Extreme Charge-Trapping by Pixels in Hubble's ACS/WFC Detectors

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Abstract

We investigate the properties of sink pixels in the Advanced Camera for Surveys (ACS) Wide Field Channel (WFC) detector. These pixels likely contain extra charge traps and therefore appear anomalously low in images with relatively high backgrounds. We identify sink pixels in the average short dark image from each monthly anneal cycle, which, since January 2015, have been post-flashed to a background of about 60 e$^-$. Sink pixels can affect pixels immediately above and below them in the column, resulting in high downstream pixels and low trails of upstream pixels. We determine typical trail lengths for sink pixels of various depths and background levels. We create a reference image, one for each anneal cycle since January 2015, that will be used by CALACS to flag sink pixels and adjacent affected pixels in science images.

Full analysis in ACS Instrument Science Report 2017-01: www.stsci.edu/hst/acs/documents/isrs/isr1701.pdf

Observations

We use short (0.5-second) post-flashed dark images from the ACS CCD Daily Monitor calibration program (PI Golimowski) from January 2015 through the present. The darks are bias-subtracted, trimmed of overscans, and average-combined with clipping to reject cosmic rays. The post-flash fills in many of the charge traps in each sink pixel, causing them to appear negatively-valued when the post-flash is subtracted. Figure 1 shows a section of the dark image from September 2016 with sink pixels selected (orange circles) according to the method described in the next section.

We also use a set of 25-second darks post-flashed to background levels between 0 and 250 e$^-$ that were taken as part of CAL-14865 (PI Anderson). These darks allow us to identify the typical length of trails for given sink pixel depths and background levels.

