WFC3 UVIS CTE and Charge Injection: June 2011 Update for Cycle 19 Observers

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I. Introduction: UVIS CTE Evolution, Cycle 19 Charge Injection

Like all CCD detectors in low-Earth orbit, the WFC3/UVIS CCDs experience a degradation of their Charge Transfer Efficiency over time, introduced by their exposure to energetic radiation. The WFC3 team has been monitoring this degradation. Recent results are published in the WFC3 UVIS CTE Whitepaper (Baggett et al. 2011, http://www.stsci.edu/hst/wfc3/ins_performance/CTE/cte.pdf), ISR-WFC3-2011-02 (WFC3/UVIS Charge Injection Behavior: Results of an Initial Test, Bushouse et al. 2011, http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2011-02.pdf), ISR-WFC3-2011-06 (WFC3/UVIS CTE External Monitoring in Cycle 17, Khozurina-Platais et al., http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2011-06.pdf) and on a dedicated website (http://www.stsci.edu/hst/wfc3/ins_performance/CTE/) .

Updated results presented herein show that in the absence of sky background, which is the worst case, moderately faint (500 - 2000 electrons) stars at detector Y coordinates far from the readout amplifiers can experience flux losses approaching 10% in small (r=3 pixel) apertures at close to zero backgrounds, as of March 2011. Losses are lower for brighter targets and/or images with higher sky backgrounds: for a background level of 20-30 electrons per pixel, CTE losses for the aforementioned stars (500 to 2000 electrons) are only ~2%. Stars with 2000-4000 and 8000-16000 electrons in images with essentially zero background show losses of ~4±2% and 2±2%, respectively.

While CTE losses can be mitigated by placing the target close to the amplifiers, this is in practice not always possible, e.g. for extended targets or survey fields. For such observations, correction algorithms are currently under development. However, correcting individual faint targets for CTE effects with such algorithms will always be challenging; CTE depends in a non-trivial way on a variety of parameters: detector Y- and also X position, the date of the observation, the flux and intensity distribution of the target, the background level, and even the distribution of other sources on the column a target resides on. In severe cases, CTE may even cause already very faint objects to not be detectable anymore, rendering a post-data acquisition correction impossible.

Beginning in Cycle 19, we offer an alternative method of mitigating CTE effects, detector charge injection (CI). By injecting a defined number of electrons into the detector prior to the exposure, the defects ("charge traps") in the detector lattice are occupied, allowing the charge of the science exposure to be read out largely loss-free. Contrary to a pre- or post-"flashing" of the detector, this process does not incur a poisson noise penalty, but merely enhances the read noise. Moreover, we inject only every Nth detector row. As these CI rows are being read out, the charge traps are filled and, due to the non-zero charge release time from these traps, remain largely filled while the rows trailing the CI rows are being transferred towards the amplifiers. This way, only every Nth row suffers a significant read-noise penalty. See the UVIS CTE Whitepaper (http://www.stsci.edu/hst/wfc3/ins_performance/CTE/cte.pdf) for details.

In Cycle 19, we offer CI in LINE17 mode, i.e. every 17th row will be charge injected.

II. Observations and Data Analysis

Data presented in this document were obtained during the Cycle 18 calibration program CAL/WFC3 12379 (Noeske et al.). To monitor the UVIS CTE, a calibration field within the star cluster 47 Tuc (NGC 104) was observed in long and short exposures. The resulting low and high fluxes for each star yield a measure of CTE because a source with a low total flux will experience higher relative CTE losses than a source with a high flux, which is relatively unaffected (see Figure 1). See the analysis by R. Gilliland in the UVIS CTE Whitepaper (http://www.stsci.edu/hst/wfc3/ins_performance/CTE/cte.pdf) for details. To probe CTE in different sky backgrounds, these observations were performed in both a narrow band and a broad band filter, F502N and F606W.

These observations were repeated with a 2000 pixel dither step in the detector POS-TARG Y direction, such that the sky area that first fell onto the UVIS2 detector was imaged again on the UVIS1 detector. Because the read-out amplifiers are on opposite ends of UVIS1 and 2, stars that were near (low row number) the amplifier in the UVIS2 image are far from the amplifier in UVIS1 and vice versa. The ratio of the fluxes of stars from both images, plotted as a function of the row number (detector Y), hence measures the absolute amount of CTE losses. See Figures 1 and 2 for examples. Note that the ratio of star fluxes shown in these panels displays *twice* the actual CTE losses from detector row 0 to 2000. In this document, we show results of the comparison of the 2000 pixel Y-dithered exposures.

