Mitigating radiation damage effects in the HST/WFC3 UVIS detectors

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CCD detectors in low-Earth orbit are known to suffer from accumulating radiation damage and the Hubble Space Telescope Wide Field Camera 3 (HST/WFC3) is no exception. In WFC3/UVIS, the damage produces a growing hot-pixel population along with charge traps that cause a progressive loss in charge-transfer efficiency (CTE) over time. The CTE decline results in both a reduction of the detected source fluxes as well as a systematic shift in the measured source centroids, and the impact can be substantial, particularly for faint sources in low-background images. In this poster, we summarize the state of the radiation-damage effects in WFC3/UVIS and discuss the available mitigation options, with a focus on the algorithm and software that comprise the pixel-based CTE correction available in the WFC3 calibration pipeline as of March 2016.

CTE in the UVIS

The on-orbit radiation environment of HST damages CCDs, generating hot pixels, increasing dark current, and decreasing CTE. The decline in CTE reduces detected source flux and is a function of:

- Distance from amplifier: more transfers = more traps. = more loss
- Signal level: higher fractional loss in fainter sources.
- Image background: higher background fills traps (Fig 1).
- Scene: sources preceding target sources pre-fill traps.
- Epoch of observation:. More time on-orbit = more traps

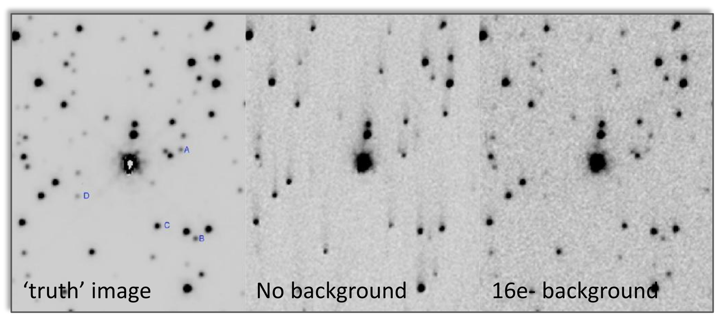


Fig 1. Traps capturing and releasing charge during readout leave trails of charge above sources. Image background (via post-flash if needed) can provide partial mitigation of CTE loss.

Sink pixels

Some pixels are charge 'sinks' i.e. they contain an abnormally large number of traps; ~0.05% of pixels have sinks deeper than 20e-. Image background determines the impact of sinks (Fig 3) e.g. the troughs can affect ~0.5% of the pixels in low-background images.

A sink-pixel mask for full-frame arrays is part of calwf3 v3.3, released March 2016. Support for subarrays will be in Fall 2016, calwf3 v3.4.

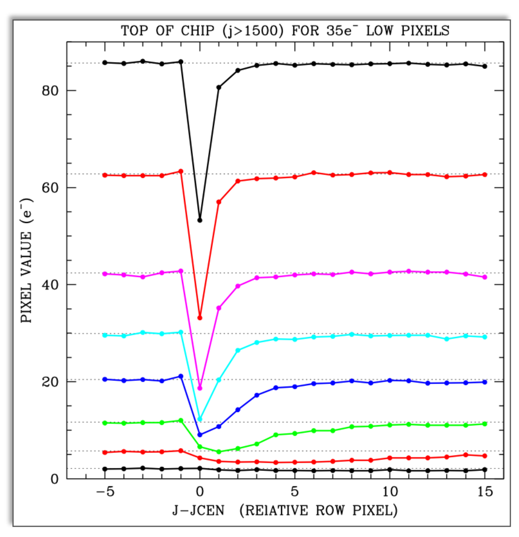


Fig 2. Sink pixels vs background.

Pixel-based CTE correction

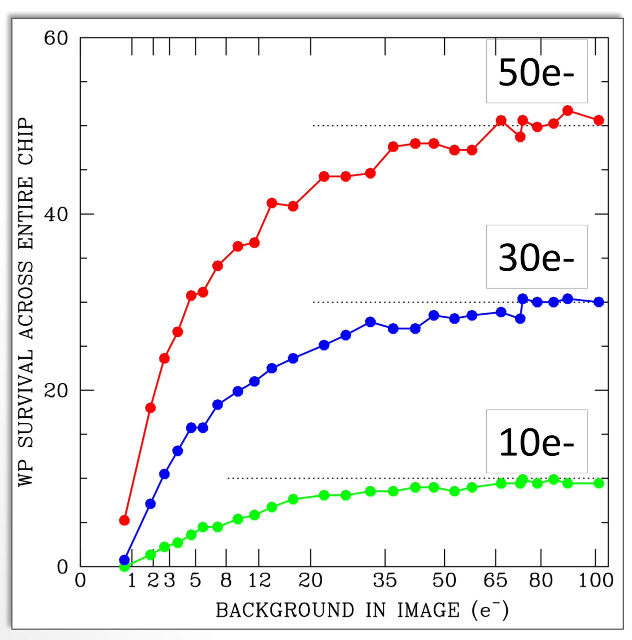


Fig 3. Warm pixel versus background.

