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Long-term Monitoring of the ACS Tungsten Lamp Brightness

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ABSTRACT

In this report, we present a study of the history of the ACS tungsten lamp brightness in the time between the 2009 Servicing Mission 4 (SM4) and 2021. For our analysis, we leverage all available archival tungsten lamp exposure data from the internal flat field monitor calibration programs. We present the brightness history in twelve filters, using both zeropoint-adjusted and -unadjusted measurements. We find that, between SM4 and now, the brightness of the lamp has decreased by as much as $\sim 3\%$ *in the reddest filters, and has increased by as much as* $\sim 2\%$ *in the bluest filters, with the exact amplitude of the change depending on whether or not the zeropoint adjustment has been applied. Relatedly, we also evaluate the absolute signal levels of recent tungsten exposures in order to assess whether any adjustments are necessary. We find that, in order to bring all the filters to a more uniform average signal level and desirable signal-to-noise ratio, the exposure times for several filters required slight adjustments. We implemented these changes to the calibration program starting in the middle of HST Cycle 28 (late 2020), and we find that the new exposures achieve the desired signal levels. The ACS Team plans to closely monitor the tungsten lamp brightness going forward.*

1 Introduction

The Advanced Camera for Surveys (ACS) instrument is equipped with a tungsten-filament lamp (Ryon et al., 2021), which is primarily used for the internal flat field monitoring (e.g., PID 16385, Hathi, 2020). Throughout the lifetime of ACS, the spectral energy distribution of the lamp has gradually changed (e.g., Bohlin & Grogin, 2015). In this work, we leverage all available post-SM4 (Servicing Mission 4) archival tungsten lamp exposure imaging data from the internal flat field monitor calibration programs to present the most up-to-date history of the tungsten lamp brightness in the twelve monitored ACS/WFC filters.

In Section 2, we explain the data selection and reduction steps. In Section 3, we describe the brightness history analysis and present the results. In Section 4, we describe the changes that we made to the internal flat field monitoring calibration program as a result of our findings, and in Section 5, we summarize the above.

2 Data and Reduction

The primary data used in this work are archival ACS/WFC internal exposures of the tungsten lamp. We downloaded all the raw image files corresponding to all such exposures from MAST. We are only interested in full-frame WFC exposures, and not those from internal CTE monitor calibration programs, since their readout type is different than the standard WFC full-frame readout. In order to achieve this selection, we impose the following conditions using the header keywords: CCDAMP=ABCD, CTEIMAGE=NONE, APERTURE=WFC. We also discarded any images with bad exposure/quality flags. This selection yields 958 images, spanning a range of dates between 2009 and 2020, and twelve filters (though the number of images is not distributed uniformly amongst the various filters). We then calibrated all the images by running the necessary CALACS calibration tasks (Lucas, R. A., et al., 2021). Since these are lamp exposures, the applied CALACS stages include BLEVCORR, BIASCORR, CTECORR, The resulting calibrated images are used in the analysis that follows.

3 Analysis and Results

The goal of our analysis is to measure the brightness history of the tungsten lamp in each monitored filter. We will use the median flux level of the internal tungsten lamp exposures as a measurement of the brightness of the lamp. In each image, we mask out all bad/undesirable pixels by selecting only those pixels with a value of 0 in the DQ arrays (`https://www.stsci.edu/hst/instrumentation/acs/data-analysis/dq-flag-definitions`). We then sigma-clip (sigma=3, maximum 3 iterations) the remaining pixel value distribution in the two science extensions (separately) in order to reject remaining bad pixels/artifacts. We then assemble a table containing, for each image and for each of the two WFC CCDs, the median and several percentiles of the pixel brightness value distribution, the filter, and the observation date/time.

We plot the resulting brightness history in the left panel of Figure 1. In an attempt to correct for the changing sensitivity of the detector (Bohlin et al., 2020, and references

