HST WFC3: UVIS Charge-Transfer Efficiency Losses: Mitigation and Correction

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AAS 224th MEETING
AMERICAN ASTRONOMICAL SOCIETY
Poster 122.05

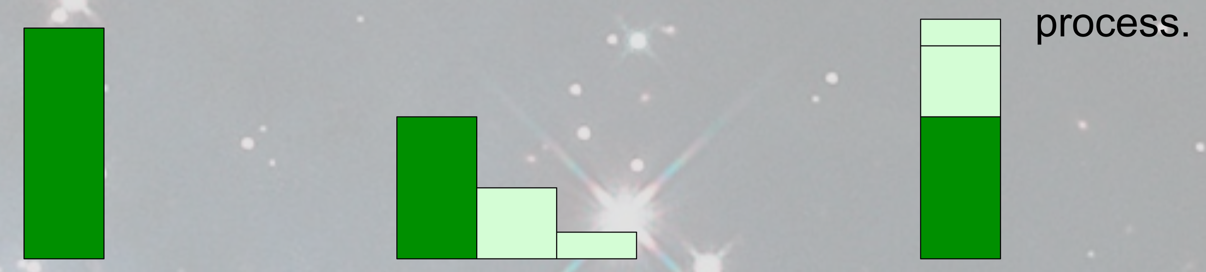
SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

0. Background

The WFC3/UVIS CCD detector started showing signs of charge-transfer efficiency (CTE) losses much sooner than ACS in terms of time on-orbit. This has been traced to the fact that CTE losses are even worse than expected when the background is low, and backgrounds in WFC3/UVIS images can be extremely low, on account of its extremely low dark current and the low backgrounds typical of many of its imaging modes (UV and narrow-band filters, more efficient short exposures, etc.). By ensuring a moderate background in their images, users can keep CTE losses below ~20%, a regime where pixel-based corrections are quite accurate.

1. The Initial ACS Pixel-Based CTE Model

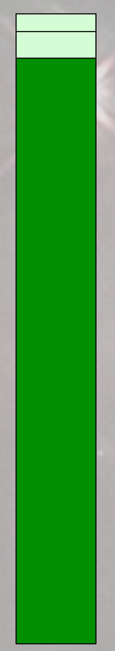
1) Assume that warm pixels (WPs) are initially delta functions.
2) Assume that the charge in the trail represents the CTE losses.
3) Construct a model that describes this trailing and invert the process.



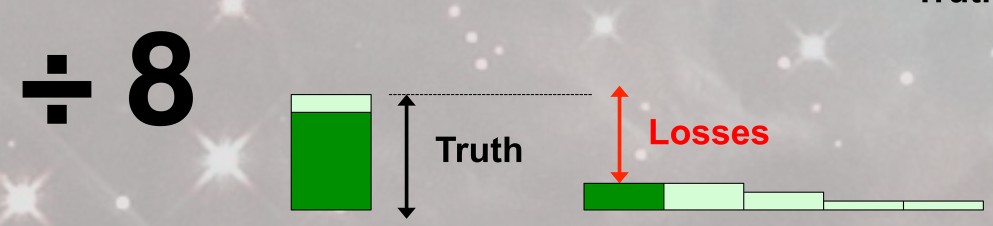
1) Original
2) After transfer/ readout
3) Infer model losses and invert

Problem: this can be hard to calibrate for small charge packets, where losses can be greater than 50%.

