ACS and WFC3 Calibration Improvements: Lessons from *Hubble* Frontier Fields

Sara Ogaz, *ogaz@stsci.edu*, **Roberto J. Avila,** *avila@stsci.edu*, **Bryan Hilbert,** *hilbert@stsci.edu*

Introduction

Hubble Frontier Fields (HFF) is an ongoing *Hubble Space Telescope* cross-instrument multi-cycle Director's Discretionary time program (PI J. Lotz/M. Mountain)[1] that will observe six lensing clusters of galaxies with both the Advanced Camera for Surveys (ACS) and the Wide Field Camera 3 (WFC3). In the past, many large *Hubble* proposals have been drivers of calibration improvements, and this side benefit is an important part of executing HFF, too. A priority of HFF is to make the new methods available to the astronomy community. The purpose of this article is to describe several calibration improvements due to HFF.

SELFCAL

The SELFCAL algorithm, written by Jay Anderson, can detect small-scale artifacts that are not corrected by the ACS default pipeline and reference files. SELFCAL uses multiple dithered images of the same field, and tracks the pixel values that move with the dither from those that don't. The consistently moving pixel values, called the "science" image, are tagged as real astronomical sources and sky background. Other artifacts, like hot pixels and amplification offsets, which are present in a majority of the image set but do not move with the dither, are compiled into a final image called the "delta dark." The delta dark is then subtracted from each of the original science images. For HFF, we see a 20% increase in signal-to-noise ratio (S/N) after SELFCAL processing [Anderson, in prep]. Figure 1 shows a HFF image with and without the SELFCAL correction. In the final HFF mosaics we see a 0.5 magnitude improvement in the depth of the cluster field after SELFCAL has been applied. The SELFCAL software is available for public use, although unsupported by the Institute. More details can be found online.[2]

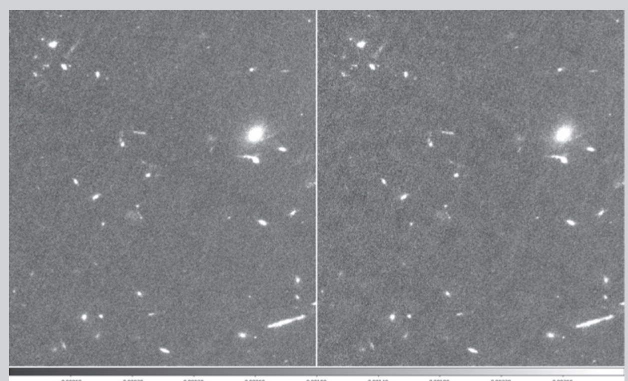

Figure 1: Final drizzle combined *Hubble* Frontier Fields image of cluster Macs 0416 in ACS/F435W. *Left:* The image has been processed with SELFCAL. *Right:* The image with standard CALACS processing.

ACS de-striping

Following Servicing Mission 4 and the replacement of the CCD electronics box, ACS has suffered from row-correlated noise, called "striping." Nevertheless, this noise is consistent enough that it can be modeled and removed. There are currently two solutions in place to subtract the noise from images. The first solution is part of CALACS, which calculates the correction using the physical prescan area (columns of pixels at the sides of each chip that are not exposed to light). Unfortunately there are not many prescan pixels to work with, so this correction is not reliable for some near-edge cases. The second solution—packaged as a stand-alone PYTHON code—uses the actual image pixels to calculate the stripe noise.

A vulnerability of this second approach is that bright objects in the image can throw off the stripe calculation. To solve this, the ACS team has included an option in the stand-alone de-stripe code to provide an object mask. The masked pixels will not be used for the stripe calculation. A new PYTHON script released by the ACS team, called ACS_DESTRIPE_PLUS, has combined these changes with the ACS charge transfer efficiency (CTE) correction and the regular components of the CALACS pipeline,[3] allowing users to easily take advantage of these improvements to the standard pipeline. Figure 2 shows the two versions of an ACS image, one processed with ACS_DESTRIPE_PLUS and one processed with default CALACS.

