WFC3: Charge Transfer Efficiency and Charge Injection in the UVIS Detectors

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Summary

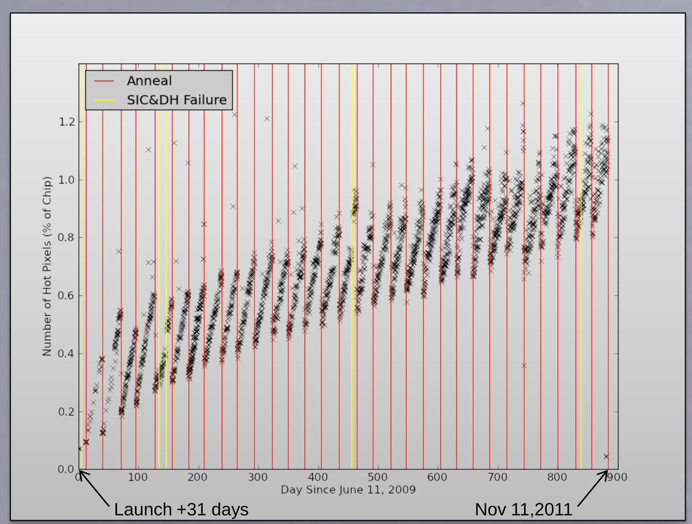
- Low-earth orbit radiation environment damages CCDs, generating hot pixels, increasing dark current, and decreasing charge transfer efficiency.
- After >2.5 years on-orbit, WFC3/UVIS detectors are showing
  - About 1000 new hot pix/day; monthly anneal procedures fix ~80-90%.
  - Median dark current of ~6e-/hr/pix, increasing by ~1.5 e-/hr/pix/yr.
  - Signal losses due to radiation damage currently are 1-2% (bright sources, high background) to ~30% (faint sources, low background).
- Mitigation options for observers include
  - Dithering (shifting images) for hot pixel removal in data processing.
  - Placement of small targets close to readout amp.
  - Charge injection, optional observing mode available now.
  - Photometric formulaic corrections, available now.
  - Pixel-based image correction in post-observation processing, similar to the one adopted for HST/ACS; available next year.

WFC3 CCD Characteristics

- Two e2v 2Kx4K thinned, back-illuminated, 4-amp readout
- FOV: 160"x160", 1.4" gap
- UVIS: covers 200-1000nm
- Cooled to -83C via thermo-electric coolers
- Readnoise ~3 e-; median dark: ~6 e-/hr/pix
- Charge injection available for CTI mitigation

Hot Pixels – Figure 1

Increasing over time: Histograms of WFC3 darks show an extended tail of hot pixels typical for CCDs. At a threshold of 54e-/hr/pix (~50x average dark current), ~1000 new hot pixels appear every day, covering ~0.8% of each chip.



Controlled via anneals: Once a month, the detectors are warmed to +20C, fixing 80-90% of the hot pixels.

Dithering removes remainder: Acquiring images in a dither pattern (small shifts between images) allows for removal of any remaining hot or bad pixels during image processing.

Dark current

Increasing over time: Median level is currently at ~6e-/hr, increasing ~1.5 e-/hr/year. No mitigation currently possible.

Charge Transfer Efficiency (CTE) – Table 1

One method of assessing CTE losses is via photometry of the same stellar field placed close to and far from the readout amps. In the absence of traps, a given signal is independent of position on the chip. With traps present, the target signals decrease as the distance from the readout amp increases.

Tabulated below are a subset of the measured WFC3 CCD CTE losses as a function of time, source brightness, and image background. Based on 3-pixel radius stellar aperture photometry, the values represent the percent loss across a full chip width (2048 pixels).

