CTE in Space Astrometry

V. Kozhurina-Platais[1], M. Sirianni[1,2] and M. Chiaberge[1,2]

[1] Space Telescope Science Institute,
3700 San Martin Dr. Baltimore, 21904, USA
email: verap@stsci.edu

[2] European Space Agency
email: sirianni@stsci.edu,marcoc@stsci.edu

Abstract. An imperfect CTE in CCD detectors is one of the most important instrumental issues affecting both photometry and astrometry, especially in space-based observations. We discuss the CTE effect in the images taken with the Hubble Space Telescope's, Advanced Camera for Surveys in Wide Field Channel (ACS/WFC). ACS is the only imaging instrument capable of delivering sub-mas astrometry from a single observation, and it is important to take into account any instrumental systematic in positions such as the CTE effect.

Keywords. astrometry, techniques: image processing, instrumentation: detectors

There is a significant Charge Transfer Efficiency (CTE) effect for all CCD detectors used in HST instruments; WFPC2: Dolphin (2000), STIS: Goudfrooij *et al.*(2006), ACS: Riess & Mack (2004), where the CTE effect was discussed in the terms of CTE-induced photometric losses in aperture photometry. However, the images taken with HST in particular with ACS, nominally yield sub-mas precision in differential astrometry. As shown by Kozhurina-Platais *et al.* (2007), the CTE-induced centroid shift depends on the magnitude of a star and its position on the CCD. In the worst case the CTE effect may induce a centroid shift exceeding 0.1 pixel (or 5 mas), that is not acceptable in high-precision astrometry. The *effective* PSF (ePSF) method in combination with distortion solution derived by Anderson & King (2006) for ACS/WFC can reach precisions at 1-2 mas level, which is significantly lower than CTE-induced systematics.

The ACS/WFC detector employs a mosaic of two CCD chips, the each with an array of $2K \times 2K$ pixels. Because of a large number of transfers, the WFC detector is expected to be more affected by CTE. To study the CTE-induced centroid shifts (ΔY), observations of 47 Tuc taken with ACS/WFC with the F606W filter were used. The residuals in X and Y positions between long and short exposures (ΔX and ΔY) derived with ePSF and corrected for geometry distortion, are plotted as a function of position for different ranges of instrumental magnitudes (Fig.1, plot on the left). ΔY on this plot shows a sharply defined discontinuity at Y = 2048. This is a clear indication of CTE-induced centroid shifts in the direction away from the read-out registers, which are located at the top of WFC1 and at the bottom of WFC2. It also shows that the amplitude of the centroid shift depends on the brightness of a star. The centroid shift is negligible for bright stars (mag $\lesssim -6.0$), while it reaches up to 0.15 pixels for faint stars (mag $\gtrsim -4.0$), if they are located far away from the read-out amplifier. As seen in the middle plot of Fig.1, the centroid shift (ΔY) is linear with instrumental magnitude for both chips.

Thus, CTE-induced centroid shift (ΔY) can be presented as a linear function of magnitude and Y, namely: $\Delta Y = a_0 + a_1 \times Mag + a_2 \times Y$. The numerical implementation of the 2-D functional fit was realized by employing a non-linear least-square fit. As a result,
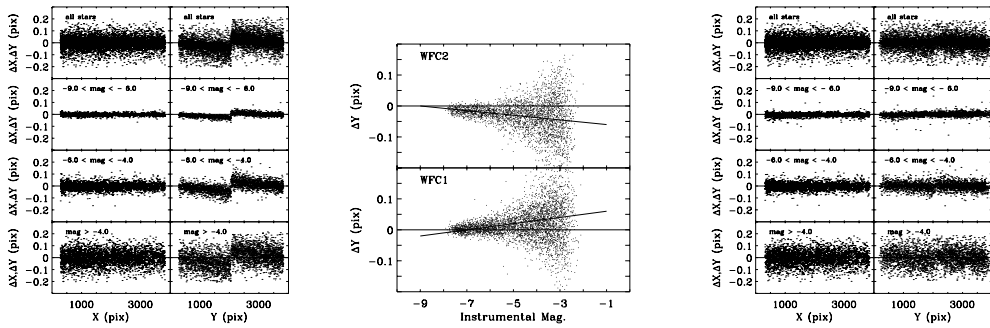
Figure 1. *The left plot* is the difference in X and Y positions between the long and short exposures. From top to bottom, the residuals ΔX (left panel) and ΔY (right panel) are shown for different ranges of magnitudes. The over-plotted lines in the right panels indicate the trend of CTE-induced centroid shift (ΔY) in the direction away from the read-out registers for WFC2 ($Y \lesssim 2048$ pixels) and for WFC1 ($Y \gtrsim 2048$ pixels). *The middle plot* is the centroid shift (ΔY) as function of instrumental magnitude for ACS CCD chips (WFC1 & WFC2 from top to bottom, respectively). The over-plotted solid line represents a linear fit of ΔY vs. instrumental magnitude. *The right plot* is residuals of X (left panel) and Y (right pannel) after the correction was applied, to be compared with plot on the left.

the post-correction residuals show only a small 0.8 mas scatter as opposed to the 10 mas scatter from uncorrected positions (Fig.1, the plot on the right).

The coefficients a_0, a_1, a_2 derived from observations of 47 Tuc with ACS/WFC show the effect of CTE degradation with time (Fig.2). For two ACS WFC CCD chips, a_0, a_1 have a symmetric appearance, whereas a_2 are identical. This is due to the fact that CTE-induced centroid shift depends on the number of transfers (i.e. Y-2048) which are symmetrical for each chip.
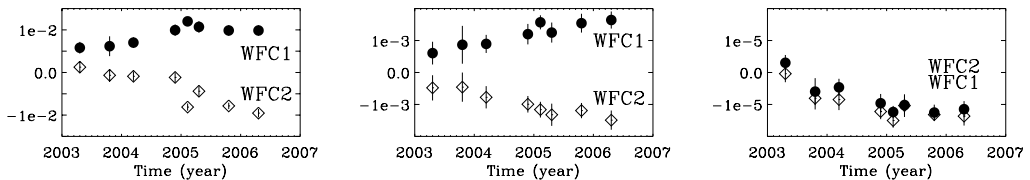

Figure 2. Coefficients a_0, a_1, a_2 (from left to the right) show the CTE degradation with time.

While empirical CTE corrections for the photometric losses have been developed in the past few years for all HST CCD instruments, this is the first attempt to characterize an empirical CTE corrections for astrometry.

References

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