

Charge Transfer Efficiency in the WFPC2 CCD Arrays

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Abstract

We present an overview of Charge Transfer Efficiency (CTE) issues in the WFPC2 CCDs, including results of recent on-orbit tests, and advice on mitigating CTE effects. CTE causes targets far from the CCD readout amplifier to appear fainter than targets near the amplifier. For bright targets, the maximum effect is only a few percent, but for faint stellar targets in images with very low background, the CTE effects can reach fifty percent or more. Studies using hotpixels, cosmic rays, and residual images as probes of CTE have revealed at least four distinct components of CTE losses. The largest effect appears related to trapping and release of charge on timescales of hundreds of milliseconds during the readout process. This is manifest as tails on images which extend for dozens of pixels in the Y-direction (parallel register direction) on the CCDs, which have the effect of robbing counts from typical small apertures used for photometry. Extended targets also are subject to CTE effects. Recent work shows the effect for faint galaxies is roughly similar to that for a stellar target with the same total counts. There are also small effects on the shapes of faint galaxies. Long-term photometric monitoring shows that CTE is steadily increasing with time, and there is also some evidence for an acceleration of the effect. Preflashing the CCDs can reduce CTE effects, but the added noise usually makes this unattractive. A noiseless preflash technique has been tested, but only appears to give a modest improvement. We discuss these and other recent results, suggest observational strategies for reducing the impact of CTE, and review photometric corrections which can be applied during data analysis.

