**Instrument Science Report COS 2019-07(v1)**

# The Lamp Template for the New COS/FUV Cenwave G160M/1533


Bethan L. James[1], Elaine M. Frazer[1], Andrew J. Fox[1], Julia Roman-Duval[1], and Rachel Plesha[1]

[1] Space Telescope Science Institute, Baltimore, MD


14 November 2019


**ABSTRACT**

*We describe the creation of the lamp template reference file for the new COS/FUV central wavelength setting G160M/1533. We obtained PtNe lamp exposures with Program 15459 in 2018 June. Analysis of the data involved first determining the effects of drift as a function of time, which was subsequently removed from each event. Accurate shifts for each FP-POS were determined by cross-correlating the lamp template data at each FP-POS with that taken at FP-POS=3. These FP_PIXEL_SHIFT values were entered into the LAMPTAB reference file, along with the drift-corrected lamp template data at each FP-POS. The file was tested for scientific accuracy and then delivered to the reference file database system in 2018 November for use in the COS calibration pipeline.*


## Contents

## 1. Introduction

For Cycle 26, two new central wavelength (cenwave) settings were introduced for the COS FUV detector, G140L/800 and G160M/1533. The 1533 cenwave extends coverage at the short-wavelength end of G160M by 44 Å to overlap with the longest wavelengths covered by cenwave G130M/1222. This allows a broad range of FUV wavelengths to be covered by just two medium-resolution settings (1222 and 1533) without placing Ly$\alpha$ on the detector, avoiding a key contributor to gain sag. Furthermore, it allows the full FUV bandpass to be observed at high S/N, since all four FP-POS positions can be used with both 1222 and 1533. This mitigates fixed-pattern noise and allows a higher S/N in the co-added spectrum.

This report forms one of a number of ISRs on the calibration of the new 1533 cenwave. Here we describe how we derived the wavecal template spectra and the offset of each template spectrum at each FP-POS, which is encoded in the LAMPTAB reference file used by the CalCOS pipeline. This ISR is a partner to the ISRs on the derivation of the spectral extraction algorithm (XTRACTAB, TWOZXTAB, PROFTAB, TRACETAB; Frazer et al. 2019a), the wavelength calibration (DISPTAB, Fox et al. 2019a), and the flux calibration (FLUXTAB, Fox et al. 2019b). Together, these reference files were delivered to the Calibration Reference Database System (CRDS) on 2018 November 20, updated for both 1533 and 800, for use with Cycle 26 observations.

When commissioning a new cenwave, we need to create a lamp template spectrum. The lamp template spectrum is a 1-D spectrum from the PtNe lamp (through the WCA aperture) and is used by CalCOS to determine the pixel offset of the data. This is done by cross-correlating the WAVECAL spectrum with the lamp template spectrum in the LAMPTAB file. The offset for each template spectrum at each FP-POS is stored in the LAMPTAB as FP_PIXEL_SHIFT (the offset is defined to be zero at FP-POS=3). These FP_PIXEL_SHIFT values are given in the LAMPTAB for each segment, optical element (i.e., grating), cenwave, and FPOFFSET, along with the wavecal array (= INTENSITY) for that observational setup. The FPOFFSET values are stepper motor offsets ranging from –2 to +1 and correspond to FP-POS settings of 1 to 4. This ISR describes how the wavecal arrays and their FP_PIXEL_SHIFT values were derived for the G160M/1533 LAMPTAB. More information about the COS wavelength calibration procedure with the LAMPTAB can be found in the COS Data Handbook (Section 3.4.12).

## 2. Observations

The G160M/1533 lamp template observations (Program 15459) involved COS/FUV PtNe lamp exposures with the G160M/1577 setting for a single internal orbit. It was necessary to use G160M/1577, as the G160M/1533 setting was not yet available in the flight software. As such, the G160M/1533 parameters were defined relative to G160M/1577 using the TEST row (see below). The program design followed that of the LP4 program 15369 (PI E. Snyder; Frazer et al. 2019b), which obtained lamp template data for all cenwaves. In turn, this was based on SMOV program 11488 and Cycle 24 program 14856. First, a long (1800 s) lamp exposure is used to allow the optics select mechanism (OSM) to settle before the lamp template data are taken. The lamp is regularly flashed for 30 s every 120 s during the long exposure using special engineering mode to sample the drift at defined regular intervals for later analysis. We then take 210 s lamp exposures for cenwave G160M/1533 in each of the four FP-POS. The lamp is flashed in 30 s intervals using special engineering mode during these exposures as well, so as to not overheat the lamp. The total lamp exposure time is 120 s per FP-POS.