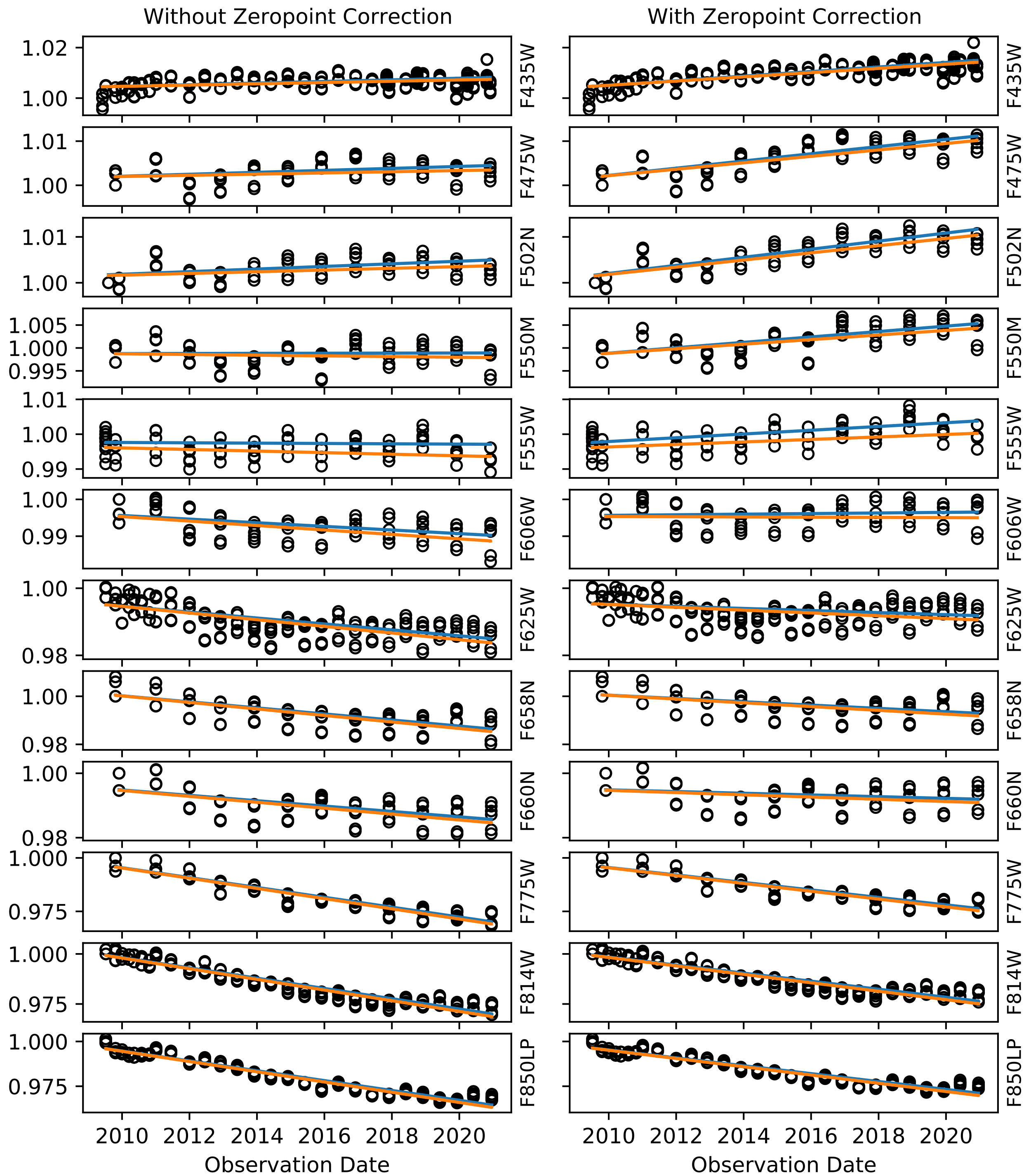

Figure 1: Change in the post-SM4 WFC internal flat field monitor data for all twelve monitored filters (with the filter indicated on the right of each panel). The plotted scatter points are median values for each exposure, divided by the earliest plotted value. The medians for both WFC CCDs are measured separately, but are both plotted with the same marker. The orange and blue lines are the linear fits to CCDs 1 and 2, respectively, to guide the eye to the overall trend for each filter. The measurements in the right column are adjusted for the time-dependent sensitivity change of the detector, while those in the left column are not.

therein), we also compute the time-dependent zeropoint for each image, using the ACS zeropoints module of ACSTOOLS (`https://acstools.readthedocs.io/en/latest/`). We then plot the resulting zeropoint-corrected brightness history in the right panel of Figure 1. Prior to SM4, only four of the ACS filters (F435W, F625W, F660N, and F814W) were used in the internal flat field monitor programs. Post-SM4, all twelve filters shown in the Figure 1 were used. For this reason, we only show the post-SM4 data in the figure. In this figure, the individual image brightness measurements from each image are shown as the black scatter points, and linear fits to the two CCDs are shown as solid, colored lines, intended to guide the eye to the overall trend.

After correcting for the zeropoint, the brightness for several of the bluer filters (especially F435W, F475W, F502N, F550M) seems to be generally increasing over time, while the brightness in some of the redder filters (especially F775W, F814W, F850LP) shows a decrease with time. Intermediate-wavelength filters appear to exhibit weaker trends, with F606W remaining roughly constant on average. This result suggests that the effective spectral energy distribution of the lamp has evolved such that bluer wavelengths have become brighter, while redder wavelengths have become fainter, with the pivot point at approximately F606W. Even the measurements that do not have the zeropoint correction applied show a constant trend or slight increase in brightness for the bluest wavelengths, and a decline in brightness for the redder wavelengths. We do not speculate upon, or attempt to model, the physics underlying this behavior, but we do note that non-uniform HST tungsten lamp evolution has been previously noted (e.g. Ryan, 2019).

