The Efficacy of Post-Flashing for Mitigating CTE-Losses in WFC3/UVIS Images

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Abstract

We report on a set of calibration observations taken recently to demonstrate the effectiveness of post-flashing on preserving signal from CTE losses. A study of warm pixels (WPs) in dark exposures has shown that CTE losses in UVIS are pathological for charge packets smaller than 10 to 12 electrons (Anderson 2012), but when packets are larger than this, the losses become less severe. This suggests that if we could introduce a background of only about 12 electrons, we might be able to markedly improve charge transfer efficiency. For this reason, the Institute and Goddard have fast-tracked a procedure for adding post-flash flux to images. The procedure was validated using internal observations in May 2012. More recently, external observations have been acquired to demonstrate the effectiveness of the mitigation on real science data. This report summarizes our findings and shows that by adding only 12 electrons background to an image, users can reduce losses for low S/N sources from the pathological level of more than 90% to a moderate level of about 15%. Adding more electrons than this does not result in additional improvement, so 12 electrons should be seen as a “sweet spot” for the UVIS detector.

A recent White Paper (MacKenty & Smith 2012) provides a variety of ways to address CTE issues in WFC3/UVIS and ACS imaging. The results presented here reinforce the general findings of that paper, adding specifics about the mitigation achieved as a function of the background in the image (see Baggett & Anderson 2012). Cycle 19 and Cycle 20 WFC3/UVIS users should take note of these results in planning (or re-planning) their Phase-2 submissions.

The Observations

Program CAL-12802 (PI-MacKenty) observed the center of Omega Centuri on 26 July 2012 for three orbits through the F336W filter. The goal of the program was to demonstrate the effectiveness of post-flash background at mitigating the CTE losses in WFC3/UVIS with a typical science target. The center of Omega Centauri was chosen to provide a nice, even, uncrowded distribution of stars. The F336W filter was chosen in order to suppress the light from the giants so that the stars at the turnoff can be studied without significant interference (or background) from brighter neighbors. The cluster luminosity function is generally flat below the turnoff, such that we have an even distribution of stars at all brightness levels of interest.

This program had several components. The main focus was to take pairs of short (10s) exposures and long (700s) exposures at a variety of background levels. In the deep exposures, the turnoff stars get about 30,000 electrons in their brightest pixel, and in the short exposures they get about 400 electrons. The deep exposures suffer much less fractional CTE losses and tell us the "truth" (how many counts each star should receive in a 10-second exposure). The short exposures tell us how many counts survived the parallel-transfer process as a function of (1) star flux, (2) sky background, and (3) number of transfers. A detailed report on the data set is in progress.

An auxiliary component of the experiment was to take some images the same way science data are typically taken. Namely, we took a set of 9 tight dithers of the scene with and without post-flash, so that we can generate the stacked data products that users are most familiar with. Stacking is the only way to detect low S/N sources, so it is natural to demonstrate CTE losses and mitigation this way. This stacked data set will be the main focus of this report.

The Stacks

We have three sets of data to work with: a set of 8 dithered, deep (700s) full-frame exposures, a set of 9 dithered, short (10s) 2048×2048 subarray exposures with no post-flash, and a similar set of 9 dithered, short exposures with 14 electrons post-flash.

We used an in-house procedure to align the images and stack the pixels into a ×2-supersampled distortion-corrected frame. The stacking was done with an effective pixfrac of 1, which means that the output pixels are somewhat correlated with one another. This should not affect the trends we see in our data.

We show in Figure 1 the results of our stacking procedure. The image on the left corresponds to the deep exposure, which should be only marginally impacted by CTE losses. This image tells us what the shallower images *should* look like, CTE losses and noise issues aside. The unflashed image is in the middle panel, and it shows clear evidence of CTE trails and CTE dropouts (stars D and A cannot be seen in the middle image). The right panel shows the post-flashed image. The trails are reduced considerably, and many stars lost in the unflashed exposure are recovered in the pre-flashed exposure. The images in Figure 1 provide a clear qualitative demonstration of how a little bit of background can preserve even small charge packets of signal.

