

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 on photometry. New 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 dozen 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. There is considerable evidence now for a quasi-linear increase in CTE effects with time, due to on-going radiation damage to the CCD arrays in the harsh space environment. We review empirical results on stellar photometry, and preliminary results of new tests on extended targets (faint galaxies). We suggest observational strategies for reducing the impact of CTE, and photometric corrections which can be applied during data analysis.

Physical Effects

We are currently studying the detailed physical effects of CTE in an effort to better understand its photometric impacts. Figure 1 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 $\sim 10^3$ msec)
- (2) Extended tail in +Y direction (decay time ~ 100 msec.)
- (3) Fast decaying tail in +X direction (decay time ~ 10 μ sec)

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).

The brightness profile along the Y-CTE tail is shown quantitatively in Figure 2. While the count levels in the extended tail are low, they make up approximately 2/3 of the total counts displaced from the hotpixel. Clearly the photometric effects will depend on aperture size. Note that the tail is much weaker in the 1994 data, which is consistent with the long-term growth in photometric CTE.

The intensity dependence can be obtained from similar measurements in separate intensity ranges (Figure 3); the total charge in the Y-CTE tail (for 1999 data and background ~ 1 DN/pixel) is approximately.

$$I_{Y-CTE} = 1.2 \cdot I^{0.37}$$

where I is the hot pixel intensity in DN. This relationship, together with Figure 2 and model PSFs, can be used to predict stellar CTE, and the results are in fair agreement with observations.

CTE Effects in Stellar Photometry

The impact of CTE on stellar photometry is a strong function of the background counts in an image. Figure 5 illustrates the CTE loss for background levels ranging from 0.03 to 70 DN for a 2 pixel radius aperture. In the worst case of a low background and $Y=800$, the loss is currently around 40% for targets in the range 20 - 50 DN. A more typical case with background ~ 1 DN (e.g. 300s F555W exposure) and target at the CCD center experiences only $\sim 5\%$ CTE loss. Correction algorithms can then be used to remove much of the remaining effect. See Whitmore, Heyer, & Casertano (1999) for details.

