Instrument Science Report COS 2022-13

Creation of the LAMPTAB Reference File at Lifetime Position 3

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ABSTRACT

A new COS/FUV lamp template reference file (LAMPTAB) for Lifetime Position 3 (LP3) was delivered for use in the COS calibration pipeline in April 2018. The LAMPTAB file contains reference spectra used during the wavelength calibration of COS/FUV spectroscopic data. The LP3 lamp spectra data were obtained in Program 14856 in October 2016 as a part of the improved wavelength calibration effort. In this ISR, we document the data analysis techniques used for the creation of the LP3 LAMPTAB file, as well as our testing procedures.

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1. Introduction

Inside the Cosmic Origins Spectrograph (COS) aboard the Hubble Space Telescope, there resides two Platinum-Neon hollow-cathode lamps that are used for the wavelength calibration of COS spectroscopic data. Though there are two lamps (referred to as Lamp #1 and Lamp #2), only Lamp #1 has been used for science data and thus is the only one used for this analysis (and will henceforth be referred to just as “the lamp”). When turned on, the lamp emits strong emission lines that cover most[1] of the wavelength range of both the far-ultraviolet (FUV) and near-ultraviolet (NUV) detectors.

The lamp light shines through the wavelength calibration aperture (WCA) and then passes through the same optical elements as the science data. The lamp spectra fall above the science spectra in the y-direction on the detector, so the two datasets do not contaminate each other. See Figure 1.8 in the COS Data Handbook for an example image of a COS FUV Spectrum. In the default “tagflash” mode for FUV observations, the lamp is flashed regularly for short durations during a time-tag science exposure in order to track how the wavelength solution changes over time due the drift of the Optics Select Mechanism (OSM). There are two OSMs on COS; OSM1 holds the FUV gratings and OSM2 holds the NUV ones. For this analysis, the OSM we refer to is OSM1. See COS ISR 2011-04 for more information about how the tagflash mode works. By comparing the lamp template to the tagflash data, `CalCOS` can remove the OSM drift

[1] The magnesium fluoride window on the lamps blocks light below 1180 Å, meaning all lamp lines fall on FUVA for the G140L/1280, G130M/1055 and G130M/1095 modes. In these cases, the wavelength calibration from the FUVA side is applied to FUVB. However, for some observations, the FUVA is turned off, to avoid an over-bright condition. In these cases, a default wavelength calibration is applied.

and calculate an accurate wavelength correction for the extracted dataset.

The LAMPTAB reference file is a binary fits table that holds the spectral line templates of the lamp (in the INTENSITY column) and the FP-POS offset value in units of pixels (in the FP_PIXEL_SHIFT column) for each segment, grating, central wavelength, and FP-POS setting available. There is also the column HAS_LINES, which holds a Boolean that is false if no lamp lines are present for that segment, grating, cenwave, and FP-POS combination. Currently, Segment B of modes G130M/1055, G130M/1096, G130M/1230 (no longer in use), and G140L/1280 are the only rows with HAS_LINES = False. More information about the contents and format of the LAMPTAB file can be found in the COS Data Handbook, in Section 3.7.10. There are LAMPTAB files for both the FUV and NUV detectors, but here we focus solely on the FUV at LP3.

The LAMPTAB needs to be updated after each lifetime position (LP) move since the focus values and y-location of the WCA change, which can impact line resolution and lead to incorrect shift offsets calculated by `CalCOS`. Here we document the creation and testing of the LAMPTAB reference file at LP3. This ISR is organized as follows: the observations are described in Section 2 and the calibrations are described in Section 3. Section 4 describes our analysis, including the removal of OSM drift of the exposures and the creation of the templates. Lastly, Section 5 describes the science validation procedures.

2. Observations

We observed the lamp spectrum at every segment, grating, cenwave, and FP-POS position available at LP3 in PID=14856 (COS/FUV Wavecal lamp template reference files at LP3, PI Rachel Plesha), which executed in October 2016 in Cycle 24. The program consisted of three visits (one visit for each of the G160M, G130M, and G140L gratings) and 15 orbits total; its structure is summarized in Table 1. The program followed the outline of the SMOV program 11488 (COS Internal FUV Wavelength Verification, PI Charles Keyes), where long (1800 second) lamp exposures are used to wait for the optical selection mechanism (OSM) to settle before the lamp template data was taken in each visit. The wavecal lamp was regularly flashed during the long exposures, using special engineering mode flash durations (30 second) and separations (90 second) in the Astronomer's Proposal Tool (APT) software to sample the drift for later analysis.

After this long exposure, we obtained 120 second exposures of the lamp with each observing mode at each FP-POS, except for G140L/1055 and G140L/1096, since these modes are operated at LP2 only. The lamp was kept on continuously for these exposures. The 120 second exposure time was chosen to be 10 times the exposure time of the tagflashes taken during science exposures. These tagflash exposure times are listed in Table 5.2 of the COS Instrument Handbook. For most G130M and G160M modes, the tagflash exposures are 12 seconds, while for G140L the exposures are 7

Table 1. Table summarizing the exposures in PID 14856. The first exposures in each visit that have very long exposure times are used to allow the OSM drift to settle before the science observations begin. All other observations are used to create the lamp templates.