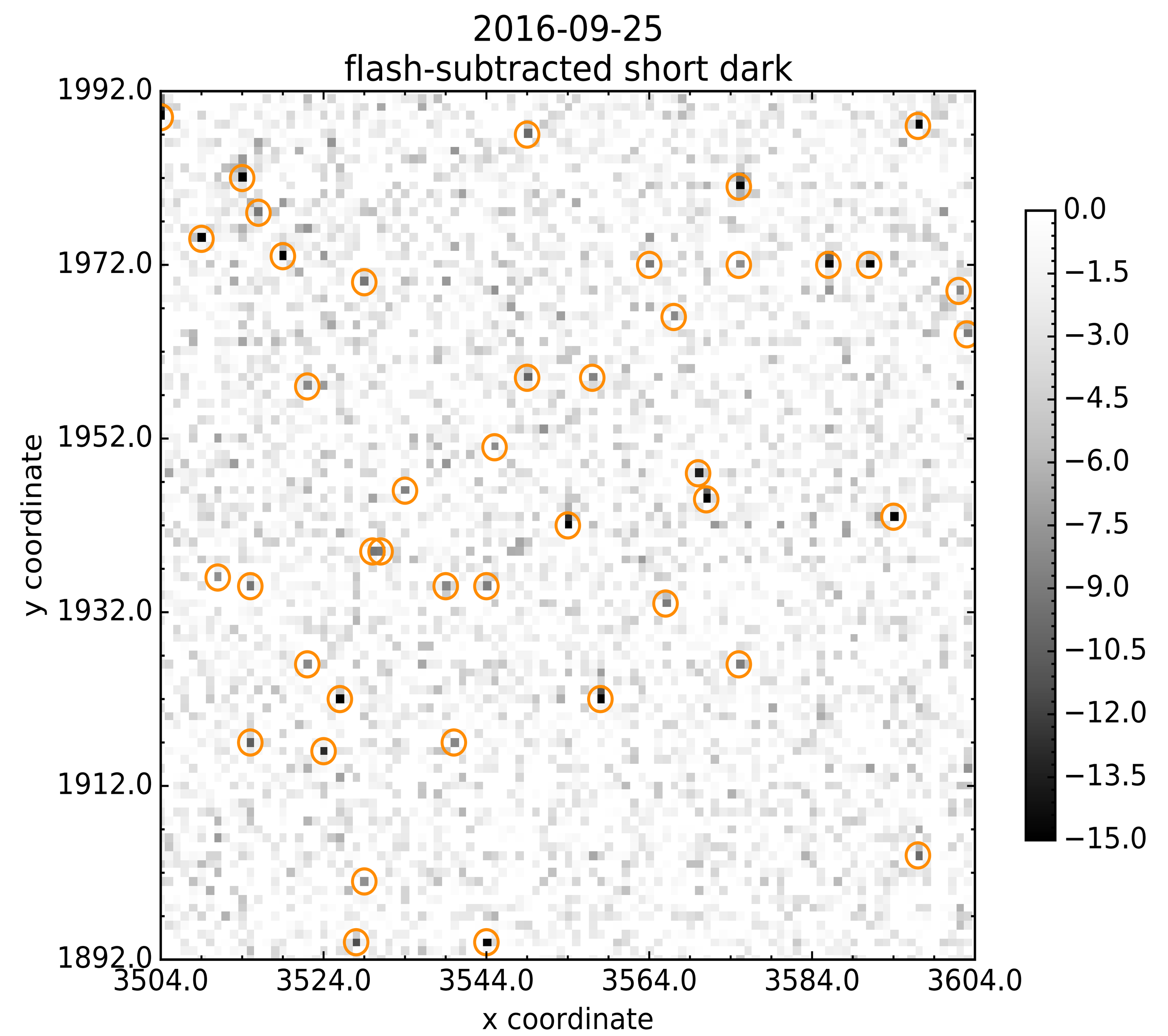

Figure 1: A 100x100 pixel region in the flash-subtracted short dark for the Sept. 2016 anneal cycle centered on a deep SP with a trail extending towards the top of the image.

References