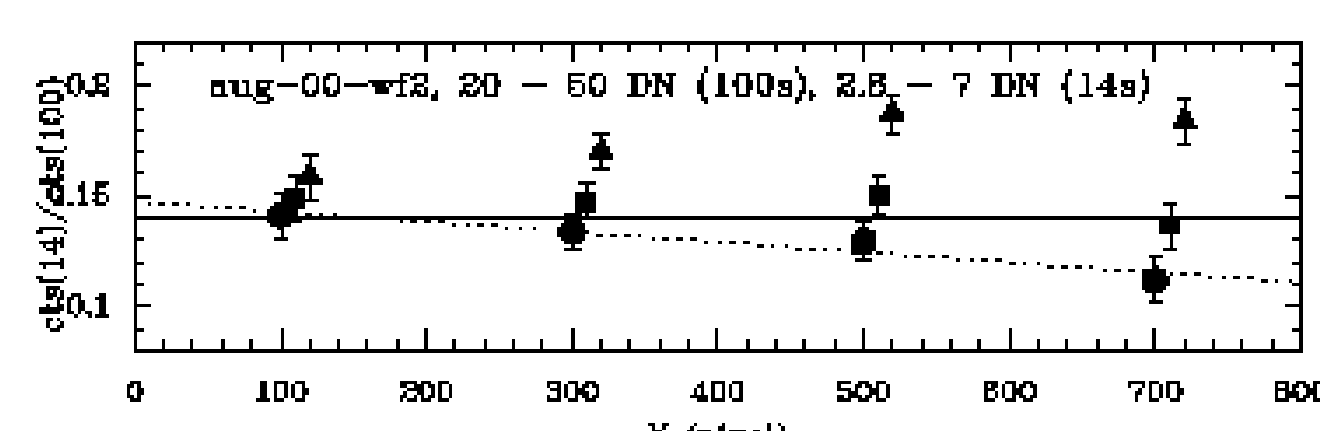
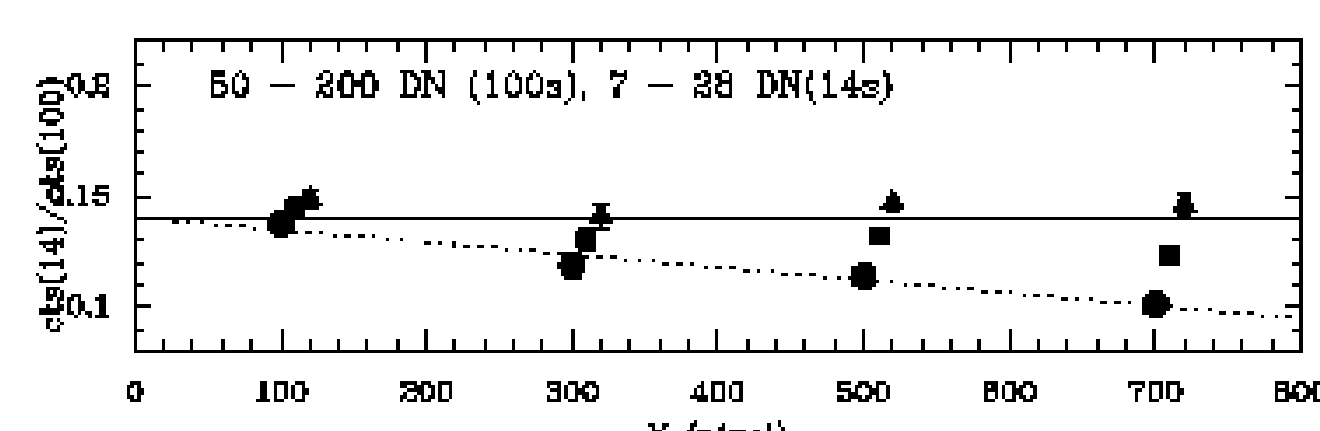
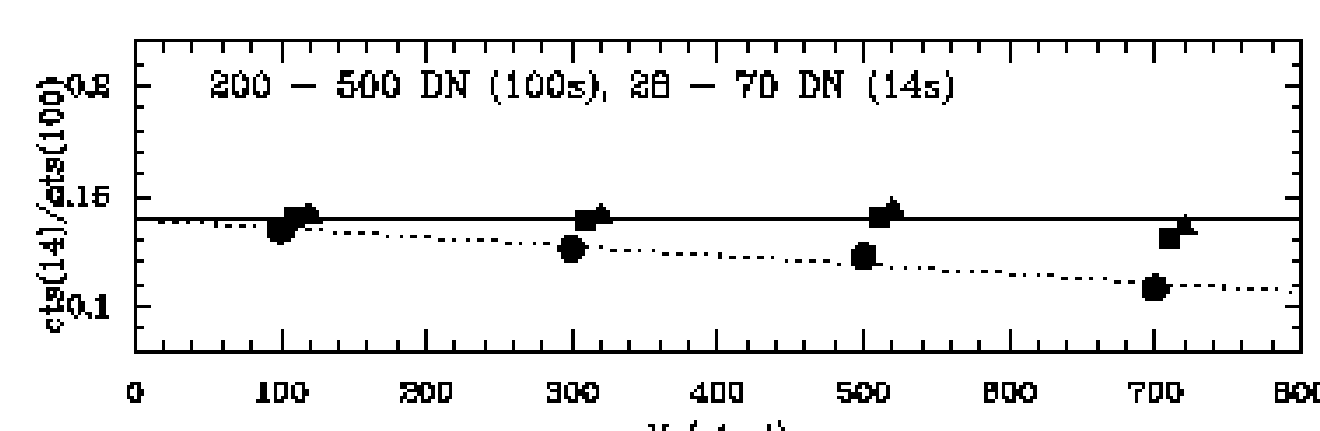
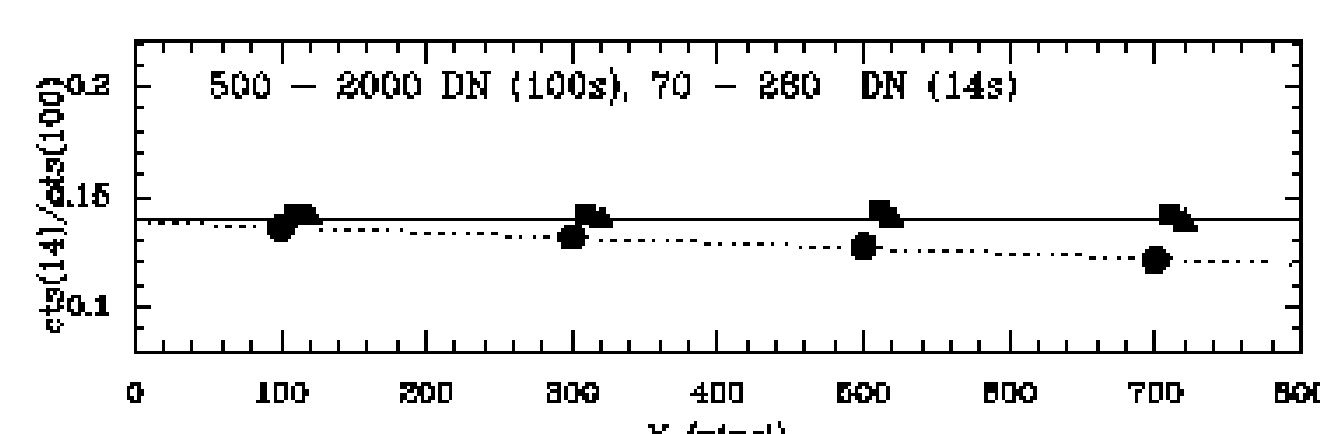
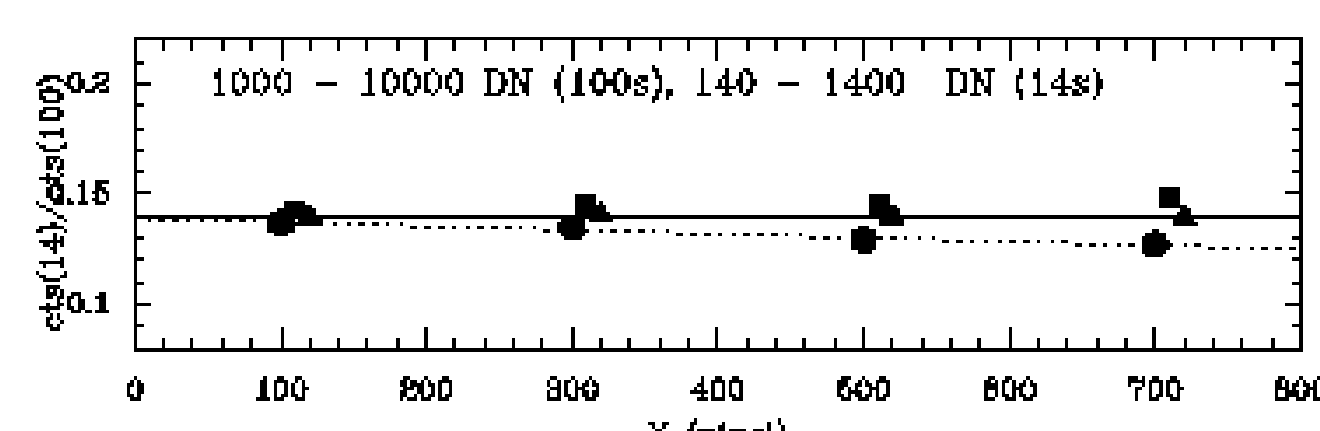
New CTE Correction Formula Available from Dolphin (2000).

