5. Conclusions

To summarize our findings:

1. the STIS CCD is continuing to produce, at gross levels, large numbers of hot pixels (i.e., pixels brighter than 0.1 e/sec);
2. the growth rate of these hot pixels has not equalibrialised;
3. the numbers of persistent hot pixels remains relatively constant over each anneal;
4. we anneal 80% of new hot pixels monthly.
5. for cuts brighter than 1 e/sec, the growth rate of new hot pixels appears to be flattening out.

It seems that the STIS CCD anneals are of comparable utility to the WFPC2 monthly decontaminations, in that both processes remove approximately the same numbers of transient hot pixels every month.

If we again look at Figure 1, we note that the overall post-anneal hot pixel creation rate appears to be roughly linear. Assuming this to be the case, we have performed linear least-squares fits to the post-anneal hot pixels to see if we can predict any trends. We find that the 0.1 e/sec data are best fit by a linear fit, while the 10 e/sec data is the most poorly fitted by a linear fit.

The regressions we obtained are:

$$N_{cr} = 13.11\delta + 117.76$$

for the 0.1 e/sec data, and where number of pixels, and is the Modified Julian Date from 1 January 1997. The correlation coefficient for these data is 0.9922 (an excellent linear fit). We have similar relations for the 1 e/sec data and the 10 e/sec data, shown below:

$$N_{cr} = 2.53\delta + 84.94$$

for the 1 e/sec data, having a correlation coefficient of 0.9841; and

$$N_{cr} = 0.24\delta + 23.19$$

for the 10 e/sec data, having a correlation coefficient of 0.9140.

Note that for all three of these fits we have omitted the Day 109 data as these are clearly not in sync with the other data as the CCD was still being cooled down to its working temperature. As a prediction, if we use the linear regression for the 0.1 e/sec, we find that for the expected lifetime of STIS, we will have about 4.6% of all our pixels remaining persistently hot in the year 2007. Reaching the 10% mark would have us operate the STIS CCD for just under 21 years! This assumes that the rate of increase remains constant. For hotter pixels, the time to reach the 10% mark would be substantially longer. As can be seen from Table 4, (our tabulation of the predictive models) the agreement between the already observed and the predicted count rates is very good. This gives confidence to our predictions for the outlying years on the rates of growth of post-anneal hot pixels.

Table 4. Predictions of STIS CCD post-anneal hot pixel growth

Day Of Year from 1-Jan-1997	Predicted 0.1 e/sec	Measured 0.1 e/sec	Predicted 1 e/sec	Measured 1 e/sec	Predicted 10 e/sec	Measured 10 e/sec
138	1927	1875	434	430	56	62
225	3067	3222	654	694	77	76
338	4549	4491	940	925	104	118
421	5637	5291	1150	1108	124	115
600	7984	---	1603	---	167	---
1000	13228	---	2615	---	263	---

As mentioned above, we find that the destruction rate of transient hot pixels on the STIS CCD is similar to that found by the WFPC2 group. At the present time, about 0.4% of the STIS pixels are persistently hot. The WFPC2 team reports that they have a persistence of roughly 4000 pixels per chip. This gives a rate of roughly 0.6% of WFPC2 pixels being persistent with time; a number very close to what we find for the STIS CCD. Therefore, the STIS CCD is responding to the current anneal program as well as the WFPC2 CCDs respond to their decontamination program, with a similar persistence problem, we find that the initial rate of growth of hot pixels on the STIS CCD was much higher. This

can be seen from the fact that about 0.4% of STIS pixels are hot after 1 year on-orbit as opposed to the 0.6% the WFPC2 group has after 4.5 years on-orbit. We will have to closely monitor the rate of growth and persistence of our hot pixels, and see how quickly we flatten out.

6. Acknowledgments

It is a pleasure to thank both Stefano Casertano and Stefi Baum for their insight and comments on various aspects of this ISR. Their comments were invaluable.

7. References

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