



# Improvements to Wavelength Calibration of the HST/COS FUV Detector

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STScI

The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope in 2009 during Servicing Mission 4. Since then, the team at the Space Telescope Science Institute have striven to provide the highest quality scientific products to the community. One of the latest improvements to COS/FUV data is an updated wavelength solution. Wavelength dispersion solutions have been improved from the current accuracy of ~15 km/s to ~7.5 km/s for medium-resolution data obtained at Lifetime Position 1 (i.e. before July 2012). Here we present the methodology and results behind the improvements of the wavelength dispersion solutions. We also discuss ongoing efforts to improve the wavelength dispersion solutions for other lifetime positions as well as updates to the geometric distortion and walk corrections.

## Motivation

While typically within the requirements of  $\pm 15$  km/s for the medium resolution gratings, the wavelength calibration of COS/FUV data has been known to suffer from deviations across the COS/FUV detectors that weren't optimally corrected by the dispersion reference file (DISPTAB) with the calibration pipeline, CalCOS. However, the higher accuracy of the STIS wavelength scale (1 STIS pixel or ~2 km/s for E140M) allows us to evaluate the accuracy of the COS wavelength scale by comparing COS and STIS data of the same target as shown in Figure 1 below.

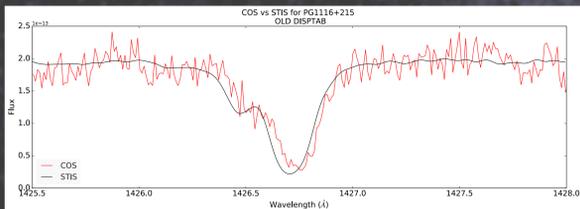


Figure 1: Comparison of COS (red) and convolved STIS (black) data using the old DISPTAB for PG1116+215.

## Methodology

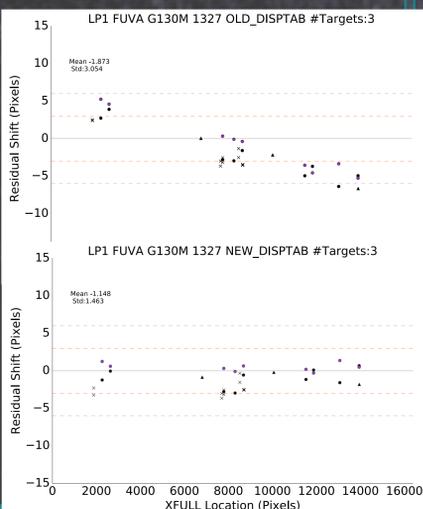
The HST archive was mined for targets observed both by COS (G130M, G160M) and STIS (E140H, E140M). 16 unique targets were identified with LP1/G130M and 17 for LP1/G160M data to derive the zero-points and slopes for the new dispersions. We determined wavelength offsets by cross-correlating COS and STIS data in pre-defined spectral windows corresponding to emission/absorption spectral features. The spectral windows excluded airglow lines (N I, Ly $\alpha$ , and O I) and stellar wind lines. The wavelength offsets between COS and STIS spectra, measured as a function of the XFULL coordinate in the COS spectra, were fit to a linear solution, which provided preliminary dispersion coefficients.

## Dispersion Coefficients

The cross-correlation of COS and STIS spectra showed that the current wavelength calibration is affected by a residual slope across the COS/FUV detector. This indicated the dispersion coefficient needed to be adjusted. Figure 2 is an example of improvement to the residual slopes and shows we now meet the new  $\pm 3$  pixels requirement (orange line). For more examples, scan this QR code.



Figure 2: Cross-correlation shift values for data calibrated with the old (top) and new (bottom) DISPTAB for the 1327 G130M cenwave.



## Ray-Trace Modeling

Ray-trace models were computed for all cenwaves and each segment for each M grating. The dispersion coefficients predicted by the ray-trace models are shown in Figure 3 below. The new dispersion slopes derived from cross-correlating COS and STIS datasets (red points) were consistent with ray-trace models (blue solid line), offset by a focus adjustment. A chi-square minimization was performed between the dispersion slopes from the COS-STIS cross-correlations and the ray-trace model predictions to determine the focus adjustment offset. The dispersion slopes adopted in the new DISPTAB file correspond to the adjusted ray-trace model (blue dashed line), while the old dispersion slopes are in black.

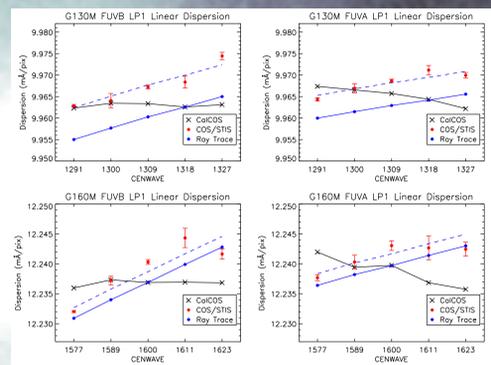


Figure 3: Shown are the new dispersion values (dashed blue line) for each grating at LP1 compared to the COS ray-trace model values (solid blue line).

## Zero-Point Adjustments

The new linear dispersion coefficients were then tested by cross-correlating COS exposures across different cenwave and FP-POS settings obtained within the same visit. This prevents bias in the analyses due to uncertainties in the target acquisition ( $\pm 3$  pixels, ~7.5 km/s). The COS-COS cross-correlation dataset includes 97 unique targets for G130M and 89 for G160M at LP1.