A recent paper "The Charge-Transfer Efficiency and Calibration of WFPC2" (Dolphin 2000) may be of interest to WFPC2 users. The paper compares WFPC2 observations with ground based observations of Omega Centauri and NGC 2419, and derive CTE corrections using a baseline through March 2000, roughly a year longer than available for a similar study by Whitmore, Heyer, and Casertano (1999, PASP, 111, 1559). In general, Dolphin finds good agreement with the Whitmore, Heyer, and Casertano results (within a few hundredths of a magnitude) with less scatter in the residuals, except for recent (1998 and later) data at low count levels.

A preliminary comparison of August 2000 data shows:

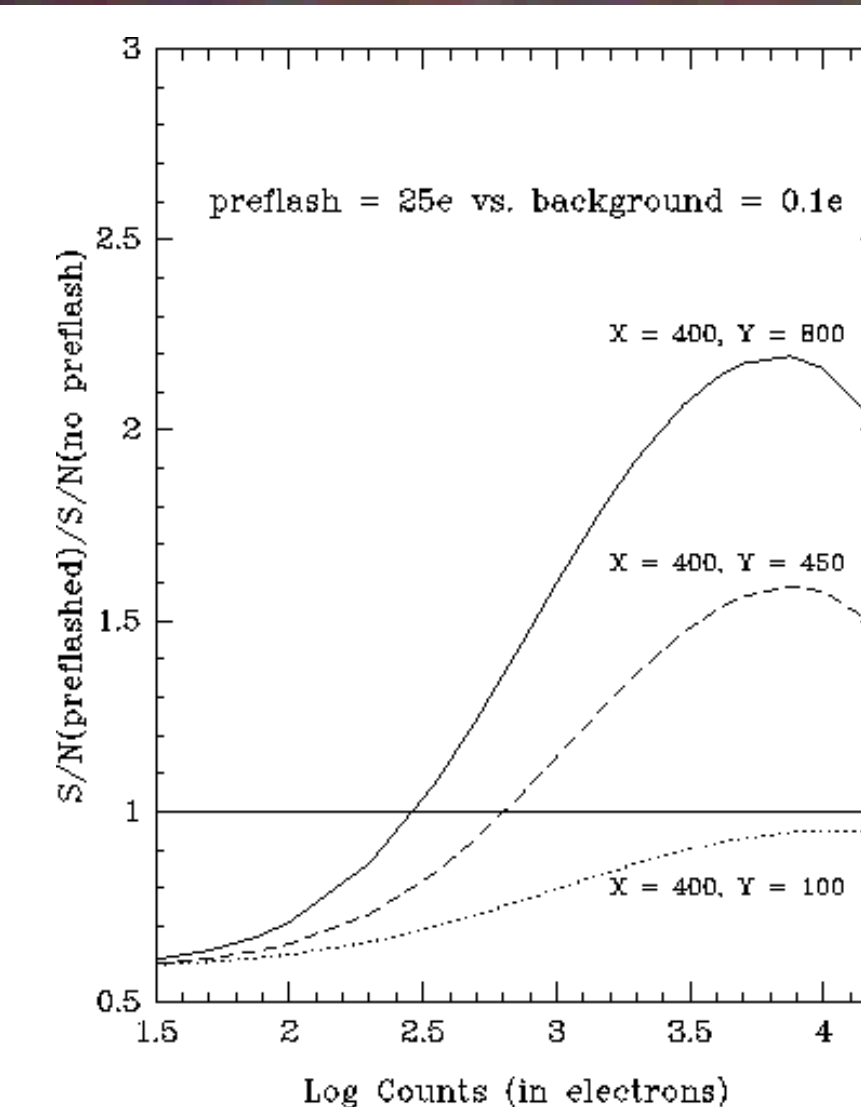
- For bright stars (> 15,000 electrons) Whitmore et al. tends to overestimate the correction by a few percent.
- For Faint stars (100 - 500 electrons) Whitmore et al. underestimates the correction.
- For extremely faint stars (20 - 50 electrons) Dolphin overestimates the correction by tens of percent, presumably due to lack of faint stars in the sample.