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Lim, P.-L., et al. 2012, Bias and Dark Calibration of ACS/WFC Data: Post-SM4 Automated Pipeline, ACS TIR 2012-01, STScI
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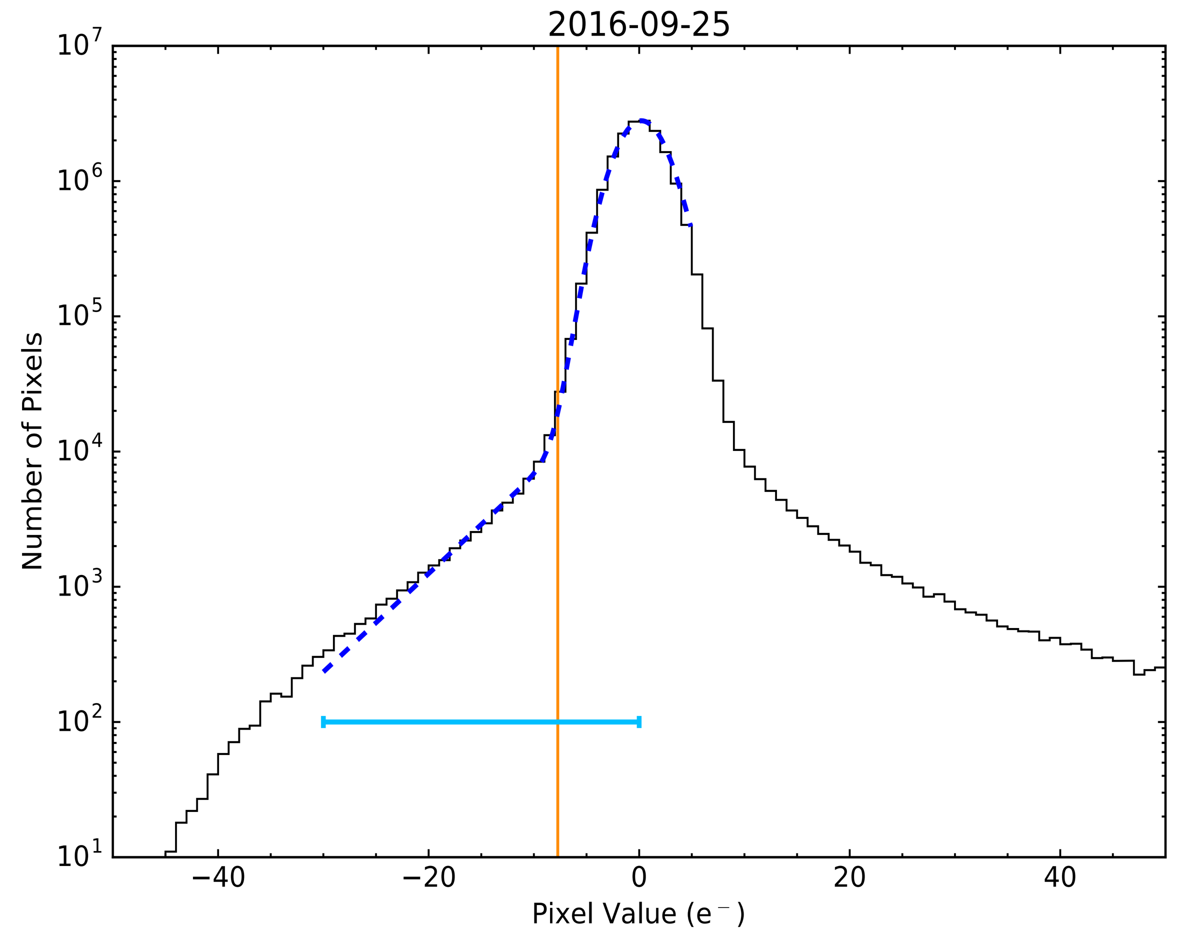

