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FLUX CALIBRATION OF THE ACS CCD CAMERAS I. CTE CORRECTION

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Abstract

The flux calibration of HST instruments is normally specified after removal of artifacts such as a decline in charge transfer efficiency (CTE) for CCD detectors and optical throughput degradation. This ISR deals with ACS/WFC CTE losses, which had been considered negligible for bright stars prior to the demise of the ACS CCD channels on 2007 Jan. 27. Following the revival of ACS WFC during the Servicing Mission 4 (SM4) in 2009 May, CTE corrections are now typically several tenths of a percent and should be included, even for our bright standard star observations that utilize a standard reference point which is only 512 rows from the CCD amplifier B readout corner. For such bright standard stars with negligible background signal, a simple correction algorithm with an accuracy of better than 0.1% is derived, which eliminates the need to execute the CTE correction code for the complete image.

Introduction

In order specify a flux calibration for imaging data, the photometry must be corrected for the non-linear effects of charge transfer losses. CCD detectors degrade with time on orbit due to bombardment by high-energy cosmic rays (CRs). This efficiency in transfering the charge from row-to-row has been decreasing since installation of ACS into HST on 2002 March 7. During read-out, the damaged pixels trap charge temporarily and reduce the measured signal in the aperture photometry of stars. Absolute calibration observations utilize bright stellar flux standards close to the readout registers at the WFC1-1K reference point, in order to minimize transfer losses. Nevertheless, the background is near zero for these short exposures, and the CTE losses are not completely negligible.

This ISR is the first (I) in a four part series that will culminate in IV with a new flux calibration for the ACS CCD detectors. ISRs II and III will deal with the change in sensitivity over time and with the aperture corrections, respectively. The sensitivity changes found from repeated observations of the flux standards will be compared with the results from repeated observations of the 47 Tuc field. Previous ACS flux calibrations utilized no CTE correction (Bohlin 2007, Sirianni et al. 2005).

Analysis

The impact of CTI=1-CTE on aperture photometry is complicated. The larger the aperture, the better the chance that the trapped charge will be released within the aperture and, thus, still counted for the star. At the same time, a larger aperture means that source pixels with low flux are included in the aperture; and these low pixel values suffer the most from CTI. For these reasons, a parameterized correction for CTI must include the sky background, the aperture size, and the source brightness. While such corrections are available (eg. Chiaberge, et al. 2009), the parameterization includes the sky to a power, which is inappropriate for small background signals that are often slightly negative.

Fortunately, there exists another way to make such a correction: The Anderson & Bedin (2010) algorithm specifies the CTE correction for every pixel of a WFC image. Using the observed image as the starting point, their algorithm provides an estimate of the original pixel distribution that was present before the charge-smearing readout process. This correction implicitly accounts for all the above issues. Although not perfect for low-charge, low-background levels, photometric tests indicate that the Anderson & Bedin algorithm is accurate to 25% of the computed correction. Their correction for negative pixel values is straightforward and is specified without ambiguity.

Six typical standard star exposures are corrected, using the individual flat field corrected (*flt*) images as input (see Table 1). To remove noise, the corrected *flt* image pairs are combined with a CR rejection algorithm into a *crj* image. The uncorrected images are similarly combined and aperture photometry is derived from the *crj* images for radii of 3, 7, 13, and 20 pixels. The 20 pixel photometry corresponds to a one arcsec radius for the WFC and is the reference aperture for the absolute flux calibration. The ratio of uncorrected to the corrected *crj* photometry provides a measure of the CTE losses as shown in Figure 1. In order to define the correction at lower signal levels, a fainter star is identified and measured on the VB8 F850LP image.

The large apertures used for the absolute flux calibration require exquisite precision in the measured sky background. Because of the striping in the background that is caused by the ASIC electronics installed in SM4 (Grogin et al. 2010), the sky level is best measured in rows corresponding to the location of the bulk of the stellar signal. For our photometry, the image is filtered with at 21 pixel median and then the 41 CCD rows centered on the y-location of the star are used to define the sky level. In particular, the 41 row average is again averaged over the 120–220 pixel range (6–11 arcsec) on either side of the stellar source to define our background levels.

