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Irregularity in Ceiling of Analog-to-Digital Conversion for Post-SM4 ACS/WFC Images

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Abstract

We document a recently noticed phenomenon in which post-SM4 ACS/WFC raw images appear to have a lower pixel value ceiling than expected. During readout of an exposure, if a given pixel would have a value in excess of $2^{16} - 1 = 65{,}535$ *DN after converting to DN from electrons given the gain setting, the A-to-D converter should simply record a value of* 65,535 *for that pixel. This is the case for pre-SM4 images, but for post-SM4 images, there appears to be a bug which causes the ceiling value to be slightly lower, and somewhat variable, typically in the range of* $64{,}500 \pm 1{,}000$ *DN. The cause of this issue is presently unknown, but it affects only a small number (*~ 100*) of archival images and is not expected to affect any future ACS observing programs. The ACS team has now rectified the data quality flagging to catch such A-to-D saturated pixels, which should be treated as unusable.*

1 Description of the Issue

At the end of an exposure, electrons that have accumulated in the ACS/WFC CCD pixels are read out and the measured charge level is converted to data numbers (DN) by the analog-to-digital converter (ADC), which are then recorded in the raw images. The number

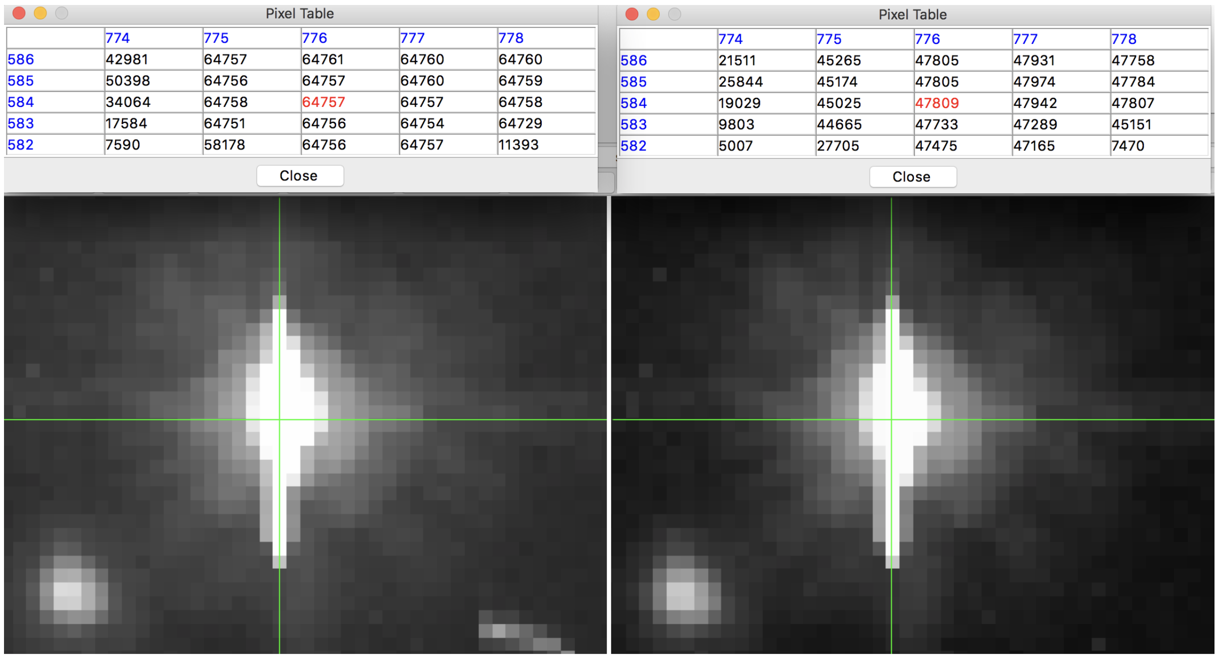

Figure 1: Side-by-side comparison of two post-SM4 raw WFC images, zoomed-in on a saturated star. The two images are from the same observing program, same filter, same pointing, but use different gain settings: CCDGAIN=1 on the left, and CCDGAIN=2 on the right. Also shown above each image is the corresponding table of pixel values of the 5×5 pixel region centered on the crosshair. Since the pixels along the central column have values in excess of 47,000 DN in the CCDGAIN=2 image (right), which corresponds to $\gtrsim$ 90,000 electrons, we expect the same pixels in the CCDGAIN=1 image (left) to have values of 65,535 DN. However, as shown, they do not. Instead, they have slightly smaller values, $\sim 64{,}750 \pm$ a few. This issue affects all relevant pixels in post-SM4 images. The cutouts shown are from image files jbbf01hzq_raw.fits (left) and jbbf01i3q_raw.fits (right).

