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The Photometric Stability of ACS: Revisiting the Hubble Deep Field

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ABSTRACT

We utilized 10 epochs of 15-tile ACS WFC mosaics imaging the HDFN in the F850lp filter over two years, and originally obtained for the science goal of finding type Ia supernovae at z>1, to examine the photometric stability of the WFC (with at least filter f850lp). Using repeated measurements of 371 stars, we performed a multi-variate linear regression to determine the dependence of photometric variations on the time-dependent components of parallel and serial CTE degradation as well as an overall time-dependence which would indicate a change in the WFC's sensitivity. Despite important differences between the HDFN scenes and those in the original calibration field of 47 Tuc (i.e., source crowding and sky level), we find the losses due to imperfect CTE to be consistent between the two independent calibrations. Interestingly, we also find a decrease in the overall sensitivity of the ACS WFC at a rate of 0.004 +/- 0.001 magnitudes per year (consistent with findings based on 47 Tuc data from work in progress by Mack et al. 2005, in prep.).

Introduction

Few fields of view are ever revisited with HST. Rare exceptions occur for the monitoring of or search for transient objects. However, revisits of fields provide the best opportunities to calibrate the photometric stability of the HST detectors. All previous calibrations of the photometric stability of the Advanced Camera for Surveys (ACS) come from repeated imaging of the rich star cluster 47 Tuc. These images have been used to characterize the time-dependence of the loss of charge transfer efficiency (Riess and Mack 2004) and more recently have shown evidence of an additional loss in sensitivity of the Wide Field Channel (WFC) in time which is independent of pixel transfers (Mack et al 2005; Mack 2004, private communication). We have sought to cross-check these results by independently examining the photometric stability of ACS WFC using observations obtained for science.

A region around the Hubble Deep Field North (HDFN) covering 15 pointings of the ACS WFC (10'x15'; see Figure 1) has been repeatedly observed on 10 separate occasions (at the time of this report, with a few more scheduled) during three years (2002-2004) by 4 programs (GO 9583, 9727, 9728, 10399) in the F850lp bandpass in order to detect type Ia supernovae at z>1. These data also provide the means to examine the photometric stability of the ACS WFC during this time interval.

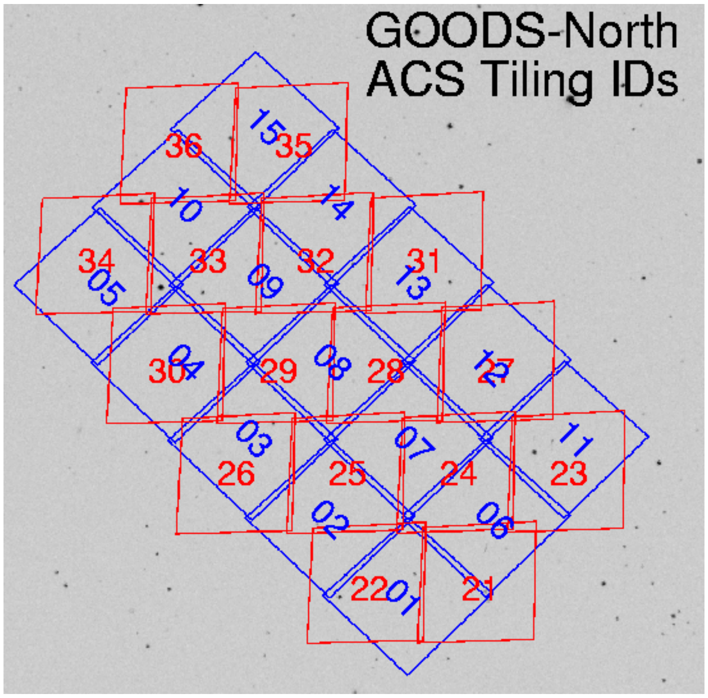

Figure 1: ACS mosaic covering a 10'x15' region of the HDFN.
Repeated footprints of the ACS WFC at 45 degree rotations are shown.
A catalog of 371 stars in the field were repeatedly imaged and used to check the photometric stability of ACS WFC.

