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Hot Pixels Growth in ACS CCDs

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Abstract. We present an analysis of the hot pixel population in ACS CCDs. The number of hot pixels increases due to on-orbit radiation damage. In order to heal the defects responsible for the hot pixels, the CCDs are heated once a month. We review the effectiveness of the anneal process.

1. Introduction

HST orbits in a Low Earth Orbit, at about 580Km of altitude. Every day HST completes about 15 orbits and on average crosses some portion of the South Atlantic Anomaly (SAA) region seven times per day. The SAA is the region where the Earths inner radiation belt makes its closest approach to the planets surface. The population of trapped particles in the inner magnetic belt is mainly composed by protons with energy between 10 and 50 Mev, but also electrons, lower energy protons and cosmic ray ions. When HST transits a portion of the SAA, all of its detectors are exposed to several minutes of strong radiation. Radiation damage mechanism in CCDs are divided in two general categories: total ionizing dose (TID) and displacement damage. Displacement damage refers to the introduction of defects in the silicon lattice. Charged particles, such as protons and neutrons can collide with the silicon atoms and displace them from their lattice sites. The vacancies created in this process can migrate in the lattice and form stable defects with another vacancy with impurities such as Phosphorus , Oxygen and others. Any defect gives rise to a new energetic level in the bandgap and degrades CCD performance by decreasing the charge transfer efficiency, increasing the mean dark current and dark current non-uniformity by introducing individual pixels with very high dark current (also known as hot pixels and or hot spikes).

2. Hot Pixels

Energy levels near midgap are responsible for generation of electron-hole pairs and therefore for an increase in the dark current. Some pixels show very high dark current, up to several time the mean dark rate. Depending on the particular collision sequence, protons of the same energy may produce very different amounts of displacement damage. Moreover, if a defect is created in a high electrical field region, the contaminated pixel can show very large dark current as result of field-enhanced emission. Hot pixels accumulate as a function of time on orbit. Figure 1 shows the evolution with time of the distribution of pixels at

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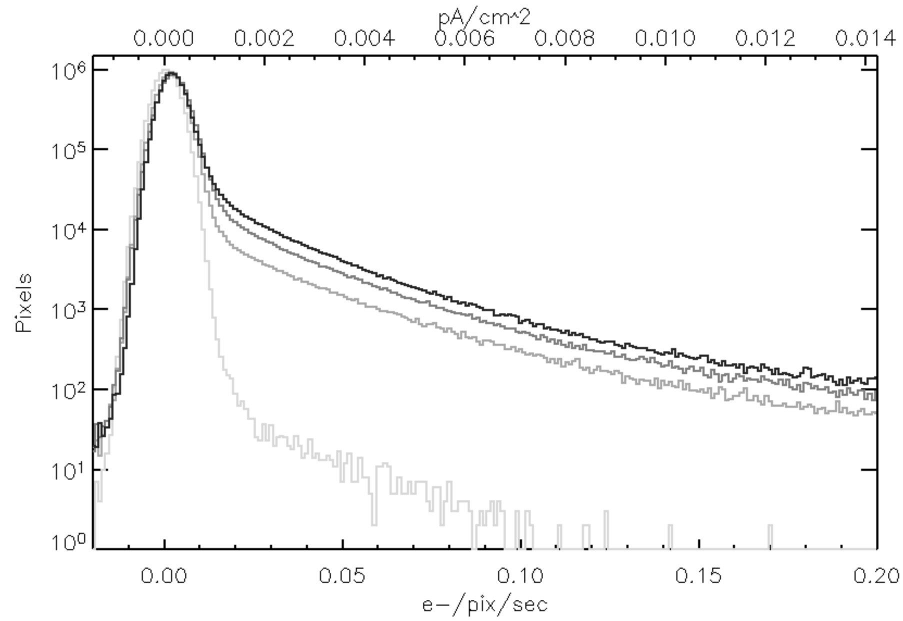

Figure 1.: Distribution of dark pixels for one WFC CCD at launch (2002) (bottom), and after 1,2, and 3 years on orbit.

different dark rate for one of the ACS/WFC CCDs as a function of time. As the proton-induced damage increases, the mean dark current (the peak of the distribution) and the hot pixels population (the tail of the histogram) increase. For practical purpose we define as hot all pixels with a dark rate greater than 0.08 e^-/sec and as warm pixels whose dark current is between 5σ of the main dark distribution and the hot pixel threshold. When more than one image is available the ACS data pipeline by default rejects the pixels flagged as hot pixels (see Mutchler et al. 2006)

The number of pixels with a dark current higher than the mean dark current increases every day by few to several hundreds depending on their signal level (Tab 1). Likely most of these new hot pixels are transient.