Visit	Exp. #	Cenwave	FP-POS	Exp. Time (seconds)	Flash On/Off (seconds)
01	1	1291	3	1200	30/90
	2−5	1291	1−4	120	None
	6−9	1222	1−4	120	None
	10−13	1300	1−4	120	None
	14−17	1309	1−4	120	None
	18−21	1318	1−4	120	None
	22−25	1327	1−4	120	None
02	1	1577	3	1800	30/90
	2−5	1577	1−4	120	None
	6−9	1589	1−4	120	None
	10−13	1600	1−4	120	None
	14−17	1611	1−4	120	None
	18−21	1623	1−4	120	None
03	1	1280	3	1800	30/90
	2−5	1280	1−4	120	None
	6−9	1105	1−4	120	None

seconds. The one exception is the G130M/1222 setting, which has a default tagflash exposure time of 52 seconds. This means that the signal-to-noise of the lamp spectra for this mode was too low to create an adequate template for use in the LAMPTAB. In Section 4.1, we discuss how the lamp template for the G130M/1222 mode was created.

3. Calibration

We calibrate the data used to create the LP3 LAMPTAB by first setting the calibration switches in the `rawtag` file headers to those listed in Table 2. In this table, the keywords listed in red have been changed from their default values, which are described next. We first change the RANDSEED value to be the same for all `rawtag` files, so that all the templates are randomized in the same manner. We set the extraction algorithm to be BOXCAR and set TRCECORR and ALGNCORR (steps in `CalCOS` used for the TWOZONE extraction method only) to OMIT. We turn off many calibration steps that are not necessary for our analysis, including FLATCORR, DEADCORR, DQICORR,

YWLKCORR[2], PHACORR[2], DOPPCORR, HELCORR, BACKCORR, FLUXCORR, BRSTCORR, and TDSCORR. It is essential to leave the WAVECORR step on, so that CalCOS produces lampflash files, which contain information about the shifts calculated between each lamp flash. We use these files later to remove the OSM drift from each exposure.

Because our 120 second exposures have the lamp on throughout the entire exposure, the header information in each rawtag file will indicate that there is only a single lamp flash, which will not give us the shift information needed to remove the OSM drift. However, by rewriting the information in the headers, we can manually instruct CalCOS to divide the exposure into flash bins. For this analysis, we therefore use four bins of 30 seconds per exposure, which provides adequate signal-to-noise per bin as well as good time sampling. This is accomplished by setting the header keywords listed in Table 3. We supply to CalCOS the number of flashes, as well as the duration and start, middle, and end times of the first and second flashes, in terms of the exposure start time. For the 120 second exposures, the number of flashes is four; the duration of all flashes is 30 seconds; the start, middle, and end times of the first flash are 0, 15, and 30 seconds, respectively; and the the start, middle, and end times of the second flash are 60, 75, and 90 seconds, respectively. We must also specify that the TAGFLASH header keyword is "uniformly spaced", which is different from the default option of "auto", which is used for regular tag-flash data. The 1800 second exposure at the beginning of each orbit already has these parameters set (since it was specified in the Phase II) to reflect that the flash lasts 30 seconds and is off for 90 seconds. Though this data is not used for the actual reference file creation, it is used as a check to ensure that the OSM drift has settled throughout the exposures.

These data were taken after the move to LP3, so we are able to use the default reference files for LP3 for these calibrations. We use the default LAMPTAB at that time, which was created for LP1 data, except for the G130M 1055, 1096, and 1222 cenwaves that were added later at LP2. We calibrate all exposures in PID 14856 in this manner (adjusting the flash keywords in the headers) using CalCOS version 3.3.4. The output of these calibrations are corrtag, lampflash, and x1d files. We describe how these are used in our analysis next.

4. Analysis and File Creation

The lampflash files created in section 3 store information about the shift calculated per flash bin in its SHIFT_DISP column. This value includes both shift from the OSM drift and the FP-POS offset of the observation. The shift in pixels between each FP-POS offset with respect to FP-POS=3 (FP_PIXEL_SHIFT) is stored in the LAMPTAB for each mode. This value in part sets the zero point in the dispersion relation for the

[2]At the time of this analysis, we did not perform the YWLKCORR and PHACORR calibration steps. Later work (see COS ISR 2019-07) revealed these steps to be crucial for these data, so other future LAMPTABs should have both steps set to PERFORM.

Table 2. The calibration switches used to calibrate the raw data from PID 14856 in CalCOS for the creation of the LP3 LAMPTAB reference file. Calibration steps shown in black are defaults, whereas those in red have been changed from the default. All of the keywords listed above are in the zeroth header extension of the rawtag files.