For now, the best compromise is probably to use the Dolphin formula for stars brighter than 100 electrons and the Whitmore, Heyer, Casertano formula for fainter stars. A report on this comparison will be available shortly.



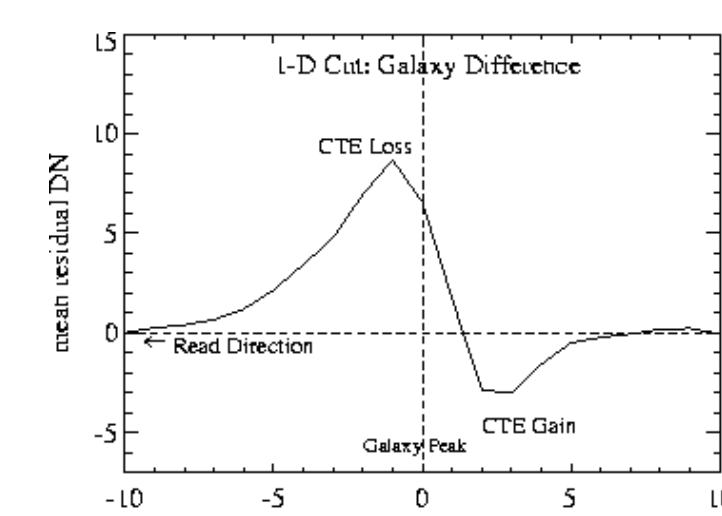
- raw values
- corrected values (Whitmore, Heyer, and Casertano formula)
- ▲ corrected values (Dolphin formula)

The above figure shows the ratio of counts from a 14 second exposure of Omega Cen in August, 2000 to the counts in a 100 second exposure, vs. the Y position on the chip (WF2, gain=15). The raw values (filled circles) fall below a ratio of 0.14 due to CTE loss (i.e., the count rate and background are both lower for the short exposure, leading to more CTE loss). The different panels are for different target brightness. The filled squares are corrected using the Whitmore, Heyer, and Casertano formula while the filled triangles are corrected using the Dolphin formula. Note that the Dolphin formula is somewhat better for the top 4 panels, but is much worse for the faintest stars in the bottom panel.



When to Consider Preflashing. CTE loss can be reduced by increasing the background, hence filling some of the traps before the target reaches them. One can artificially enhance the background by adding a preflash. The problem with this approach is that this also adds noise. The above figure shows a calculation based on the Whitmore, Heyer, Casertano (1999) correction formula, assuming a very low background for the raw image (i.e., 0.1 electron, appropriate for a very short exposure, a narrow-band exposure, or an exposure in the UV) versus an exposure which has been preflashed with 25 electrons. The ratio of the S/N (including uncertainties in CTE corrections) for the preflashed image versus the non-preflashed image is plotted vs. the log of the target brightness. The three curves show the effects for a star near the bottom of the chip (i.e., X = 400, Y = 100, where the preflash is never an advantage since CTE loss is low and the preflash adds noise), near the center of the chip, and near the top of the chip (where the preflash is an advantage for the brighter targets). For more typical cases where the background is already sizeable, the gains due to a preflash are even smaller. *Note:* Using preflashes will mean incurring significantly increased overhead times.