We performed such observations without CI, to measure the current detector CTE, and with CI in LINE10 and LINE17 modes. The CI data were taken as long exposures only, and each of the 2000 pixel Y-dithered exposures was taken in 5 subexposures of 348 seconds each, dithered by few pixels to step between the LINE10 and LINE17 CI row patterns.

Photometry of the stars was performed using DAOPHOT under IRAF in aperture radii of 3 pixels, with sky annuli with an inner radius of 10 pixels and a width of 10 pixels. Star detector coordinates were corrected for geometric distortion and stars were cross-identified between both detectors. The ratios of the fluxes between UVIS1 and 2 (expressed in magnitudes) is shown as a function of the detector Y coordinate (row number) of UVIS2, for different observation setups, in Figures 1 and 2.

The plots show stars with a formal photometric error of <0.1 mag. To reject stars in individual CI exposures that were affected by cosmic rays or image artifacts, we compared star fluxes in pairs of subdithered (few pixels) exposures that were taken on the same side of the 2000 pixel Y dither throw. We removed stars that in the subdithered image pairs showed flux differences > 2 times the formal photometric error of that star. Blue lines in the figures are linear least squares fits to the data with a one-pass clipping of 3-sigma outlier data points.

III. UVIS CTE as of March 2011: Current CTE Losses, Dependence on Sky Background

Figure 1 shows the state of the UVIS CTE in March 2011, for data with essentially zero sky background (left column, 2-3 electrons per pixel in the 30 second F606W images) that will be most significantly affected by CTE degradation, and medium sky backgrounds (right column, 20-30 electrons per pixel in 350 second F606W images). All of the data shown in Figure 1 were taken without CI.

An estimate of the continuing degradation of the UVIS CTE can be obtained from the top left panel (stars with 500 to 2000 electrons in low backgrounds). For stars with the same fluxes in images with essentially zero background (F502N), data summarized in the UVIS CTE Whitepaper (http://www.stsci.edu/hst/wfc3/ins_performance/CTE/cte.pdf) showed a strong CTE evolution, likely related to the minimum of the solar activity during that period. The flux difference between stars in the 500 closest and furthest rows from the amplifiers evolved from 2.4±0.4% to 8.2±0.5% within 12 months (Oct 2, 2009 to Sep 27, 2010). Our new data, taken 5 months later in March 2011, fortunately indicate a slower rate of CTE degradation. The top left panel in Figure 1 yields a flux difference of 8.4±0.4% for stars on the same rows that were considered earlier. Errors of the CTE slopes are formal errors from non-weighted linear least square fits. A conservative estimate of the true errors, including systematic uncertainties, should be considered ~2%. The CTE values we list here should still be considered preliminary; a full analysis of all available CTE data is in progress.

The dependence of relative CTE losses on the flux of the source is illustrated in the three rows of Figure 1 that show stars in different flux bins. Brighter sources have lower relative flux losses, reflecting that CTE losses are limited by a finite number of charge traps in the detector. The number of electrons lost from a source will be a non-linear function of the source flux and intensity distribution. However, Figure 1 suggests that the CTE loss for stars far from the amplifier in all three flux bins is of the order of $1\text{-}2 \times 10^2$ electrons in low backgrounds. Note that in low backgrounds, CTE effects remain significant (formal fit errors) for stars up to the 8000 to 16000 electron bin (lower left panel). Even for a conservative estimate of a slope error of 2%, the slope in that panel (1.8%)

