

CALACS: The Seventeen Year Evolution of a Space Telescope Data Pipeline

Tyler D. Desjardins¹ & The ACS Team

¹Space Telescope Science Institute, Baltimore, MD 21218, USA



Tyler D. Desjardins
Email: desjard@stsci.edu

What is the Advanced Camera for Surveys (ACS)?



ACS was installed during Servicing Mission 3B (SM3B; March 2002) replacing the Faint Object Camera on the *Hubble Space Telescope (HST)*. The instrument is made up of three channels: the **Wide Field Channel (WFC)**, **High Resolution Channel (HRC)**, and **Solar Blind Channel (SBC)**. The WFC and HRC are back-illuminated CCDs, while the SBC is a multi-anode micro-channel array (MAMA) detector. WFC provides a large (202" x 202") field of view with sub-sampled pixels (sizes ~0.05"/pixel), HRC has very small pixel sizes (~0.027"/pixel), coronagraphy, and near-UV imaging, and SBC provides far-UV imaging and spectroscopy. See Figure 1.

In January 2007, ACS suffered the second of two electronics failures that rendered the WFC and HRC inoperable. Until Servicing Mission 4 (SM4; May 2009), only the SBC remained in operation. During SM4, new electronics were installed to replace the CCD electronics box (CEB-R), which successfully recovered the WFC; HRC remains offline.

