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The Lamp Template for the New COS/FUV Cenwave G140L/800

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ABSTRACT

We describe the creation of the lamp template reference file for the new COS/FUV central wavelength setting G140L/800. We obtained Pt-Ne lamp exposures with Program 15484 in 2018 June. Analysis of the data involved determining the effects of drift from the Optics Select Mechanism (OSM), which can blend the lamp's spectrum lines, and then removing it from each event to create the lamp template spectra. Accurate shifts for each FP-POS position were determined by cross-correlating the lamp template data for 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 Cycle 26 COS calibration pipeline.

Contents

1. Introduction

For Cycle 26, two new central wavelength (cenwave) settings were introduced for COS/FUV: G140L/800 and G160M/1533. The efforts involved in preparing G160M/1533 are described in James et al. (2019a, b); Frazer et al. (2019); and Fox et al. (2019a, b). The parallel documents for G140L/800 are Fischer (2019a, b); and Sankrit (2019a, b).

The new central wavelength mode G140L/800 was originally studied by McCandliss et al. in Cycle 19 program 12501. That team's preliminary characterization of the mode (Redwine et al. 2016), served as a starting point for our analysis. Cenwave G140L/800 is a mode that uses only the FUVA detector, covering 800-1950Å. This provides far-ultraviolet spectra about 300Å below what is available with G140L/1105, and without the detector gap present when using G140L/1280. The G140L/800 mode places wavelengths from 912 to 1000 Å in a region of the detector with the least astigmatic height, thereby minimizing the background. The ability to detect faint sources at these wavelengths beyond the Lyman limit is the primary motivation for developing this mode.

When commissioning a new cenwave, we need to create a lamp template spectrum. The lamp template spectrum is a 1-D spectrum from the Pt-Ne lamp (through the WCA aperture) and is used by CalCOS to determine the pixel-to-wavelength conversion of an observation. This is done by cross-correlating the WAVECAL spectrum that is obtained alongside each science spectrum with the lamp template spectrum that is stored in the LAMPTAB reference 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 lamp template 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 lamp template arrays and their FP_PIXEL_SHIFT values were derived for the G140L/800 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 G140L/800 mode extends the accessible wavelength range of COS/FUV, meaning that the appropriate exposure time for the lamp template spectrum needed to be determined. Sembach (2006) has specified the lamp data used for calibration and the derivation of the lamp template. The specifications were given for each existing cenwave expected to be used following launch. That meant that the central wavelength of G140L/800 was not accounted for and it was particularly difficult to make assumptions due to the lamp producing fewer counts at shorter wavelengths (Figure 1), especially given the reduced throughput below Lyman-alpha (1215Å) because of the MgF-coated optics.

In Sembach (2006), the suggested exposure time of 90 seconds was established from a number of conditions imposed on the calibration process for accuracy. The wavelength calibration was required to be accurate to 0.25 spectral resolution element (3 pixels), which primarily requires accuracy within the dispersion solution and the zero-point for wavelength assignment. For the G140L grating, the goal was a template spectrum with more than 20-40 lines with a minimum of 50 counts each, to account for complications in line identification and measurement from line blending. The exposure time suggested to achieve those specifications was 90 seconds for G140L/1105 and G140L/1230, the closest analogs. However, when reviewing datasets from the LP4 lamp template calibration program (15369, PI Frazer) for these modes total exposure times of 120 seconds were used (Fig. 1), but were insufficient to meet the criterion for 20 to 40 lines at a 50 count minimum, likely due to the aging of the Pt-Ne lamp. By extrapolating the exposures from program 15369, it was determined that the minimum exposure time necessary to achieve this criterion was 180 seconds. However, the final calibration program ultimately used a total lamp exposure time of 240 seconds (See Fig. 2) in the interest of achieving the best possible calibration spectrum.

