The LAMPTAB Reference File at Lifetime Position 4

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26 September 2023

ABSTRACT

A new COS/FUV lamp template reference file (LAMPTAB) for Lifetime Position 4 (LP4) was delivered for use in the COS calibration pipeline in April 2018. The LAMPTAB contains reference spectra used during the wavelength calibration of COS/FUV spectroscopic data. The data used to derive the lamp spectral templates were acquired in August 2017 in Program 15369 as a part of the LP4 calibration activities. In this ISR, we document the creation and testing procedures for this reference file.

Contents

1. Introduction

The Cosmic Origins Spectrograph (COS) aboard the Hubble Space Telescope (HST) houses 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 to calibrate science data and thus is the one used for this analysis (and will henceforth be referred to just as "the lamp"). 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.

Light from the lamp shines through the wavelength calibration aperture (WCA) and then passes through the same optical elements as the science data. The lamp spectra are intentionally placed higher on the detector than the science spectra, which come through either the primary science aperture (PSA) or the bright object aperture (BOA), to prevent contamination. 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 dispersion solution changes over time due to small settling movements ("drift") of the Optics Select Mechanism (OSM), which can cause artificial spectral line broadening. There are two OSMs on COS; OSM1 holds the FUV gratings and the NUV Collimating Mirror 1, while OSM2 holds the NUV gratings and a mirror for target acquisitions or imaging. For this analysis, the OSM we refer to is OSM1. See COS ISR 2011-04 (Keyes 2011) for more information about how the tagflash mode works. By comparing the lamp template in the LAMPTAB to the tagflash data, `CalCOS` can remove the OSM drift and calculate an accurate wavelength correction for the extracted dataset.

The LAMPTAB reference file is a binary fits table that holds spectral line templates of the lamp in its INTENSITY column and the FP-POS x-offset value in units of pixels in the FP_PIXEL_SHIFT column for each segment, grating, central wavelength, and FP-POS setting available. The reference file also includes the column HAS_LINES, which holds a Boolean that is false if no lamp lines are present for that segment, grating, cenwave, 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.

In this ISR, we describe the creation of a new LAMPTAB for lifetime position 4 (LP4). The LAMPTAB needs to be updated after each lifetime position (LP) move since the focus values and y-location of the WCA are different at each LP, which can impact

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[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.

line resolution and lead to incorrect shift offsets calculated by `CalCOS`. This work builds largely upon the LP3 LAMPTAB effort, which is described in COS ISR 2022-13 (Frazer et al. 2022). 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 observe the lamp spectrum at every segment, grating, cenwave, and FP-POS position available at LP4 in PID 15369 (COS FUV Lamp Templates at LP4, PI Elaine Snyder), which executed in August 2017. This program follows the outline of the Servicing Mission Orbital Verification (SMOV) program 11488 (COS Internal FUV Wavelength Verification, PI Charles Keyes) and Cycle 24 program 14856 (COS/FUV Wavecal lamp template reference files at LP3, PI Rachel Plesha), where long (1800 second) lamp exposures are used to wait for the OSM to settle before the lamp template data are taken in each visit. The wavecal lamp is regularly flashed during the long exposures, using special engineering mode flash durations (30 seconds) and separations (90 seconds) in the Astronomer's Proposal Tool (APT) software to sample the drift for later analysis.

This program consists of 4 visits, which are summarized in Table 1. As stated above, the first exposure in each visit is a long (1200-1800 second) lamp observation to allow the OSM to settle. With this first exposure, we also set LIFETIME-POS=LP4 in APT. Since these data were taken while COS/FUV was still operating at LP3, this was necessary in order to adjust the PSA and WCA to the correct positions for LP4, as well as to set the HV to the nominal LP4 settings, which was 163 on both segments at the time.

The second exposure in each visit is a dark observation used to raise the HV setting from the nominal LP4 setting to the highest HV allowed for both segments (178/175). This is necessary because the WCA at LP4 falls on top of the heavily-gainsagged LP2 PSA region (see White et al 2018 for more details). Raising the HV before taking the template observations helped mitigate the effects of the lamp emission lines falling in gain sag holes. The last exposure of each visit is another dark used to lower the HV back to the nominal LP3 levels (167/175 at the time). The dark exposure time needed to raise the HV is calculated by multiplying the maximum number of HV steps moved by 1.1 seconds, then adding that rounded-up result to 39 seconds (the overhead time necessary to execute the special commanding). This gives an exposure time of 56 seconds needed to raise the HV from 163/163 to 178/175. The exposure time needed to lower the HV is always 39 seconds.