CTE losses on a pixel-by-pixel basis are modeled using warm pixels (Ref 1,2). Applied to science images, the model restores charge to its original location. To pin the model:

1) Find warm pixels (WPs) in long darks taken with various post-flash levels (i.e. backgrounds).
2) Scale WPs to estimate levels in short darks.
3) Measure surviving WP counts in short darks.
4) Track WP losses versus background (Fig 2).
5) Fit a forward model to the data.
6) Invert to obtain correction for science images.

Implementation in calwf3

Prepare image — From original raw image: subtract custom bias image then remove additional bias level measured from physical overscan and convert to electrons.

Identify noise — CTE affects measurement of electrons in the pixels *not* the electrons associated with amplifier readout noise. Therefore, the best-possible smoothed image which is equivalent to the observation without the read noise component is calculated.

correct — From the smoothed image, a correction for the flux in each pixel is calculated using a parameterized model and then applied to the *original* untouched raw file.

Calibrate — The CTE-corrected raw image is calibrated as usual for CCD data (apply bias, CTE-corrected superdark, flatfield, etc.).

Software Implementation Details

- CTE correction depends on pixel distance from the readout amp so detector quadrants are rotated to amp align: parallel-shift down and serial-shift left.
- Pipeline algorithm, in C, is compute intensive because of how it measures and shifts flux between pixels in a column. Each column is independent so processing can be sped up in parallel by instructing OpenMP to farm out columns. Not all loops inside the algorithm are vectorizable because of lexical data dependence.
- Arrays are loaded and read such that columns of data live near each other in memory to avoid page faults and excessive cache rebuilding.
- Currently built with gcc v4.4.7, including OpenMP v3.1, without C99 styles. May update compiler to a later version which includes SIMD instructions and perhaps hyperthread the inner loops.
- Example timing runs:
  - With 16 cores, 2 threads per core, no parallel processing, typical runtime for 1 image to complete calwf3: 189 minutes.
  - On same machine but using all (32) processing units, runtime is 40 minutes (~4 times faster).
  - Note: the CTE algorithm is scene dependent so runtimes shorter (or longer) are possible using different images.

Correction works well

Fig 4. WFC3 image subsections farthest from the amplifier before (top) and after (bottom) application of the pixel-based CTE correction.