Keyword	Value	Description
FLATCORR	OMIT	Apply flat-field correction
DEADCORR	OMIT	Correct for deadtime
DQICORR	OMIT	Data quality initialization
STATFLAG	T	Calculate statistics?
TEMPCORR	PERFORM	Correct for thermal distortion
GEOCORR	PERFORM	Correct FUV for geometic distortion
DGEOCORR	PERFORM	Delta Corrections to FUV Geometric Distortion
IGEOCORR	PERFORM	Interpolate geometric distortion in INL file
RANDCORR	PERFORM	Add pseudo-random numbers to raw x and y
RANDSEED	12345	Seed for pseudo-random number generator
XWLKCORR	OMIT	Correct FUV for Walk Distortion in X
YWLKCORR	OMIT[2]	Correct FUV for Walk Distortion in Y
PHACORR	OMIT[2]	Filter by pulse-height
TRCECORR	OMIT	Trace correction
ALGNCORR	OMIT	Align data to profile
XTRCTALG	BOXCAR	BOXCAR or TWOZONE
BADTCORR	OMIT	Filter by time (excluding bad time intervals)
DOPPCORR	OMIT	Orbital Doppler correction
HELCORR	OMIT	Heliocentric Doppler correction
X1DCORR	PERFORM	1-D spectral extraction
BACKCORR	OMIT	Subtract background (when doing 1-D extraction)
WAVECORR	PERFORM	Use wavecal to adjust wavelength zero-point
FLUXCORR	OMIT	Convert count-rate to absolute flux units
BRSTCORR	OMIT	Switch controlling search for FUV bursts
TDSCORR	OMIT	Switch for time-dependent sensitivity correction

wavelength calibration in CalCOS by fixing where the lamp's spectral lines should be after the OSM's movement has settled. CalCOS then calculates the difference between where the flash is located versus where the template says it should be, which results in a measurement of the OSM drift calculated per flash time bin for each exposure, which we remove in the next step.

The corrtag files created in section 3 contain the x-location, y-location, and time of arrival for each lamp photon captured in the exposure in the columns XCORR, YCORR, and TIME, respectively. We subtract the appropriate OSM drift value

Table 3. Additional header keywords needed to calibrate the 120 second exposure raw data from PID 14856 in CalCOS for the creation of the LP3 LAMPTAB reference file. All keywords above are in the first header extension of the rawtag files, with the exception of TAGFLASH, which is in the zeroth header extension. All times/durations are in seconds.

Keyword	Value	Description
TAGFLASH	UNIFORMLY SPACED	Type of flashed exposures in time-tag
NUMFLASH	15	Integer number of flashes
LMPDUR1	30.0	duration of 1st flash
LMP_ON1	0.0	1st lamp turn-on time
LMPOFF1	30.0	1st lamp turn-off time
LMPMED1	15.0	median time of 1st flash
LMPDUR2	30.0	duration of 2nd flash
LMP_ON2	120.0	2nd lamp turn-on time
LMPOFF2	150.0	2nd lamp turn-off time
LMPMED2	135.0	median time of 2nd flash

calculated above in the lampflash from the XCORR of each event in each corresponding flash time bin to create a "deshifted" corrtag file. Events that arrived in time 0-30 seconds will have the OSM drift measurement from the 0-30 second flash time bin in the lampflash subtracted from their XCORR value. Once complete for all time bins, we must copy the updated XCORR column into the XFULL column of the corrtag, because the values from that column CalCOS are what uses next for the spectral extraction.

We then re-extract the spectra by running these corrtag files through CalCOS once more to create a new set of x1d files. These "deshifted" x1d files are what are used to make the new LAMPTAB. For each observing mode, we replace the INTENSITY column of the LP1 LAMPTAB with the net counts (in units of counts per second) of the corresponding x1d file multiplied by its exposure time. Then, for each cenwave observed, we cross-correlate the FP-POS=3 lamp spectrum to those taken at FP-POS=1, FP-POS=2, and FP-POS=4 to calculate an updated FP_PIXEL_SHIFT value for each observing mode. These new values are also written into the updated LAMPTAB file to create the final LP3 LAMPTAB.

One special case is the B segment of G140L/1280. This setting has no observable lamp lines, and thus the intensity is set to an array of zeros in the LAMPTAB. CalCOS copies the shifts calculated from the A segment into the B segment to use for the wavelength correction.

We lastly also use these data to update the zero-point column of the dispersion table reference file (DISPTAB). This is done by cross-correlating the LP1 LAMPTAB spectra to the newly created LP3 LAMPTAB spectra. These zero-point offsets are written to the "D" column of the DISPTAB, and then are later folded into the "a0" offset column. See COS ISR 2018-24 for more information about how this data is used and calculated. This pair of LAMPTAB and DISPTAB files must be used together for file testing, which is described in Section 5.

4.1 Creation of the Cenwave 1222 Lamp Spectra

As mentioned in Section 2, the 120 second exposure time was too short to provide adequate signal-to-noise to create the template spectra for G130M cenwave 1222, which has a default tagflash exposure length of 52 seconds, compared to the 12 seconds of the other modes. Since the FUV detector was operating at LP3 at the time of this analysis, there was tagflash data available at LP3 in cenwave G130M/1222 that we used to create the template spectra for each FP-POS instead. To do this, we downloaded all LP3 data using the cenwave 1222 mode, and cross-correlated, aligned, and stacked all of the tagflash spectra within the GO datasets. We then adjusted the zero-point x-pixel offset of each stacked GO dataset (one for each FP-POS) to the de-shifted zero-point of the G130M/1222 data taken from the lamp template program, so that the FP_PIXEL_SHIFT values would be accurate. We calculated the FP_PIXEL_SHIFT values and zero-points for these modes in the same way as above. Using the stacked spectra yielded templates with much greater signal-to-noise than the data in the lamp template program.