With the exception of lengthening the total lamp exposure time to achieve the necessary line counts, the lamp template program (15484) designed for G140L/800 followed the same methodology as used by the LP4 program. The LP4 program, in turn, was designed following two earlier lamp calibration programs: SMOV program 11488 and Cycle 24 program 14856. The overall goal of the program was to achieve the total necessary lamp exposure time to meet all the criteria for calibration, and this was done by splitting the exposure time into flashes of the lamp on and off to preserve the life of the lamp, and to avoid overheating and avoid drift within each flash of the lamp. An initial long lamp exposure of 1800 seconds was taken to allow the Optics Select Mechanism (OSM) to settle and avoid drift associated with the movement of the OSM, as well as to sample the drift at regularly-defined intervals. During this long exposure, the lamp was flashed on in intervals of 30 seconds on and 90 seconds off. The following lamp template exposures for G140L/800 were taken at each of the four FP-POS in a similar pattern, although these intervals are 8 flashes on of 30 seconds each separated by 30 seconds, totaling 450 seconds. This allows a cumulative lamp exposure time at

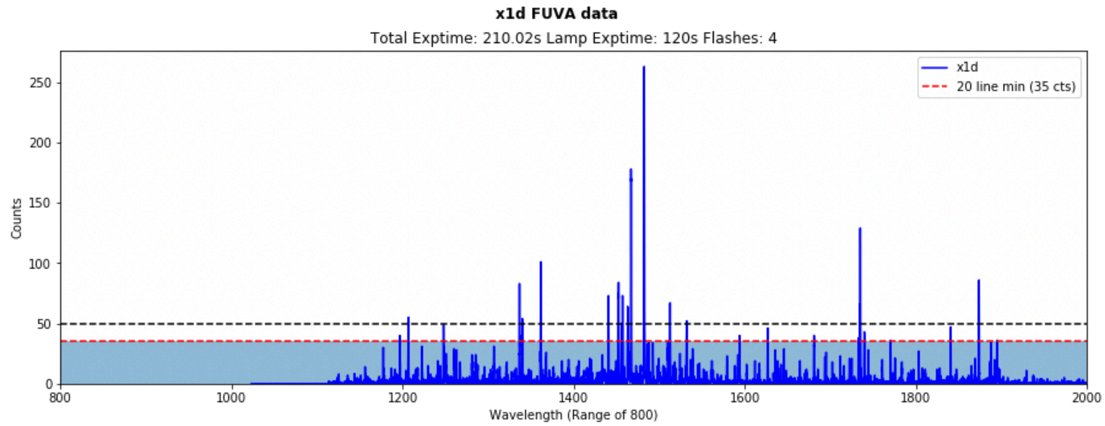

Figure 1. `x1d` data from LP4 lamp template calibration program 15369, taken at each FP-POS with a cumulative lamp exposure time of 120 seconds. The 50-count threshold for 20-40 lines is denoted by the black dashed line, whereas the actual threshold for the 20 lines with the most counts falls at 35 counts, significantly below the required threshold.