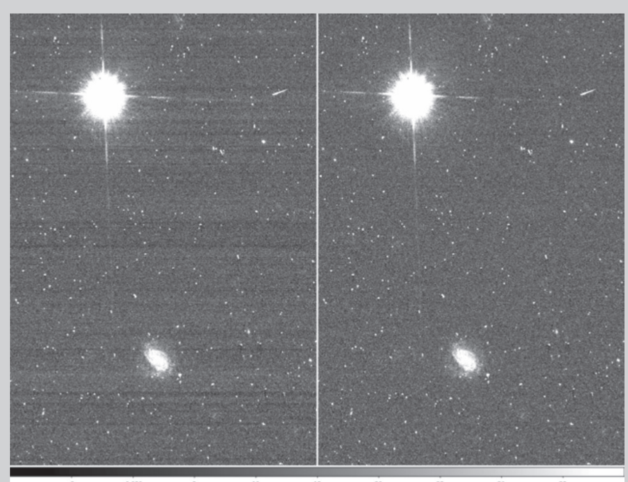

Figure 2: *Left:* A 2013 ACS sub-array image processed with the default CALACS pipeline. *Right:* The same image, processed with the ACS_DESTRIPE_PLUS script, which combines CTE correction and the stand-alone de-stripe code with object masking.

WFC3 IR time-variable background

Recent analyses have discovered that emission from helium in the atmosphere above *Hubble* causes an excess background signal in

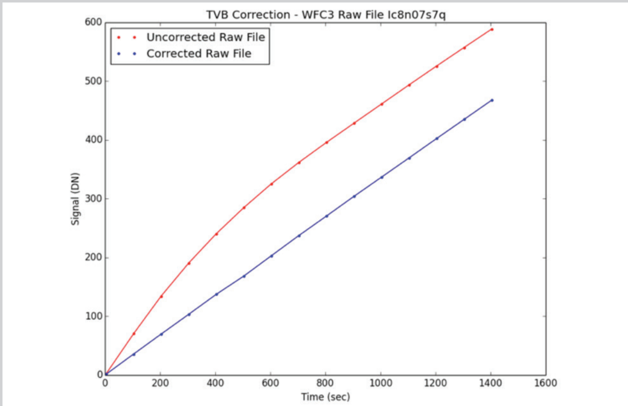

Figure 3: The red curve shows the original reads from image ic8n07s7q, while the blue curve shows ic8n07s7q after performing the TVB correction, returning the background to a linear function. Data courtesy of Harish Khandrika.

some Wide Field Camera 3/Infrared (WFC3/IR) data (MacKenty & Brammer 2014; Brammer et al. 2014). This excess signal, dubbed "time-variable background" (TVB), varies with the orbital geometry of *Hubble*. For long IR exposures, this varying background can cause a noticeable non-linearity in the resulting data (see Figure 3).

To remove the effects of TVB, an algorithm was created that works on raw WFC3/IR images (Robberto, M. 2014).[4] It calculates the amount of TVB signal from each readout, and subtracts it from the data. The corrected raw data can then be run through the CALWF3 pipeline to produce an uncontaminated signal-rate image. To find the amount of TVB signal in the reads of a given pixel, we model the expected signal of an uncontaminated pixel and compare this with the measured signal. Since the correction is performed on raw data, our model consists of a signal that is a linear function of time, multiplied by a function that represents the non-linearity inherent to the IR detector. This idealized model is fitted iteratively to the data. Reads with a large residual compared to the model are assumed to contain TVB signal and are thrown out, and the fit is repeated.

Refining the ACS/WFC Distortion Solution

The ACS instrument team has been working to develop more accurate geometric distortion solutions. The old solution lacked an accurate way to describe the pixel grid distortion and the non-polynomial components. There were also inaccuracies with the time-dependent component. These problems meant that the alignment derived for images taken with a long time baseline, or with large offsets, were not optimal. Additionally, the alignment of ACS images with other *Hubble* instruments was not optimal. Included in the changes made to the solution are an added polynomial term for distortion solution and calibrations for the linearly evolving terms of the time dependency.

The HFF program has strict requirements on the alignment precision. Alignment needs to be done across filters and instruments. Additionally, some of the targets in the HFF program have extant data taken with large offsets and with long time baselines. Thus, the HFF data provides an exquisite testbed for updated distortion solutions. The ACS team used these data to vet the updated distortion solution and ensure it met the strict alignment requirements of the HFF project. The updated solutions are now capable of obtaining astrometric alignment residuals below 0.05 ACS/WFC pixels (2.5 milliarcseconds; Borncamp et al. 2015).

Conclusion

With ambitious projects such as HFF, *Hubble* continues to reach deeper into the sky and produce a wealth of new science discoveries. With this increased depth, precision calibration becomes increasingly important and an absolute necessity for successful science. The *Hubble* instrument teams will continue to collaborate with science-driven initiatives, stimulating improved calibrations in the future.

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Robberto, M. 2014, Proceedings of the SPIE, Volume 9143, id. 91433Z

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1 http://www.stsci.edu/hst/campaigns/frontier-fields/

2 http://www.stsci.edu/hst/acs

3 http://www.stsci.edu/hst/acs/software/destripe/

4 http://archive.stsci.edu/pub/hlsp/frontier/scripts/time-variable-sky/