The remaining exposures in the visit are the wavecal lamp observations that will be used as the templates. They are divided into visits by grating: Visits 01 and 02 contain G130M, Visit 03 contains G160M, and Visit 04 contains G140L. Differing from the SMOV and LP3 LAMPTAB programs, these observations employ a 30 second interval

on/off lamp flash pattern in order to keep the lamp cooler and reduce these exposures' impact on the lamp lifetime. The exposure times are calculated to have at least 10 times the exposure time of the flashes that occur during regular tagflash observations. These flash durations are given in Table 5.2 of the COS Instrument Handbook. The flash durations are 7-12 seconds for all G140L, G160M, and G130M modes (except G130M/1222 and G130M/1223), which necessitates 120 seconds of lamp time. With the 30 second on/off intervals, this adds to a total exposure time of 210 seconds per observation. The flash durations of the G130M/1222 and G130M/1223[2] modes are 52 seconds. Therefore the exposure time needed for those observations is 1050 seconds, which gives a total lamp time of 540 seconds with the 30 second on/off intervals.

3. Calibration

We calibrate the data used to create the LP4 LAMPTAB in a very similar manner as for LP3 LAMPTAB (Frazer et al 2022a). The calibration switches in the `rawtag` file headers are set to those listed in Table 2. In this table, the steps listed in red have been changed from their default values, which are described next. The RANDSEED value is set the same for all `rawtag` files, so that all the templates are randomized in the same manner. This is not strictly necessary; however it was useful for testing between file creation iterations. The extraction algorithm is set to BOXCAR, and TRCECORR and ALGNCORR (steps in `CalCOS` used for the TWOZONE extraction method only, which is not enabled for the WCA region) are changed to OMIT. We turn off many calibration steps that are not necessary for our analysis, including FLATCORR, DEADCORR, DQICORR, YWLKCORR[3], PHACORR[3], DOPPCORR, HELCORR, BACKCORR, FLUXCORR, BRSTCORR, and TDSCORR. The WAVECORR step must be left 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.

The `rawtag` files also include information in their headers that tell `CalCOS` how many tagflashes there are in each exposure. These keywords are listed in Table 3. Usually, when a special engineering flash parameter is set for an observation in APT, these header keywords will be auto-populated correctly in the `rawtag`, but we double checked this for our analysis. `CalCOS` needs 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, in order to produce accurate `lampflash` files. For example, for one of the 210 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,

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[2] The G130M/1223 cenwave was implemented in 2017 as part of the COS2025 effort, but was later discontinued due to its having a spectral resolution similar to that of the G130M/1222 mode.

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

Table 1. Table summarizing the exposures in PID 15369. The first exposures in each visit are long to allow the OSM movement to settle. The second and last exposures in each visit are darks used to raise and lower the HV values. 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	—	—	56	—
	3−6	1291	1−4	210	30/30
	7−10	1222	1−4	1050	30/30
	11−14	1300	1−4	210	30/30
	15−18	1309	1−4	210	30/30
	19	—	—	39	—
02	1	1318	3	1800	30/90
	2	—	—	56	—
	3−6	1318	1−4	210	30/30
	7−10	1223	1−4	1050	30/30
	11−14	1327	1−4	210	30/30
	15	—	—	39	—
03	1	1577	3	1800	30/90
	2	—	—	56	—
	3−6	1577	1−4	210	30/30
	7−10	1589	1−4	210	30/30
	11−14	1600	1−4	210	30/30
	15−18	1611	1−4	210	30/30
	19−22	1623	1−4	210	30/30
	23	—	—	39	—
04	1	1280	3	1709	30/90
	2	—	—	56	—
	3−6	1280	1−4	210	30/30
	7−10	1105	1−4	210	30/30
	11	—	—	39	—

respectively; and the start, middle, and end times of the second flash are 60, 75, and 90 seconds, respectively. These numbers are the same for the G130M/1222 and 1223 exposures, except for the number of flashes. For the long exposures at the beginning of each visit, the numbers will be adjusted for the 90 second rest between the 30 second flashes. The headers must also specify that the TAGFLASH type is "uniformly spaced", which is different from the default "auto" option, which is used for regular tagflash data.