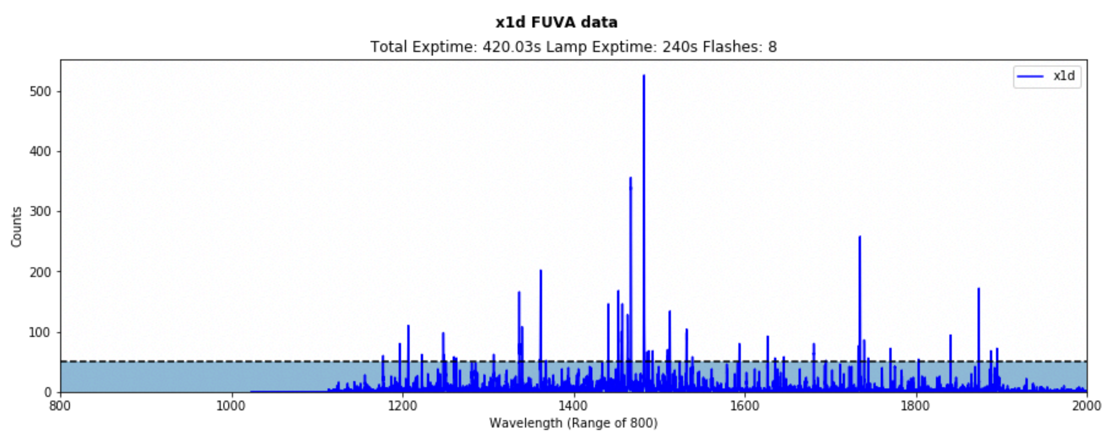

Figure 2. `x1d` data from LP4 lamp template calibration program 15369, extrapolated to a cumulative lamp exposure time of 240 seconds. Sufficient lines now exceed the 50 count minimum denoted by the horizontal dashed line.

each FP-POS of the desired 240 seconds. Additionally, special commanding was used to overwrite the TEST row with the closest associated cenwave mode, G140L/1105, with the focus value set to the focus value earlier determined by analysis of G140L/800 focus sweep program 15451. We also raised the high voltage level of the detector because lamp spectra obtained for science spectra at lifetime position 4 (LP4) actually fall at LP2, which is already affected by gain sag.

3. Data Reduction and Reference File Creation

Program 15484 provided the raw data necessary to create the INTENSITY array and FP_PIXEL_SHIFT values for the updated LAMPTAB file, but the process to calibrate the data to become the final template values was iterative. During calibration, CalCOS will remove drifts in raw data and shifts due to the the FP-POS offsets, but of course that is dependent on the template spectra in the LAMPTAB file for each mode and FP-POS, which as of then did not exist. To use CalCOS in performing the calibration required, the first step was to produce an interim LAMPTAB file with entries that could serve as an approximation for template spectra. During the calibration process, another product produced was the associated LAMPFLASH file, containing events from extracted WAVECAL lamp flashes. The first of these flashes from the dataset would only have a flash duration of 30 seconds, short enough to avoid significant OSM drift. These data would serve as a starting point for populating an interim LAMPTAB. For a first approximation in this step, we created an interim LAMPTAB exactly the same as the most up-to-date reference file used in the pipeline, with values appended for G140L/800 that were merely a copy of the closest mode, G140L/1105. The following sections describe this procedure.

3.1 Creation of Interim LAMPTAB File

As explained above, the goal for the interim LAMPTAB was to populate it with LAMPFLASH data from Program 15484, which required a very basic calibration. CalCOS has a default set of calibration switches for BOXCAR extractions which perform this calibration, and the pipeline requires complete and accurate reference files for the mode being calibrated. Additionally, and in the same vein, the calibration steps associated with pixel-to-pixel variation on the detector were less necessary, and the calibration switches BACKCORR, DEADCORR, and FLATCORR were set to OMIT. Even after removing these calibration steps, the wavelength calibration is intertwined with the extraction calibration, which requires a DISPTAB and XTRACTAB in tandem with the preliminary LAMPTAB. Because the necessary values for these reference files depended on a final LAMPTAB, we similarly created preliminary reference files for these that used the same values for these reference files for G140L/800 as G140L/1105, and set these as the reference files to use in our first round of calibration

Table 1. Calibration Switches Set to Non-standard Values Used to Process Raw Program 15484 Data in CalCOS

Calibration Step	Value	Decsription
RANDSEED	12345	Seed for random number generator
EXPTYPE	WAVECAL	Exposure type
FLATCORR	OMIT	Apply flat-field correction
DEADCORR	OMIT	Correct for deadtime
TRCECORR	OMIT	Trace correction
ALGNCORR	OMIT	Align data to profile
BACKCORR	OMIT	Subtract background (when doing 1-D extraction)
WAVECORR	OMIT	Use wavecal to adjust wavelength zeropoint

of the raw data. A summary of all the non-standard calibration switches that were used in this calibration can be seen in Table 1.