of electrons per DN is specified by the user as the gain value (header keyword CCDGAIN). The ADC output is a 16 bit number, producing a maximum of $2^{16} - 1 = 65{,}535$ DN in any given pixel (Ryon et al., 2019), even if that pixel would have had an intensity value larger than 65,535 DN; this number represents the absolute ceiling of WFC pixel values.

The WFC CCD pixel full-well depth, i.e. the maximum number of electrons that a pixel can hold (under normal operating circumstances), varies somewhat over the detector area with typical value of $\sim 90{,}000\,e^-$, but never exceeds $\sim 105{,}000\,e^-$ under normal post-SM4 operating conditions (Cohen & Grogin, 2020), including imaging of highly saturated astronomical sources. Thus, for any commanded CCDGAIN value ≥ 2, the full-well can be sampled without ever exceeding the ADC maximum during conversion to DN. For CCDGAIN ≤ 1 however, pixels containing more than $65{,}535\,e^-$ at the end of an exposure would have a DN value larger than the ADC maximum, so they should simply be assigned the ceiling value of 65,535 DN in the raw image files, and would then flagged appropriately in the data quality arrays during calibration[1].

For images taken before Servicing Mission 4 ('pre-SM4') using CCDGAIN ≤ 1, this is indeed the case, easily verified by visual inspection of images of any saturated star or

[1] http://www.stsci.edu/sites/www/home/hst/instrumentation/acs/data-analysis/dq-flag-definitions.html

saturated hot pixel. However, it was recently noticed that in the handful of post-SM4 images using CCDGAIN ≤ 1, there appears to be an issue such that for pixels which exceed the ADC maximum, the actual DN value recorded for them is always slightly less than 65,535, and varies somewhat, in the range of $\sim$ 63,560 to $\sim$ 65,500, with a mean of $\sim$ 64,500. That is to say, pixels which are expected to have a recorded value of 65,535 DN, do not in post-SM4 images, but do in pre-SM4 images.

An example of this issue is shown in Figure 1, which displays a side-by-side comparison of cutouts of two raw WFC images of a star from the same observing program, at the same pointing, same exposure time, and same filter, but for CCDGAIN=1 (left) and CCDGAIN=2 (right). Also shown above the corresponding images are the pixel tables for the 5×5 pixel region centered on the crosshair. We know that this star is saturated since it exhibits the familiar vertical charge blooming trail indicative of saturation, and also because the pixel values along the trail in the CCDGAIN=2 table are in excess of 47,000 DN, which corresponds to $\sim$ 90,000 e^- after accounting for bias and gain. Thus, we expect the saturated pixels in the CCDGAIN=1 image to have values of 65,535 DN, but instead they have values $\sim$ 64,757 DN. A thorough check reveals that all similarly saturated pixels in post-SM4 CCDGAIN ≤ 1 images are affected by this issue. The exact cause of this phenomenon is presently under investigation. The onset of the behavior subsequent to SM4 could implicate the new A-to-D converter aboard the SM4 replacement electronics' SIDECAR^{TM}(Teledyne Imaging Sensors' system image, digitizing, enhancing, controlling, and retrieving) ASIC (Application Specific Integrated Circuit; Loose et al. (2005))

2 Impact on Observations and Data Calibration

We searched for all potentially affected archival images by selecting images which contain one or more pixels with a value larger than 62,000 DN, a threshold that should select very few pixels other than those affected Since gain settings other than CCDGAIN=2 have not been supported by the ACS team since shortly after ACS returned to science observations post-SM4 (mid-December 2009), there are only small number of images using CCDGAIN < 2, and of those there are only $\sim$ 100 images potentially affected by this issue, all of which are from calibration programs. For images using CCDGAIN=2, the ADC maximum cannot be exceeded under any normal circumstances, for the reasons mentioned above. Despite that, there are about a dozen archival images using CCDGAIN=2 which are affected by extremely rare readout anomalies, resulting in some of their pixels nearing the ADC maximum and being potentially affected by this issue.