2. Better Constraints for the UVIS Model



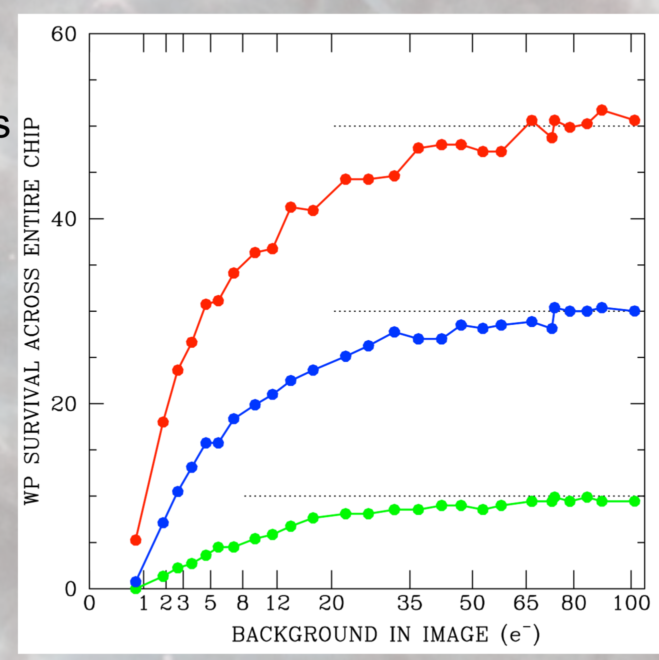
1) Identify bright WPs in long darks with lots of counts and small corrections.
2) Scale down to estimate "truth" in short-exposure darks.
3) Observe the surviving counts in short darks (trail is too faint to measure)
4) Tabulate losses as a function of WP size and background.
5) Fit a comprehensive forward model to this data.
6) Invert for science.



1) Bright WP in an 800s long dark
2) Expected WP in a 100s short dark
3) Observed WP in the 100s short dark on no bkgd
4) Observed WP in 100s short dark dark w/post-flash

3. Examining the CTE Losses

1) Study a range of WPs on a range of backgrounds