5. Validation

5.1 Technical Testing

Our technical testing for the new reference file included performing a 'fitsdiff' between the newly updated LAMPTAB and the original LP1 LAMPTAB. The 'fitsdiff' returns which rows and header keywords in the fits files differ. With this output, we can confirm that the INTENSITY and FP_PIXEL_SHIFT columns are updated correctly for each observing mode. Second, we calibrate the `rawtag` files our PID 14856 dataset through the latest `CalCOS` version (3.3.4 at the time of file creation). This ensures that the format of the fits file is uncorrupted and can be used for calibration.

5.2 Scientific Testing

Our first scientific test was to check that the drift from the OSM was correctly removed from the deshifted `corrtag` files used to create the INTENSITY arrays in the LAMPTAB. To do this, we recalibrate the deshifted `corrtags` using the newly created LP3 LAMPTAB and DISPTAB files and the calibration switches as in Table 2 to create new deshifted `LAMPFLASH` files. If the test is successful, we should see that the residual SHIFT_DISP value (in the deshifted `LAMPFLASH` files) between each flash bin relative to the first flash is near zero pixels. The results of this test are shown in Figures 1 to 12 for all modes, with the exception of G130M/c1222, since these templates were made in a different way. The figures show for each cenwave, FP-POS, and segment, the SHIFT_DISP value of first flash bin subtracted from the SHIFT_DISP value of the subsequent flash bins for both the original (unshifted) `LAMFLASH` files and the deshifted `LAMPFLASH` files. The figures illustrate that in almost all cases, the residual shift of the deshifted data is 0±0.1 pixel. The one exception (G130M/1291/FUVB in Figure 3 that has deshifted residuals <0.2 pixels) is likely due to uncertainties in `CalCOS`'s cross-correlation routine.

The second test is to verify that the FP_PIXEL_SHIFT values in the new LAMPTAB are internally consistent. We do this by cross-correlating the FP-POS=1, 2, and 4 INTENSITY arrays for each mode to the FPPOS=3 INTENSITY array, and then subtracting that value from the FP_PIXEL_SHIFT column in the LAMPTAB. If the test is successful, we will see that the two values agree. The results from this test are shown in Figures 13 and 14. All residuals are under 1 pixel, which is well within our ±3 pixel error budget for FUV wavelength calibrations (see COS ISR 2018-24; Plesha et al 2018).

6. Conclusion

After completing the appropriate header keyword updates to the validated reference file, we delivered the new LAMPTAB to the HST Calibration Reference Data System on April 6, 2018. The new LAMPTAB (5b91919tl_lamp.fits) is in use for all LP3 observations. This file has since been superseded to include rows for the G140L/800 mode that was commissioned in October 2021. Details on this effort can be found in COS ISR 2022 XX (Hirschauer et al 2022).

Change History for COS ISR 2022-13

Version 1: - 25 October 2022: Original Document

References

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Soderblom, D., et al. 2021, COS Data Handbook, Version 5.0, (Baltimore: STScI).

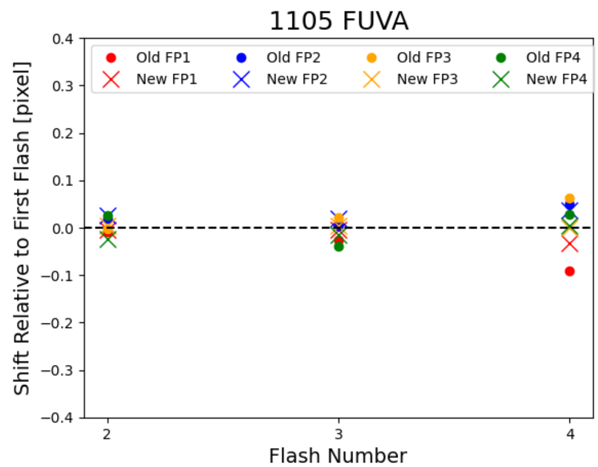

Figure 1. Scientific testing to check that OSM drifts have been correctly removed in the `corrtag` files used to make the G140L/1105 entries in the LP3 LAMPTAB. This figure shows the shift in pixels for each flash bin relative to the shift of the first flash for each exposure. The rows are ordered by FP-POS, and the columns are for FUVA and FUVB consecutively. The circles show the relative shift of the original (unshifted) `LAMPFLASH` files and the crosses shows that of the deshifted `LAMPFLASH` files. The deshifted residuals are much closer to zero pixels than those of the unshifted ones, showing that the drift from the OSM has been removed.

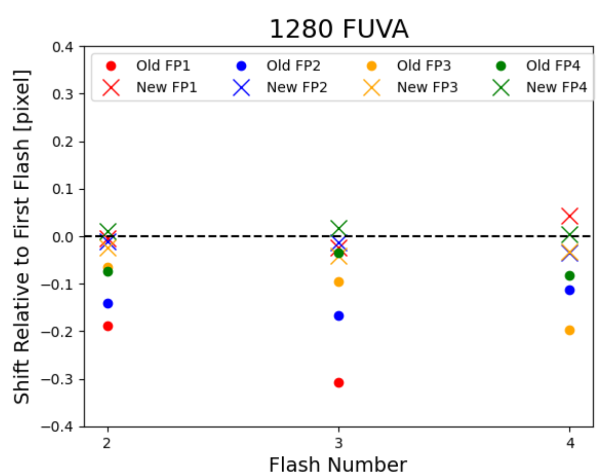

Figure 2. Same as Figure 1, but for the G140L/1280 FUVA mode (the FUVB segment has no lamp emission lines).