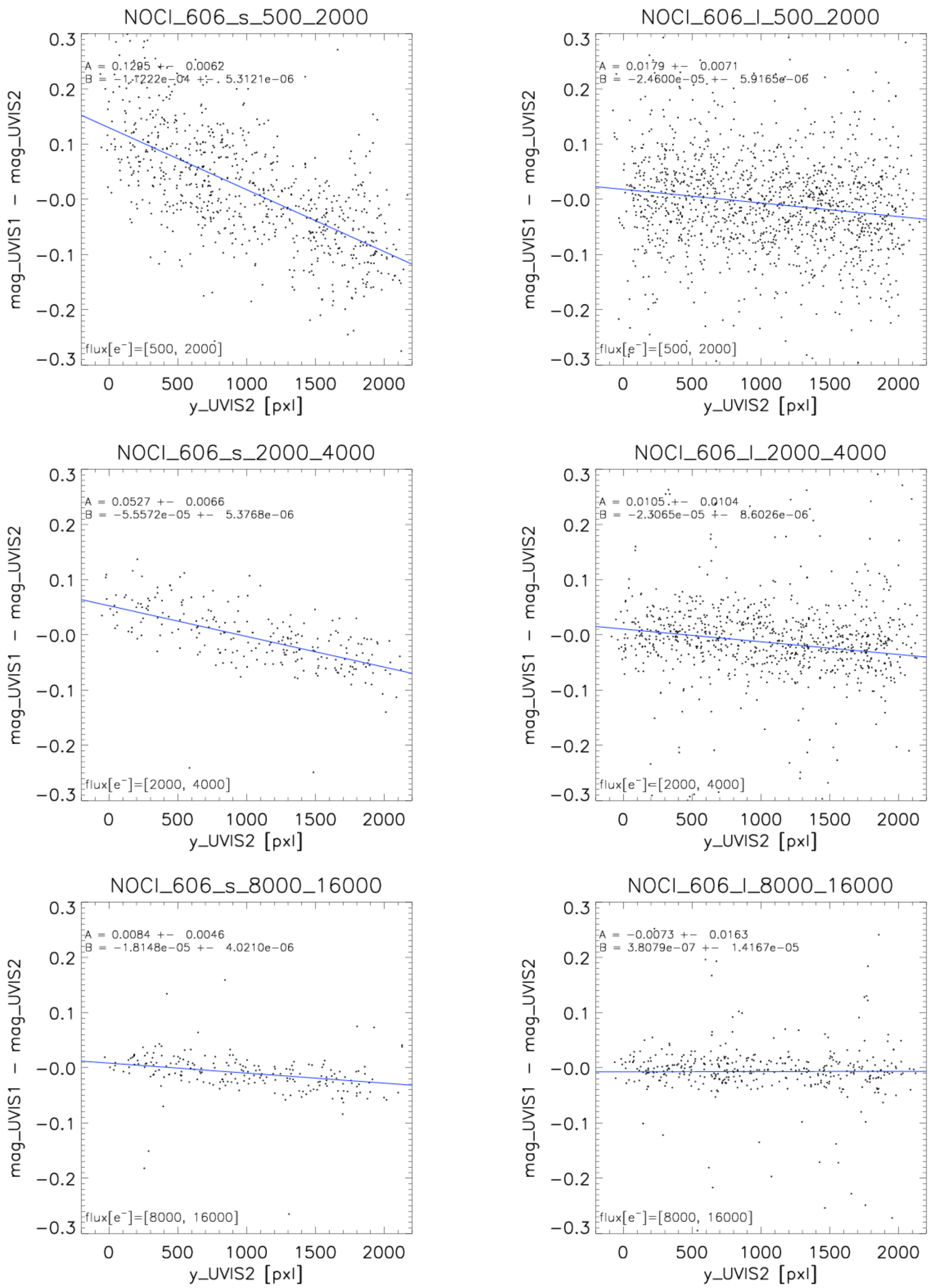

Figure 1. CTE in non-charge injected F606W images for low backgrounds (left column, 2-3 electrons per pixel, 30 second exposure) and medium backgrounds (right column, 20-30 electrons per pixel, 350 second exposure). Panels show stars with total fluxes of: 500 to 2000 (top row), 2000 to 4000 (middle), 8000 to 16000 (bottom) electrons. CTE losses for 500 to 2000 electron stars in low backgrounds amount to ~8.4±0.5% between the 500 rows closest vs the 500 rows furthest from the amplifiers, and 1.8±0.5% in the higher background image. Note that the plots display twice the amount of CTE losses across each detector (see Sect. II).

indicates a high likelihood that these stars experience a non-zero CTE effect.

The dependence of CTE on the sky background of the image is illustrated in the left and right columns of Figure 1, where we compare F606W exposures with short (30 seconds, left) and long (350 seconds, right) exposure times. Note that these panels do not show the same stars, but stars that yield equal total fluxes within the exposure time of each image: we compare sources of the same flux within different backgrounds. The long exposure has a sky background in the range 20 to 30 electrons per pixel, the short exposure in the range 2 to 3 electrons per pixel. While the short exposure shows the very significant CTE slope discussed above, the CTE effects are much shallower in longer exposures. Comparing once more stars in the 500 rows nearest and furthest from the amplifiers, stars with 500 to 2000 electrons show CTE losses of 1.8±0.5% in long vs 8.4±0.5% in short images; stars with 2000 to 4000 electrons show losses of 1.7±0.7% vs 4.2±0.5% in long vs short images. Stars with 8000 to 16000 electrons show no significant CTE slope in long images.