Special commanding was required for three parts of our observational setup. First, since the wavelength calibration spectra land at LP2 for LP4 observations, we need special commanding to raise the HV to the highest possible values to mitigate any gain sag effects. Second, since this program uses all four FP-POS, special TEST row commanding was needed to configure 1533, since the cenwave was not available in the flight software at the time of execution. The TEST row parameters for G160M/1533 are STEP=11218, RES1=18775, RES2=23405, FOCUS4=–646 (as derived from the G160M/1533 focus sweep program; James et al. 2019). Finally, we used special commanding to switch off calibration and disassociate the 1533 exposures, since the back-end software was (at the time of execution) not ready for processing 1533 files. The data were obtained on 2018 June 4.

The overall structure of the observations was as follows: (1) special commanding to define the TEST row with G160M/1533 parameters; (2) dark exposure to raise HV to 178/175; (3) long (1800 s) lamp exposure to allow the OSM mechanism to settle; (4) short (210 s) lamp exposures at FP-POS 1,2,3,4; (5) dark to return to nominal HV 163/163; (6) special commanding to restore the TEST row.

## 3. Data Reduction and Reference File Creation

The creation of the LAMPTAB reference file involved four separate steps, each with its own customised data reduction. We describe each of these below. All scripts listed in these steps can be found on our internal git server (`https://grit.stsci.edu/cos/newcenwave_c1533/tree/master/lamptab`).

### *3.1 Creation of Placeholder LAMPTAB File*

Before the formal analysis could begin, a "placeholder" LAMPTAB was required that contained the 1533 lamp template spectra. To create this, the raw data were manually reduced using CalCOS, with calibration switches as specified in Table 1, in order to create extracted spectra from the lamp template exposures. The extracted lamp data (i.e., the NET column from the X1D files) were then entered into the intensity column of the placeholder LAMPTAB file for a newly created 1533 row. As mentioned previously, the LAMPTAB file also contains FP_PIXEL_SHIFT values, which are the pixel offsets of the spectra at each FP-POS relative to FP-POS=3. This column was populated by cross-correlating the lamp template data at each FP-POS. It should be noted that since these values had been calculated on data that had not been corrected for drift, they were merely used as placeholder values for the following steps where we created the CORRTAG and LAMPFLASH files. The latter contain extracted wavecal lamp flashes in the form of events lists, where each row in the events lists corresponds to a different segment and flash number (in this case 1 to 4). Of particular use here are the LAMPFLASH SHIFT_DISP values listed for each event, which are dispersion direction shifts determined by comparing each tagflash wavecal with the wavecal template. Each of these steps is covered in the script *make_interim_lamptab.py*.

### *3.2 Creation of* CORRTAG *and* LAMPFLASH *Files*

In order to accurately determine the FP-POS shifts between each lamp template, it was first necessary to extract data that were affected by both drift (due to the OSM mechanism) and FP-POS shifts and remove the drift effects as a function of time. This was done by generating CORRTAG files, where the events have been corrected for thermal, geometric, and walk effects, but still contain drift and FP-POS shifts, alongside the LAMPFLASH files that contain drift information in 60 s time bins. The latter information is used in the following section to remove the drift.

For this procedure, the raw files were again manually reduced using CalCOS with calibration switches set as shown in Table 1, with the exception of WAVECORR, which was now set to PERFORM. For this calibration step, a specific DISPTAB (*newcenwaves_disp.fits*) was supplied that contained temporary dispersion solutions for 1533 (here WCA values were copied from the 1577 values, whereas the PSA dispersion solution entries were temporary placeholder values and extrapolated down from 1577). A placeholder XTRACTAB was also specified (*newcenwaves_1dx.fits*), with an extraction zone created from the 1533 focus sweep observations obtained in program 15452 and the placeholder LAMPTAB file described in Section 3.1. This reduction procedure results in extracted spectra (X1D files) and LAMPFLASH files with