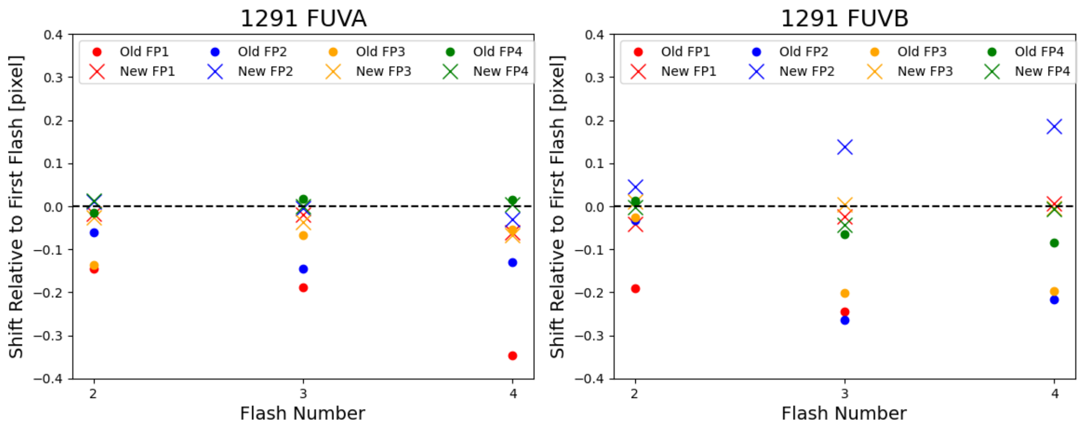

Figure 3. Same as Figure 1, but for the G130M/1291 mode.

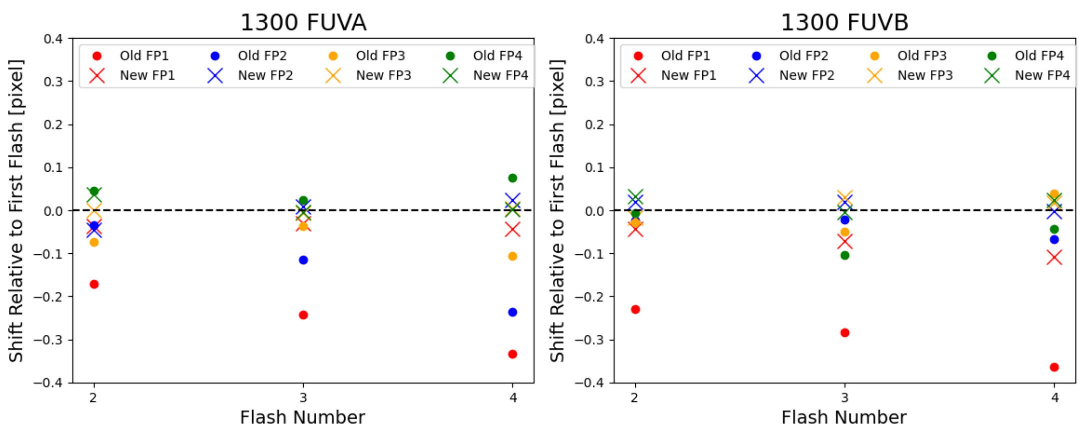

Figure 4. Same as Figure 1, but for the G130M/1300 mode.

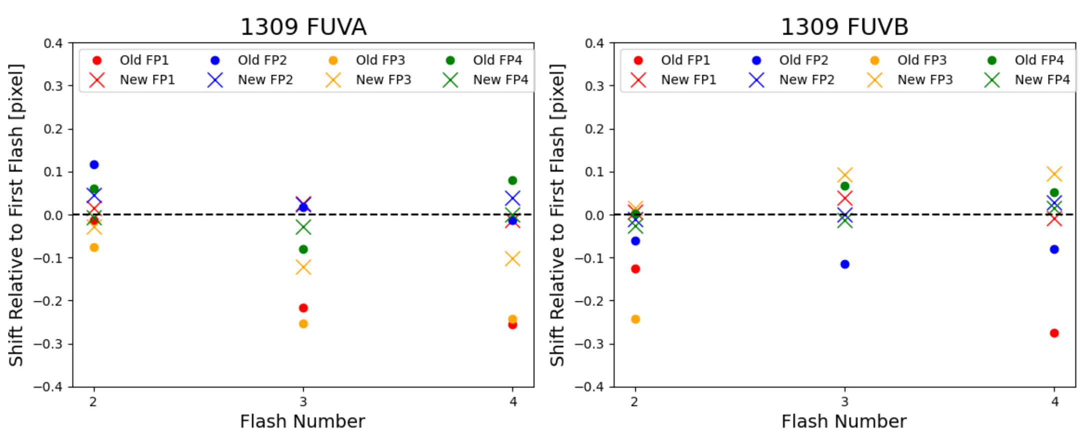

Figure 5. Same as Figure 1, but for the G130M/1309 mode.