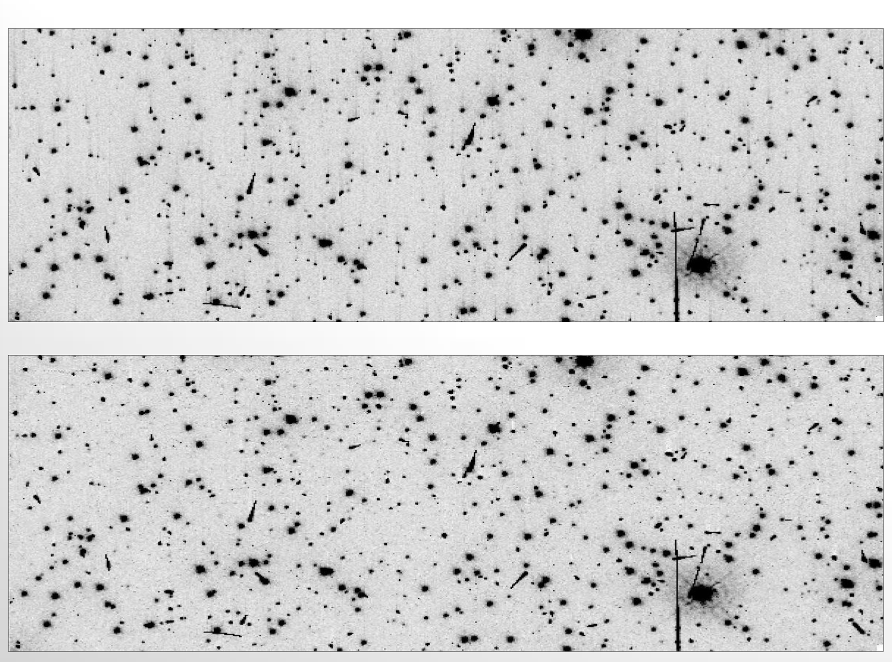
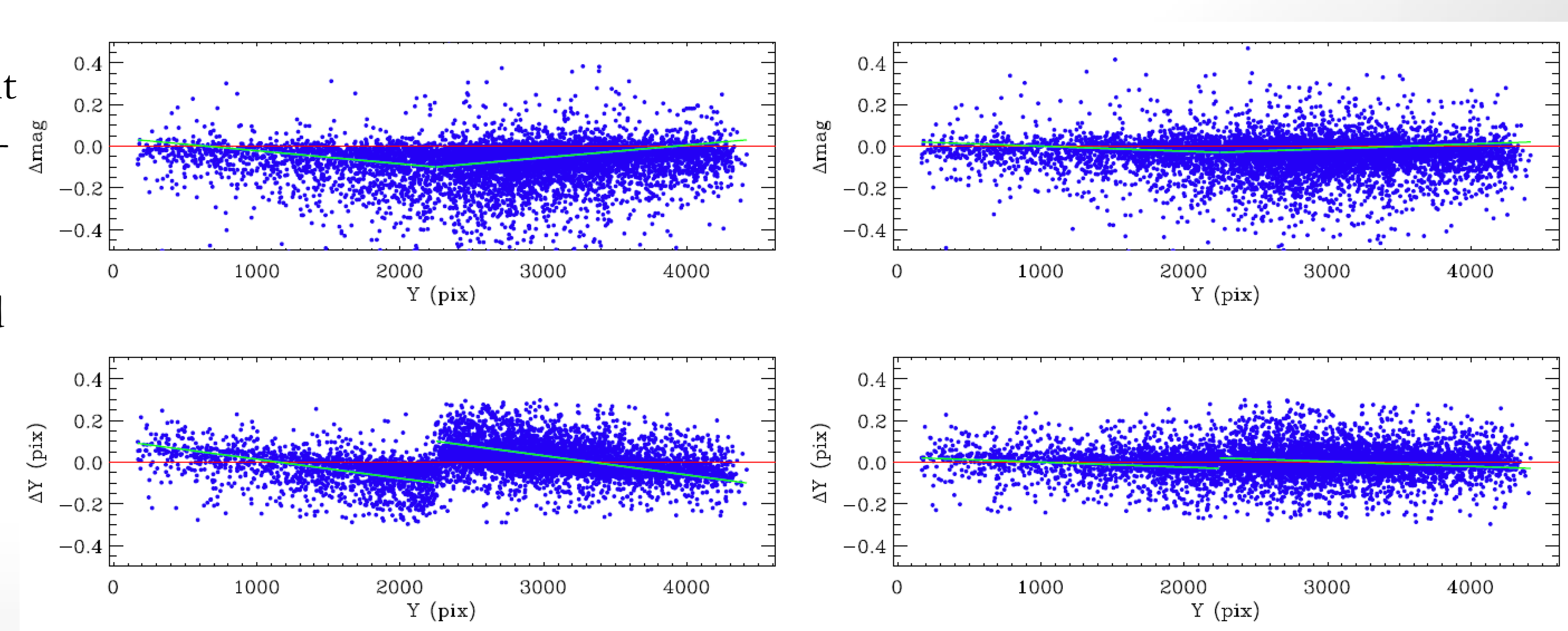


Fig 5. Improvement in brightness and y-position using CTE-correction. Based on short and long exposures. Figure courtesy V.Platais (from Fig 10, ISR 2016-02).



No CTE correction

With CTE correction

References

UVIS CTE: www.stsci.edu/hst/wfc3/ins_performance/CTE
WFC3: www..stsci.edu/hst/wfc3
STScI help desk: help@stsci.edu
1. Massey, R., et al., "Pixel-based correction for CTI in HST/ACS", MNRAS 401, 2010.
2. Anderson, J., & Bedin, L., An Empirical Pixel-Based Correction for HST/ACS, PASP 122, 1035, 2010.

WFC3 reports

ISR 2016-02 – The updated calibration pipeline for WFC3/UVIS: a cookbook to calwf3 v3.3
ISR 2016-01 – The updated calibration pipeline for WFC3/UVIS: a reference guide to calwf3 v3.3
ISR 2015-03 – WFC3/UVIS charge transfer efficiency 2009-2015
ISR 2014-22 – Flagging sink pixels and ISR 2014-19 – Sink pixels and CTE in the WFC3/UVIS detector
TIR 2014-03 – WFC3/UVIS CTE correction: requirements for new keywords and reference files