2) Tabulate losses as a function of WP level and BKGD. The plot to the right shows the surviving e⁻ in WPs that had 10, 30, and 50 e⁻ at the top of the detector. Data were taken in March 2014.
3) Fit a smooth model to determine the marginal losses as a function of e⁻ packet size.



4. The Current Pixel-Based Model

1) Standalone FORTRAN code available to correct _raw exposures
2) Recently modified to run in parallel (up to 40x faster!)
3) Recently modified to run on many subarrays
4) Next: re-constrain model with recent data (Mar 2014)
5) Fall 2014: implement correction in MAST pipeline
6) A small amount of serial CTE is present (see WFC3/ISR-2014-02)

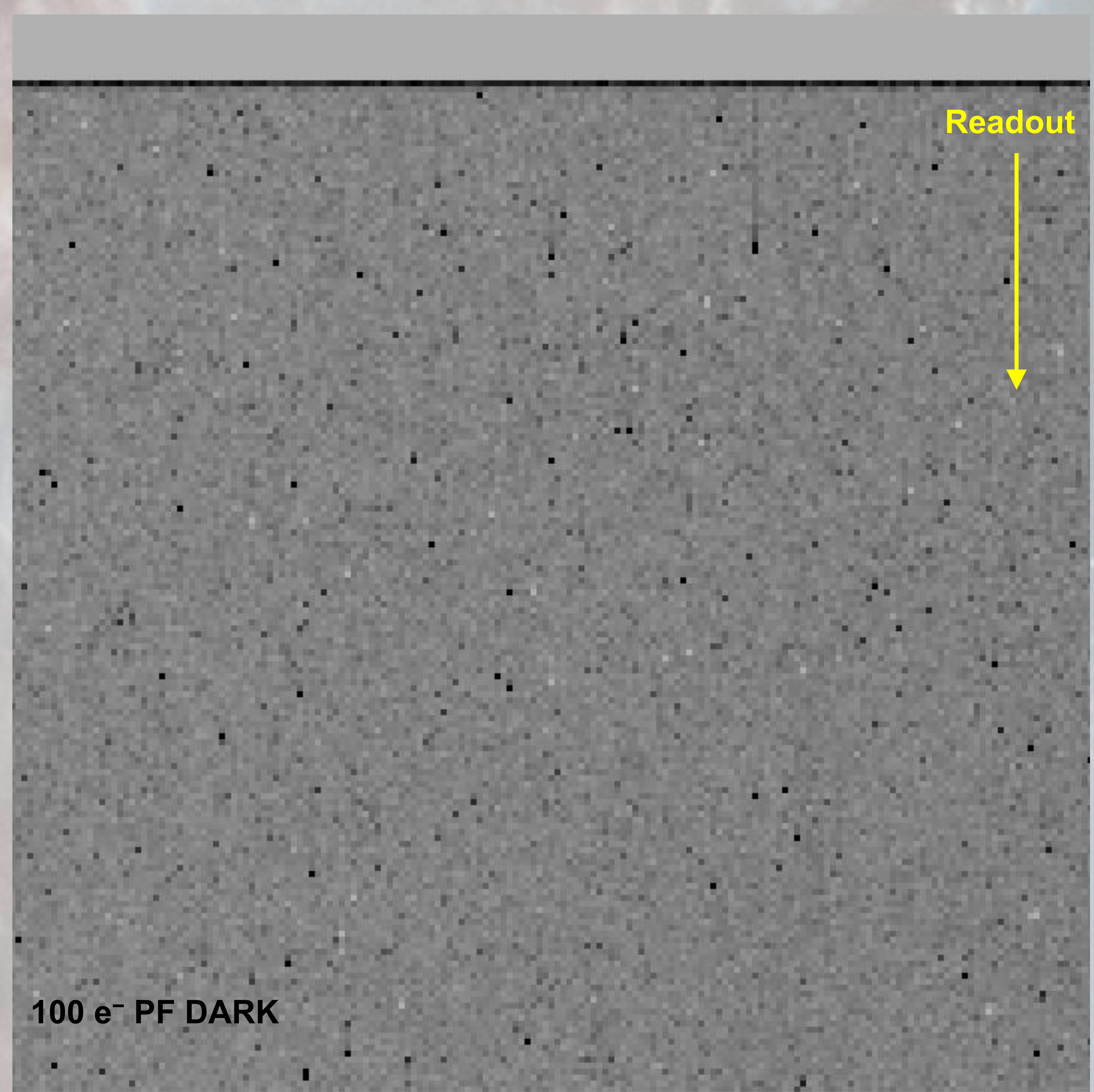
5. Post-flashing Reveals New "Sink Pixel" Defects