3.2 Creation of CORRTAG and LAMPFLASH Files

This calibration process produced the first set of calibrated data, including the LAMPFLASH files containing the flash information necessary to put into the interim LAMPTAB. The data in the NET column (net count rate for the extracted spectrum) corresponding to the first flash for each FP-POS was used in conjunction with the exposure time for the flash (30 seconds, as outlined by the proposal for Program 15484) to determine the counts for each wavelength and was thus used for the INTENSITY column in the interim LAMPTAB. The FP PIXEL SHIFT value associated with each FP-POS corresponds to the offset from the "home" position of FP-POS=3, meaning the value for FP-POS=3 is zero. For each of the other FP-POS, this value is computed by cross correlating the INTENSITY column to FP-POS=3, hence the significance of the lamp spectrum lines with 20-40 lines exceeding 50 counts.

3.3 Creation of the Final LAMPTAB

A second round of calibration was performed with the interim reference file once an interim LAMPTAB was available. Similarly, we used the calibration switches as altered and described in creating the LAMPFLASH data for the interim LAMPTAB. At this point, the files of interest were primarily the newly generated LAMPFLASH and CORRTAG files, although the CORRTAG files had not been drift corrected nor has the FP_PIXEL_SHIFT between each FP-POS computed. However, the XCORR column of these corrtags had already been corrected for thermal and geometric effects,

Table 2. Summary of G140L/800 FP_PIXEL_SHIFT Values

Segment	FP_PIXEL_SHIFT FP-POS 1	FP-POS 2	FP-POS 3	FP-POS 4
FUVA	−485.11	−214.07	0.00	+277.24

meaning all that remained was drift correcting the CORRTAG files.

From there, these drift-corrected CORRTAGs could then be reprocessed with CalCOS from that point forward to create the final target `x1d` files. Each LAMPFLASH file contains information about computed shifts in the SHIFT_DISP column, as compared to the template wavecal spectrum (in this case, the first flash spectrum in the interim LAMPTAB), determined partially by the FP_PIXEL_SHIFT. Because the FP_PIXEL_SHIFT value contributing to the SHIFT_DISP was also the result of cross correlating the first flash information, we subtracted these values from the total shift. These shifts are computed in 60 second time bins, so in order to remove this shift from the XCORR events in the CORRTAGs, the shifts were subtracted from the corresponding XCORR time bins created during analysis in the CORRTAG file.

After creating new CORRTAG files corrected for drift and all other necessary calibration steps, we then calibrated the CORRTAG data according to the standard calibration pipeline with the exception of the wavelength correction (WAVECORR set to OMIT); this was done to not overwrite the shift subtraction we had computed analytically external to the pipeline by the wavelength correction that would be automatically computed by CalCOS based on the interim LAMPTAB. This round of calibration produced `x1d` files, from which we retrieved the NET column information and derived from the exposure time the total count information to create the template spectrum inserted into the INTENSITY column for the final LAMPTAB. Again, cross correlating the template spectrum for each FP-POS against FP-POS=3 enabled us to compute the final FP_PIXEL_SHIFT values, given in Table 2.

4. Reference File Testing

Following the creation of the final LAMPTAB, we determined a series of tests to validate both the technical aspects and scientific ability of the new reference file in the calibration pipeline. Technically, it was simple enough to verify that our analysis was doing what was intended by comparing the data we intended in each case of the interim and final LAMPTABs with the data now stored in each version of the reference file (the first flash data and the final drift-corrected `x1d`s, respectively). Additionally, by performing a new set of calibrations entirely from scratch on the raw data, we could