If CTE is measured per row y as counted from the bottom of chip 1 at y=0, the distance from the read-out amplifier at the top of the chip is 2047-y and the total charge efficiency, i.e. the correction C, is

$$C(y) = CTE^{(2047-y)} \ , \tag{1}$$

where CTE is the average transfer efficiency from row to row, eg. CTE=0.99998 for a 1% loss at 512 rows from the amplifier. Figure 1 shows that the loss of signal, or charge transfer inefficiency CTI, can be fit to better than 0.1% accuracy with a linear fit in the log with coefficients (a, b), so that

$$CTI = 1 - CTE = 10^{a+b \ log(E)} \ , \tag{2}$$

where E is total number of electrons in the measurement aperture. Table 2 contains the coefficients for four aperture sizes.

Equation 2 is valid for the epoch of the observations in Table 1, i.e. 2009.6. Assuming a linear dependence of the CTI with time (t) and for CTI=0 at 2002.2 when ACS was inserted into HST, the full equation for the ACS/WFC CTE correction becomes

$$CTE = 1 - T \ CTI = 1 - T \ 10^{[a+b \ log(E)]} \ , \tag{3}$$

where

$$T = (t - 2002.2)/7.4 \ . \tag{4}$$

Bohlin & Goudfrooij (2003) and Goudfrooij, et al. (2006) provide similar correction algorithms for the STIS CCD detector.

Star	*R.A.* J2000	*Decl.* J2000	Filter	x (px)	y (px)	Date	Exp. (s)	electrons s^{-1}
GD153	12 57 02.37	+22 01 56	F435W	3568.8	1533.1	2009.605	3	117854
P330E	16 31 33.85	+30 08 47	F606W	3550.2	1540.3	2009.600	2	259219
VB8	16 55 35.1	-08 23 44	F435W	3590.5	1533.6	2009.605	125	524.8
VB8	16 55 35.1	-08 23 44	F850LP	3590.4	1534.3	2009.605	3.5	174477
...	...	...	F850LP	3494.5	1205.4	2009.605	3.5	10182
KF06T2	17 58 37.9	+66 46 52	F435W	3566.4	1548.6	2009.605	20	16867
KF06T2	17 58 37.9	+66 46 52	F550M	3566.3	1549.3	2009.605	7	24325

Table 1: *Photometry Corrected for CTE. The exposure time is for one image of the CR-split, flt pairs; and the measured electrons s^{-1} is in a 20 pixel, one arcsec radius aperture. A second star is measured on the VB8 F850LP image.*

Coef.	Aperture Radius (px)			
	3	7	13	20
a	-2.60	-2.71	-2.77	-2.60
b	-0.474	-0.465	-0.479	-0.543

Table 2: *Coefficients for the linear fits to the log of the CTI.*

Summary

Our correction formula for the effects of CTE losses in the ACS/WFC can be used in lieu of computing the fully corrected images with the Anderson & Bedin (2010) code. However, our algorithm is valid only for bright stars with a total signal greater than 20,000 electrons in the extraction aperture and for short exposures with negligible background signal. The accuracy of the correction is better than 0.1%, i.e. better than one-sigma of the Poisson photon statistics.