Table 2. The calibration switches used to calibrate the raw data from PID 15369 in `CalCOS` for the creation of the LP4 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 below are in the primary header of the `rawtag` file.

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[3]	Correct FUV for Walk Distortion in Y
PHACORR	OMIT[3]	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

As these data were taken before the move to LP4, we used most of the default reference files that were available for LP3 at the time for these calibrations. Two exceptions to the default reference files include a preliminary XTRACTAB that holds the information about the spectral extraction locations at LP4 and a LAMPTAB from LP1 as the LP3 LAMPTAB was not yet available. We calibrate all exposures in PID 15369 in this manner (adjusting the flash keywords in the headers as necessary) 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.

Table 3. Additional header keywords needed to calibrate the raw data from PID 15369 in `CalCOS`. All keywords are in the first extension header of the `rawtag` files, with the exception of TAGFLASH, which is in the primary header. The numbers listed are valid for the 210 sec exposures in the program. They must be adjusted for the longer G130M/1222 and 1223 exposures in Visits 01 and 02, which have a larger number of flashes, as well as the long exposures that are at the beginning of each visit, which have a different flash pattern. All times/durations are in seconds.

Keyword	Value	Description
TAGFLASH	UNIFORMLY SPACED	Type of flashed exposures in time-tag
NUMFLASH	4	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	60.0	2nd lamp turn-on time
LMPOFF2	90.0	2nd lamp turn-off time
LMPMED2	75.0	median time of 2nd flash

4. Analysis and File Creation

The analysis for this work is the same as what was done for the LP3 versions (Frazer et al 2022a). To briefly summarize that work, we use the SHIFT_DISP (sum of the OSM drift) values from the lampflash files created in Section 3 to calculate the OSM drift per flash time bin in each exposure, along with the FP_PIXEL_SHIFT, which can be obtained from the LAMPTAB used in the calibration. Then, with the `corrtag` files, we subtract the appropriate drift value from the `XCORR` of each event in each corresponding flash time bin to create a "deshifted" `corrtag` file. Once complete for all time bins, we must copy the `XCORR` column to the `XFULL` column of the `corrtag`, becuase the values from that column are what `CalCOS` uses during the spectral extraction.

We then re-extract the spectra by running these `corrtag` files through `CalCOS` once more with WAVECORR=OMIT to create a new set of `x1d` files. These "deshifted" `x1d` files are used to make the new LAMPTAB. For each observing mode, we replace the INTENSITY column of the LP1 LAMPTAB with the product of the NET count rate (counts per second) and the exposure time from the corresponding `x1d` file. 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 LP4 LAMPTAB.

Lastly, we also use these data to update the zeropoint column of the dispersion table reference file (DISPTAB). This is done by cross-correlating the LP1 LAMPTAB spectra to the newly created LP4 LAMPTAB spectra. These zeropoint offsets are written to the "D" column of a temporary DISPTAB that is used when first deriving dispersion solutions at a new LP. They are later folded into the "a0" offset column of the final DISPTAB. See COS ISR 2018-25 (Plesha et al 2018c) for more information about how these data are used and calculated. This pair of LAMPTAB and DISPTAB files must be used together for file testing, which is described next.

5. Validation

5.1 Technical Testing

Our technical testing for the new reference file included a detailed comparison between the newly updated LAMPTAB and the original LP1 LAMPTAB. The `fitsdiff` python package was used to examine the differences between these two files. `fitsdiff` provides a detailed account of which rows and header keywords in the fits files differ. With this output, we confirm that the INTENSITY and FP_PIXEL_SHIFT columns are updated correctly for each observing mode. A separate test involved calibrating the `rawtag` files from our PID 15369 dataset through the latest `CalCOS` version (3.3.4 at the time of file creation) using the newly created reference files. 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 LP4 LAMPTAB and DISPTAB files and setting 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 13 for all modes. 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 all cases, the residual shift of the deshifted data is sub-pixel, with most within 0±0.2 pixel. The cases with higher residuals are likely due to uncertainties in `CalCOS`'s wavelength calibration routine.

The second test is to verify that the FP_PIXEL_SHIFT values in the new LAMPTAB are correct. We do this by cross-correlating the FP-POS=1, 2, and 4 INTENSITY arrays for each mode to the FP-POS=3 INTENSITY array, and then subtracting that value from the FP_PIXEL_SHIFT column in the LAMPTAB. We find

the difference between two values is zero for each mode, which validates the file entries.