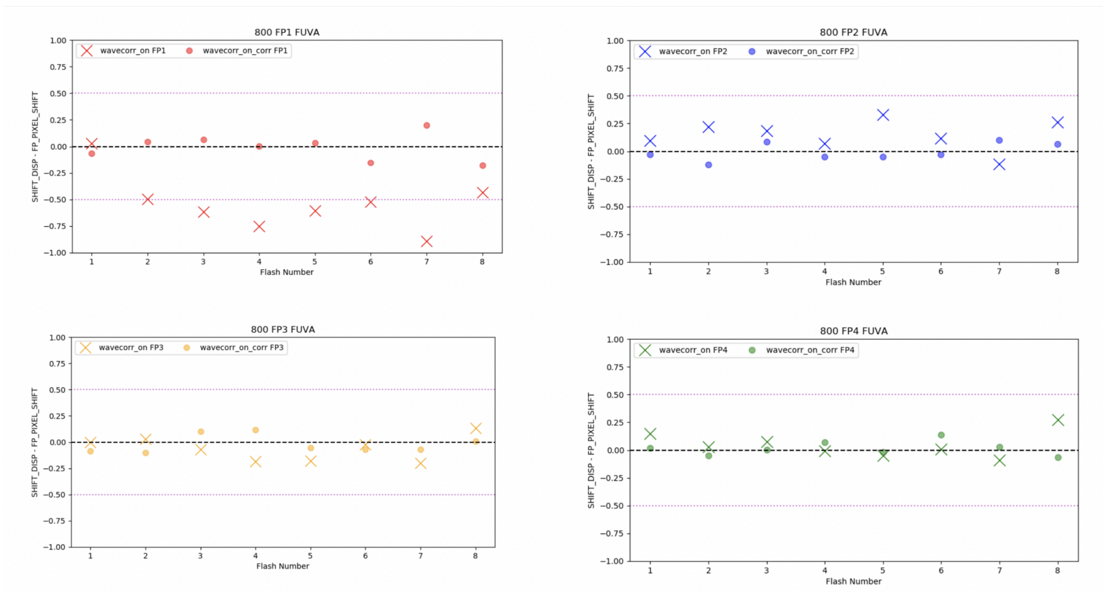

Figure 3. Scientific testing of the G140L/800 LAMPTAB to check for removal of drift in the CORRTAG files used to derive the final LAMPTAB. When the shifts due to drift are removed from the CORRTAG files, the SHIFT_DISP value given in the LAMPFLASH files derived from these CORRTAG files should be equal to the FP_PIXEL_SHIFT value in the LAMPTAB file. Each panel shows the SHIFT_DISP minus 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 minus 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.

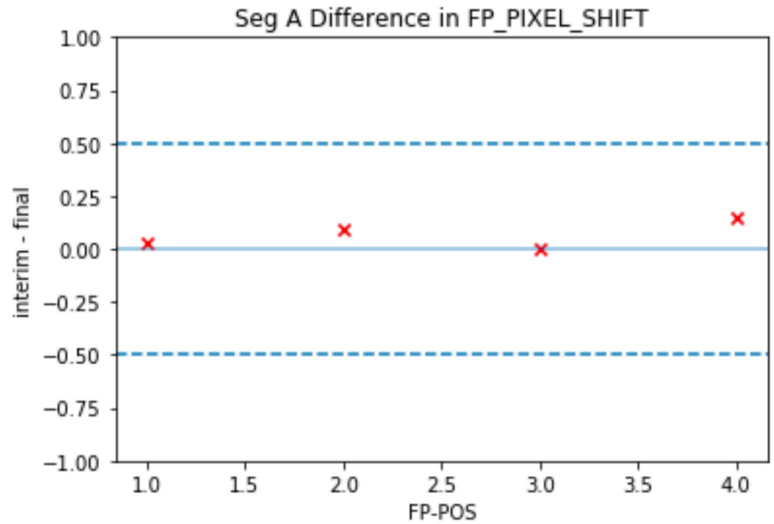

Figure 4. Difference in computed FP_PIXEL_SHIFT values used for the interim minus the final LAMPTAB values.