There are some important differences between the HDFN imaging and the calibration imaging of 47 Tuc which give reasons for yielding possible differences in the measured photometric stability. The HDFN region is very sparse compared to the 47 Tuc scene (and thus more comparable to most extragalactic programs). Because degraded CTE is caused by charge traps encountered during readout and is mitigated by trap-filling background, nearby stars in the dense field of 47 Tuc may similarly "shield" sources (i.e., fill traps) from charge loss for sources in the same row or column. Another difference between these programs is the exposure times which are brief for 47 Tuc (30 sec) and long (400-500 sec) for the HDFN. Although we do not expect the difference in exposure time to cause a non-linearity in the measured count rates of sources (Gililland 2004), such a non-linearity was seen for WFPC2. Linearity aside, this difference does yield greater sky background for the HDFN (of ~25e vs ~3e for 47 Tuc) and a sky which is more typical of science programs. The overall subtleties of the perceived photometric changes to ACS makes it valuable to characterize them in an independent way and in the same types of scenes and exposure times generally used for science applications.

Observations and Analysis

In order to insure that the epochs of the HDFN were reduced in the same way and with consistent reference files we re-retrieved all of them from the archive on October 30, 2004. The images were processed using the OPUS pipeline version of *calacs* and *multidrizzle*, the latter step automatically rejecting cosmic rays apparent by the 4-dither combinations of each pointing in each epoch.

We used a complete list of 371 stars in each HDFN epoch which were selected as matching the PSF of the telescope from the GOODS mosaic (Moustakis 2004, private communication) and were too faint to be saturated (corresponding to m(f850lp; Vega) > 18.0) and bright enough to yield a signal-to-noise ratio of >10 (corresponding to m < 25.5) in each 1-orbit epoch. Because not every star was seen in every epoch (due to an incompleteness in covering the mosaic's edges) the dataset contained a total of 3164 stellar images. For each star we identified its location in each epochs's imaging, recorded its number of parallel and serial pixel transfers and measured its photometry in a 3 and 7 pixel aperture (using a local sky annulus to subtract the background). To account for the effect of telescope "breathing" or focus variation on the smallest-sized aperture photometry, we adjusted each epoch for variations in the epoch's median difference between the 3 and 7 pixel aperture photometry (this step does not correct for any PSF field-dependence). After this step we used the photometry resulting from the 3 pixel radius because of its greater precision.

To establish a baseline and thereby analyze *differential* magnitudes, we calculated the difference in each epochs's photometry with the *initial* epoch (from September of 2002). We then performed a multilinear regression of the magnitude change for each epoch against the interval of time between the observation and Sept 2002, the differential number of serial transfers, and differential number of parallel transfers. Assuming a linear progression of CTE loss with years on orbit (as in Riess and Mack 2004) the relation assumed in the regression was:

$$\Delta mag = const + cx\Delta X\Delta T + cy\Delta Y\Delta T + ct\Delta T$$

Where *cx* and *cy* are the coefficients of the time-dependent component of CTE-loss and *ct* is the time-dependent sensitivity loss, ΔX, ΔY, and ΔT are the differential (from the first epoch) X and Y transfers and epochs (in years), respectively. (The constant term, const, is not strictly necessary and averaged to an insignificant 0.002 mag in practice, but we included it in case the first, baseline epoch showed a discrete “jump” with respect to the other epochs of a size inconsistent with being caused by a linear regression to the dependent parameters). Due to the expected dependence of CTE on stellar flux we performed the regression in three independent, two-magnitude wide bins centered on bright (41000 e), middle (4000 e), and faint stars (650 e), with ~125 stars per bin. A 3-sigma clipping of outliers was used in the regression to eliminate variable stars.