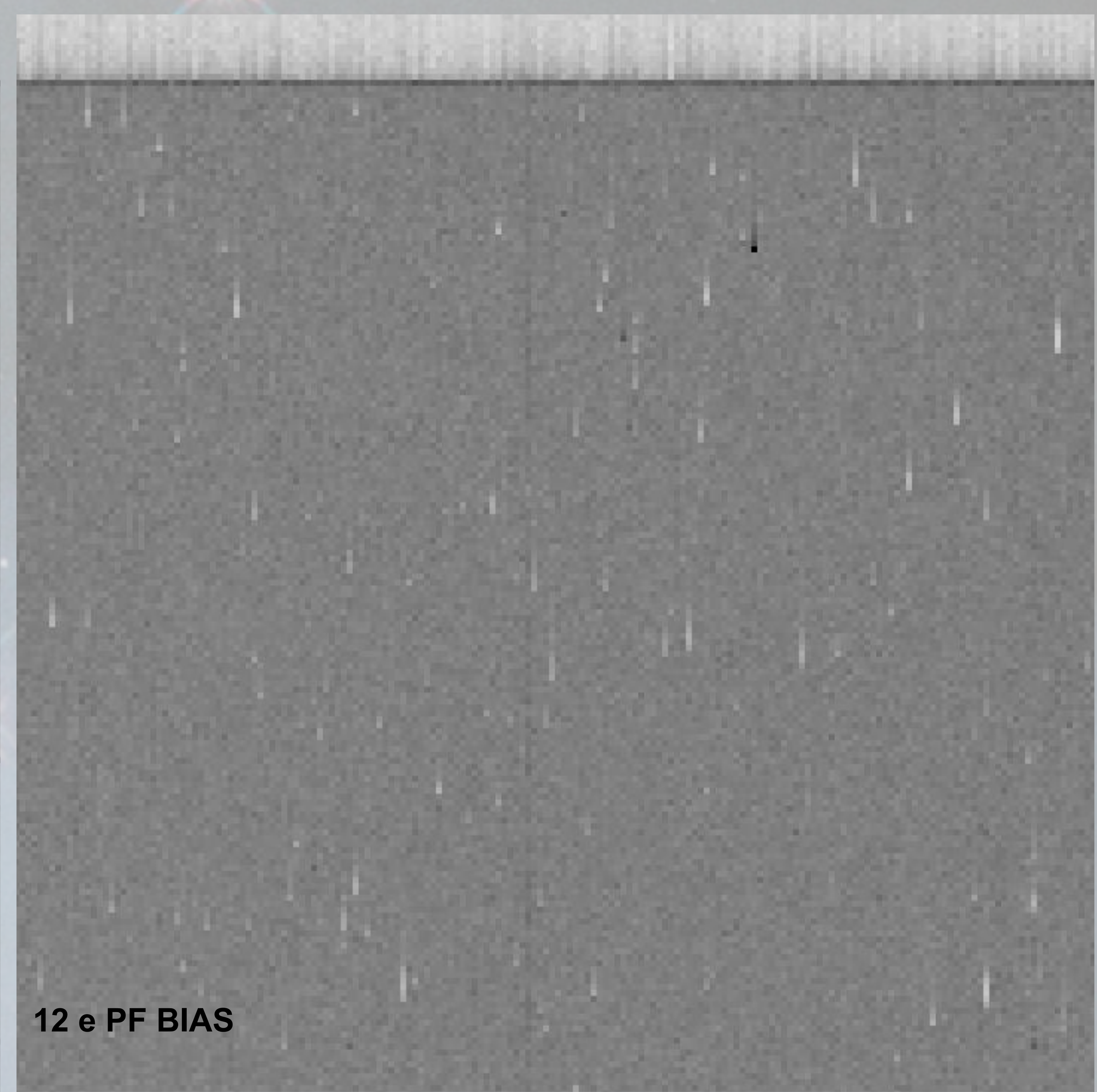
The realization that CTE losses in WFC3/UVIS are manageable at moderate backgrounds has led to the development of post-flash procedures to allow users to add background when the natural background is too low. This is important both for science images and for calibration images. Most darks are now post-flashed, and some post-flashed biases must be taken to remove the added electrons from the new darks and from science images. These post-flashed files have revealed a new kind of peculiar pixel: pixels that appear to trap some of the electrons they collected and, as a result, end up registering low counts. We dub these "sink" pixels, since they appear to contain some kind of charge sink. The number of "sink" pixels appears to increase steadily over time.

