Hot Pixels Growth in ACS CCDs

Introduction:
Hot pixels hang in a Low Earth Orbit (LEO) at about 550 km of altitude. Every day HST completes about 16 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 Earth’s inner radiation belt makes its closest approach to the planet’s surface. The population of trapped particles in the inner magnetic belt is vastly composed by particles of lower energy (between 15 and 35 MeV), but also electrons, lower energy protons and cosmic ray ions. When HST crosses a portion of the SAA, all of its detectors are exposed to severe 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 energy gap: the midgap, the valence or the conduction band. Vacancies and other lattice defects such as interstitials can lead to the generation of electron-hole pairs and therefore to charge displacement. 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 energy gap: the midgap, the valence or the conduction band. Vacancies and other lattice defects such as interstitials can lead to the generation of electron-hole pairs and therefore to charge displacement. For practical purpose we define as "hot" all pixels with a dark current rate greater than 0.08 e-/s-sec and as "warm" pixels whose dark current rate is between 5.10^-4 e-/s-sec and 0.005 e-/s-sec. The number of pixels that do not anneal become permanently hot. The rate of growth of permanent hot pixels depends on the signal (right). As any threshold the number of hot pixels increases linearly with time. By 2006 the number of pixels permanently hot will be as much as the number of pixels contaminated by cosmic rays in a 1000 sec exposure.

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 median dark current. 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 electron hole level, the contaminated pixel can show very large dark current as result of fast-electron emission.

The CCDs of ACS:
The Focal Plane array of the Wide Field Channel is comrised of two SITe 2048x4096 thinned backside illuminated CCDs. The pixel size is 15 µm. The CCDs are operated at ~77 °C. The CCD of the High Resolution Channel (HRC) is a SITe 1024x1024 pixel device, thinned and backside illuminated. The pixel size is 21 µm and the operating temperature is ~80 °C.

Annealing rate:
The annealing rate is strongly dependent on the dark current of the hot pixel. 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 varied from 24 hrs to 15 hrs and since spring 2006 to 6hrs. No variation in the annealing rate has been observed.

The life of hot pixels:
It is interesting to follow the status of pixels that become hot due to radiation damage. The three panels on the right show typical behaviors we observed in hot pixels in ACS CCDs. In each panel, the vertical red lines show the annealing dates and the green horizontal line marks the threshold for hot pixel definition.

HOT PIXELS AND ANNEALS: LESSON LEARNED:
• Hot pixels acummulate as a function of time on orbit. The figure below (right) shows the evolution with time of the distribution of pixels at different dark rate for one of the ACS/WFC CCDs. 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) grow.
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HOT PIXELS AND ANNEALS: LESSON LEARNED
• 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 saffing 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 to the same amount as in normal cycles at ~30 °C.
• The anneal rate does not seem to be related to the length of the anneal.
• 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 regain their population of normal dark pixels.
• 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 vica versa.