**Table 1**. Calibration Switches Used to Process Raw Program 15459 Data in CalCOS[1]

| Calibration Step | Value | Description |
|---|---|---|
| FLATCORR | PERFORM | Apply flat-field correction |
| DEADCORR | PERFORM | Correct for deadtime |
| DQICORR | PERFORM | Data quality initialization |
| 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 |
| XWLKCORR | OMIT | Correct FUV for Walk Distortion in X |
| YWLKCORR | PERFORM | Correct FUV for Walk Distortion in Y |
| PHACORR | PERFORM | 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) |
| DOPCORR | PERFORM | Orbital Doppler correction |
| HELCORR | PERFORM | Heliocentric Doppler correction |
| X1DCORR | PERFORM | 1-D spectral extraction |
| BACKCORR | PERFORM | Subtract background (when doing 1-D extraction) |
| WAVECORR | OMIT | Use wavecal to adjust wavelength zeropoint |
| FLUXCORR | PERFORM | Convert count-rate to absolute flux units |
| BRSTCORR | PERFORM | Switch controlling search for FUV bursts |
| TDSCORR | PERFORM | Switch for time-dependent sensitivity correction |

[1]Calibration steps shown in gray are defaults, whereas those in black have been changed from the default.

**Table 2**. Summary of G160M/1533 FP_PIXEL_SHIFT Values

| | FP_PIXEL_SHIFT | | | |
|---|---|---|---|---|
| Segment | FP-POS 1 | FP-POS 2 | FP-POS 3 | FP-POS 4 |
| FUVA | −511.39 | −258.88 | 0. | 235.76 |
| FUVB | −512.75 | −258.96 | 0. | 236.87 |

timing events that allow us to extract and remove the drift as a function of time (Section 3.3).

### *3.3 Removal of Drift*

In order to extract events that are no longer affected by drift, we first needed to remove the drift information as a function of time from the CORRTAG events. This enabled us to determine accurate FP-POS shifts, which can be measured and used for the the LAMPTAB FP_PIXEL_SHIFT values. In order to obtain the drift information, we used the LAMPFLASH files described in Section 3.2, which contained the FP_OFFSET and shift information (listed as SHIFT_DISP entries) in each 60 s time bin, such that the SHIFT_DISP = FP_PIXEL_SHIFT − FP_OFFSET. These shift values were subsequently subtracted from the XCORR value of each event that landed in each time bin and written into a new CORRTAG file with updated XCORR values. The new lamp data, now with any shifts due to drift removed, were extracted by processing the new CORRTAG files in CalCOS with calibration switches as specified in Table 1. Each of these steps is covered in the script *removedriftfromwavecorr.py*

### *3.4 Creating the Final LAMPTAB Reference File*

The X1D files that resulted in the process described in Section 3.3 contain events that only have offsets due to FP-POS offsets. As such, these spectra were used to populate the final LAMPTAB in two ways. First, the final FP_PIXEL_SHIFT values (i.e., without contamination from drift) were calculated by cross-correlating the lamp template data at each FP-POS with FP-POS=3. These final FP_PIXEL_SHIFT values were inserted into the final LAMPTAB G160M/1533 reference file and are listed in Table 2. Second, the NET column from the X1D files (i.e., the wavecal spectrum array now corrected for drift) were used to update the LAMPTAB INTENSITY column for the respective FP-POS. Each of these steps is covered in the script *updating_newcenwave_lamptab.py*.

## 4. Testing the LAMPTAB

Several steps were taken to ensure that the process used to create the G160M/1533 LAMPTAB was successful and the information contained within the reference file was correct. We describe each of the technical and scientific testing steps below.

### *4.1 Technical Testing*

The technical testing for the reference file consisted of ensuring that the LAMPTAB could be parsed by CalCOS during a standard reduction without any errors. This test confirmed that the LAMPTAB has the correct data format.

### *4.2 Scientific Testing*

First, we tested whether the shift was correctly removed. This was achieved by running the de-shifted CORRTAG files produced in Section 3.3 through CalCOS with the final LAMPTAB and DISPTAB files, with WAVECORR = PERFORM. If the shift was correctly removed, the SHIFT_DISP value listed within the output lampflash file should be identical to the FP_PIXEL_SHIFT value given in the LAMPTAB. In Figure 1 we show the SHIFT_DISP − FP_PIXEL_SHIFT for each of the flashes in the output lampflash files, before and after drift removal (i.e., using the CORRTAG files from the processes described in Section 3.2 and 3.3, respectively). It can be seen that the SHIFT_DISP − FP_PIXEL_SHIFT values calculated from lampflash files after drift removal are indeed zero. As such, we were able to confirm that the shift was correctly removed by the process described in Section 3.3, and the FP_PIXEL_SHIFT values derived from these data were accurate.