6. Conclusion

After completing the appropriate header keyword updates to the validated reference file, the new LAMPTAB (named 24915198l_lamp.fits) was delivered to the HST Calibration Reference Data System on April 6, 2018 for use for all LP4 observations. This file has since been superseded to include rows for the G140L/800 and G160M/1533 cenwaves that were commissioned in November 2018. Details on this effort can be found in COS ISRs 2019-07 (B. James et al 2019b) and 2021-01 (C. Magness et al 2021).

Change History for COS ISR 2023-21

Version 1: 26 September 2023- Original Document

References

Fischer, W. J., et al. 2018, "Cosmic Origins Spectrograph Instrument Handbook", Version 10.0 (Baltimore: STScI)

Frazer, E. M., et al. 2022a, COS ISR 2022-13, "The LAMPTAB Reference File at Lifetime Position 4"

James, B., et al. 2019b, COS ISR 2019-07, "The Lamp Template for the New COS/FUV Cenwave G160M/1533"

Keyes, T., 2011, COS ISR 2011-04, "Details of COS TAGFLASH Execution"

Magness, C. et al. 2021, COS ISR 2021-01, "The Lamp Template for the New COS/FUV Cenwave G140L/800"

Plesha, R., et al. 2018c, COS ISR 2018-25, "Improvements to the COS FUV G130M and G160M Wavelength Solutions at Lifetime Position 4"