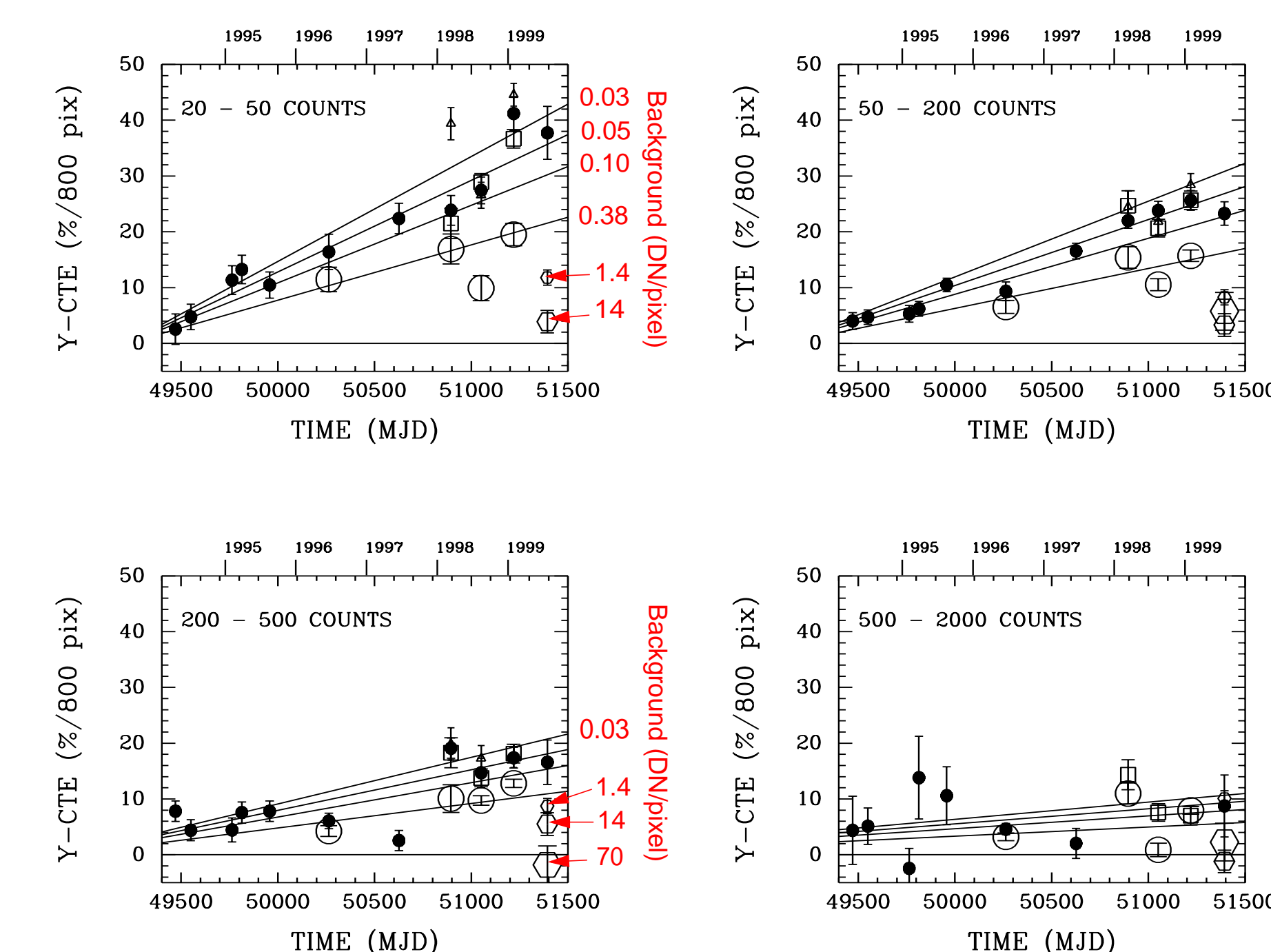


Figure 5: Y-CTE loss as a function of epoch and background level for four different ranges of stellar brightness (counts at gain 14 electrons/DN). The lines represent best-fit multilinear regressions for different background levels (labeled in red). Different symbols correspond to images with different background levels. From Omega Cen data.

Introduction

The CCD detectors in WFPC2 suffer from an imperfect charge transfer efficiency (CTE), which causes images far from the readout amplifier to appear fainter than they would if positioned near the amplifier (near X,Y=1). This effect appears to be increasing with time, presumably due to on-going radiation damage in the space environment. The effect is thought to be caused by localized defects in the CCD, which temporarily trap electrons as the image is being read out. The trapped charge is later released after some time delay, usually after the target has moved some distance away on the CCD. Herein we summarize a number of recent results on the CTE effect in WFPC2. We begin by looking at studies of "physical effects" and later consider practical photometric effects.