Table 1.: Daily growth of hot pixels

e^-/pix/sec	HRC	WFC
0.02	136	824
0.04	98	607
0.08	68	489
0.10	36	390
1.00	1	16

The best approach to mitigate the impact of hot pixel in science frames is to dither the observation by one or more pixels. Only warm pixels are properly corrected after the subtraction of a "dark frame" that brackets the observation. The population of hot pixels for any given day is recorded in the Data Quality array of each image. For more on dithering strategy visits www.stsci.edu/hst/acs/proposing/dither.

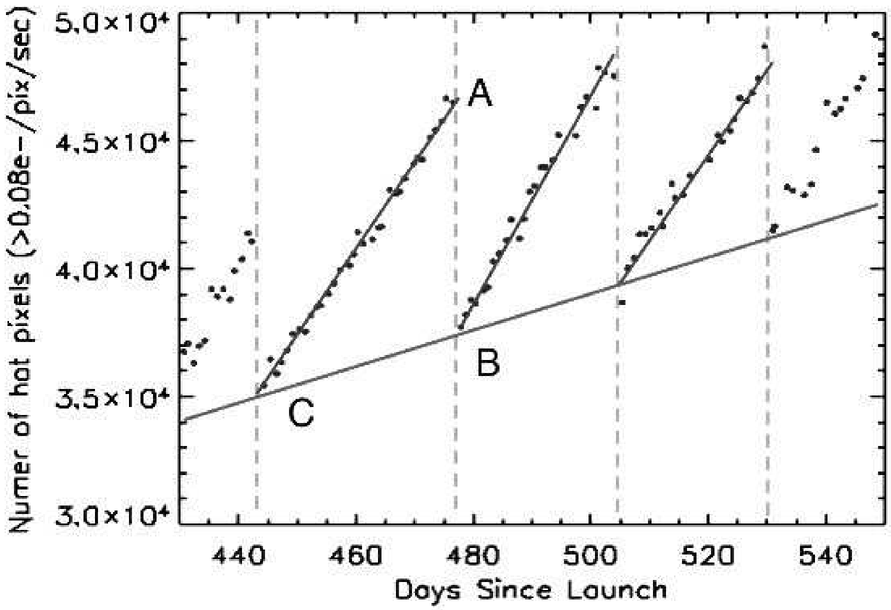

Figure 2.: Determination of the anneal rate for WFC. Dots show the population of hot pixels above the threshold of 0.08e-/pix/sec at each day. The vertical dashed lines mark the annealing dates. After each anneal cycle, the population of hot pixels pre-anneal [A] drops to the level [B]. The ratio (A-B)/(A-C), where [C] is the population of hot pixels at the end of the previous anneal cycle, determines the anneal rate for that cycle.

3. Annealing of Hot Pixels

Like other CCDs on HST the ACS detectors undergo a monthly annealing process. The TECs are turned off and the heaters are turned on to warm up the CCD to $\sim$ 19 C for few hours. It is still not clear why at such low temperature a significant annealing is observed: the most common defects anneal at much higher temperature. By comparing the hot pixel population before and after each anneal (Figure 2) it is possible to measure the effectiveness of the anneal process.

The annealing rate is strongly dependent on the dark current of the hot pixel (Table 2). Very hot pixels show a higher anneal rate than warm pixels and there is no impact on the average dark current level. Since launch, the duration of the CCD warming period has been reduced from 24 hrs to 12 hrs and since spring 2005 to 6hrs. No variation in the annealing rate has been observed.

Pixels that do not anneal become permanently hot. The rate of growth of permanent hot pixels depends on the signal level. At any threshold the number of hot pixels increases linearly with time (Figure 3). By 2008 the number of pixels permanently hot will be as much as the number of pixels contaminated by cosmic rays in a 1000 sec exposure.

It is interesting to follow the status of pixels that become hot due to radiation damage. The four panels on Figure 4 show typical behaviors we observed in hot pixels in ACS CCDs. In each panel, the vertical lines show the annealing dates and the horizontal line marks the threshold for hot pixel definition. The two panels on the top show two normal hot pixels become hot and resume their normal status after the first anneal cycle. The plot on the left shows a pixel that is fully healed. The one on the right is only partially healed; even after the anneal the dark current of this pixel is more elevated than normal pixels, but it remains below the hot pixel threshold. The two panels on the bottom of Figure 4 show

Table 2.: Anneal Rate for ACS CCDs

	WFC		HRC	
Temp (C)	-77		-81	
Annealing Temp	-10 to +20 C		-10 to +20 C	
Annealing Time	6 to 24 hr		6 to 24 hr	
Threshold				
e-/pix/sec	%	±	%	±
> 0.02	0.55	0.02	0.64	0.02
> 0.04	0.70	0.07	0.84	0.07
> 0.06	0.78	0.04	0.84	0.04
> 0.08	0.82	0.03	0.87	0.03
> 0.10	0.84	0.02	0.85	0.02
> 1.00	0.55	0.15	0.64	0.15

pixels that, once damaged, respond to almost every anneal cycle. When they are hot the annealing can restore their status, but subsequent anneals can activate it again as hot pixel (reverse annealing).