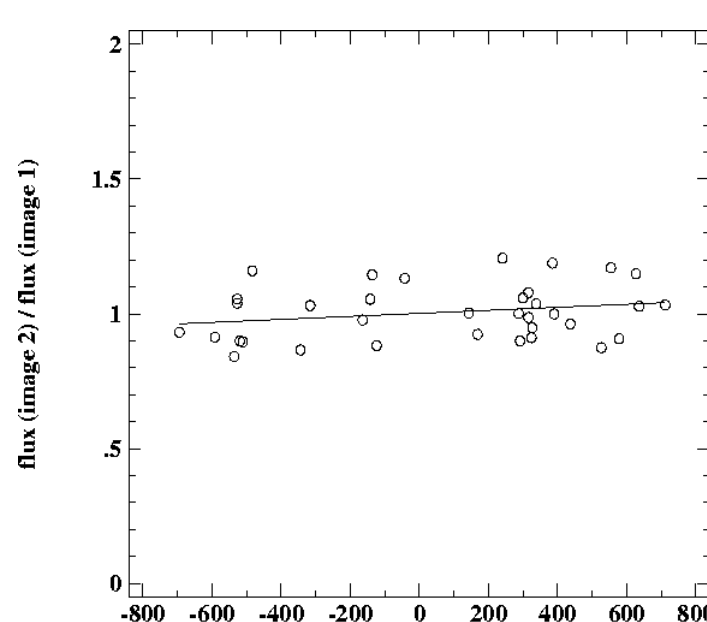
Extended Source CTE - Galaxy Profile Shapes. We investigate the effect of CTE on the shape and structure of extended sources. We subtracted pairs of images of individual galaxies observed near and far from the read-out amplifier. The average profile of the galaxy residuals is distinctly asymmetric and indicates that charge is primarily lost from the amplifier-side of the galaxy image (see figure below). The side of the galaxy away from the amplifier suffers little charge loss because charge traps encountered during the read-out have been filled and in addition, charge is detrapping. These results are reproduced by a simple model of the read-out process.



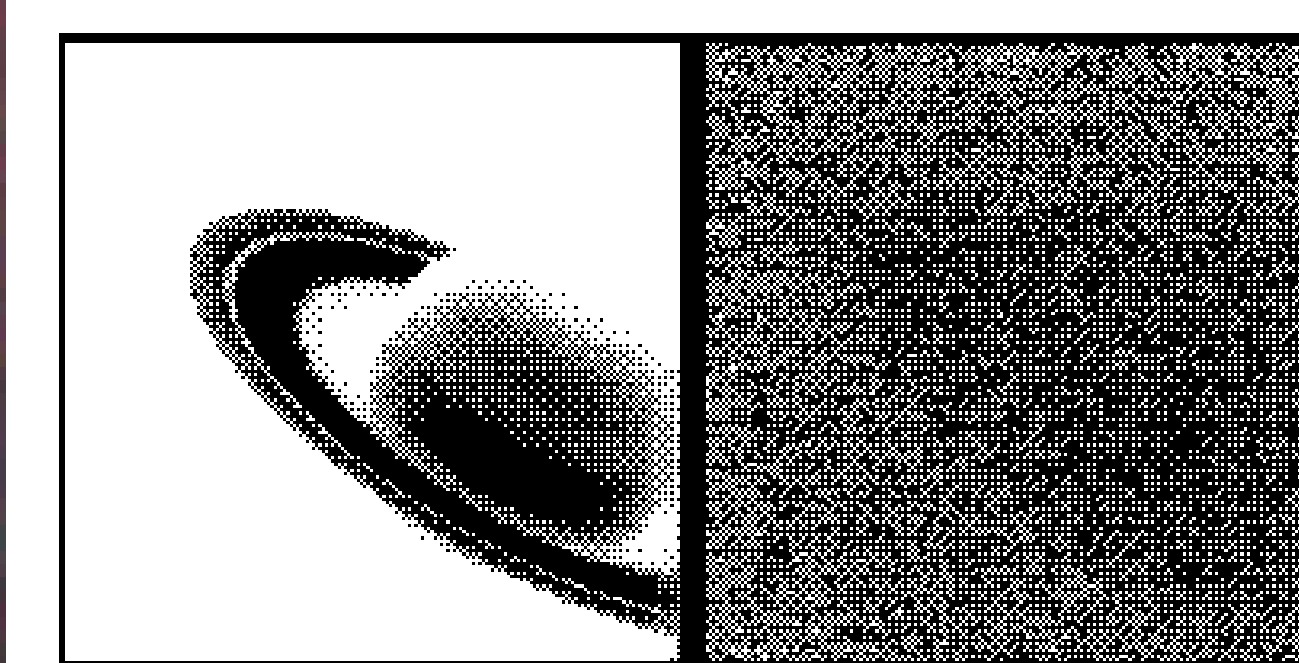
Comparative difference profile showing the residuals from the subtraction of 30 galaxy pairs (orange) and 30 from the read-out amplifier. A 1-dimensional cut of this profile along the Y-axis (pointing the galaxies) is shown.