6. Manifestation of "Sink Pixel" Defects in Post-Flashed Images

The image below shows an 800s dark with a 100 e⁻ post-flash. The portion shown is far from the readout amplifier. The dark pixels are warm or hot pixels. Note the minimal WP trailing with higher backgrounds. The white pixels are the "sink pixels" and are lower than the background, often by 50 e⁻ or more.

The image below shows a "bias" image with 12 e⁻ post-flash. Note that the low white pixels in the image on the left are now trailed upwards and can impact up to 10 pixels. The top 19 pixels are virtual "vertical overscan" pixels; imperfect CTE causes the real pixels to bleed into them.

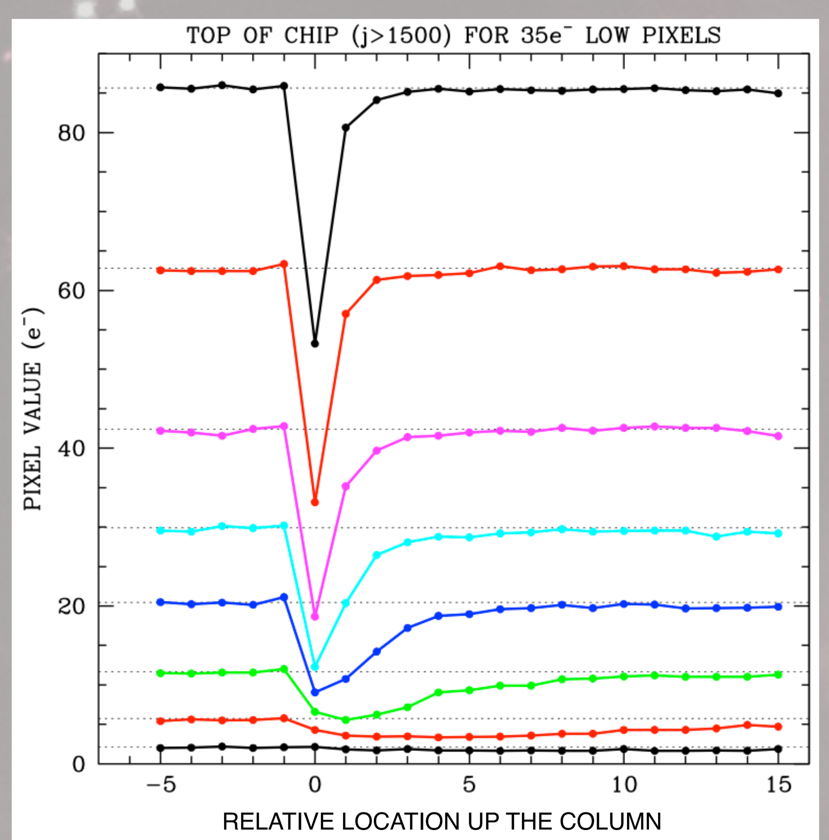




7. Behavior of Sink Pixels.

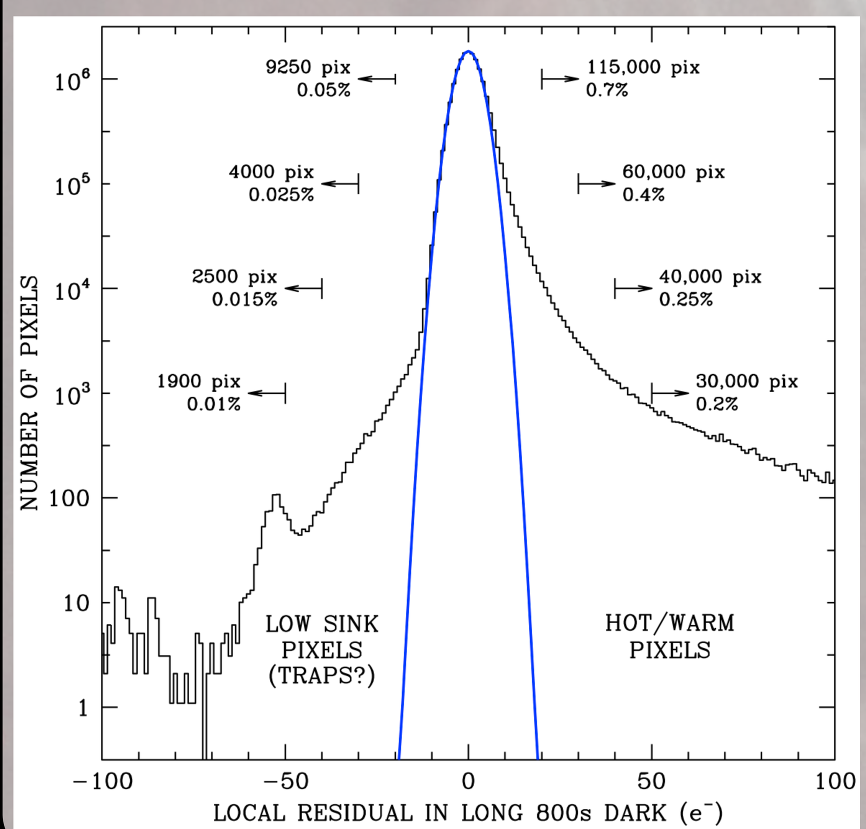
The previous panel showed that these low "sink" pixels (SPs) sometimes manifest themselves differently when the background is higher or lower.

Below, we show how a "typical" pixel with a 35 e⁻ sink impacts its surrounding pixels. It has almost a delta-function impact in high-background images, but it creates more of a broad trough in images with lower background.



8. Distribution of SPs.

It seems clear that these sink pixels represent pixels with multiple traps in them, and we can only see the total number of traps when the background is high enough. The figure below shows the distribution of pixels in the 100 e⁻ post-flashed dark. While only 0.05% of the pixels have sinks deeper than 20 e⁻, the associated troughs impact about 0.5% of of the pixels in low-background images, similar to the fraction of pixels considered warm/hot.



9. Conclusions

Although radiation damage continues to degrade the WFC3/UVIS detector day by day, our knowledge and characterization of the detector is improving even faster than the degradation, such that WFC3/UVIS is a more powerful tool than ever before. By post-flashing, we can keep CTE losses below the 25% "perturbation" level for years to come. Over the coming year, the WFC3 instrument team will develop a calibration strategy that will characterize the newly discovered sink-pixel phenomenon and document the affected pixels. These low "sink pixels" (and the pixels impacted by them) will be flagged, and to the extent that they can be corrected with reference files, we will correct them in the pipeline These calibrations, along with implementation of the CTE correction in the MAST pipeline later this year, will help keep WFC3/UVIS at peak performance.