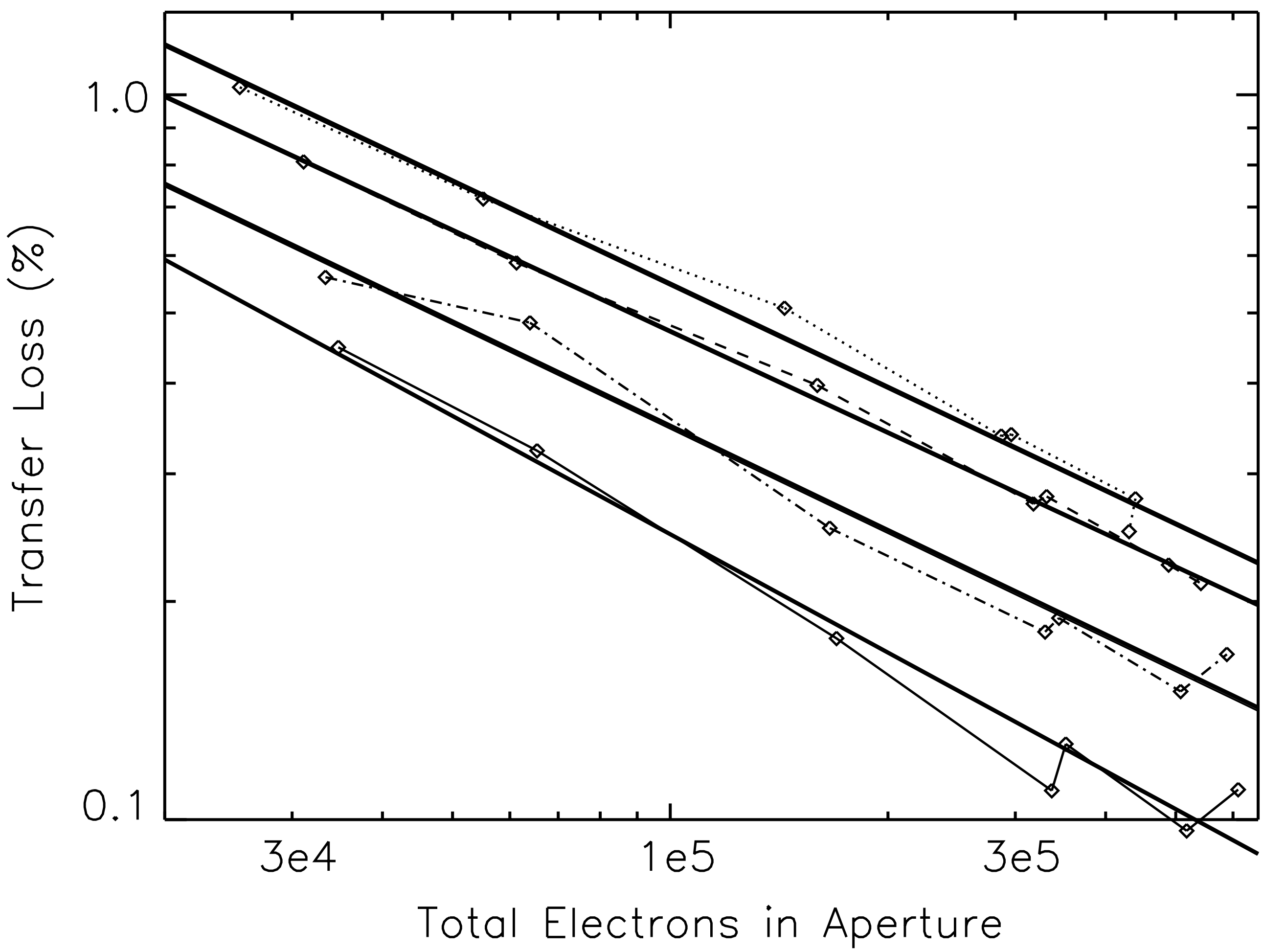

Fig. 1.— CTE losses in percent for four extraction apertures of 3, 7, 13, and 20 pixels in radius from top to bottom. The diamond points are the measured losses defined by the ratio of the uncorrected to the corrected photometry, while the heavy solid lines are the linear fits in log-log space. The measurements are converted to the expected CTE loss at 512 pixels from the B amplifier. Every stellar image is close to this row 1535, except for the faint star at row 1205.

References

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