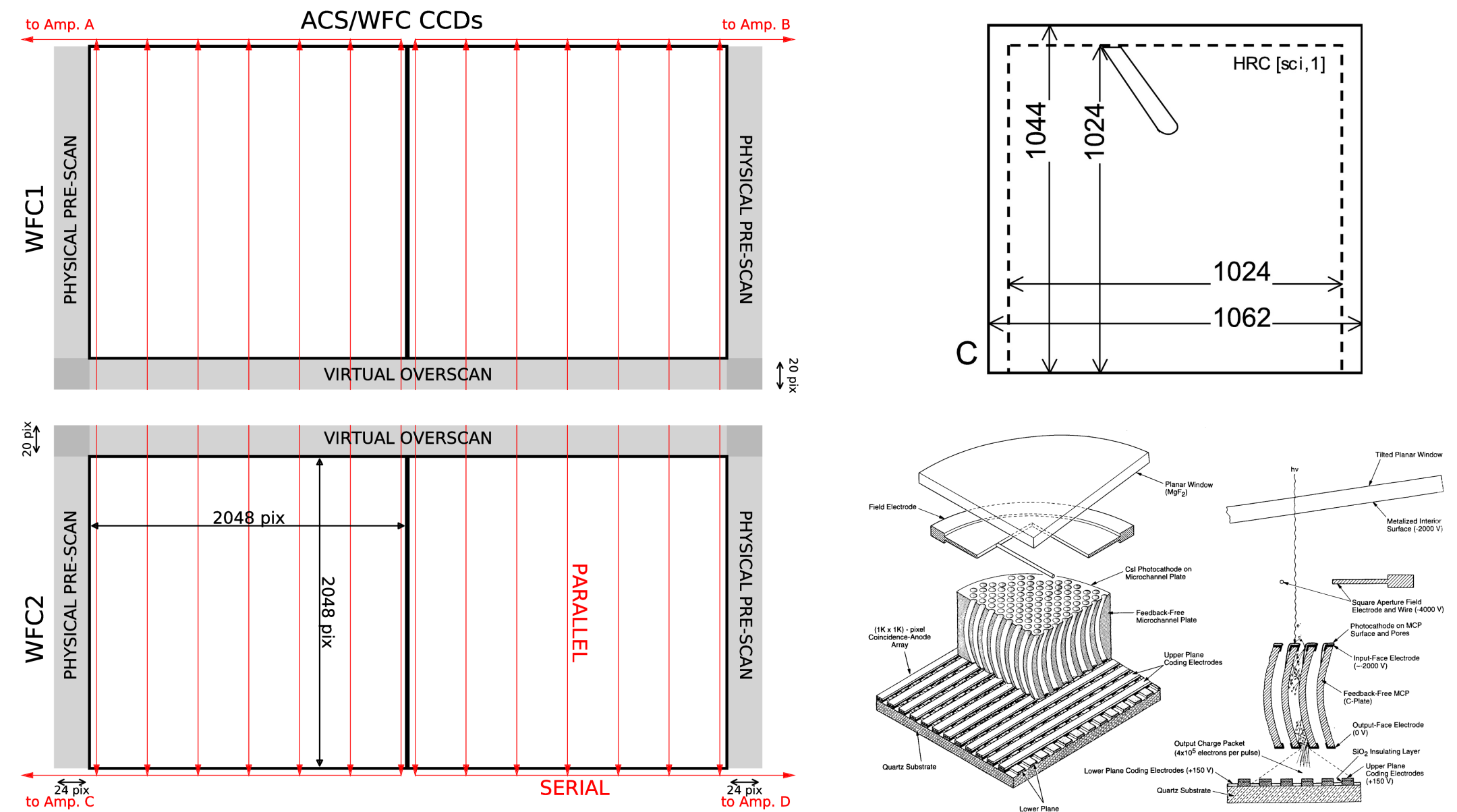
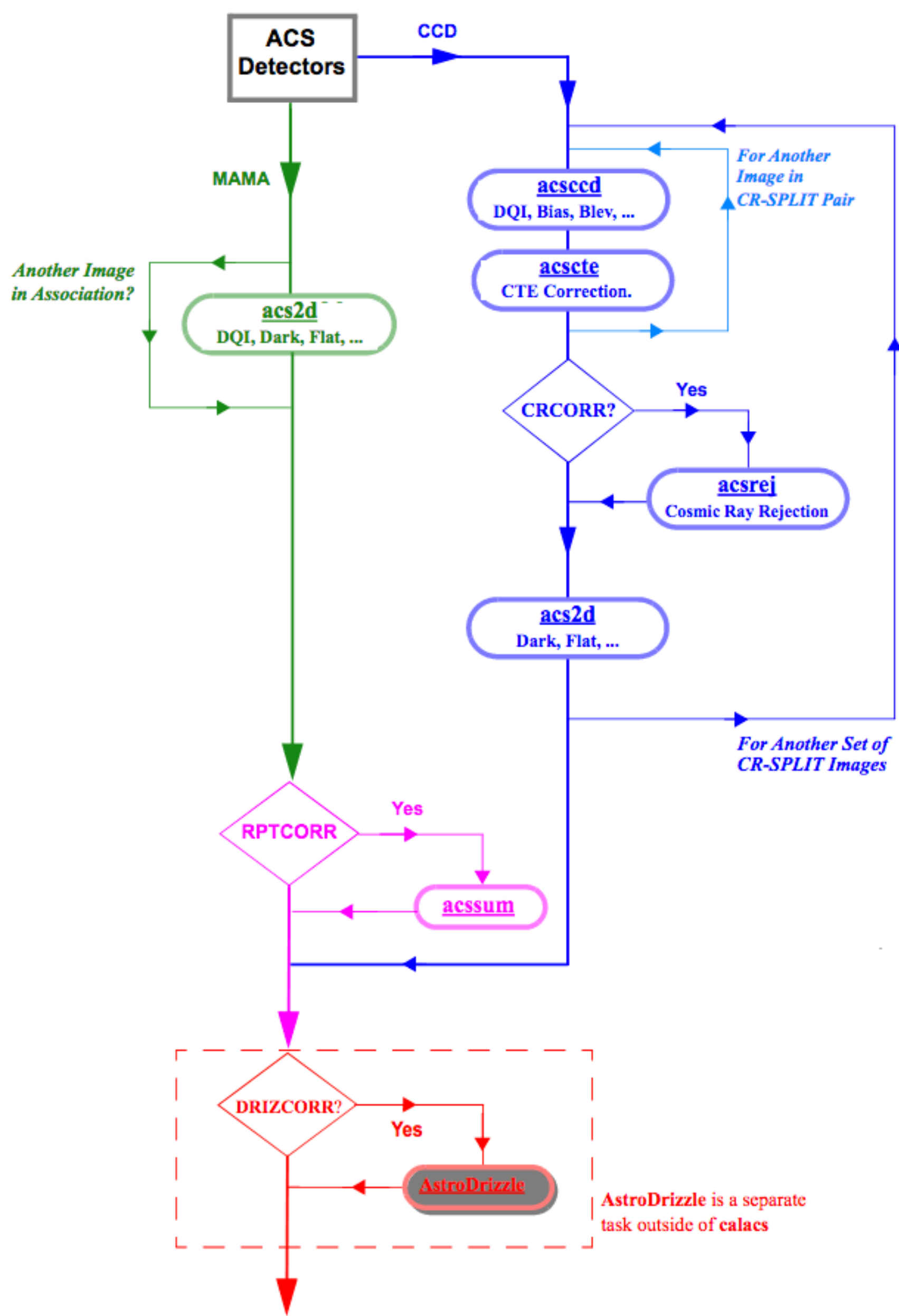