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

White, J., et al. 2018, COS ISR 2018-15, "Performance of the CalCOS FUV WAVECORR Algorithm at Lifetime Position 4"
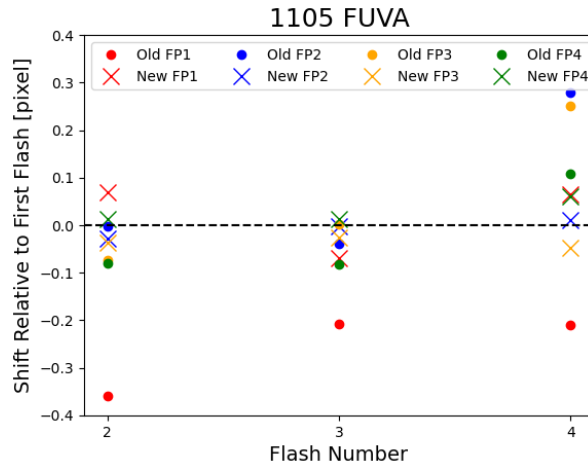
Figure 1. Scientific testing to check that OSM drifts have been correctly removed in the `corrtag` files used to make the G140L/1105 entries in the LP4 LAMPTAB. This figure shows the shift in pixels for each flash bin relative to the shift of the first flash for each exposure. The circles show the relative 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.
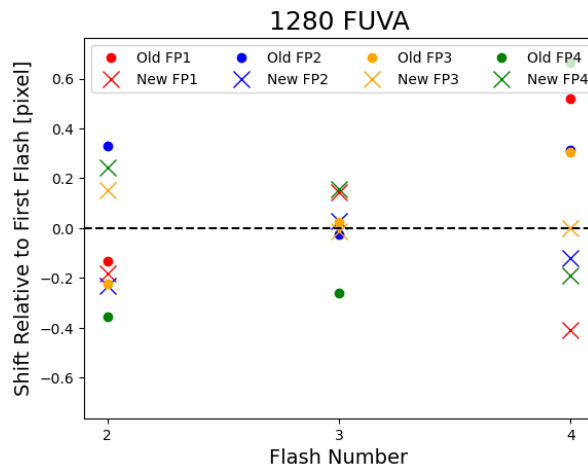
Figure 2. Same as Figure 1, but for the G140L/1280 FUVA mode (the FUVB segment has no lamp emission lines).
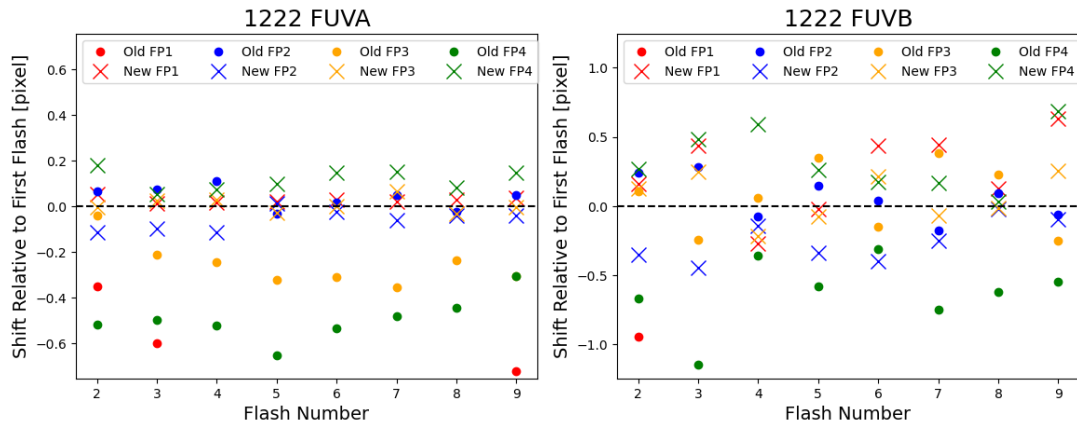
Figure 3. Same as Figure 1, but for the G130M/1222 mode.
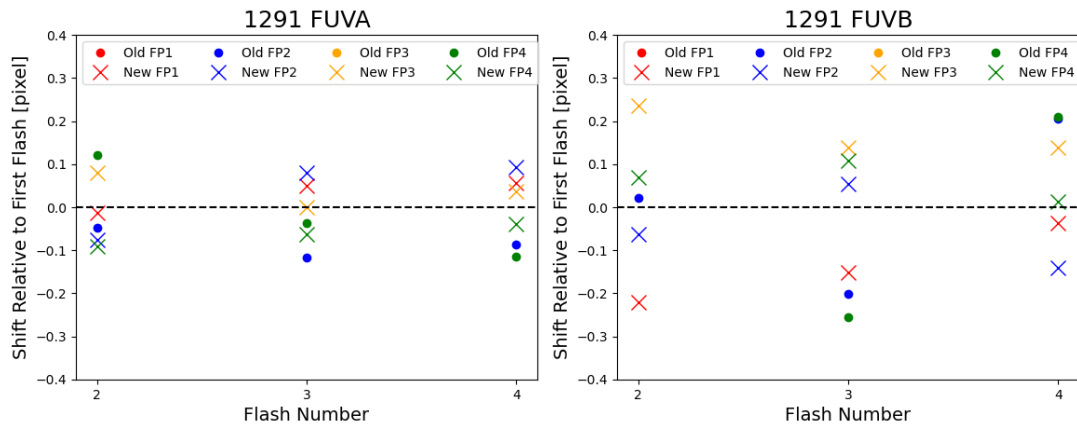
Figure 4. Same as Figure 1, but for the G130M/1291 mode.