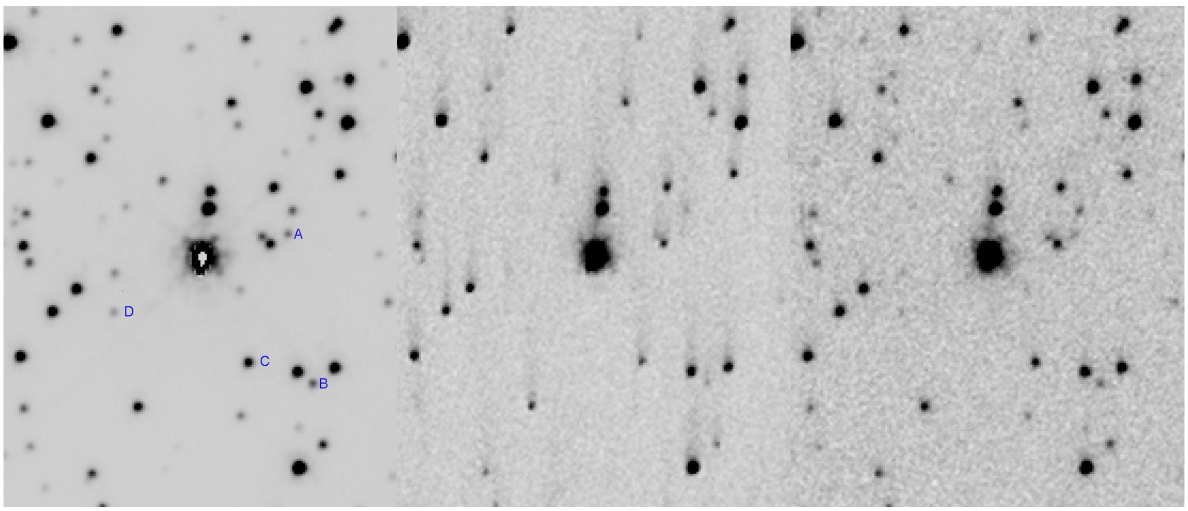

Figure 1: This shows a ×2-supersampled stack of a part of the Omega Cen field far from the readout amplifier. The left image shows the stack from the eight 700s exposures; the middle image shows the stack from the nine 10s exposures with no post-flash (natural background ~2 electrons); and the image on the right shows the stack from the nine 10s exposures with post-flash (total background ~16 electrons). All images have been scaled and zero-pointed to be as similar as possible. The deep stack tells us that Star A (identified in the left panel) should have 22 electrons above sky in its central pixel in the short exposures; Star B should have 28 electrons; Star C should have 65 electrons; and Star D should have 13 electrons. The Stars A and D are completely lost to the unflashed image, but can be clearly detected in the post-flashed image.

We can also use the stacks to make a more quantitative assessment. To do this, we used an automated routine to identify all the sources in the stack. We then measured fluxes (above sky) within a 5×5-pixel aperture that was centered on the star's central pixel. Fluxes were measured for each star in each of the three stacks (8×700s deep, 9×10s short without post-flash, and 9×10s with post-flash). We then compared the observed fluxes in the short exposures against what we would expect from the deep exposures.