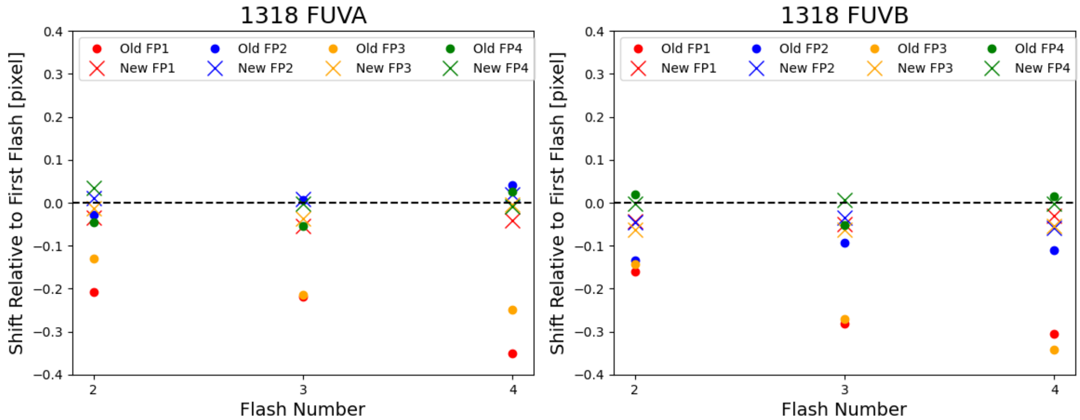

Figure 6. Same as Figure 1, but for the G130M/1318 mode.

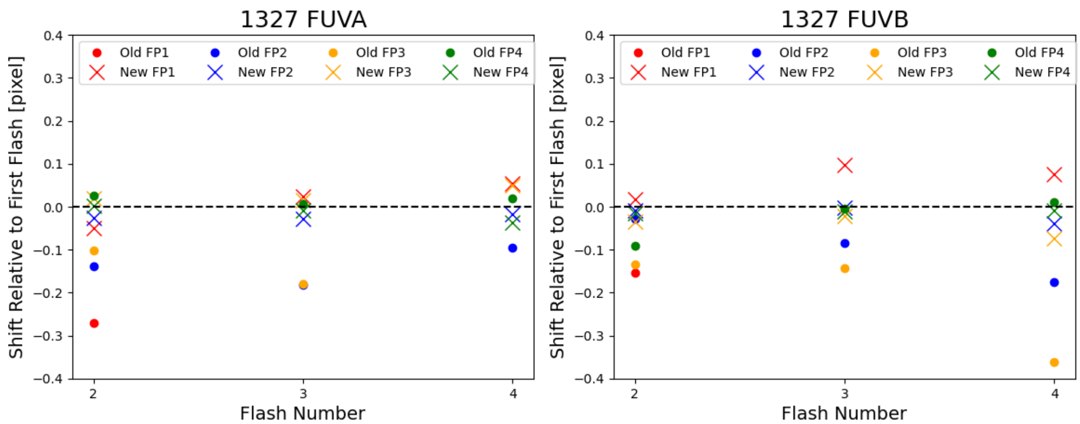

Figure 7. Same as Figure 1, but for the G130M/1327 mode.

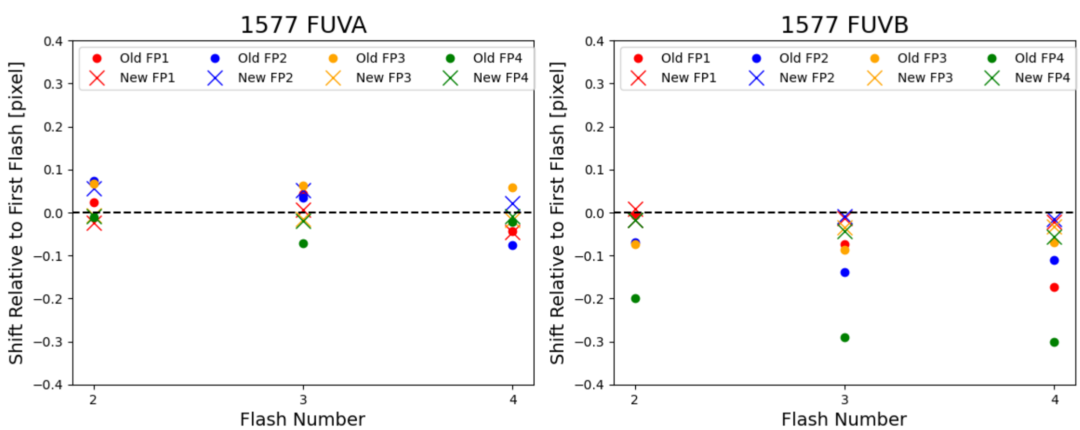

Figure 8. Same as Figure 1, but for the G160M/1577 mode.