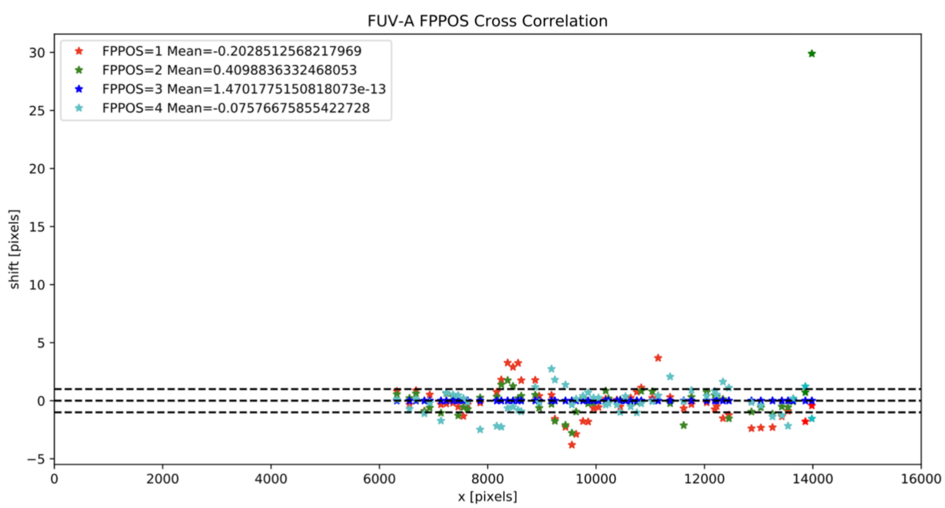

Figure 5. Scientific testing of the G140L/800 LAMPTAB to check for internal consistency of the FP_PIXEL_SHIFT values within the LAMPTAB. The plot shows the residual differences between the data at each FP-POS after the individual FP_PIXEL_SHIFT values have been subtracted. On average, the residuals are within 1 pixel (i.e., well within the ±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.

confirm the reference file was correctly formatted for use in the calibration pipeline. Furthermore, the internal STScI team for Reference Data for Calibration and Tools (ReDCaT) has their own standard scripts required by every instrument team to be performed on a new reference file before submitting for delivery to the Calibration Reference Database System (CRDS). In all cases, the new LAMPTAB file passed.

On the scientific side, we tested the ability of the new file with the `x1d` values to correctly remove drift during calibration by wavelength calibrating the CORRTAG files that we had analytically removed the drift from. Had we originally calibrated these files with the interim LAMPTAB, `x1d` files would have been created based on a not fully derived template lamp spectrum, as the drift we had removed would have effectively been overwritten. Should the final LAMPTAB have a more correct template spectrum, the difference in the drift removed by this test calibration versus the drift removed analytically should be near zero. Successfully, we found the difference to be minimal.

Another test conducted, in a similar vein, was to calibrate the raw data following standard calibration with the interim LAMPTAB versus the final reference file and compare the ability of each to calculate and remove the drift in the final CORRTAGs. The results of this comparison for each FP-POS can be seen in Figure 3, showing that the final LAMPTAB does remove the drift.

To test the FP_PIXEL_SHIFT values for accuracy, we first compared them against the interim values found for each FP-POS, although not a significant difference was found (see Figure 5). This is not entirely surprising as since these values are derived from the cross correlation from each FP-POS to FP-POS=3, provided the spectra used in correlation have a sufficient signal-to-noise, these values should be fairly similar regardless of which spectra are being compared.

The final test, to also test the FP_PIXEL_SHIFT values, was to remove the FP_PIXEL_SHIFT from each of the FP-POS exposures and perform a cross correlation again on the presumably drift-corrected and pixel-shift-offset-corrected data. From this we should expect to see very small residual shifts and the shift remaining in the "home" position of FP-POS=3 should be nearly zero. In Figure 5, we see that the shifts generally fall within one pixel deviation, with the mean for each FP-POS significantly within one pixel. This confirms that the FP_PIXEL_SHIFT values derived for the G140L/800 LAMPTAB are correct to sufficient accuracy and are well within the overall 3 pixel (DISPTAB + LAMPTAB + centering from the acquisition) wavelength error budget for COS FUV observations.

5. Summary

The G140L/800 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 G140L/800 DISPTAB (containing dispersion coefficients used to calculate the wavelength from pixel number), as detailed in James et al. (2019a).

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