Figure 2: Pixel value distribution of the flash-subtracted short dark from Sept. 2016. The blue dashed curve shows the best likelihood function from MCMC sampling. The cyan line shows the range over which MCMC sampling was performed. The orange line is the best transition location, -7.7 e$^-$ for this anneal.

Selecting Sink Pixels

We remove post-flash electrons from the short dark with a scaled flash reference image. Figure 2 shows the distribution of flash-subtracted pixel values for an example dark. Sink pixels and trailing low pixels are located in the negative-valued tail. We find the transition location between the 'normal' (Gaussian) and sink pixel (exponential) distributions by Markov Chain Monte Carlo (MCMC) sampling over the range -30 to 0 e$^-$. The transition location varies between -7.7 and -6.3 e$^-$ among anneal cycles.

Not all pixels below the breakpoint are sink pixels (i.e., contain an excess of charge traps), some are trailing (upstream) pixels from which electrons have been trapped by the sink during readout. For each negative trail, we throw out other low pixels directly upstream of the first, so only the pixel closest to the readout amplifier is selected as a sink pixel. We find between 59,000 and 74,000 sink pixels (0.35% and 0.44% of the detector, respectively) in each anneal.

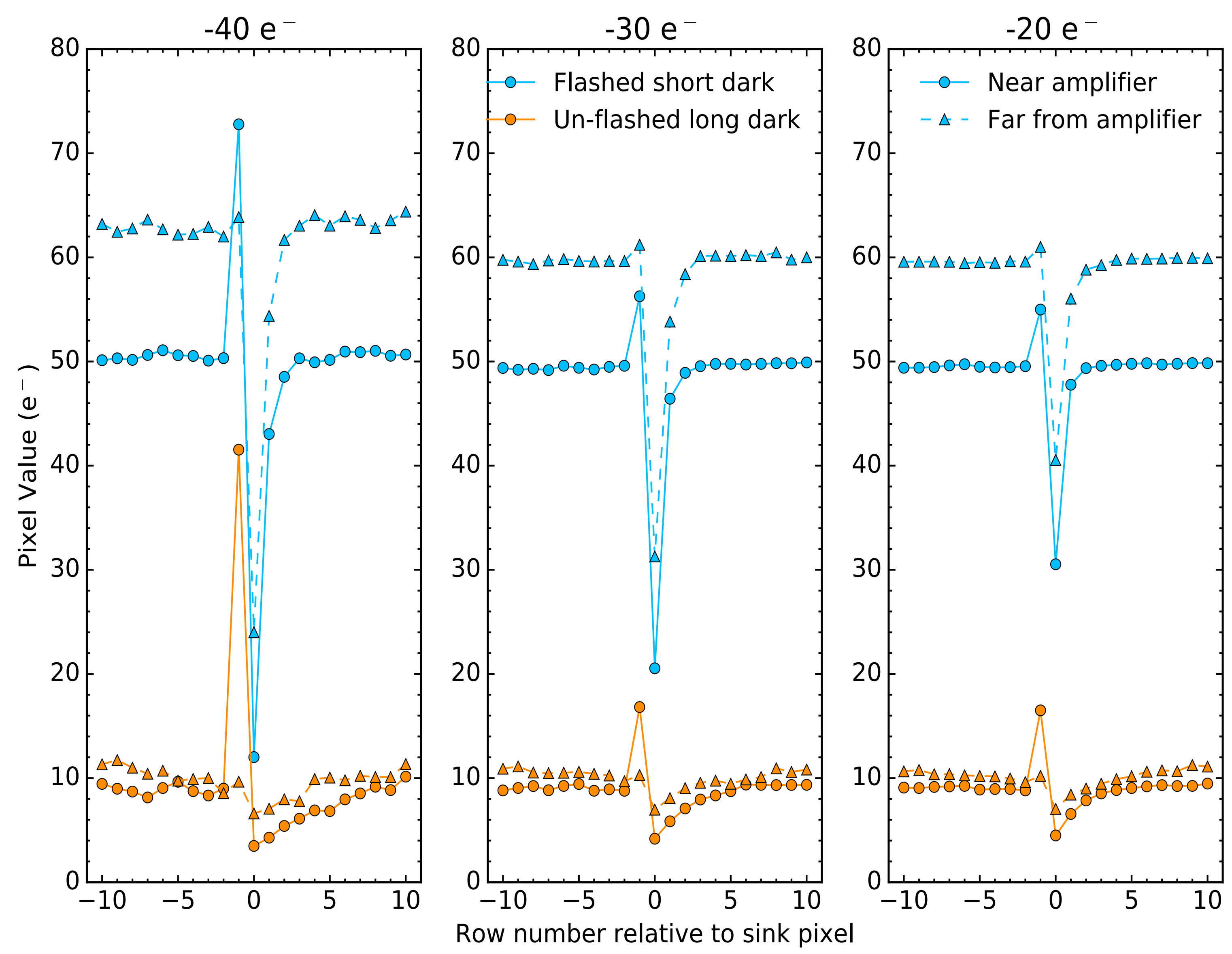

Figure 3: Column profiles of sink pixels with depths of -40±5, -30±5, and -20±5 e$^-$ (left to right). Triangles (Circles) are sink pixels in the half of the detector near to (far from) the amplifier. Blue curves are from the short dark and orange curves are from the un-flashed long (1000s) dark from the Oct. 2015 anneal cycle.

Impact on Adjacent Pixels

In Figure 3, we bin sink pixels of similar depths and plot the median values of ±10 pixels in the sink pixel's column. At high background levels, sinks of all depths are almost delta functions. At low backgrounds, sinks affect several upstream pixels because many traps in the sink are not filled, causing extra trapping from upstream pixels during readout. We determine typical trail lengths for sinks in several depth bins by analyzing trails in the 25-second darks post-flashed to 28 different background levels. Table 1 shows a portion of the reference table containing trail lengths for several sink pixel depths and backgrounds.

A charge excess is sometimes found in the downstream pixel next to sink. We identify those downstream pixels with values >5 e$^-$ relative to the local background for each anneal cycle. About 28% of sink pixels in a given anneal are next to a high downstream pixel.

SP Depth Bin Limits (e$^-$)	Background (e$^-$)	Trail Length (pix)	SP Value (e$^-$)
-25 to -15	150	2	116.8
-25 to -15	50	3	33.0
-25 to -15	35	4	20.0
-25 to -15	20	5	11.9
-25 to -15	15	6	7.8
-25 to -15	10	7	6.6

Table 1: Portion of the sink pixel trail length reference table for sinks of depth -20±5 e$^-$.

New Reference Image & SINKCORR

We create one reference FITS image per anneal cycle (Figure 4, left). Each sink pixel is assigned the sink's depth, high downstream pixels are assigned a value of -1.0, and the first upstream pixel is assigned the value 999.0. The next upstream pixels are assigned the values listed in the last column of Table 1.

To flag pixels in science image data quality (DQ) extensions, a new CALACS module called SINKCORR is implemented. We first set the charge trap flag, 1024, for the sink pixels (<-1.0 in the reference image). We set the same flag for downstream pixels (-1.0 in the reference image). Then, if the value of the sink in the science image is less than the value of the first upstream pixel in the reference image, we flag that first trailing pixel in the DQ array. We continue along the column in this way. Once the value of the trailing pixels in the reference image return to zero, or the sink pixel value in the science image is greater than that of the *n*th pixel in the reference image, we stop flagging for that sink. More trailing pixels are flagged for deeper sinks and in lower background images (Figure 4, right).