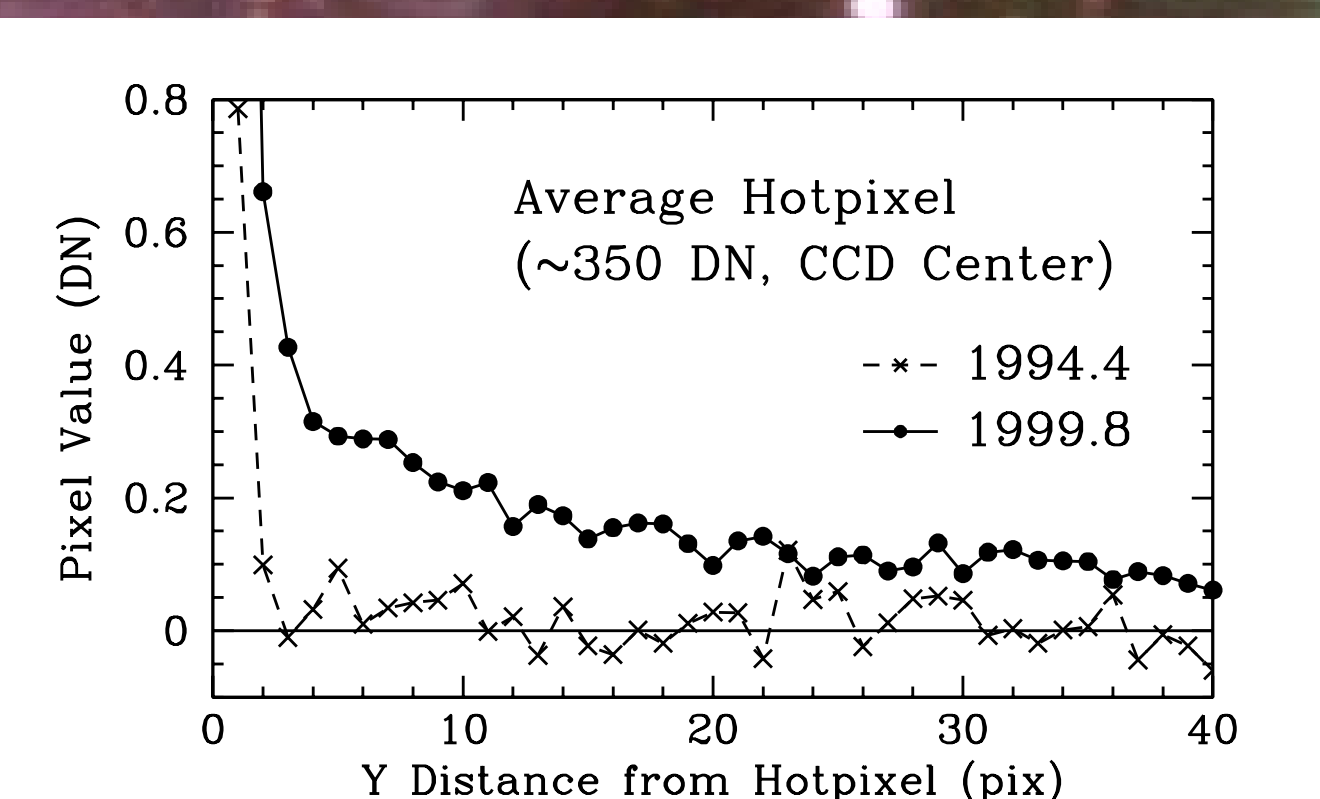


Figure 2: Intensity profile of CTE tail in Y direction for averaged hot pixel (~ 350 DN) in 1994 and 1999.