Figure 1: Readout diagrams of the ACS WFC (left) and HRC (top right) CCD detectors. A schematic of the ACS SBC MAMA detector is shown on the bottom right. Reproduced from Ryon et al. (2018).

ACS Data Calibration Pipeline (CALACS)



The ACS data pipeline is originally based on the Space Telescope Imaging Spectrograph (STIS) pipeline (Hack et al. 1998). This is because CALSTIS was the first *HST* pipeline to be written in C (rather than as IRAF scripts) and use the multi-extension FITS data format. CALACS itself was subsequently used as the basis of the Wide Field Camera 3 (WFC3) data pipeline.

The ACS data format presented new challenges compared to previous instruments. In particular:

- Historically large data volume of WFC images (4096 x 4096 pixels x 6 extensions for calibrated full-frame images = ~160 MB per image)
- Complex ACS associations – groupings of images with common targets/filters

CALACS is designed to work in concert with the Calibration Reference Database System (CRDS; formerly CDBS) to map reference file data (biases, darks, but also CCDTAB, OSCNTAB, etc.) to observations. **The calibration pipeline is agnostic to the instrumental setup, and relies upon header keywords and reference files to control the path data take through CALACS** (see Figures 2 and 3). These calibration switches are set in raw data files using a set of logical rules for generic pipeline processing.

/ CALIBRATION SWITCHES: PERFORM, OMIT, COMPLETE		/ CALIBRATION REFERENCE FILES	
STATFLAG=	F / Calculate statistics?	BPIXTAB =	'jref\$3n1116nj_bpx.fits' / bad pixel table
WRITER =	T / write out error array extension	CCDTAB =	'jref\$xa81715gj_ced.fits' / CCD calibration parameters
DQICORR =	/ data quality initialization	ATODTAB =	'N/A' / analog to digital correction file
ATODCORR =	/ correct for A to D conversion errors	OSCNTAB =	'jref\$17717071j_osc.fits' / CCD overscan table
BLEVCORR =	/ subtract bias level computed from overscan img	BIASFILE =	'jref\$23t1544qj_bia.fits' / bias image file name
BIASCORR =	/ Subtract bias image		

Figure 3: Sample sections of the ACS primary header. A section of calibration switches instructs the data pipeline whether individual subroutines need to be run (or, in the case of this file, have been completed). The calibration reference files are used by various CALACS subroutines to provide either calibration data or supplemental instructions for the calibration (e.g., the location of viable bias pre-scan columns).