In total then, we find 118 potentially affected full-frame images, which are listed in the Appendix. For these images, the team plans to reprocess the raw data such that pixels with DN values $> 62{,}000$ are flagged as having exceeded the ADC maximum in the calibrated data products. Again, since the ACS team only supports observations taken with CCDGAIN=2 (for several reasons), this issue should not impact any future observing programs.

Acknowledgements

This work made use of: NumPy (Van Der Walt et al., 2011), matplotlib (Hunter, 2007), and Astropy (Price-Whelan et al., 2018).

References

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Loose, M., Beletic, J., Blackwell, J., et al. 2005, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 5904, The SIDECAR ASIC: focal plane electronics on a single chip, ed. J. B. Heaney & L. G. Burriesci, 293–302

Price-Whelan, A. M., Sipőcz, B. M., Günther, H. M., et al. 2018, Astronomical Journal, 156, 123

Ryon et al. 2019, ACS Instrument Handbook, `https://hst-docs.stsci.edu/display/ACSIHB/ACS+Instrument+Handbook`, version 19.0

Van Der Walt, S., Colbert, S. C., & Varoquaux, G. 2011, Computing in Science & Engineering, 13, 22

Appendix

List of potentially affected datasets:
ja7z02req, ja7z02rfq, ja7z02saq, ja7za2sgq, ja7za2skq, ja8wa0e0q, ja8wa1e4q, ja8wa4jeq, ja8wa5jiq, ja8wa8l3q, ja8wa9lhq, ja8waddjq, ja8wagm7q, ja8wakb2q, ja8walbuq, ja8waomqq, ja8wapmvq, ja8wb3ivq, ja8wbaj6q, ja8wbbkbq, ja8wbeygq, ja8wbfyyq, ja8wbjheq, ja8wbmefq, ja8wc0fbq, ja8wc4vuq, ja8wc5w2q, ja8wc8b3q, ja8wcctbq, ja8wcdtmq, ja8wcghzq, ja8wcpsoq, ja8wd2glq, ja8wd3h1q, ja8wd6v8q, ja8wdakwq, ja8wdbluq, ja8wdewoq, ja8wdii8q, ja8wdmc0q, ja8wdncdq, ja9553lvq, ja9553lxq, ja9553lzq, ja9553m1q, ja9553m5q, jac3a1c7q, jac3a6kzq, jac3absgq, jac3abt0q, jacna1c1q, jacna1cvq, jacna6g1q, jacna6glq, jacnabjnq, jacnabjrq, jacs02u4q, jbbf01hxq, jbbf01hzq, jbbf01i1q, jbbgaalyq, jbbgabm5q, jbbgahe9q, jbbgbgo2q, jbbgbhofq, jbbgcadmq, jbbgcbdsq, jbbgcginq, jbbgdai1q, jbbgdbieq, jbbgdgneq, jbbgdhnrq, jbbgeajiq, jbbgegobq, jbbgehofq, jbbgfac6q, jbbgfbciq, jbbgfgetq, jbbgfhf1q, jbbgghxsq, jbbghas7q, jbbghgz7q, jbbgibdtq, jbbgigl6q, jbbgihleq, jbbgjaf7q, jbbgjbfgq, jbbgjgkdq, jbbgkafiq, jbbgkbfmq, jbbgkhjuq, jbbglalxq, jbbglgqnq, jbbglhqsq, jbbgmauiq, jbbgmbvzq, jbbgnbarq, jbbgnhfbq, jbbgoagvq, jbbgobh5q, jbbgoglcq, jbbgpbgdq, jbbgqasbq, jbbgqbsgq, jbbgqgvyq, jbbgqhw2q, jbbgrag5q, jbbgrbg9q, jbbgrcgfq, jbbne4kdq, jbbni8vhq, jbvvdfu0q, jc0540kaq, jd01a9csq, jd4yepzdq, jdond5b7q, jdondieaq, jdooaavgq