4. Lesson learned

- The anneal rate depends on the dark current level of the pixel (Table 2).
- The number of permanently hot pixels increases linearly with time. The only solution to mitigate their presence is to dither the observations.
- The same anneal rate can be obtained at colder temperature. In at least four instances, in occurrence of HST safing events, the temperature of the CCDs raised to only -10 C for periods between 24 and 48 hours. After these periods the population of hot pixels decreased by the same amount as in normal cycles at +20 C (Figure 5).
- The anneal rate does not seem to be related to the length of the anneal (Figure 5).

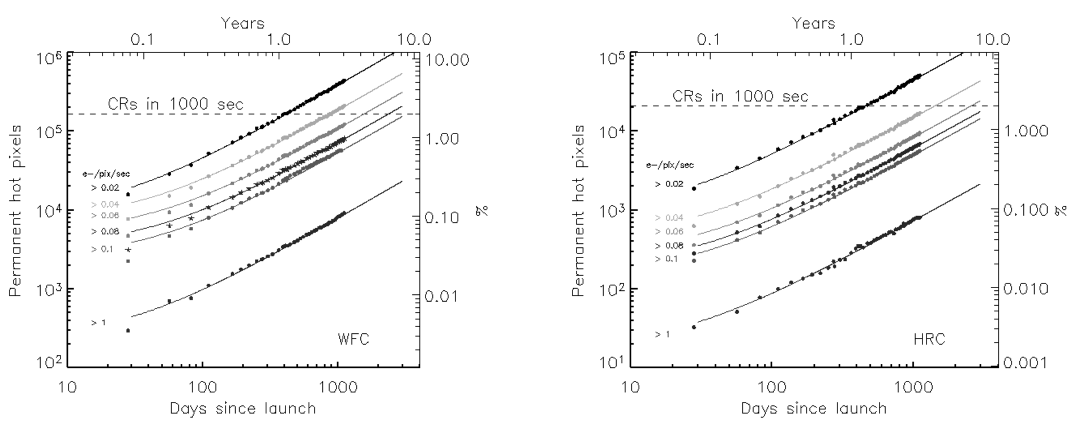

Figure 3.: Growth of permanent hot pixels as a function of time for different signals.

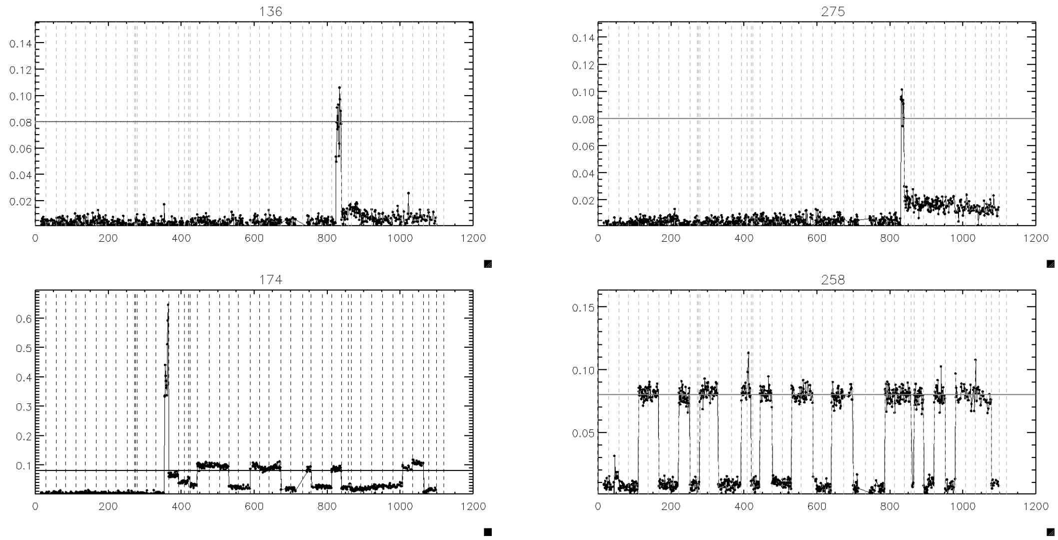

Figure 4.: Dark current of selected hot pixels as a function of time (see text).