Our results indicate that CTE losses to extended sources are not uniform across the source. Rather, they are proportionally greater closer to the read amplifier, decrease in the direction away from the amplifier, and charge is regained at the extreme edge of a source. Our knowledge of how CTE affects galaxies is still primitive and it is difficult at this point to provide a quantitative correction which can be employed by WFPC2 users. Nevertheless, we suggest that users consider that the total CTE loss expected for a galaxy (Whitmore, Heyer, & Casertano 1999) likely applies only to the half of the galaxy near the amplifier, with the other half facing negligible losses. This statement appears to robustly apply to the different methods and filters (i.e., backgrounds) employed in our analysis.

Extended Source CTE - Aperture Photometry. Preliminary results of photometry on faint galaxy cores show effects consistent with those predicted for CTE in stellar photometry.



The figure illustrates the effect of CTE on 0.2" radius aperture photometry of small, extended sources (2-3" in size). Results are for targets on WF chips, with flux values between 200 and 500 DN, and sky level ~40 DN. The observed field, A1689, was positioned such that targets at low Y (rows) in image 1 were at high Y in image 2 and vice-versa. Plotted is the ratio of the fluxes in the images as a function of difference in Y position. Formal fit to the data yielded a CTE loss over 800 pixels of 4.5% +/- 3.2%. An ISR with details on aperture photometry of small extended sources is in prep.



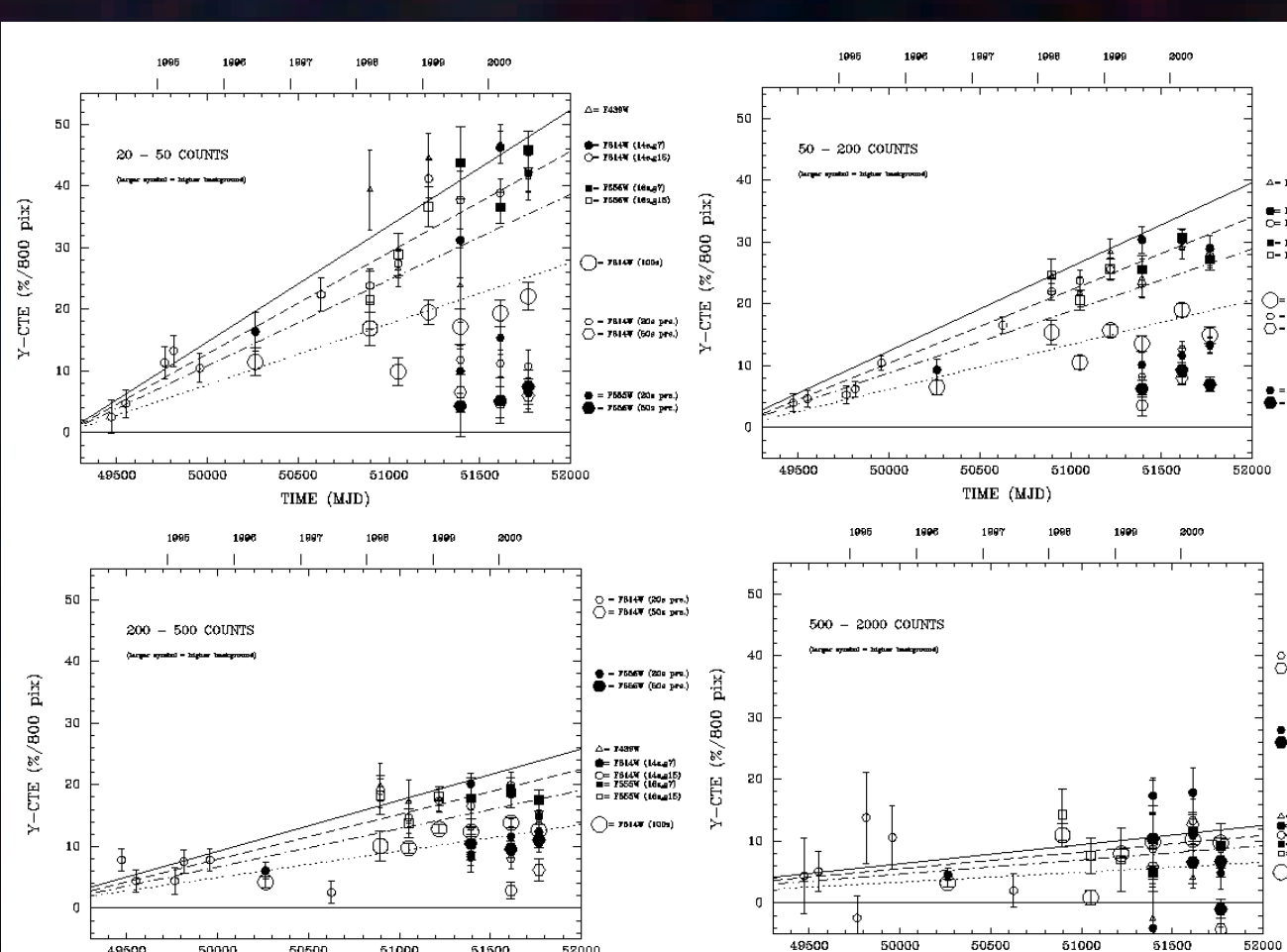
Residual Images: Update on the status of charge trapping in WFPC2 CCDs.