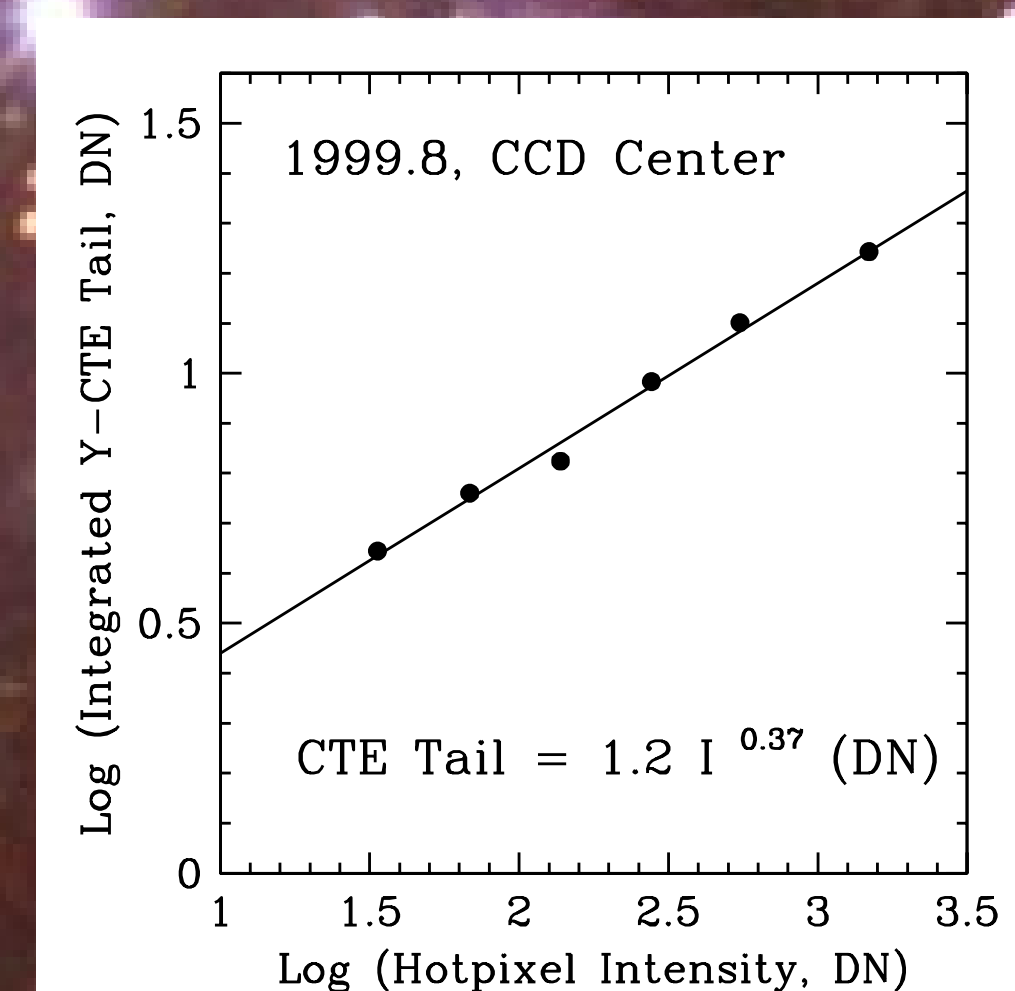


Figure 3: Counts in Y-CTE tail vs. pixel intensity. Data from late 1999 with background ~ 1 DN/pixel.

CTE in Extended Targets

We are currently studying the effects of CTE on faint galaxy images. Preliminary results already show two effects:

- (1) Small aperture photometry on galaxy cores suffers effects very similar to those predicted for stellar photometry.
- (2) The galaxy profile becomes slightly distorted (few %) with counts being removed from the low-Y side of the galaxy.

Long-Term Evolution

CTE causes an asymmetry in the shape of cosmic ray hits, and this can be used as a measure of CTE (Riess, Biretta, and Casertano 1999). This is particularly useful for studying the long-term evolution, since enormous numbers of cosmic rays are available throughout the history of WFPC2. Figure 4 shows the effective number of counts in CTE tails (scaled to X or $Y=800$) as function of time. A quasi-linear increase in CTE vs. time is clearly present, along with preliminary evidence for an accelerating growth rate.