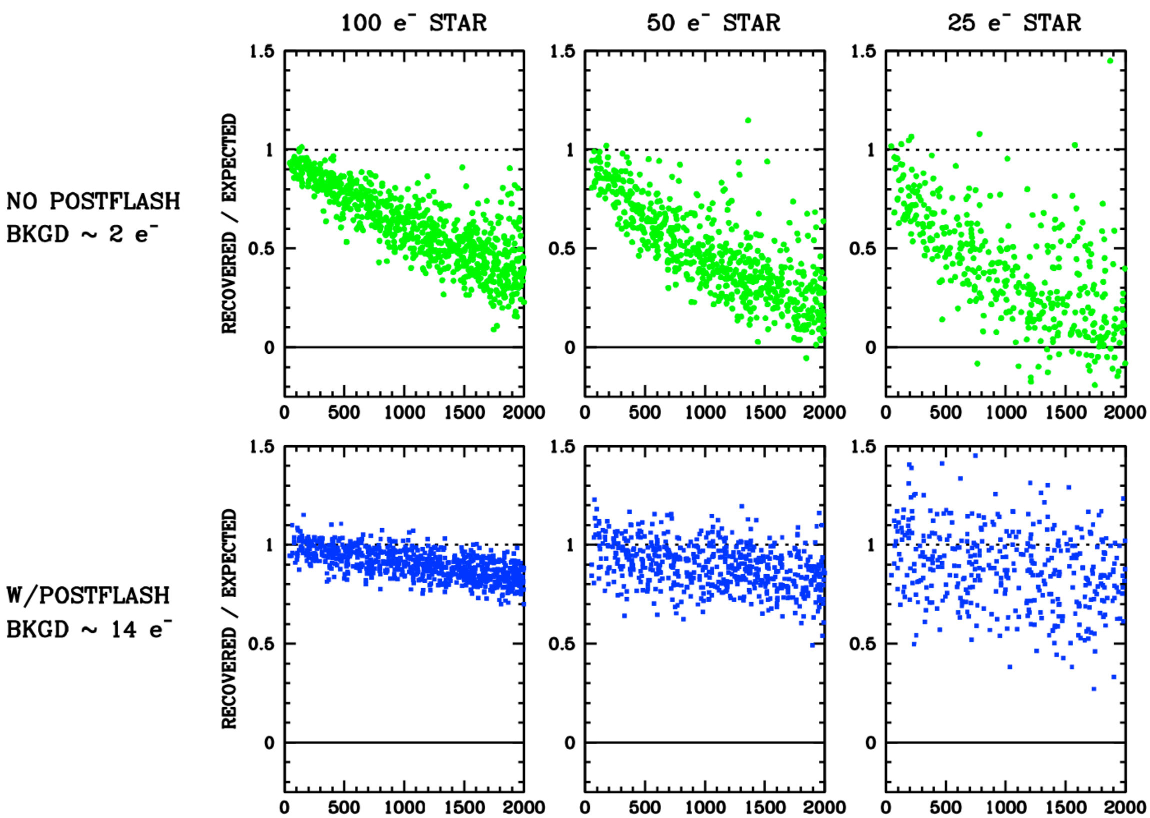

Figure 2: We show the observed fluxes for three brightness levels of star for unflashed (green) and post-flashed (blue) observations. On the left we show a star that the deep exposures tell us should have ~100 electrons within a ~3×3-pixel aperture in an individual short exposure. Each point is a star at a particular location on the detector. We plot the recovered flux fraction as a function of the number of parallel transfers (just the raw y coordinate of the star). The middle panels show stars with ~50 electrons, and the right panels a star with ~25 electrons in the aperture. The upper panels show the number of electrons that remained within the aperture during the parallel-transfer journey to the readout register. The top panels show the results for the stacks made from unflashed images, and the bottom panels show the results for the post-flashed images. It is clear that losses go from severe (70%) at the moderate S/N level to pathological (>90%) at the low S/N level for the unflashed images. But even the lowest S/N sources in the post-flashed images retain ~85% of their electrons.

Figure 2 summarizes our findings. In brief, we find that faint stars on low backgrounds can be completely trailed out of existence by charge-transfer inefficiency. However, even a small amount of background, be it natural or via post-flash, can serve to keep the charge traps filled, so that signal from sources can survive the journey to the readout register with only minimal losses (~15%).

Sensitivity to Background

It is clear from the previous images and plots that a moderate background can have a very salutary effect on CTE. One of the goals of this calibration program was to determine exactly how much background is needed to achieve good transfer efficiency. In this section, we do a quick reduction of the other half of the data to get a rough answer to this question.

The short-deep portion of this data set involves 10s short exposures at various post-flash levels at the same pointing as a 700s deep exposure through the same F336W filter, so that the deep exposure can tell us how many electrons each star started out with in the short exposure, and the short exposure tells us how many electrons actually survived to the readout register (within the aperture). Since the pointings are identical, we do not need to worry about PSF-fitting or aperture corrections: we can simply compare sky-subtracted aperture fluxes directly.

To construct Figure 3, we have identified stars that the deep exposures say should have roughly 100 electrons within their central 3×3-pixel apertures. We focus here on stars that should suffer the largest CTE losses, namely those more than 1750 pixels from the serial readout register. Each point in the plot corresponds to a star observed in one short exposure. We plot the observed aperture flux against the observed sky value. There is a very clear trend. When the sky background is low, we detect only 30 or so electrons in the aperture (compared to the 100 electrons we would expect). As the sky background increases, we detect more and more until the background reaches about 12 electrons. At this point, we detect 85 out of the original 100 electrons. It is worth noting that *adding background beyond this does not improve transfer efficiency.* Even adding 30 electrons background still results in 85 electrons being detected. Of course, increasing the background to 30 electrons increases the noise by more than a factor of $\sqrt{2}$, and that is clearly not desirable.

In summary, data taken in late July 2012 clearly demonstrate the effectiveness of having ~12 electrons background in UVIS images. Some images will have natural backgrounds, so post-flash will only be needed to bring the total background up to 12 electrons. Cycle 19 and 20 WFC3/UVIS users should take these findings into account in planning (or re-planning) their observations. Baggett & Anderson (2012) report on the observed background count rate in actual UVIS science exposures through various filters, so users should consider a post-flash level that will bring the total up to 12 electrons.