Charge trapped during the read out of science images is slowly released and can show up in subsequent images. The above figure shows an image of Saturn and the dark that immediately followed; note that the residual in the dark appears both at the target location and in the pixels in the direction of read-out (in this case to the right of the target). Such science image / calibration frame pairs are ideal for investigating the characteristics of long time scale CTE trapping.

The HST archive was mined for all non-saturated planetary science images followed closely in time by dark frames.

The primary conclusions are (details may be found in Baggett, Biretta, Hsu 2000):

- The new images support the original finding that the amount of charge trapped appears correlated with the *maximum* intensity clocked through the pixel during readout (Biretta & Mutchler 1997; Baggett, Biretta, Hsu 2000).
- The charge in a residual image is given by $\ln(\text{residual}) \sim 0.36 \ln(\text{Imax})$, where Imax is the maximum value clocked through that pixel.
- The amount of charge seen in the residual images appears to have been stable over the six years. This is in marked contrast to the increasing photometric CTE (e.g., Whitmore et al., 1999).
- Some residuals are long-lived (>20 minutes).



WFPC2 CTE Monitor. We continue to monitor photometric CTE using a standard field in Omega Cen. The observations indicate that for very faint stars on a very faint background, the CTE loss from the top to the bottom of a chip has increased from about 3% shortly after the cool-down of WFPC2 (April 23, 1994) to roughly 52% in August 2000. In general, typical WFPC2 exposures are much longer than these short calibration images, resulting in higher background which significantly reduces the CTE loss and minimizes the CTE problem for most science exposures.

How Observers Can Mitigate CTE Effects:

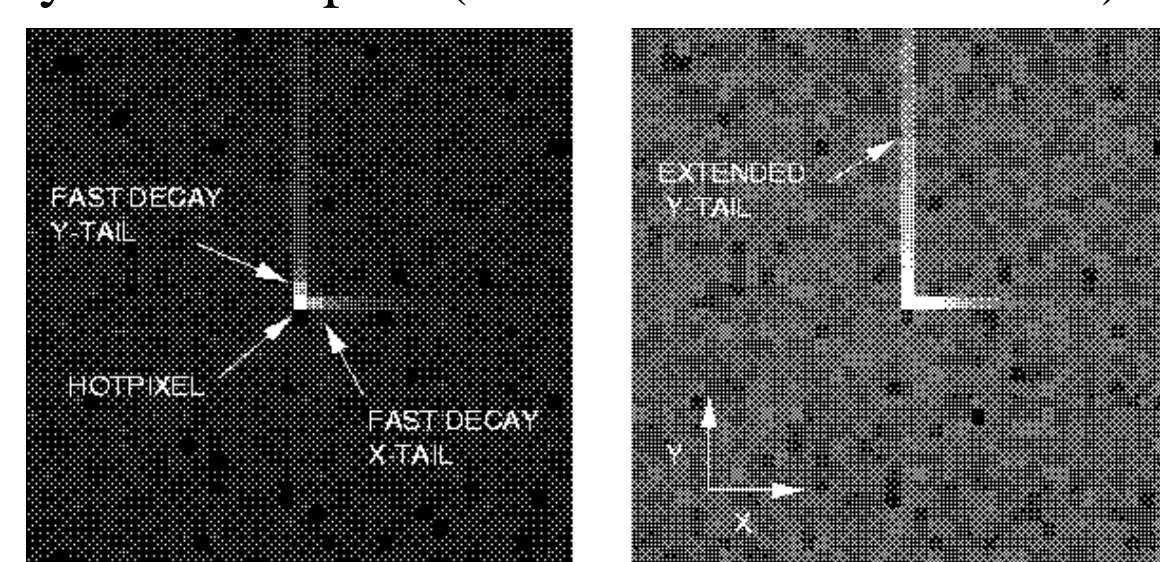
- Avoid excessively short exposures (i.e. avoid low background).
- Place small targets near read-out amplifier. (X,Y ~ 150)
- Preflashing may be beneficial in certain situations.
- Apply corrections after observations.

Physical Effects.