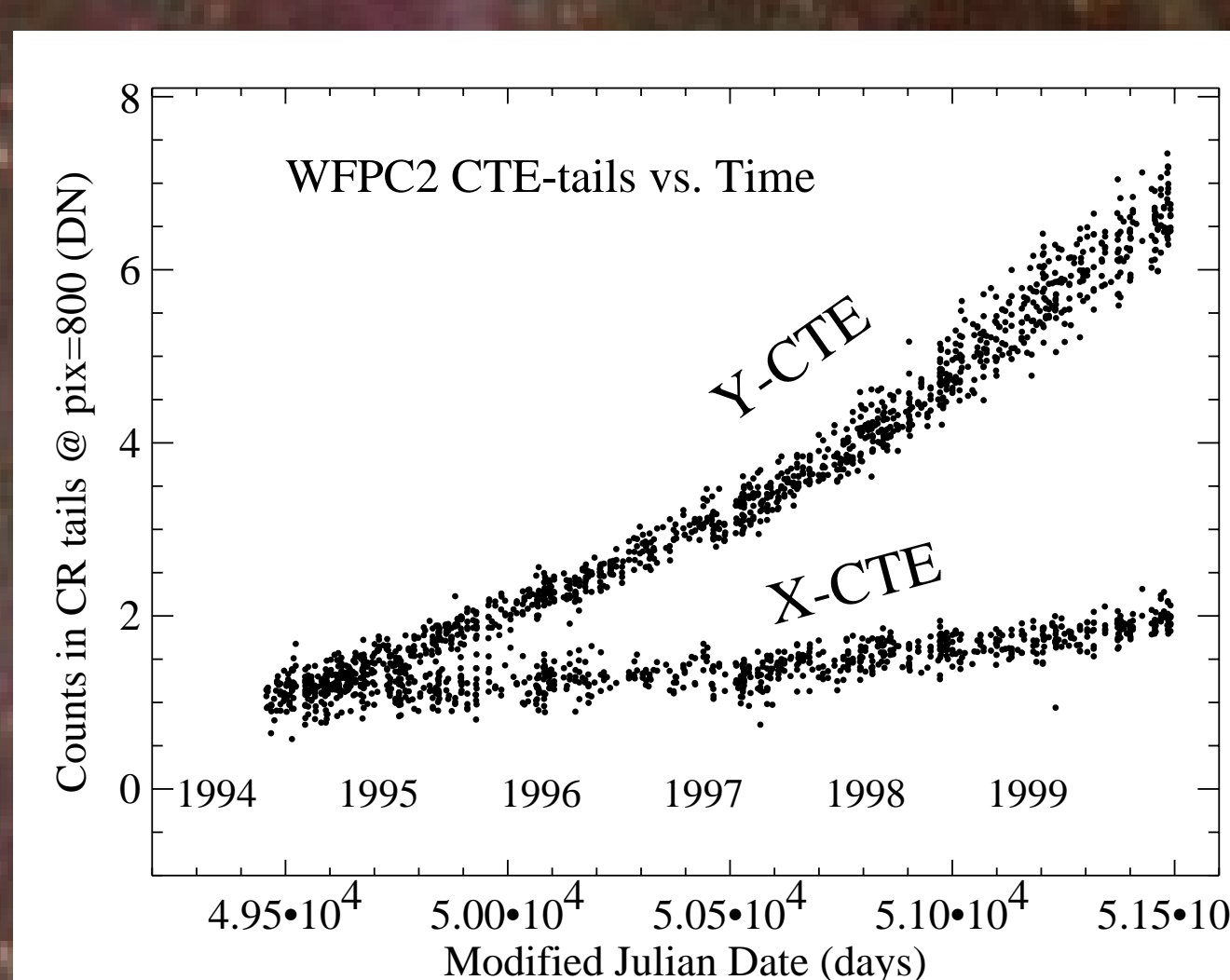


Figure 4: Counts in fast-decay CTE tails vs. epoch. Separate distributions are shown for the X-CTE and Y-CTE. From measurements on cosmic rays.