A second test was performed to inspect the accuracy of the drift removal using the lampflash files reduced using the final LAMPTAB and de-shifted CORRTAG files produced in Section 3.3. In Figures 2 and 3 we show the lamp template spectrum with the four individual lamp flashes overlaid, before (left panels) and after (right panels) drift removal. By comparing the left and right panels of Figures 2 and 3, it can be seen that there is an excellent alignment between the lamp template spectra and the four individual lamp flashes after the drift removal has been performed, thereby confirming that the drift was successfully removed.

Finally, we tested that the FP_PIXEL_SHIFT values were internally consistent inside a given LAMPTAB by cross-correlating each FP-POS to FP-POS=3 after the individual FP_PIXEL_SHIFT values have been subtracted from the data. The results of this test can be seen in Figure 4, where we plot the residual shift for FP-POS=1,2,4 when cross-correlated against FP-POS=3. It can be seen that for both FUVA and FUVB, the differences between each FP-POS after FP_PIXEL_SHIFT values have been subtracted are within 1 pixel. This confirms that the FP_PIXEL_SHIFT values derived for the G160M/1533 LAMPTAB are correct to a sufficient accuracy and well within the overall

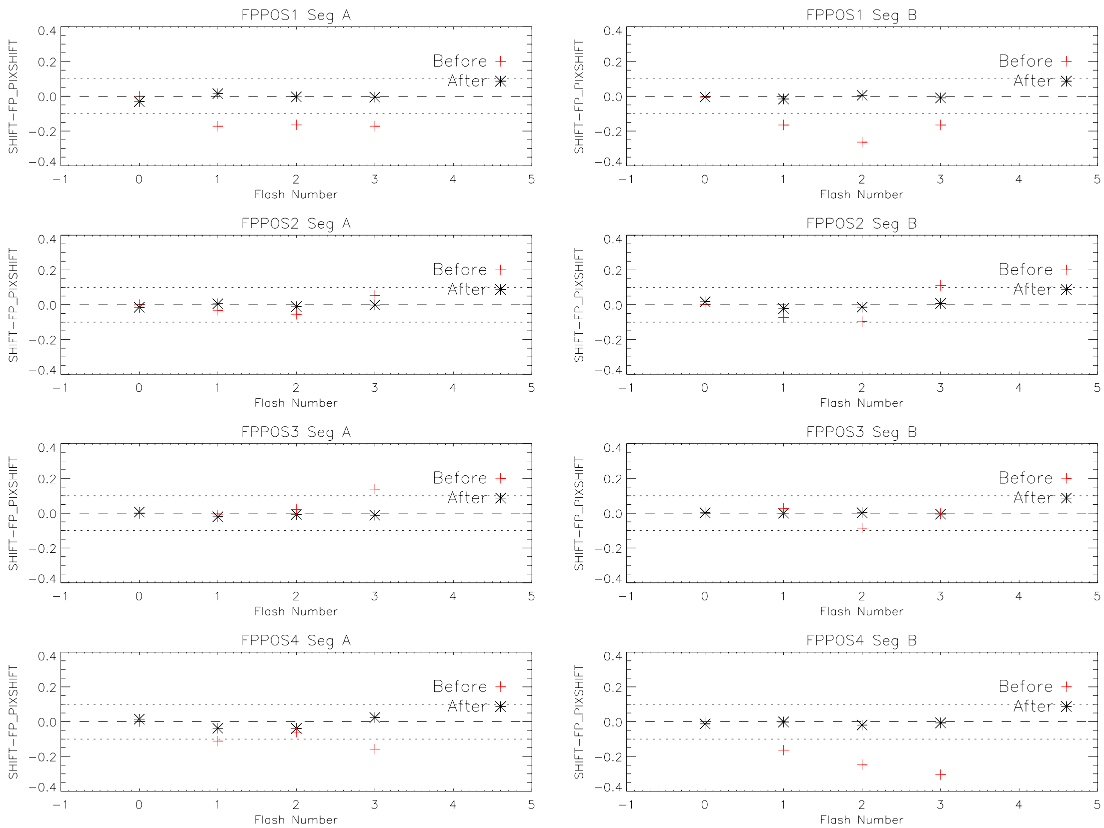


**Figure 1.** Scientific testing of the G160M/1533 LAMPTAB to check for removal of drift in the CORRTAG files used to derive the final LAMPTAB. When the shifts due to drift are removed from the CORRTAG files, the SHIFT_DISP value given in the lampflash files derived from these CORRTAG files should be equal to the FP_PIXEL_SHIFT value in the LAMPTAB file. Each panel shows the SHIFT_DISP – FP_PIXEL_SHIFT value for each of the four lamp flashes within the lampflash files, for each FP-POS and segment, before and after drift removal. It can be seen that the SHIFT_DISP – FP_PIXEL_SHIFT for lampflash files derived from shift-corrected CORRTAG files is always $0.0 \pm 0.1$, thereby confirming that the drift was removed.