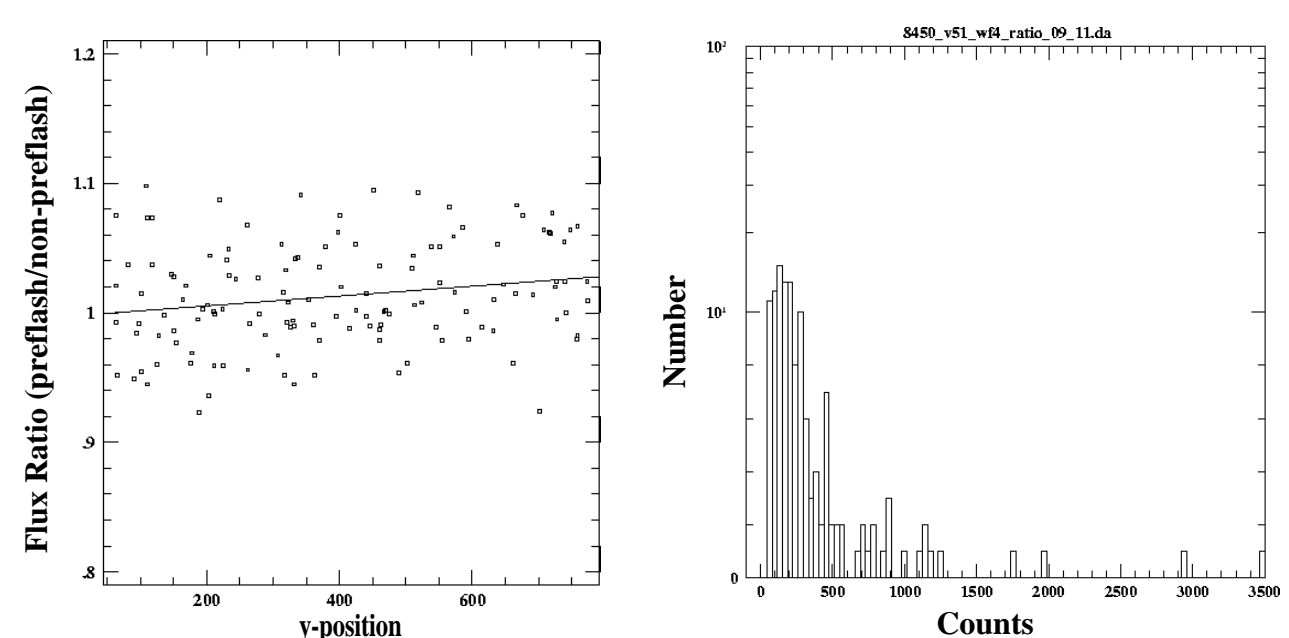
We are currently studying the detailed physical effects of CTE in an effort to better understand its photometric impacts. The figure below illustrates the effect of CTE at the single pixel level. This image is derived from hotpixels in WFPC2 images, and effectively shows the system response to a single bright pixel at the CCD center (Biretta, Baggett, and Riess 2000). Three components of CTE, perhaps related to different types of traps, are immediately obvious:

- (1) Fast decaying tail in +Y direction (decay scale ~10's msec)
- (2) Extended tail in +Y direction (decay time ~ 100 msec.)
- (3) Fast decaying tail in +X direction (decay time ~10 μsec)

All of these components have the effect of robbing charge from typical small apertures (few pixel radius) used for stellar photometry. A fourth component of CTE is responsible for long-lived residual images, but has only minor impact (Biretta & Mutchler 1997).



Average of 700 hotpixels illustrating the impact of CTE on a single pixel. Data were taken from dark frames in late 1999 in all four CCDs in region 50<Y<750; hot pixel intensities were in range 100 to 4000 DN. The right panel is the same image enhanced to illustrate faint pixels.



Left, the ratio of the noiseless preflash/non-preflash flux in (uSka5106r/uSka5104r) vs. vertical position on the WF4 chip for 16 sec. exposures. Right, histogram of the measured stellar flux for stars used to determine the Y-preflash.

Results of the Noiseless Preflash Test. Analysis of preflashing the WFPC2 CCDs with the calibration lamp, and then reading out this exposure (noiseless preflash) prior to imaging a field in the globular cluster Omega Cen (HD 116790), shows an enhancement of only ~3% in the detected counts for sources far from the horizontal shift register (at Y=800). This indicates that the noiseless preflash electrons are not held in traps long enough to significantly reduce the effects of CTE loss on faint stellar targets.

A series of short and long exposures (16 sec., 80 sec., 400 sec.) were obtained of a field in Omega Cen. Photometry of stars before and after preflashing the CCDs were obtained and ratioed. The mean counts at high CCD Y positions increased by about 3% regardless of the exposure time. This behavior is consistent with a reduction in the CTE photometry ramp. The preflash appears to help only the image following it; the second image after it suffers normal CTE.

References

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http://www.stsci.edu/instruments/wfpc2/Wfpc2_isr (available ISRs)