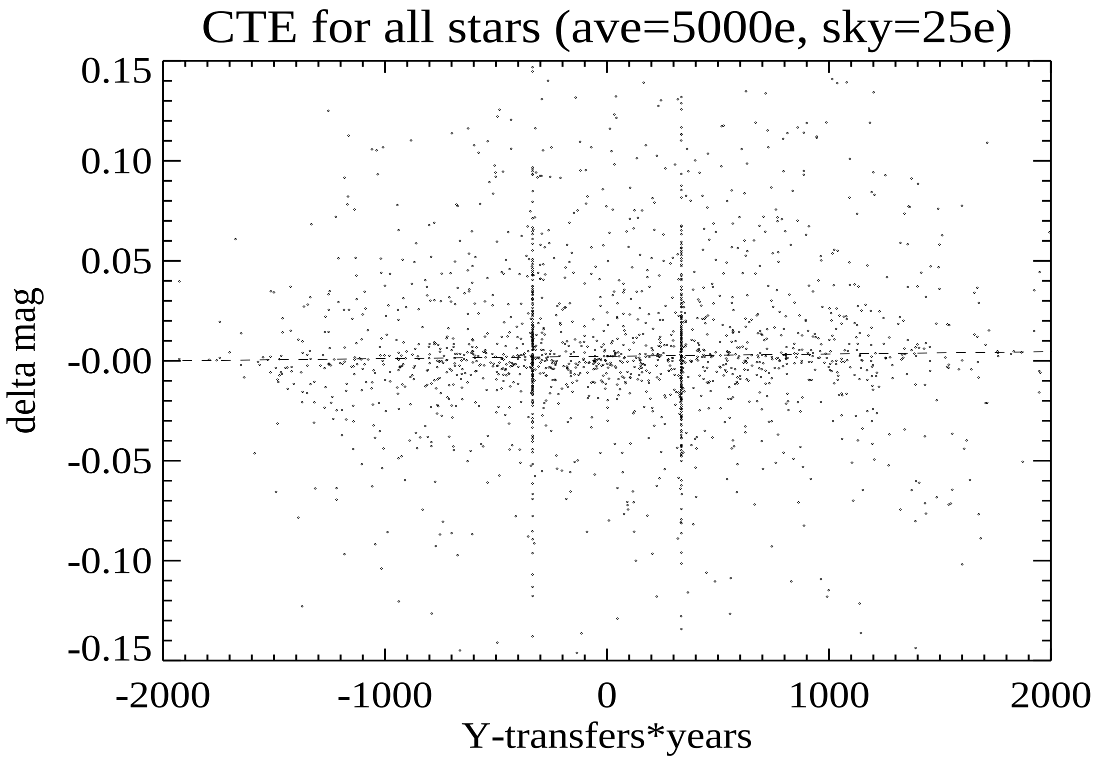

Figure 2: Dependence of photometric residuals on Y-transfers*years from the HDFN campaign data. The average star has 5000e and a background of 25e.
The vertical stripes at +/-300 units on the x-axis result from epochs with parallel orientation (e.g., 180 degrees different). The losses due to imperfect CTE match those calibrated by Riess and Mack (2004) from 47 Tuc. The line-fit was determined these data.

Time-dependent CTE

The CTE-related results derived from the first two terms of the regressions (cx and cy) are given in the Table in units of magnitude loss per 2000 transfers per year (i.e., 2000cx and 2000cy). The only significant losses occur from Y-transfers (imperfect *parallel* CTE) for faint (650e) and medium (4000e) bright stars, with values consistent with those found by Riess and Mack (2004), though with less precision, as seen in the table. (This data in general is not optimal for revealing imperfect CTE because of the limited number of stars, the lack of faint stars in the catalog due to the high galactic latitude and the high sky background.) The consistency of the results indicates that the crowding of 47 Tuc did not significantly affect (i.e., reduce, as might be expected) the CTE losses and that the results from Riess and Mack (2004) should be widely applicable for science exposures. For very bright stars subject to Y-transfers (41000e) and for all brightnesses of stars subject to X-transfers (serial CTE) we see no evidence of charge loss. These results are as expected

(Riess and Mack 2004) who found no evidence of losses due to imperfect serial CTE. The dependence of the photometric losses on Y-transfers*years for all stars is shown in Figure 2 (the average charge of all stars is 5000e). We emphasize that the average stellar brightness in this set is high and the average loss is much lower than would be seen for very faint stars (of a few hundred electrons).

Table: Time-dependent CTE Measurements in the HDFN

	Y-CTE loss/ 2000 trans/ Year(mag)	**sigma**	**Riess and Mack 2004**	**X-CTE loss/ 2000 trans/ year(mag)**	**sigma**
faint(650e)	0.011	0.005	0.008	0.001	0.005
mid(4000e)	0.004	0.002	0.003	-0.002	0.002
bright(41000e)	-0.001	0.002	0.001	0.000	0.002

Time-dependent Sensitivity

We can derive the change in the sensitivity of the ACS WFC with time from the *ct* term in the regression. We averaged the results across stars of all brightness levels (ignoring any possible non-linearity in the sensitivity). We find a *decrease* in the overall sensitivity of the ACS WFC at a rate of 0.004 +/-0.001 magnitudes per year. This decrease is significantly detected and agrees well with the value found independently by Mack et al (2004, private communication) of 0.003 mag per year using 47 Tuc observations. The photometric variation as a function of time can also be seen by binning the residuals in each epoch as seen in Figure 3, though this kind of analysis is not identical to the regression (which simultaneously fits the CTE and sensitivity effects). The overall decrease in sensitivity is small, reaching only 1% of the flux after ~2.5 years (the total on-orbit time for ACS to date) but may be important for some, time-sensitive science applications and may ultimately necessitate an update to the ACS zeropoints. Additional studies may also determine if there is a color (or filter-to-filter) dependence of the sensitivity decline (Mack et al. 2005).