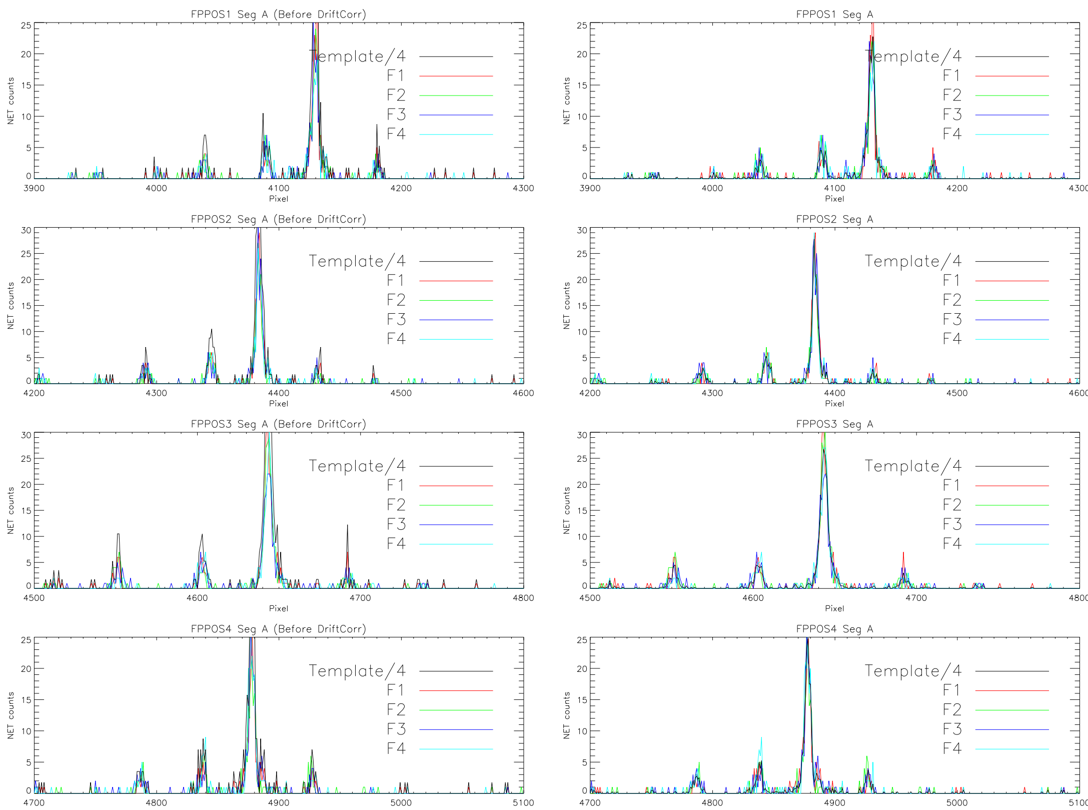


**Figure 2.** Scientific testing of the G160M/1533 LAMPTAB to check for removal of drift in the CORRTAG files used to derive the final LAMPTAB. The lamp template spectrum (scaled downwards by a factor of four) is shown, compared with the four individual flashes, at different pixel windows along Segment A of the detector. The left and right panels show lampflash files derived from CORRTAG files before and after drift correction, respectively. It can be seen that the template spectra are well aligned with the lampflash spectra after drift correction, confirming that drifts were removed.