4 Changes to Internal Flat Field Monitor Program

In light of the lamp brightness changes noticed through the course of this work, we also examined the absolute signal level of recent tungsten exposures from the internal flat field monitor program (e.g., PID 16385, Hathi, 2020). Ideally, the signal level in all the filters should be similar and large enough for a desirable signal to noise ratio, but well below the saturation level of approximately 77,000 electrons (Cohen & Grogin, 2020). As shown below (Figure 2, blue circles), our analysis revealed that the signal level was somewhat lower than desired in several redder filters, and somewhat higher than desired in several of the bluer filters. As a result, in the middle of Cycle 28 (mid-2020), we adjusted the exposure times for all the filters in the calibration program in order to bring them to a more uniform median signal level just under 60,000 electrons. The exposures immediately following these changes exhibit the desired brightness (Figure 2, orange squares).

5 Conclusions and Future Monitoring

In this work, we presented the post-SM4 brightness history of the ACS tungsten lamp as measured using the brightness values of tungsten lamp exposures from the ACS internal flat field monitor calibration program. From SM4 (May 2009) to 2020, we find that the brightness of the lamp has increased by as much as $\sim 2\%$ in the bluest filters, and has decreased by as much as $\sim 3\%$ in the reddest filters, with smaller changes at intermediate

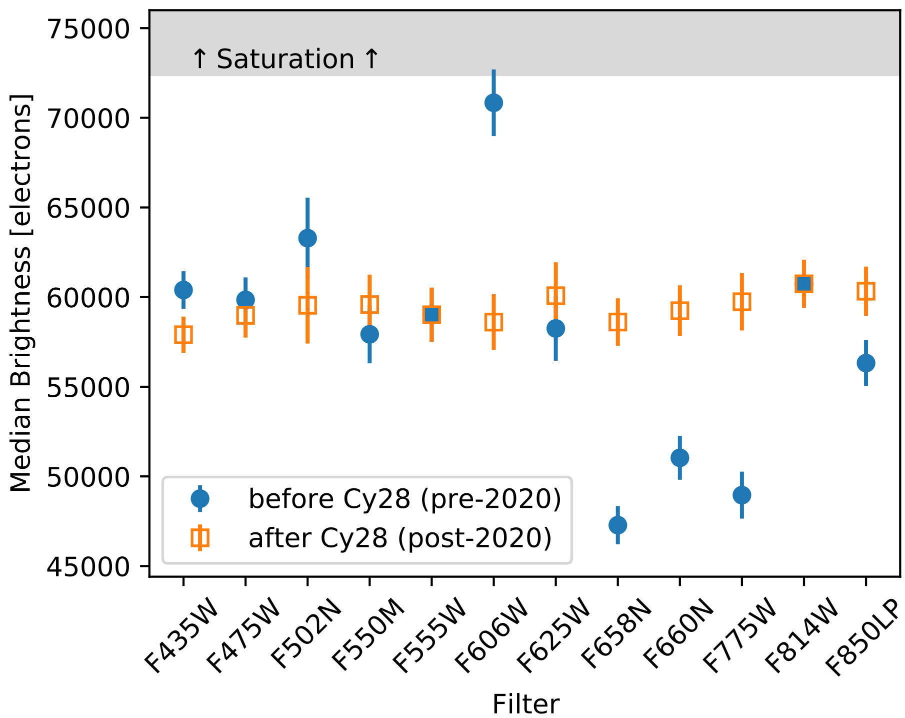

Figure 2: Median brightness of the tungsten lamp exposures for all twelve monitored filters, immediately before (blue cirles) and after (orange squares) the exposure time adjustments made in mid-2020. For the most recent exposures prior to the changes, there was a large disparity in the median signal level of the exposures, with several of the redder filters at a lower brightness than desired, and several of the bluer filters at a higher brightness than desired, with the exposures in the F606W filter even approaching saturation. After the exposure time adjustments were made, the median brightness in all the filters is much closer to uniform, with an average of just under 60,000 electrons for all the filters, as desired.

wavelengths. Despite these gradual changes to the ACS tungsten lamp brightness, at the time of this writing, we find no immediate cause for concern about the longevity of the lamp.

In the context of these findings, we re-examined the absolute signal levels of recent tungsten lamp images from the internal flat field calibration program, and determined that the exposure times for several of the filters could be adjusted slightly to optimize signal to noise ratio across all the filters. These changes to the calibration program were implemented in the middle of Cycle 28, and the resulting images have been analyzed and are seen to exhibit the desired signal levels. Going forward, the ACS Team will continue to monitor the filter-dependent brightness in future HST Cycles, and will make minor adjustments to the exposure times as needed to maintain the desired signal level.

References

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