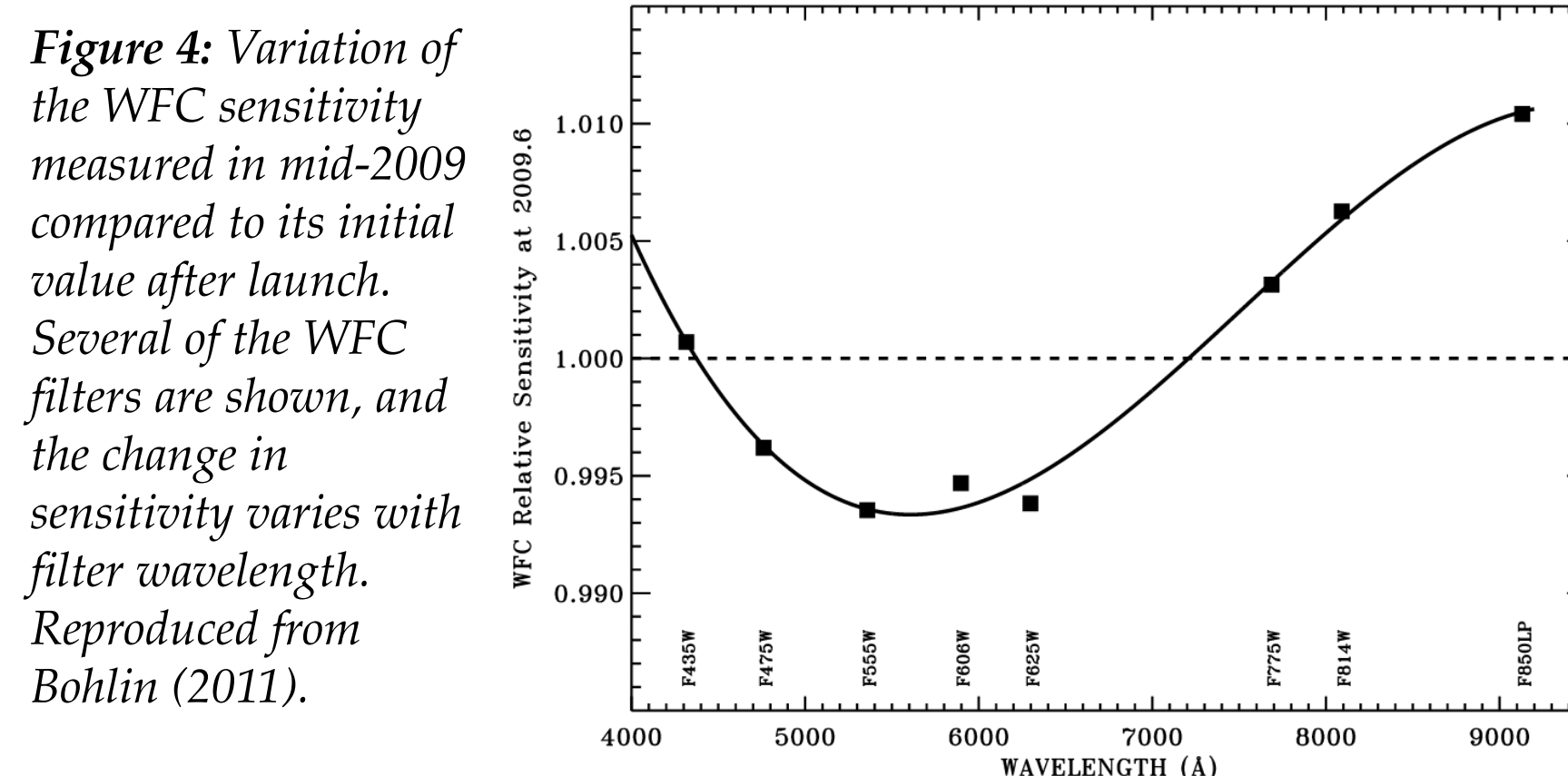
After successful installation of the instrument during SM3B, in-flight calibration and characterization necessitated updates to the pipeline and reference files:

- Reduced selection of bias pre-scan columns in WFC CCDs -> columns far from the sky-exposed pixels are unsuitable due to ramp in bias level
- Disabling shutter shading corrections (deemed unnecessary; Gilliland & Hartig 2003)
- Gain conversion (ATODCORR) disabled and gain information consolidated to CCDTAB file
- ACS flat fields consolidated to 1 per mode (+1 for coronagraphy)