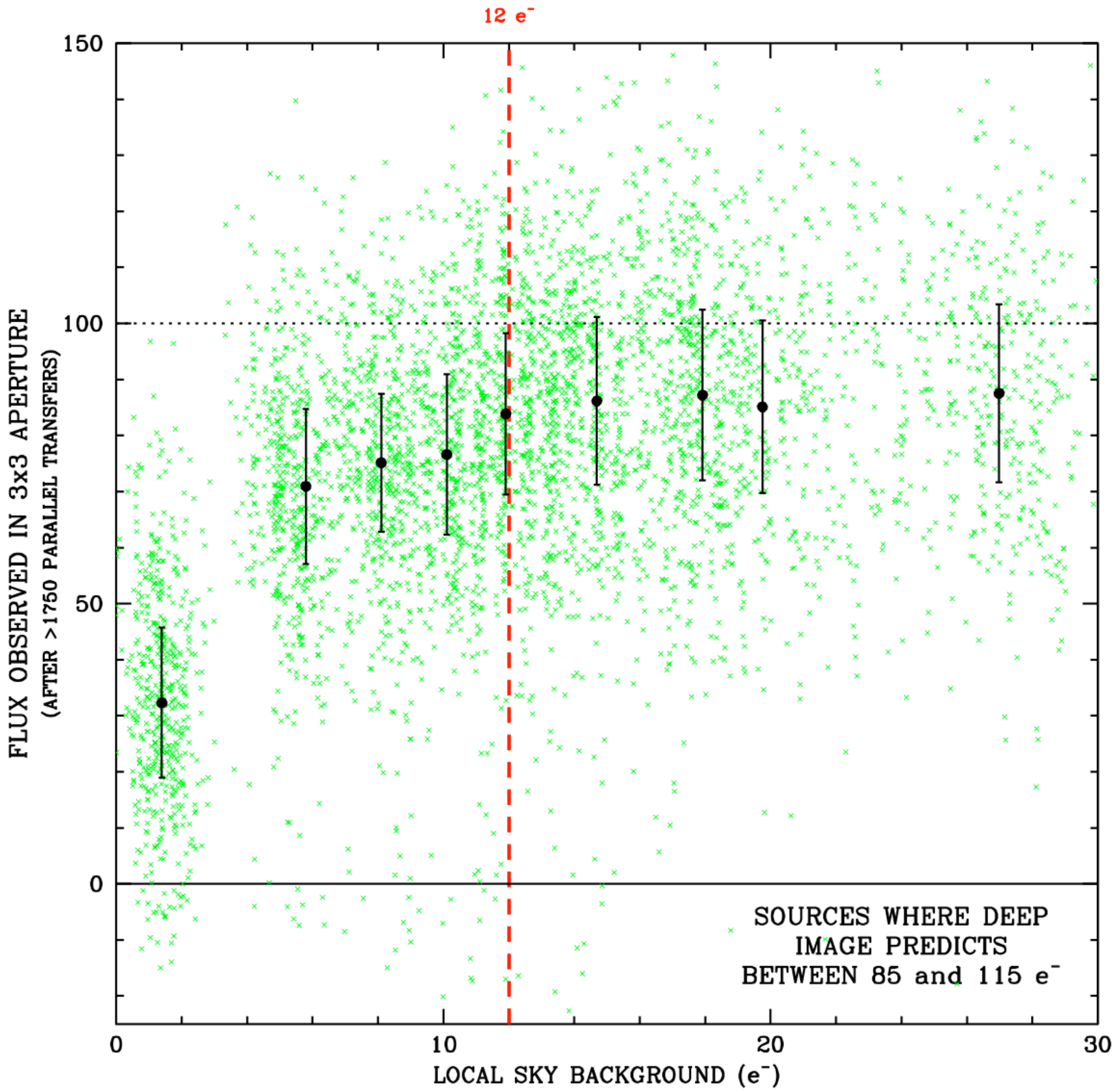

Figure 3: Each green point in this figure represents a star that started with ~100 electrons in its central 3×3 pixels at the top of the chip (far from the readout register). These points come from several exposures that were taken with a wide range of post-flash backgrounds, from no-post-flash (2 electrons natural background) to 25 electrons post-flash (for a total of 27 electrons background). The observed flux within the aperture is plotted as a function of sky background. It is clear that when the background is low, the detector records about 30% of the original ~100 electrons; but when the background increases, the number of observed electrons increases as well. Once the background reaches 12 electrons, however, the improvement plateaus with 85% of the original charge surviving the transfer all the way down the chip to the readout register. The solid points show averages and inter-quartile ranges for selected sky bins.

Future Plans

This report has focused primarily on the dithered-stack portion of the recent Omega Cen data set. Most of the data for program CAL-12802 were taken in short-deep pairs to allow an accurate calibration of the impact of background on the formula-based photometric correction (as in Noeske et al 2012) and to allow a real-world evaluation of the upcoming pixel-based correction (as is already included in the ACS/WFC pipeline). The improved photometric corrections and the pixel-based correction should be available during Cycle 20.

It is worth underlining, however, that both of these corrections work best when CTE losses are small. Indeed, there is *no* way to restore the flux of a faint source on a low background that has been trailed out of existence. Therefore, any kind of mitigation of CTE losses that can be achieved before processing — either by ensuring adequate background or by a judicious observation strategy — will make the corrected data all the more accurate.

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