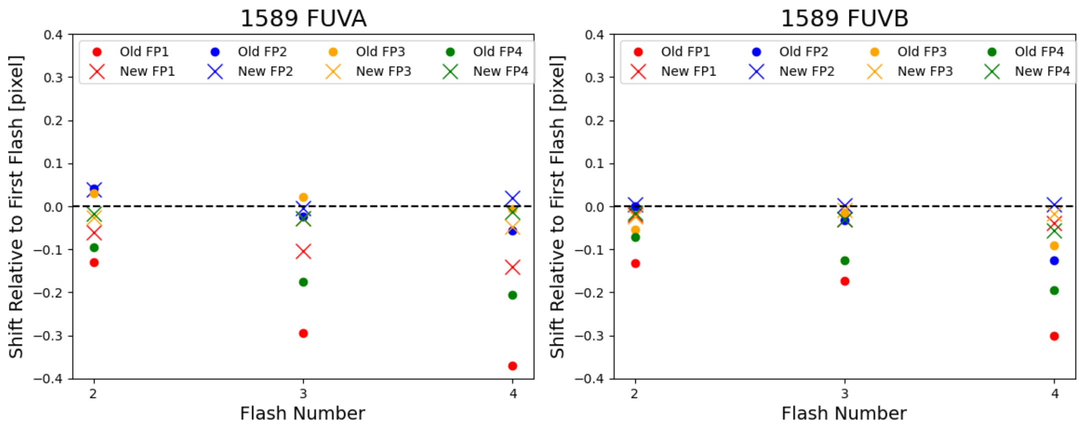

Figure 9. Same as Figure 1, but for the G160M/1589 mode.

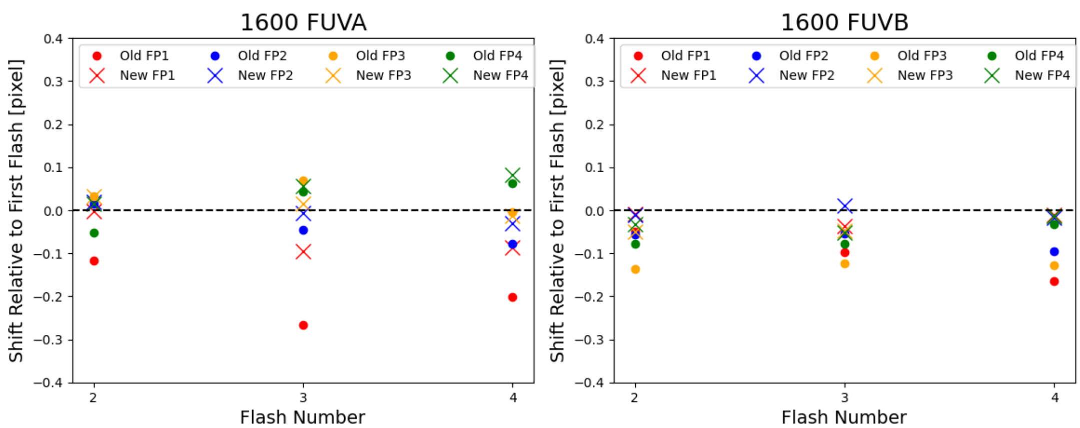

Figure 10. Same as Figure 1, but for the G160M/1600 mode.

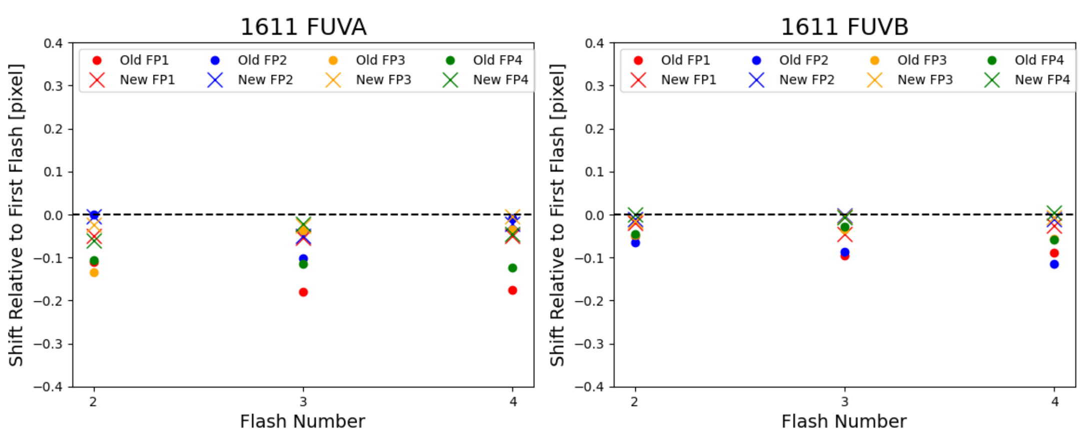

Figure 11. Same as Figure 1, but for the G160M/1611 mode.

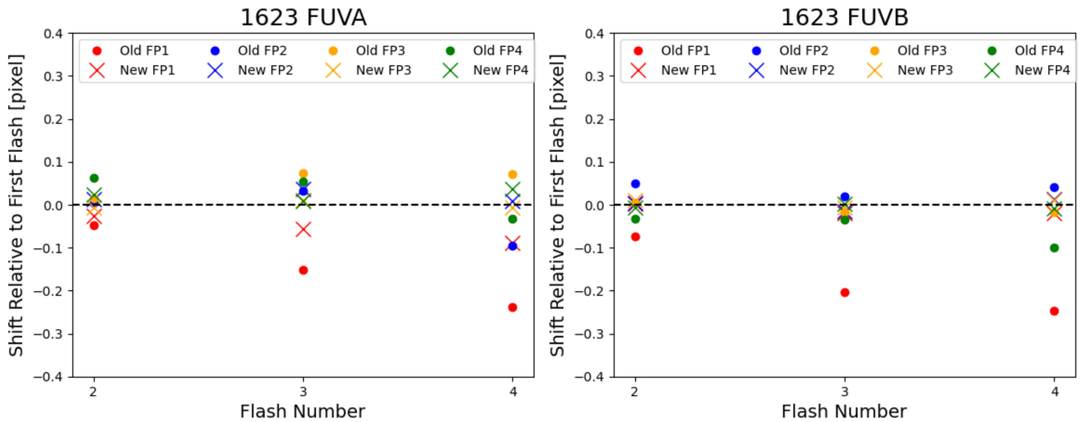

Figure 12. Same as Figure 1, but for the G160M/1623 mode.