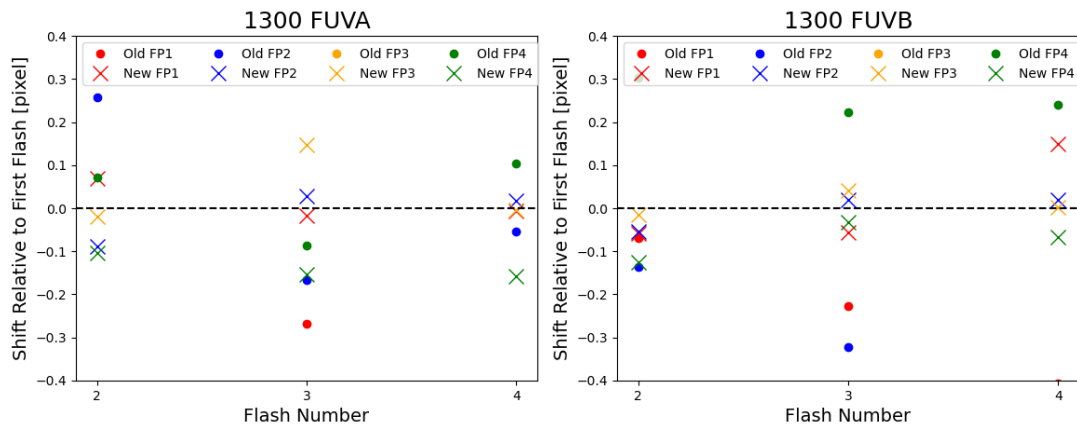
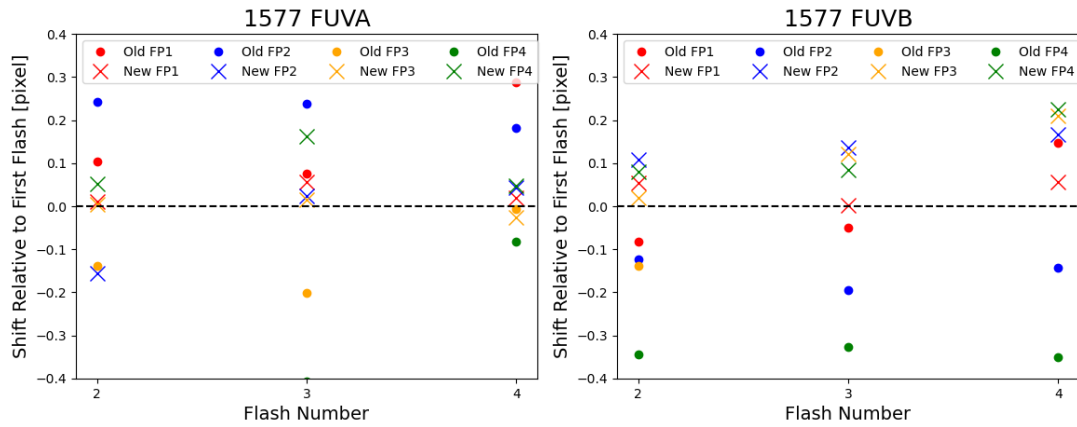**Figure 5.** Same as Figure 1, but for the G130M/1300 mode.
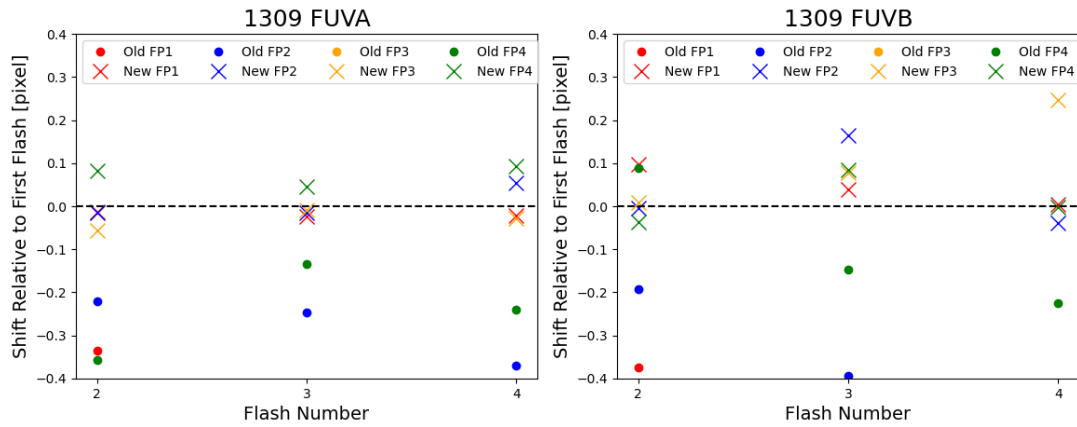
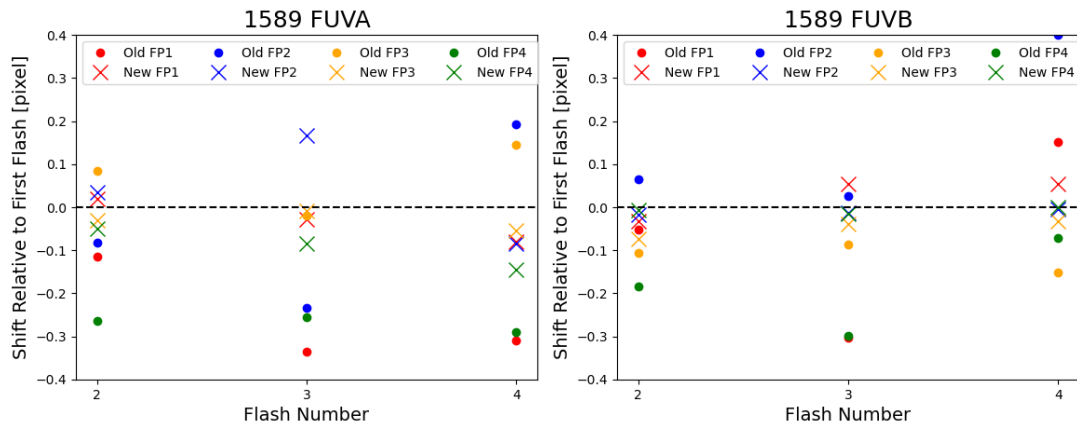**Figure 6.** Same as Figure 1, but for the G130M/1309 mode.
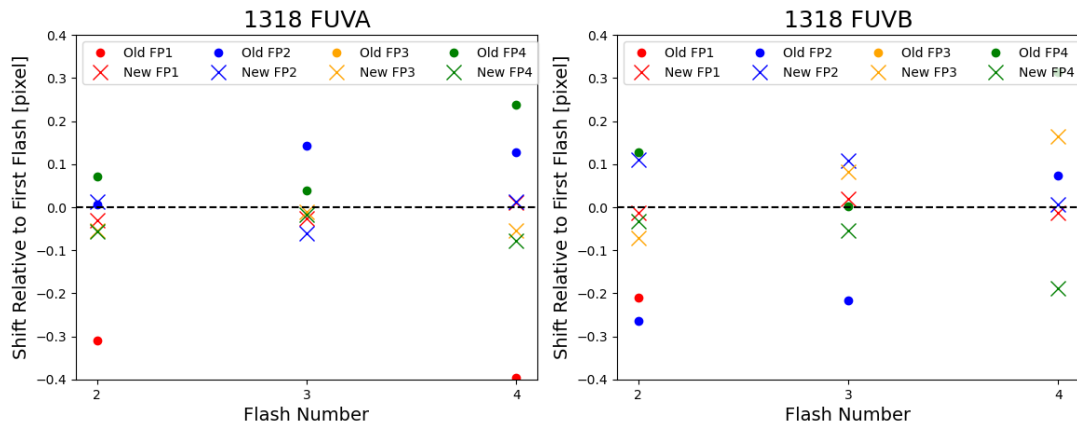
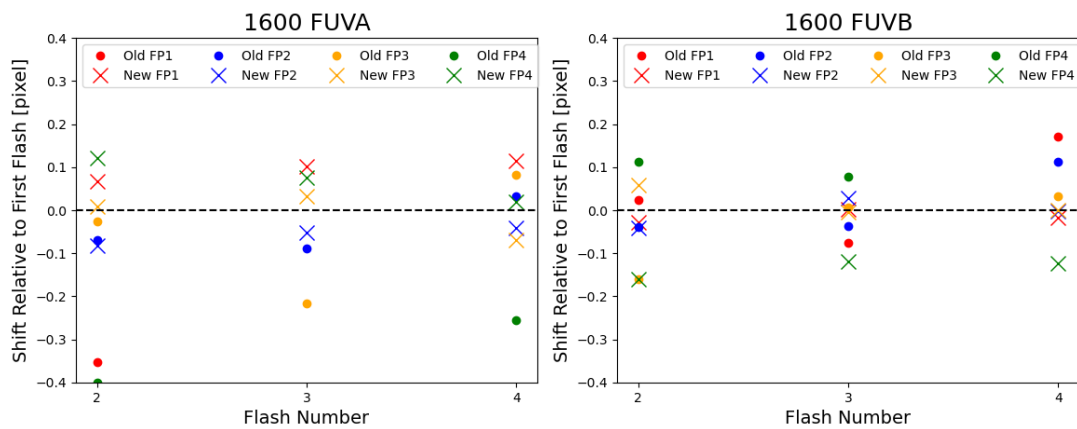**Figure 7.** Same as Figure 1, but for the G130M/1318 mode.