Because we couldn't eliminate target acquisition uncertainties in the COS-STIS correlations, the wavelength zero-points were adjusted using the results of the COS-COS cross-correlations. This ensured that mean offsets between COS exposures observed with different cenwaves averaged out to zero. The residual shifts between COS exposures after applying the new dispersion coefficients (slope and adjusted zero-points) are shown below in Figure 4. For most modes, one standard deviation of the residual wavelength offsets is now well within  $\pm 3$  pixels.

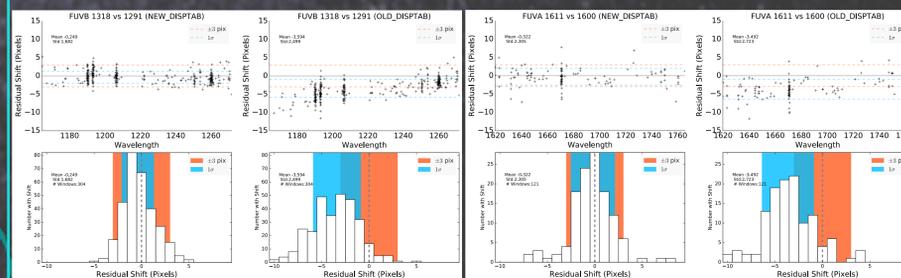


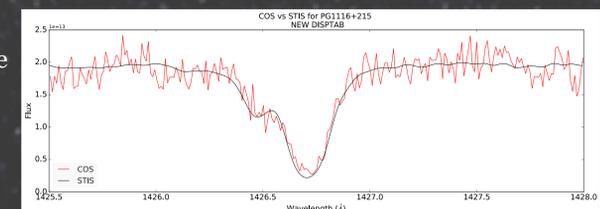
Figure 4: Examples of the residuals of the COS-COS cross-correlations for G130M/FUVB (left 4 panels) and G160M/FUVA (right 4 panels). On each panel, results using the old DISPTAB are shown on the right while results obtained with the new DISPTAB are shown on the left.



## Improvements

A new dispersion reference file (DISPTAB) intended for use of data taken at Lifetime Position 1 (LP1) was released on May 18, 2016. Any data taken before July 23, 2012 with G130M or G160M standard modes (1291, 1300, 1309, 1318, 1327, 1577, 1589, 1600, 1611, 1623 cenwaves) now use this DISPTAB, *05i1639ml\_disp.fits*. The G130M and G160M dispersion relations are given by first order polynomials, i.e. a zero point and a slope, which assign wavelengths based on the corrected pixel position (corrected for thermal, geometrical, and drift effects). With the new dispersion solutions, the alignment of the COS and STIS data is much better.

Figure 5: Similar to Figure 1, but using the new dispersion solution. COS data is shown in red, and convolved STIS data in black.



The uncertainty in the COS dispersions solutions with the old DISPTAB was typically  $\pm 15$  km/s. For most settings of the G130M and G160M standard modes we were able to improve this uncertainty to  $\pm 7.5$  km/s (~3 pixels and does not include errors due to target acquisition uncertainties). Figure 6 shows the improvement of mean shift values for the COS-COS cross-correlation comparisons across all cenwave pair combinations.

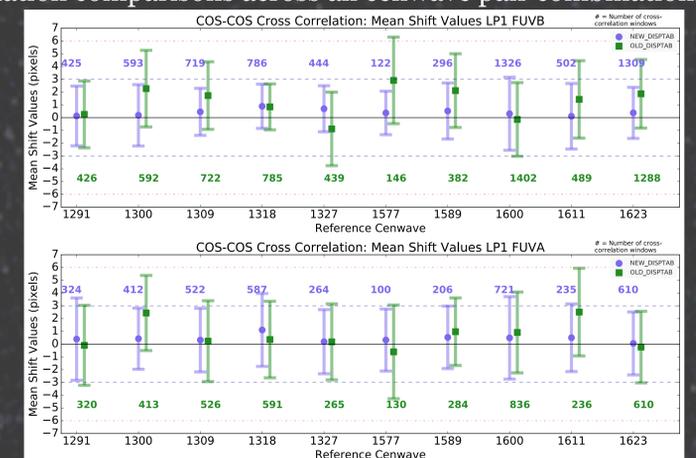


Figure 6: Mean shift values for COS-COS comparisons for all cenwaves with the new (purple) and old (green) DISPTAB. The error bars correspond to the standard deviations of the different cross-correlations.

## In the Future

Dispersion solutions for LP2 and LP3, derived using the same methodology, will be released in the next few months. Additionally, work is ongoing to improve the walk and geometric distortion corrections, which will lead to improvements in some of the scatter seen in the residuals in Figure 4.

## For More Information:

- COS May 2016 STAN:** [www.stsci.edu/hst/cos/documents/newsletters/cos\\_stis\\_newsletters/stan1605.html](http://www.stsci.edu/hst/cos/documents/newsletters/cos_stis_newsletters/stan1605.html)
- COS Instrument Handbook:** [www.stsci.edu/hst/cos/documents/handbooks/current/cos\\_cover.html](http://www.stsci.edu/hst/cos/documents/handbooks/current/cos_cover.html)
- COS Data Handbook:** [www.stsci.edu/hst/cos/documents/handbooks/datahandbook/COS\\_cover.html](http://www.stsci.edu/hst/cos/documents/handbooks/datahandbook/COS_cover.html)
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