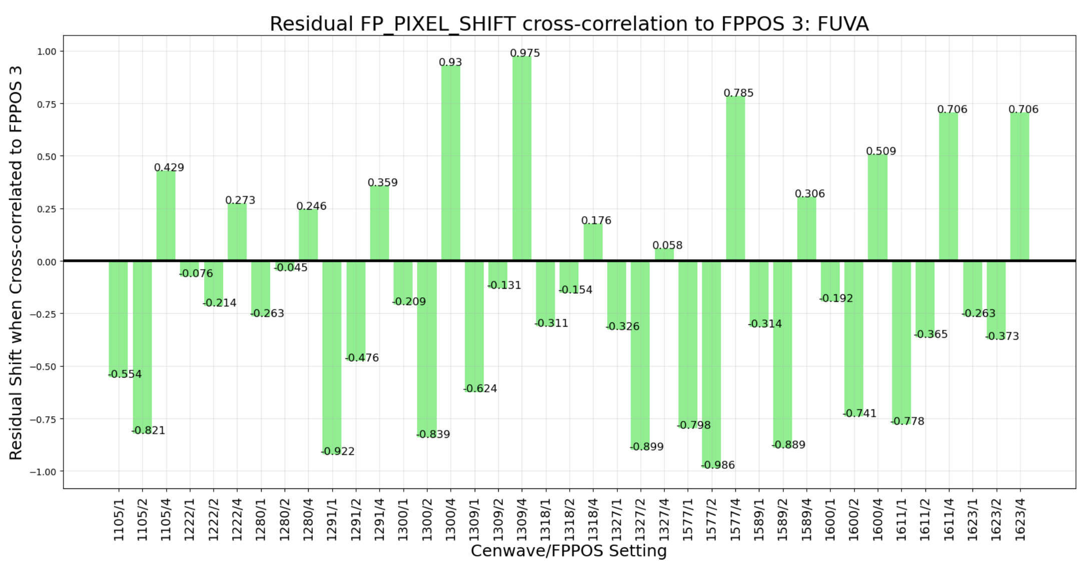

Figure 13. Scientifc testing to verify the FP_PIXEL_SHIFT is calculated correctly for the FUVA segment for all cenwaves and FP-POS combinations at LP3. The residual shift (y-axis) is calculated by cross-correlating the FP-POS=1, 2, and 4 INTENSITY arrays for each mode to the FPPOS=3 INTENSITY, and then subtracting that value from the FP_PIXEL_SHIFT column in the LAMPTAB. All values match within 1 pixel, meaning the FP_PIXEL_SHIFT calculations are accurate.

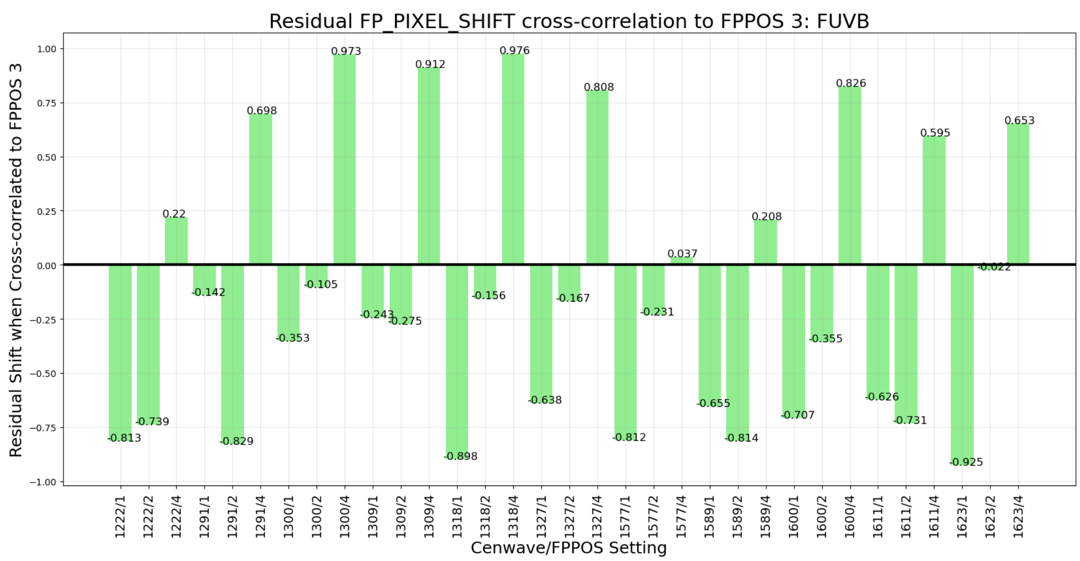

Figure 14. Same as for Figure 13, but for the FUVB segment.