This result suggests that a moderate background signal of 20-30 electrons per pixel does not fill a large enough fraction of the charge traps to entirely eliminate CTE degradation effects on moderately faint sources. However, as we discuss in Section IV below for the LINE17 mode, moderate residual CTE slopes of few % across the detector might be first-order correctable using an empirical dependence of CTE on the detector row number, and possibly secondary parameters, with a remaining uncertainty that is below the Poisson flux errors of individual sources.

IV. Tests of Charge Injection: LINE10 vs LINE17

Previous analyses of CI data (CAL/WFC3 12348, see WFC3-ISR-2011-02, http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2011-02.pdf) had shown that CI in "Continuous" mode (CI in every row) generates a significant read noise penalty (sigma ~20 electrons) across the image. Choosing a CI mode that only injects charge into every 10th, 17th or 25th row limits this enhanced read noise to the injected rows, which can be rejected or assigned a low weight when dithered images are combined.

On the other hand, studies of CI data have shown that a large CI row spacing does leave residual charge transfer inefficiency (CTI) effects, likely because charge traps with rapid release times are not replenished frequently enough by passing CI rows during readout.

The LINE25 CI mode left a residual CTE of ~3% between the 500 rows closest and furthest from the amplifiers (R. Gilliland, private communication, stars with 500 to 2000 electrons, low sky background, September 2010 data, program 12348). Given that the CTE will degrade further over time, we decided against the LINE25 mode and weighed the benefits and penalties of the LINE10 and LINE17 modes.