Required Updates to CALACS for an Aging Instrument

Time Dependent Sensitivity Correction

Observations of standard star fields have shown that both the CCDs and the MAMA detector exhibit changes in sensitivity with time, and that this sensitivity change varies with wavelength. In 2007, CALACS was updated to use a time-dependent zeropoint for photometry-related header keywords in HRC and WFC observations (Bohlin 2007, Bohlin 2011, Ubeda & Anderson 2013). This required changes to reference file formats and yearly monitoring of standard star fields. In 2019, the photometric header keywords for the SBC were also updated to address time dependent changes (Avila 2019). See Figure 4 below.



Post-SM4 WFC Bias Striping

After its recovery during SM4, the WFC detector exhibited new bias structure called “striping” (see Figure 5 below). New algorithms were added to the bias subtraction code to handle de-striping full-frame images (Grogin et al. 2011), though subarray images were not de-striped automatically. The de-striping algorithm uses bias pre-scan columns on both sides of the CCDs to determine the variation of the bias level, but in subarray images without enough pre-scan pixels, sky-exposed pixels are used instead. This makes the correction scene-dependent, and thus not automatically performed before archiving.

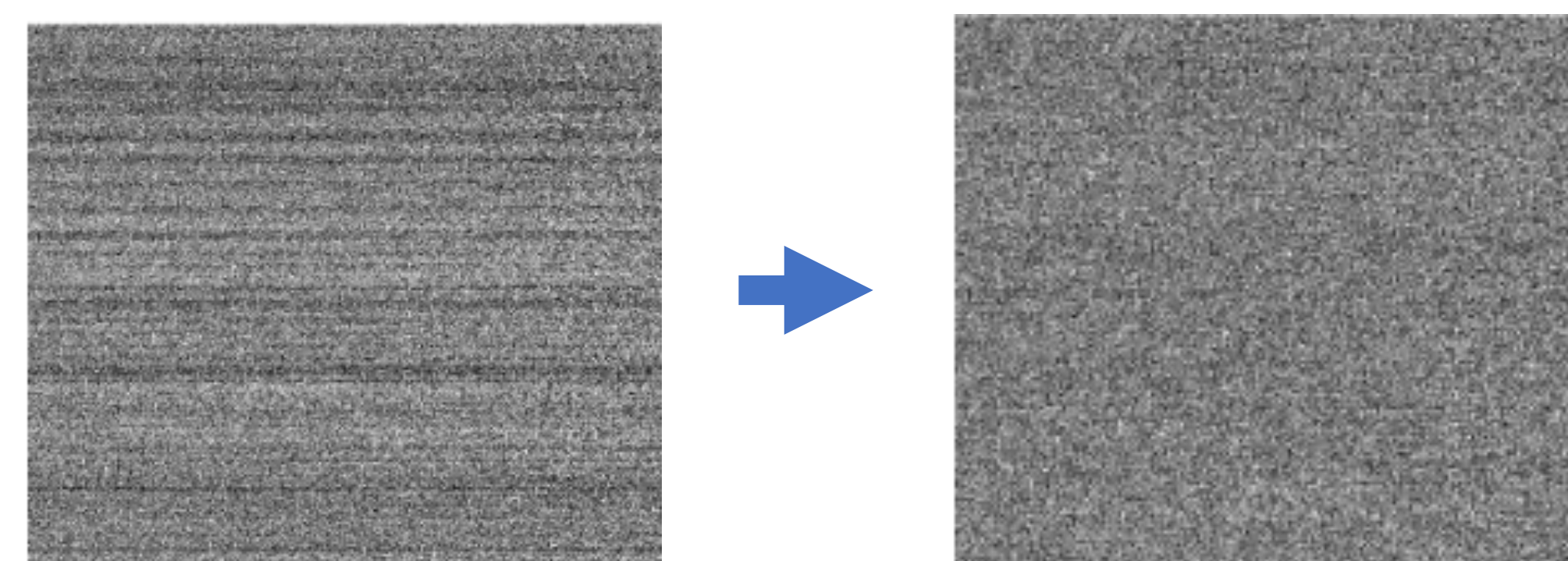


Figure 5: Subsection of a bias image from the WFC before (left) and after (right) the de-striping algorithm has been applied. The bias striping manifests as 1/f noise due to the Application Specific Integrated Circuit (ASIC) installed in the CEB-R during SM4. Partially reproduced from Grogin et al. (2011).