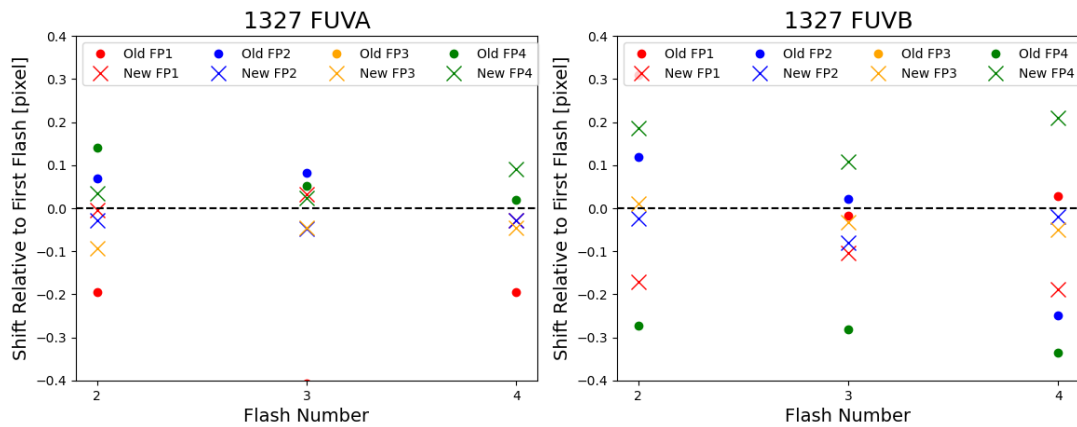
Figure 8. Same as Figure 1, but for the G130M/1327 mode.
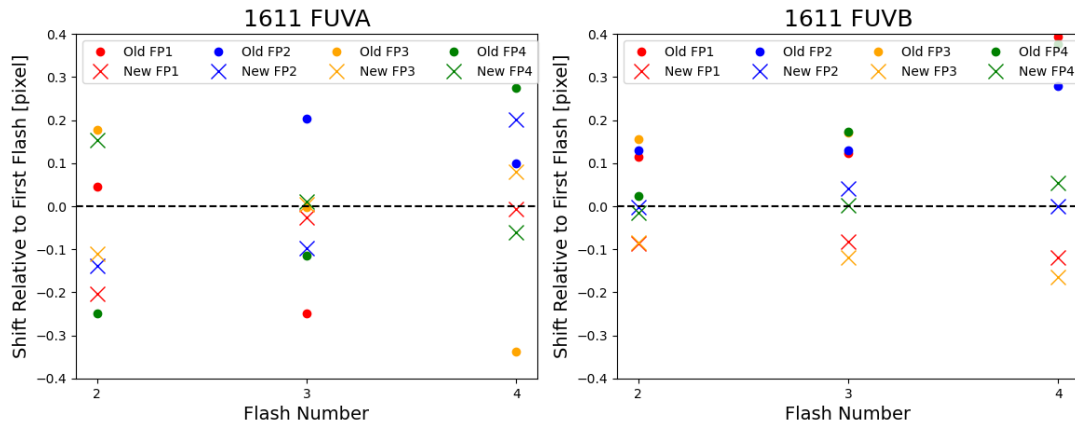
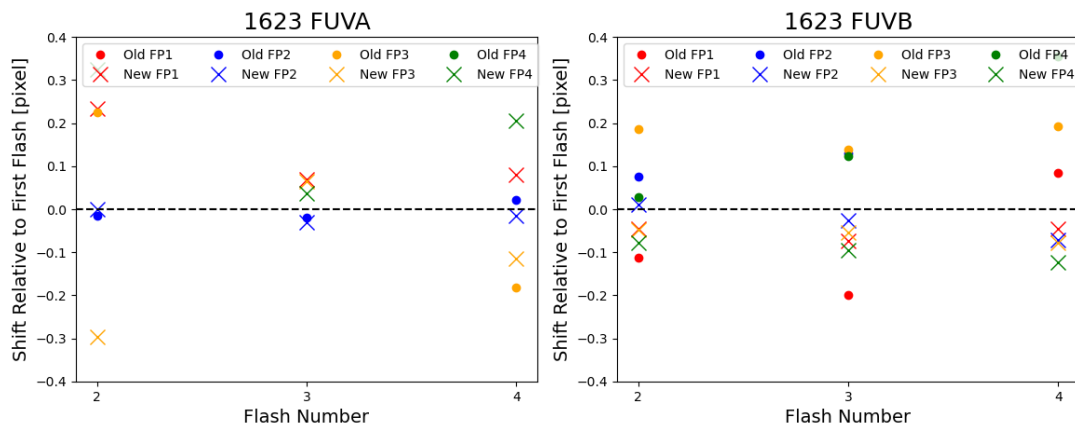**Figure 9.** Same as Figure 1, but for the G160M/1577 mode.

Figure 10. Same as Figure 1, but for the G160M/1589 mode.

Figure 11. Same as Figure 1, but for the G160M/1600 mode.

Figure 12. Same as Figure 1, but for the G160M/1611 mode.

Figure 13. Same as Figure 1, but for the G160M/1623 mode.