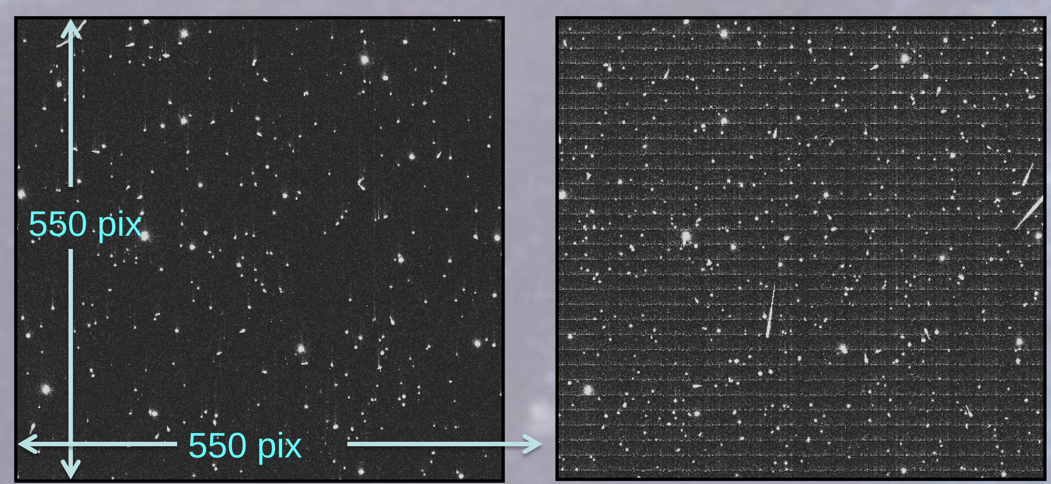
Days On-orbit	Back-ground (e-)	Source signal 400 e-	Source signal 1600 e-	Source signal 5000 e-	Source signal 12000 e-	Source signal 25000 e-
Oct 2009	<1	3 +/- 2	3 +/- 2	2 +/- 2	0.5 +/- 2	0 +/- 2
	10-15	~0 +/- 2	0 +/- 2	0 +/- 2	0 +/- 2	0 +/- 2
Sep 2010	<1	13 +/- 2	7 +/- 2	3 +/- 2	1 +/- 2	0 +/- 2
	10-15	3 +/- 2	1 +/- 2	~0	0 +/- 2	0 +/- 2
Oct 2011	<1 e-	30 +/- 2	15 +/- 2	7 +/- 2	3 +/- 2	1 +/- 2
	10-15	4 +/- 2	3 +/- 2	2 +/- 2	1 +/- 2	~0 +/- 2

Signal losses are a function of
1) Distance from amplifier: more transfers=more traps
2) Signal level: higher fractional loss in faint sources
3) Image background: higher background fills traps

CTE with Charge Injection (CI) – Figure 2

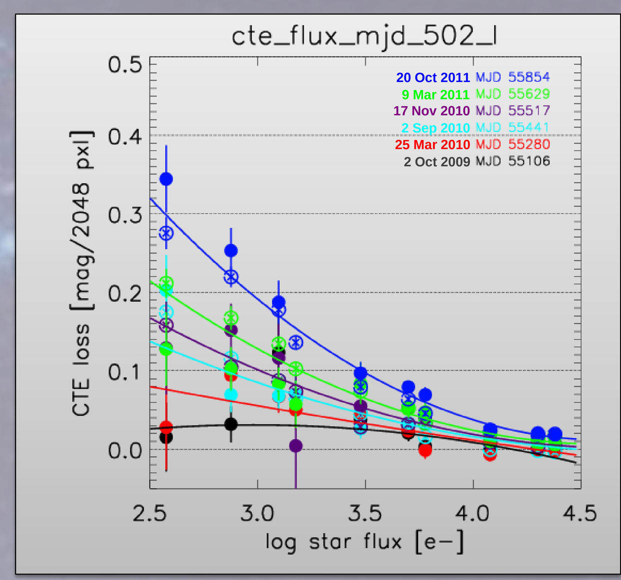
To fill the traps reducing CTE, WFC3 can insert charge electronically. The charge-injected electron signal has lower noise than the same amplitude pre- or post-flash photon signal, affecting every Nth(= CI) row. Below at left is a ~550x550 pixel section of a 360 sec F502N image (low background, hard stretch) far from the readout amp while at right is the same field with CI every 17 rows.