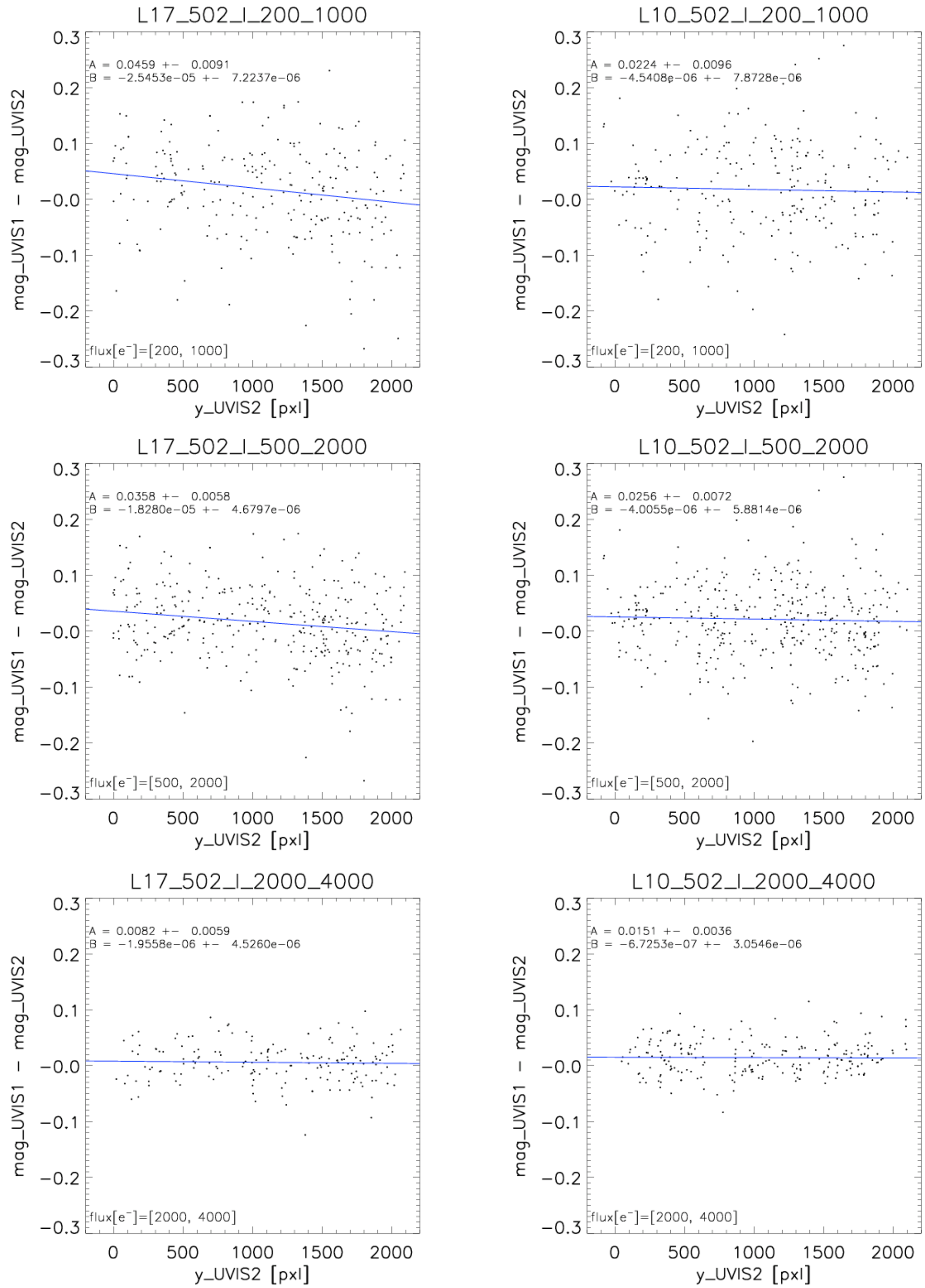

Figure 2. CTE in zero background for stars with fluxes of 200 to 1000, 500 to 2000 and 2000 to 4000 electrons (top to bottom) with Charge Injection modes LINE17 (left) and LINE10 (right). Note that the plots display twice the amount of CTE losses across each detector (see Sect. II).

Figure 2 confronts LINE17 (left column) with LINE10 data (right column), for stars in moderate to faint flux bins in low sky backgrounds (F502N), i.e. data most affected by CTE degradation. It is obvious that LINE10 data show no significant CTI, given our CTE slope error estimate of 2%, and even within the formal errors of the linear fits. LINE17 shows residual CTI slopes for stars up to 2000 electrons, with 2.6±0.8% and 1.8±0.5% (formal fit errors) for stars with 200-1000 and 500-2000 electrons, respectively, measured over the entire detector (2048 rows).

While LINE10 seems to correct CTE entirely within the measurement uncertainties, down to moderately faint sources of few 100 electrons, the WFC3 team decided to offer LINE17 as the mode available in Cycle 19. Penalties of LINE10 use are considerable. CI affects not just every charge injected row, but the degraded CTE causes a transfer of some of the CI rows' charge into the rows that are trailing the CI rows during readout. The resulting residual signals and elevated noise profiles for rows adjacent to CI rows have been studied on data from CAL/WFC3 12348 and are described in detail in WFC3-ISR-2011-02, http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2011-02.pdf . During image combination, it is likely that not only the CI rows, but also some of the adjacent rows will need to be either rejected or assigned lower weights. Depending on the required image quality, this may lead to a sizable decrease in useful detector area and efficiency of the observations. Furthermore, the number of rows affected by CI imply that for LINE10 *every* point source's PSF will overlap with significantly CI-affected rows within a radius of about 3 pixels, which is important for most applications.

The LINE17 mode, on the other hand, affects a smaller fraction of rows with CI signals, and provides more detector area that is less severely affected by CI residuals. The residual CTI effects will be more easily correctable than CTI in the absence of CI: Applying an empirical detector Y-dependent correction, possibly including secondary parameters, should remove the residual CTI effects with a precision of better than ~2% (given the true error estimate stated above), which is below the Poisson flux error of sources in the flux range where residual CTI is seen.

V. Summary

We have tested the current state of the WFC3/UVIS CTE and mitigation of any inefficiencies through Charge Injection (CI). Observations obtained in March 2011 indicate a slower decline in CTE than earlier data from October 2009 to September 2010 had shown. For stars with fluxes of 500 to 2000 electrons, in images with backgrounds of 2 to 3 electrons per pixel, we find losses of 8.4±0.5% (preliminary), if stars in the 500 rows closest and furthest from the amplifiers are compared. For the same star fluxes and similar backgrounds, data obtained in September 2010 had shown a comparable value, 8.2±0.4% . In low sky backgrounds, even stars with fluxes of 8000 to 16000 electrons are likely to experience some low level CTI effects.

A comparison of CTE in the presence of a low and moderate sky background (2-3 vs 20-30 electrons per pixel) shows that a moderate background does not entirely eliminate CTI losses for stars with fluxes up to 8000 electrons. It does, however, mitigate CTI for such stars to levels that may be correctable through empirical relations to a precision that is better than the sources' Poisson flux errors.

We have furthermore compared the merits and penalties of the LINE10 and LINE17 CI modes. Based on small residual CTI losses that will likely be correctable within the Poisson flux errors of individual sources, and on the modest fraction of rows that are affected by the injected charge, LINE17 will be offered and supported during Cycle 19.

References:

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