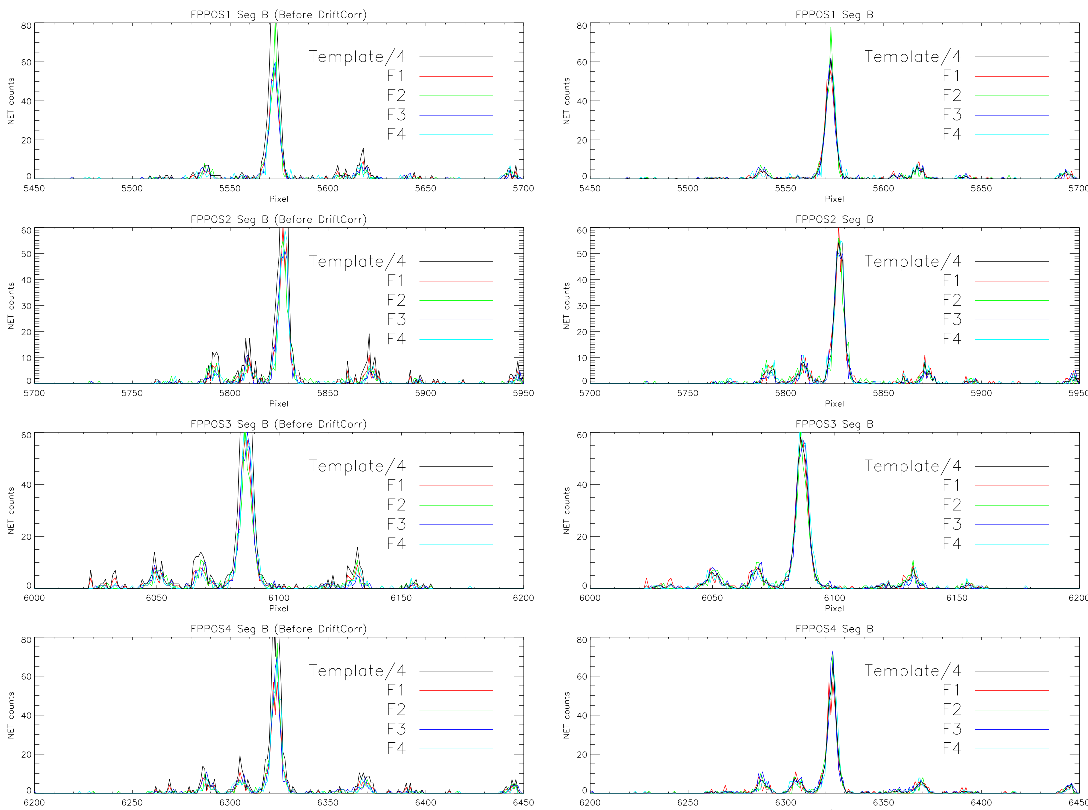


**Figure 3.** Same as Figure 2 but for Segment B.

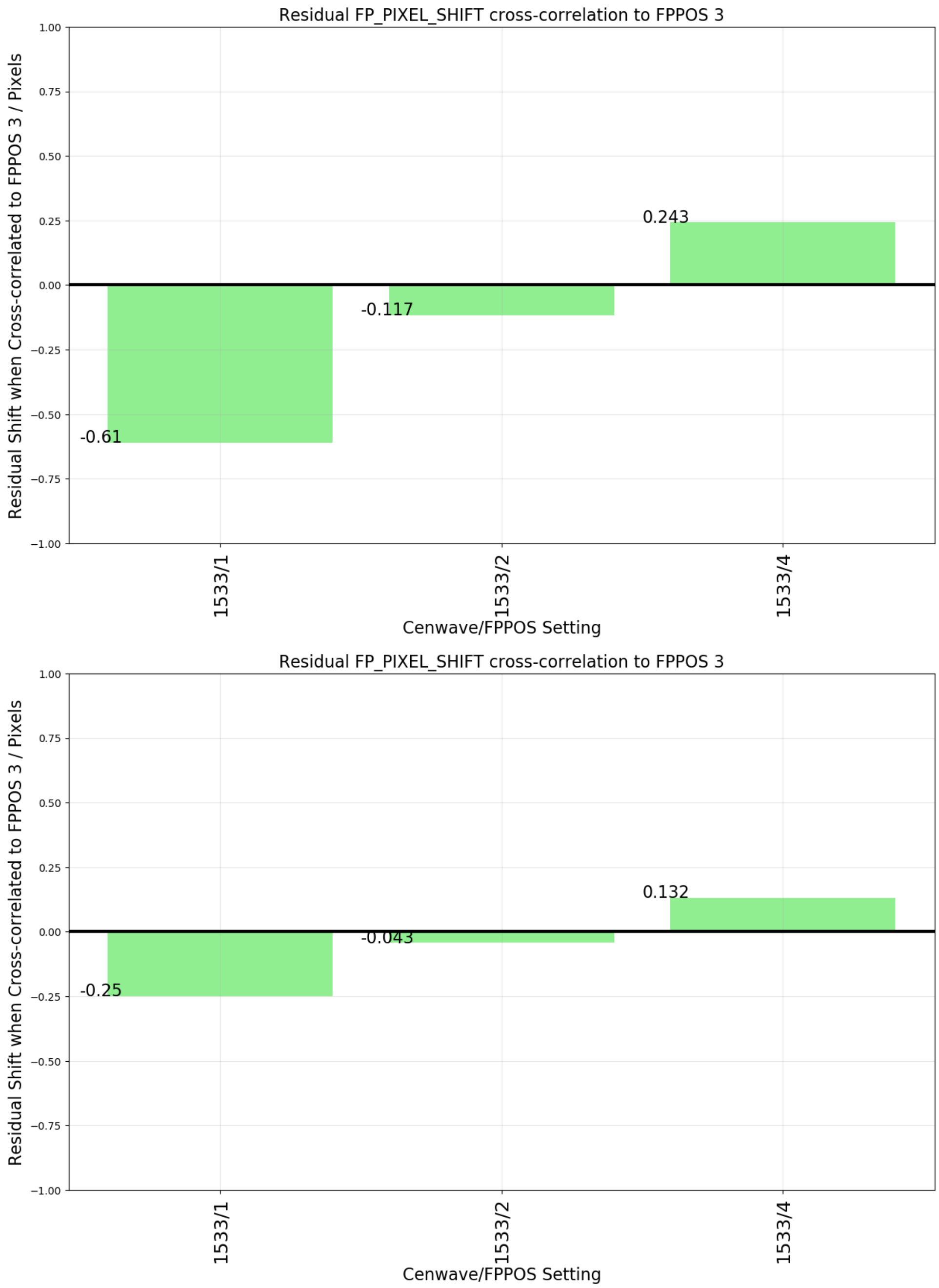


**Figure 4.** Scientific testing of the G160M/1533 LAMPTAB to check for internal consistency of the FP_PIXEL_SHIFT values within the LAMPTAB. The plot shows the residual differences between the data at each FP-POS after the individual FP_PIXEL_SHIFT values have been subtracted. All residuals are within 1 pixel (i.e., well within the $\pm 3$ pixel FUV wavelength total error budget that includes contributions from other sources such as centering and wavelength scale), and therefore the FP_PIXEL_SHIFT values are deemed sufficiently accurate.

±3 pixel (DISPTAB+LAMPTAB+centering from TA) wavelength error budget for COS FUV observations.

## 5. Summary

The G160M/1533 wavecal spectrum array and FP_PIXEL_SHIFT (offset in pixels from FPOFFSET=0) for both segments (FUVA and FUVB) derived in this analysis were merged into the LAMPTAB submitted to the CRDS reference-file database on 2018 November 20. The new LAMPTAB (named `2bj2256ol_lamp.fits`) contains