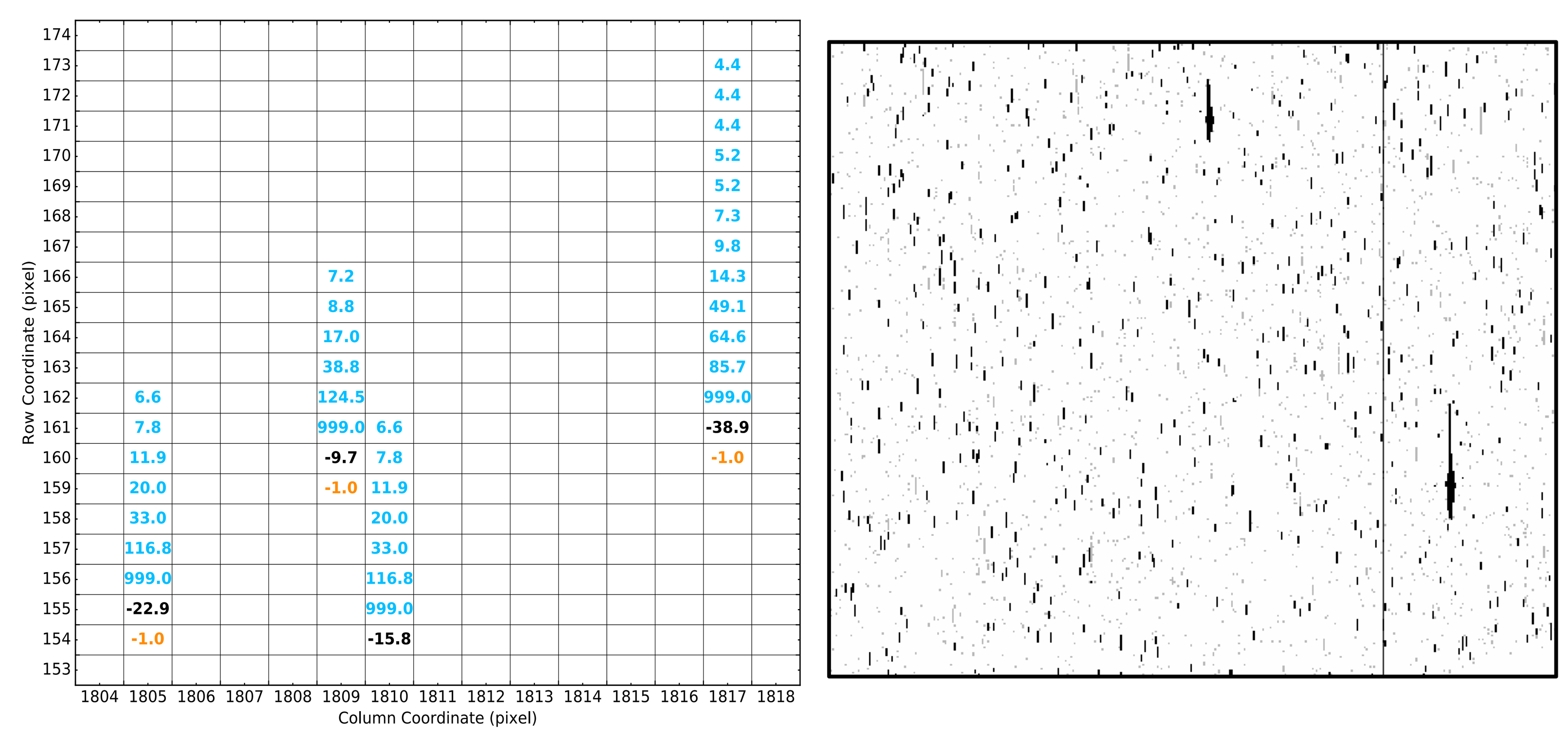

Figure 4: (left) A section of the Sept 2016 reference image. Each square is a pixel. Black numbers are sink pixel depths, orange numbers are high downstream pixels, and blue numbers are upstream trails. **(right)** A section of a science image DQ extension showing flagged sink pixels and trails (vertical dashes) and other flags.

Conclusions & Implications

We tested the new SINKCORR module on example images. About 1-2% of all pixels in an ACS/WFC image will be flagged in the DQ array, depending on the background level. A routine to generate reference images for future anneal cycles is included in the ACS/WFC reference file pipeline. A preliminary analysis suggests that sink pixels are rarely healed, but further work may study the rate of sink pixel creation over the history of ACS.