At this time we can offer no explanation for the change in sensitivity. Results from Mack et al. should include data from the HRC which, if consistent with the WFC, may direct the origin to the OTA rather than the WFC detector, contamination on the mirrors along the path to the WFC, or individual filter effects.

We thank Jennifer Mack for providing results from her work in advance of completion and for helpful discussions. We thank members of the observing teams who acquired this rich data of repeated observations of the HDFN. We thank Ron Gilliland and Roeland van der Marel for reviewing this work.

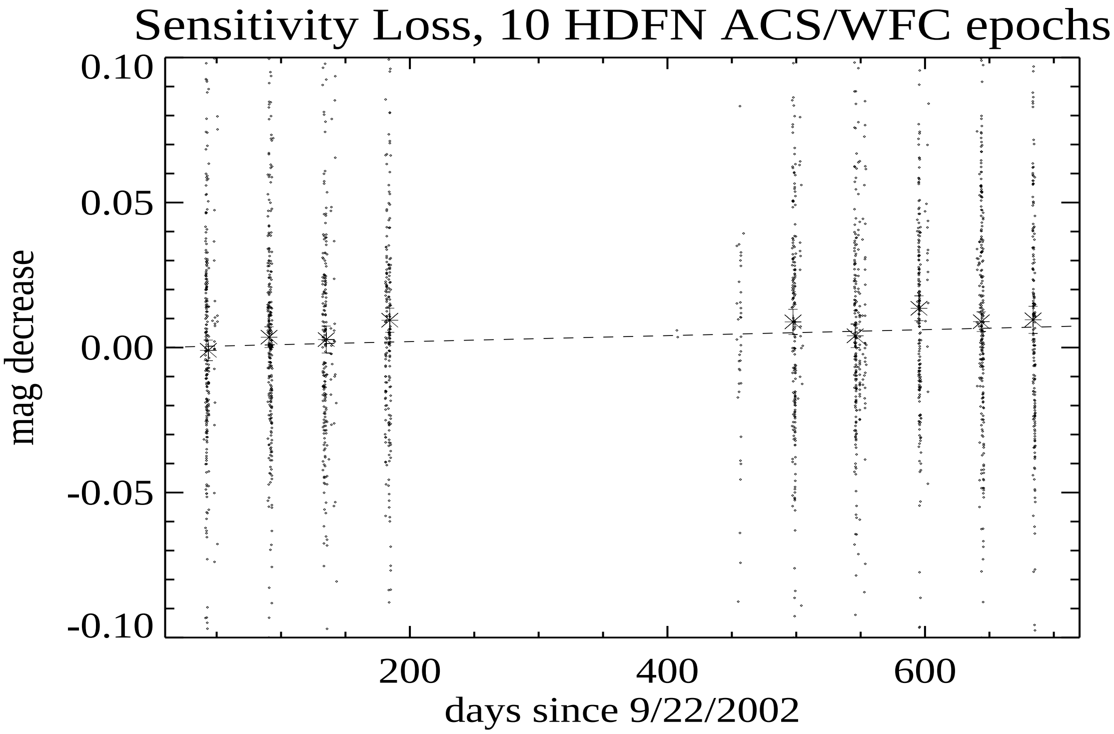

Figure 3: Dependence of photometric sensitivity on epoch for the HDFN since Sept 2002. Crosses with errorbars show the average and its error for the measurements in each epoch. The line shows the results of the multivariate regression. The regression simultaneously fits CTE so is not identical to the binning process. We find a *decrease* in the overall sensitivity of the ACS WFC by a rate of 0.004 +/- 0.001 mag per year.

References

Riess and Mack 2004, ISR, ACS 2004-006

Mack et al, 2005, in progress,

Gilliland 2004, ISR, ACS 2004-001