Pixel-based Charge Transfer Efficiency Correction

Continuous bombardment by high-energy particles in Low-Earth Orbit causes damage to CCDs. This manifests in a number of ways with one such aspect being charge transfer efficiency (CTE) loss caused by an increasing population of charge traps. The effect of CTE loss becomes more pronounced with time. The impact of CTE is a function of distance from the serial register, background signal level, and source signal. In 2012, CALACS was updated to correct for CTE loss using an inverted model of the charge loss to restore the lost charge back to the original pixels (Anderson & Bedin 2010, Anderson & Ryon 2018). See Figure 6 below. This pixel-based correction allowed for increased photometric accuracy of extended sources in an aging detector.

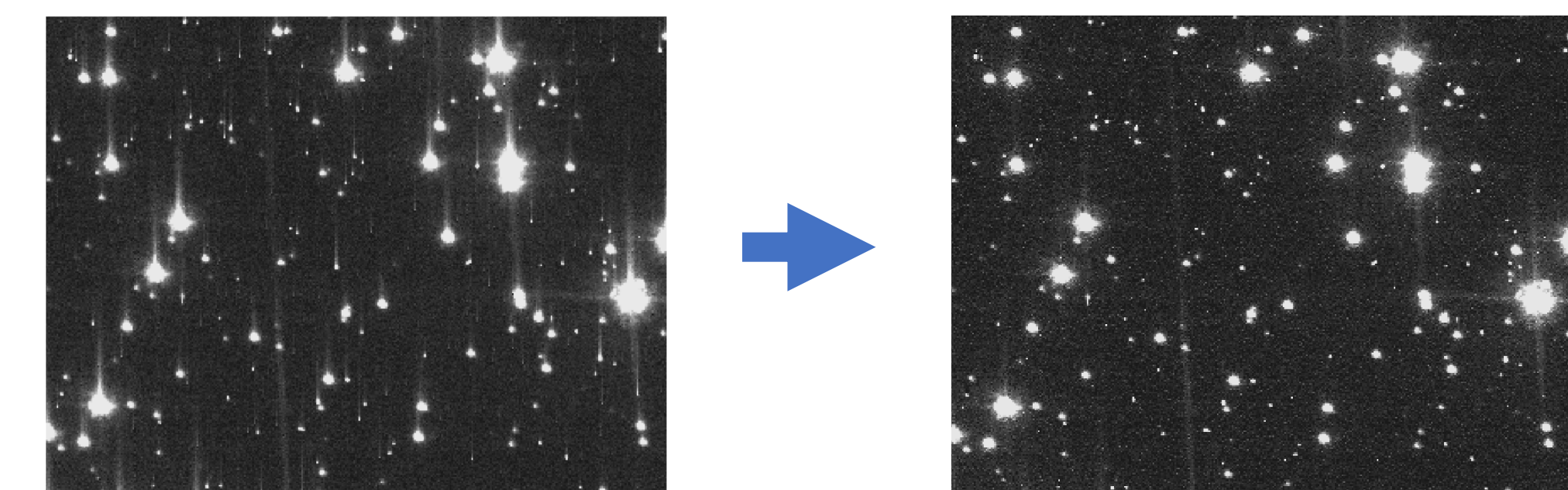


Figure 6: Subsection of an star field imaged with the WFC detector in 2018. The effect of CTE can be observed as long trails in the readout direction in the uncorrected image (left), while no CTE trails are observed in the corrected image (right).