→ Aperture photometry of CI images has shown that the majority of CTE loss can be recovered, at the expense of higher noise:15-20e- in CI rows, 4-5e- in non-CI rows (~3.5 e- in images without CI). See table at right for S/N effects.



Mitigation Options

Corrections for aperture photometry - Figure 3



The measured CTE losses as a function of MJD and signal level have been fit with 2-parameter polynomials. Separate fits are done for four different background levels. The fit coefficients are available to observers who may wish to either estimate CTE losses in their data or apply them as a correction to their aperture photometry (Noeske, 2012).

Charge injection mode – Table 2

CI can reduce CTE losses; however, it adds a small amount (~5 e-) of noise in images. *The Exposure Time Calculator (ETC) does not take the extra noise into account.*

The effect of CI on S/N and limiting magnitude is tabulated below for some sample observing scenarios. All use a flat spectrum (ν) target, measured in a 5x5 box. Exptime factor is that required to achieve the same S/N attainable in a 1000-sec no-CI image.

Scenario	Exptime (sec)	Target (e-)	Sky (e-)	Dark (e-)	S/N (ETC)	S/N (CTE)	Exptime factor (CI)	Loss of lim mag (S/N=5)
V=25,F606W	1000	2100	1378.3	12.5	34.4	32.7	1.09	0.11
V=25,F657N	1000	90	70.3	12.5	4.5	3.2	1.45	0.45
V=21,F275W	1000	3309	19.6	12.5	55.4	52.5	1.1	0.4
V=21,F656N	1000	709	9.2	12.5	22.9	19.3	1.28	0.46

Pixel-based correction

A technique successfully applied to ACS data has been to use hot pixels in dark frames to empirically model CTE losses on a pixel-by-pixel basis (Anderson & Bedin, 2010). The model is then applied to science images to restore charge to its original location in the image.

WFC3 has been acquiring the necessary data for constraining the model and work is underway to optimize the algorithm for UVIS. A first version should be available in 2012.

While the correction is expected to work well, the nature of the algorithm is such that it may never be able to completely recover what was lost, particularly at the faintest levels. In addition, noise may get amplified, generating artifacts.

Abstract

Devices in low-earth orbit are particularly susceptible to the cumulative effects of radiation damage and the Hubble Space Telescope Wide Field Camera 3 (HST/WFC3) UVIS detectors, installed in May 2009, are no exception. Such damage not only generates new hot pixels but also degrades the charge transfer efficiency (CTE), causing a loss in source signal due to charge traps as well as a systematic shift in the object centroid as the trapped charge is slowly released during readout. Based on an analysis of both internal and external monitoring data, we provide an overview of the consequences of the more than 2.5 years of radiation damage to the WFC3 CCD cameras. The advantages and disadvantages of available mitigation options are discussed, including use of the WFC3 charge injection capability, a mode now available to observers, and the status of an empirical correction similar to the one adopted for the HST Advanced Camera for Surveys (ACS).
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References

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- CTE/CI advice: www.stsci.edu/hst/wfc3/ins_performance/CTE
- WFC3/UVIS CTE Monitor Results, Noeske, K., WFC3 ISR in draft, 2012.
- CTE/CI Whitepaper, Baggett et al., www.stsci.edu/hst/wfc3/ins_performance/CTE/cte.pdf
- Cycle 17 CTE Monitoring Results, Khozurina-Platais et al., WFC3 ISR 2011-06
- UVIS Charge Injection Behavior, Bushouse et al., WFC3 ISR 2011-02
- An Empirical Pixel-Based Correction for Imperfect CTE. I. HST's Advanced Camera for Surveys, Anderson, J., & Bedin, L., PASP 122, 1035, 2010. See also the ACS posters at this AAS meeting.
- STScI help desk: help@stsci.edu