- For any particular hot pixel, a complete anneal is a rate event. Most of the annealed hot pixels significantly reduce their dark current level but never rejoin the population of normal dark pixels (Figure 4).
- Several hot pixels show evidence of reverse annealing. The process of heating the CCD or simply a power cycle can cause previously-damaged pixels to change from hot to normal and vice-versa (Figure 4).

References

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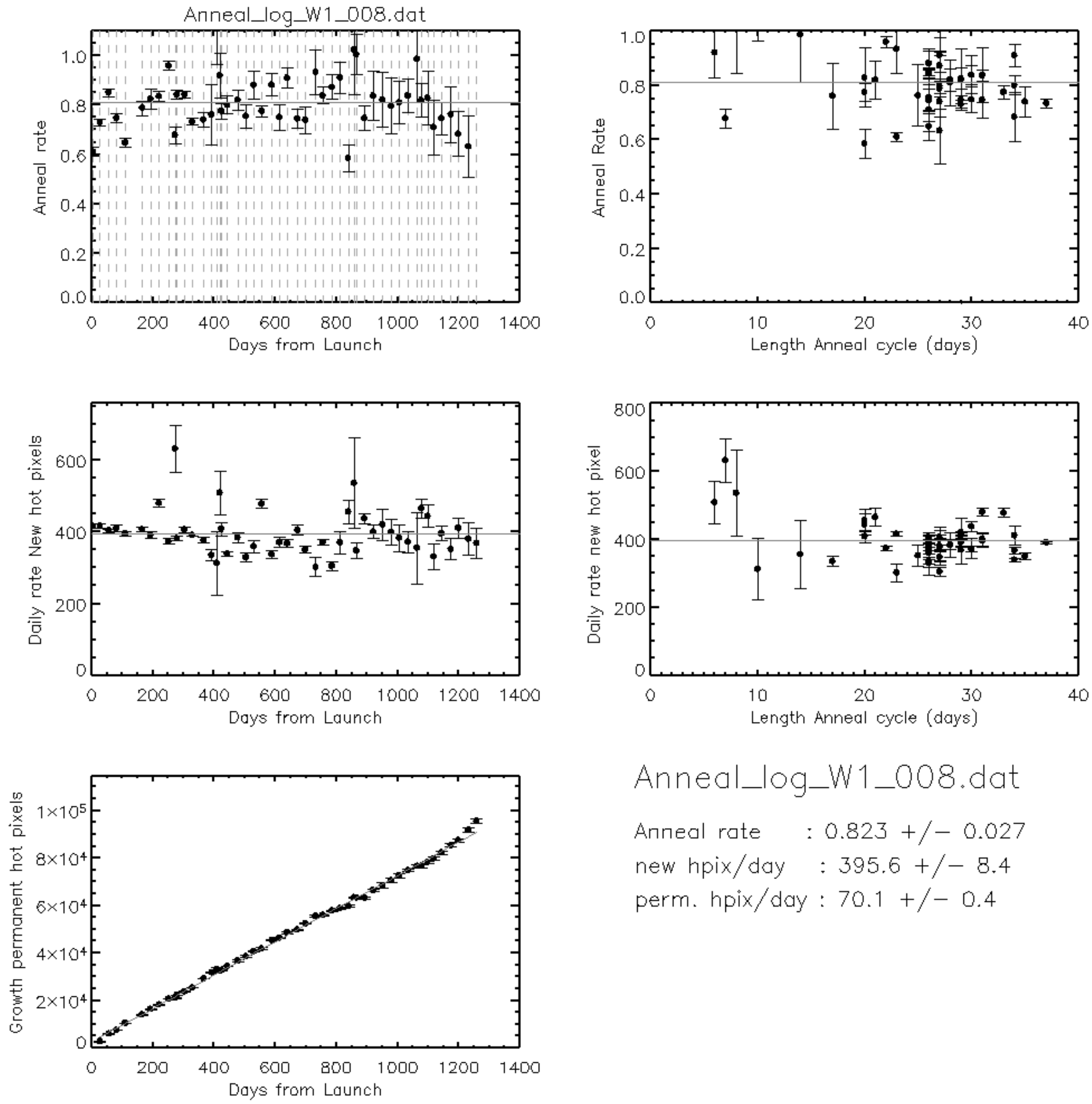

Figure 5.: Example of the analysis of hot pixels for WFC. Top: Anneal rate as a function of time (left) and as a function of anneal frequency (right). MIDDLE: daily rate of hot pixel creation as a function of time (left) and as a function of the anneal frequency (right). BOTTOM: growth of permanently hot pixels.