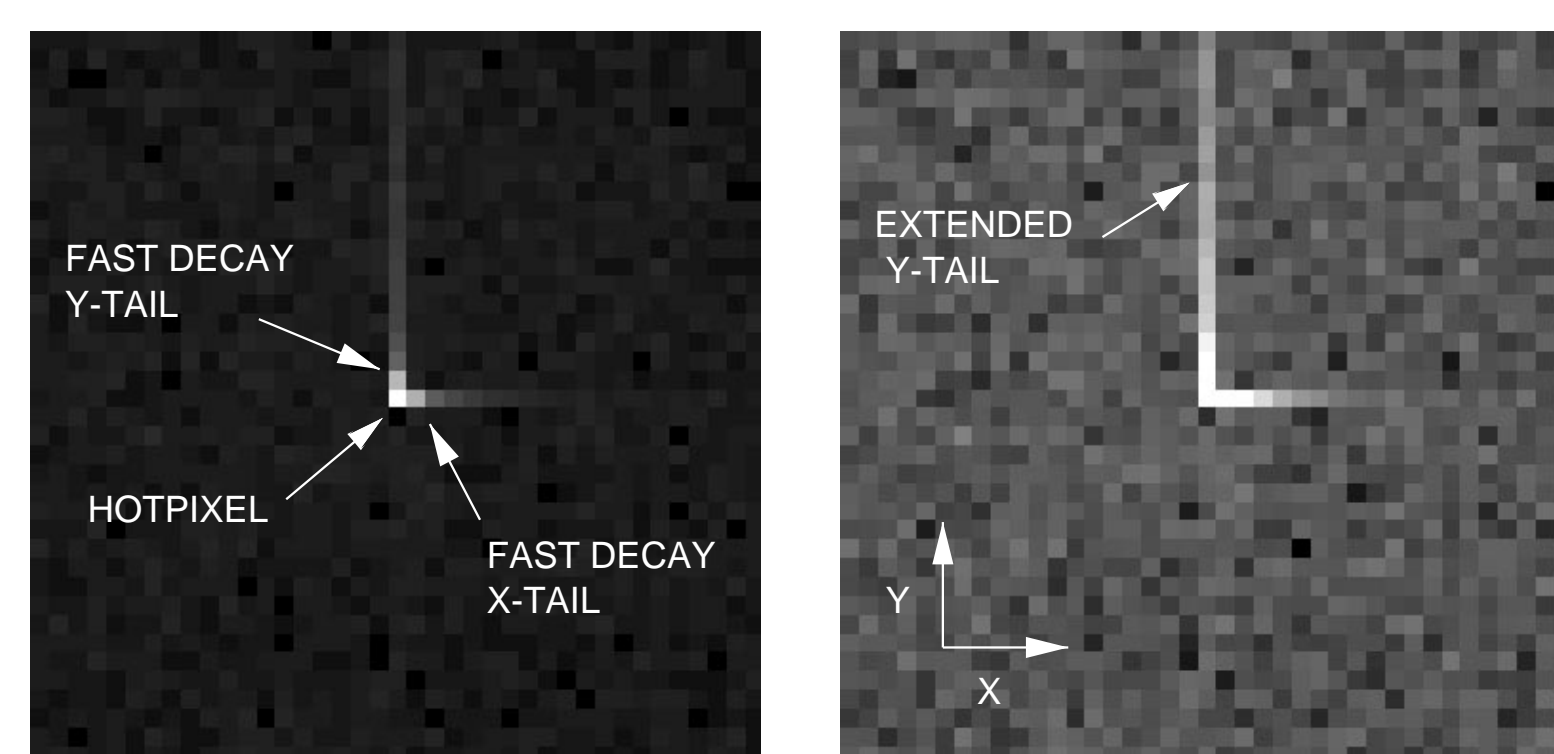


Figure 1: Average of 700 hot pixels illustrating the impact of CTE on a single pixel. Data were taken from dark frames in late 1999 in all four CCDs in region $50 < Y < 750$; hot pixel intensities were in range 100 to 4000 DN. The right panel is the same image enhanced to illustrate faint pixels.

Mitigating CTE in Observations

Observers can use a number of strategies to minimize CTE effects in their data:

- (1) Avoid excessively short exposures, or large numbers of position dithers for a given total exposure. Longer exposures will have higher background, thus reducing CTE.
- (2) Small targets may be placed at low Y pixels on the CCD (closer to readout amplifier) so that fewer charge transfers are seen.
- (3) Preflash: a short internal flat can be taken at the start of an exposure to raise the background. In general, this will only be advantageous for very short exposures where background is otherwise near zero.
- (4) Use post-observation empirical corrections, such as those given by Whitmore, Heyer, & Casertano (1999).