entries for both cenwaves 1533 and 800 and is in use for LP4 observations from Cycle 26 onward. Subsequently, this LAMPTAB was used to create the 1533 DISPTAB (containing dispersion coefficients used to calculate the wavelength from pixel number), as detailed in Fox et al. (2019a).

## Change History for COS ISR 2019-07

Version 1: 14 November 2019 – Original Document

## References

Fox, A. J., James, B. L., Frazer, E. M., & Fischer, W. J. 2019b, COS ISR 2019-09, "The Flux Calibration of the New COS/FUV Cenwave G160M/1533"

Fox, A. J., James, B. L., Frazer, E. M, Plesha, R., & Ake, T., 2019a, COS ISR 2019-10, "The Dispersion Solution for the New COS/FUV Cenwave G160M/1533"

Frazer, E. M., Fox, A. J., James, B. L., Roman-Duval, J., & Sankrit, R. 2019a, COS ISR 2019-08, "Spectral Extraction of the New COS/FUV G160M/1533 Mode: Extraction, Trace, and Profile Reference Files"

Frazer, E. M., et al. 2019b, COS ISR in prep., "The LAMPTAB Reference File at Lifetime Position 4"

James, B. L., Fox, A. J., & Frazer, E. M. 2019, COS ISR 2019-06, "Focusing the New COS/FUV Cenwave G160M/1533"