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Cycle 29 COS FUV Wavelength Scale Monitor

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ABSTRACT

We report results of the Cycle 29 COS FUV dispersion solution zero point monitoring program 16534. Monitored modes include G130M cenwaves 1096, 1222, 1291, and 1327, G160M cenwaves 1577 and 1623, and G140L cenwaves 1105 and 1280. Spectra of target star AV 75 were obtained approximately one year from the Cycle 28 iteration of this program. Results from cross-correlations with reference COS, STIS and FUSE data show that the wavelength accuracy of all monitored modes are within the established specifications of 3 pixels for G130M and G160M settings, and 9 pixels for G140L settings.

Contents

1. Introduction

Thermal-vacuum data testing completed in 2003 (TV03) indicated that grating-dependent zero point offsets could develop over time in the Cosmic Origins Spectrograph Far-Ultraviolet (COS FUV) channel wavelength solutions (Oliveira et al. 2010). Starting in Cycle 20, the COS FUV wavelength scale monitor annually obtains data across a selection of G130M, G160M, and G140L cenwaves to check for any such offsets. These data are cross-correlated with FUSE/STIS spectra of the same target, as well as COS data from the Cycle 22 version of this program, to measure any changes to the accuracy of the dispersion solution zero points.

We take advantage of the superior wavelength accuracy of the STIS E140M mode for this comparison. STIS E140M calibration achieves an absolute accuracy of 3.3 $\mathrm{km\,s^{-1}}$ (Medallon et al. 2023), compared to 7.5 $\mathrm{km\,s^{-1}}$ and 150 $\mathrm{km\,s^{-1}}$ for COS/FUV M and L gratings, respectively (Plesha et al. 2019b; Kumari et al. 2020; Hirschauer et al. 2023). The bluest-wavelength COS settings (G130M cenwaves 1096, 1222, and 1105) require comparison with FUSE data as the STIS E140M wavelength coverage ends at $\sim$ 1140 Å. Similar to COS, FUSE calibration achieves 7 $\mathrm{km\,s^{-1}}$ accuracy (Dixon et al. 2007). However, these FUSE data were taken through the low-resolution aperture (LWRS), which suffers from a zero point offset of up to 0.15 Å. We discuss below the derivation of this offset and how we account for it in this analysis.

2. Observations

The Cycle 29 FUV wavelength calibration monitoring program (PID 16534; PI W. Fischer) executed on June 30, 2022. The program observed AV 75, a star of spectral

Table 1. COS/FUV Modes Monitored in PID 16534

Grating	Cenwaves	LP	Segments	FP-POS	Exposure Time (s)[a]	Windows [b]
G130M	1096	2	BOTH	2, 4	1276	FUVA: 10 (8), FUVB: 7
G130M	1222	4	BOTH	1, 3	492	FUVA: 9, FUVB: 14 (12)
G130M	1291	5	BOTH	3, 4[c]	372	FUVA: 6, FUVB: 8
G130M	1327	5	FUVA[d]	1, 3	380	FUVA: 4
G160M	1577	4	BOTH	2, 4	644	FUVA: 5 (4), FUVB: 3
G160M	1623	4	BOTH	1, 3	778	FUVA: 3, FUVB: 3
G140L	1105	3	FUVA	3	80	FUVA: 7
G140L	1280	3	BOTH	3	80	FUVA: 4, FUVB: 5

[a] The exposure time listed is the total, which is split equally between FP-POS when more than one is observed.

[b] Number of windows used for cross-correlation. If different than the COS-COS number, the COS-FUSE/STIS number is given in parentheses.

[c] Only FP-POS 3 and 4 are allowed for G130M/1291 when Segment B is on due to the COS2025 rules (Oliveira et al. 2018).

[d] FUVB is not allowed for G130M/1327 due to the COS2025 rules.

type O5.5I, for a single 3-orbit visit.

The acquisition sequence consisted of a ACQ/SEARCH and then an ACQ/IMAGE, both using the Bright Object Aperture (BOA) and Mirror A. Given that AV 75 is located in a crowded field, orient constraints were necessary to place several bright nearby objects away from the Primary Science Aperture (PSA). The PSA was not in use but remained open to the sky and thus could be inadvertently aimed at a bright source. To minimize gain sag, only two FP-POS exposures were taken in each medium resolution mode, and only FP-POS=3 was used for G140L cenwaves. All four FP-POS positions are used in each medium resolution grating by alternating pairs between cenwaves. Exposures were taken with the following modes: G130M (cenwaves 1096, 1222, 1291, and 1327), G160M (cenwaves 1577 and 1623), and G140L (cenwaves 1105 and 1280). Table 1 summarizes the exposure times and settings used.

This Cycle 29 program was identical to the Cycle 28 version (PID 16325; PI T. Fischer; Fischer 2022), except for minor adjustments to exposure times to maintain S/N and efficiently fill the orbits. All Cycle 25 and later iterations of this program were adjusted based on the COS2025 rules designed to prolong the COS detector lifetime (Oliveira et al. 2018). See Fischer (2019) for a discussion of these adjustments.

3. Analysis and Results

3.1 Cross-Correlation Windows

The stability of the COS FUV wavelength scale is measured yearly by cross-correlating new observations with reference spectra. Cross-correlation is performed across a selection of spectral windows each containing strong absorption lines. The windows used are tabulated in the Cycle 25 report for this program (Fischer 2019). Below 1090Å, the windows were selected from a FUSE spectrum of AV 75 (PID P115; PI J.M. Shull). Above 1090Å, the windows are taken from Plesha et al. (2019b), which were selected for the 2018 dispersion solution improvements for G130M and G160M and resulted in the delivery of the current LP1-LP4 FUV DISPTAB reference files. This list is supplemented above 1300Å by a selection of windows used in the Sonnentrucker et al. (2013) dispersion solution analysis. A subset of these windows was then used for the low-resolution modes, with some adjustments to window sizes as needed due to line broadening. The number of windows used in the cross-correlation for each observing mode is given in Table 1.

3.2 COS-COS Results

These new Cycle 29 COS spectra were cross-correlated with data from the Cycle 22 version of this monitoring program to check the internal stability of the wavelength solution zero points. AV 75 has been used as the wavelength monitor target since Cycle 20 (2013), when all COS FUV cenwaves were obtained at the second Lifetime Position (LP). LP refers to the Y-location on the COS detector where spectra fall, which is periodically adjusted due to the affects of gain sag. All cenwaves were acquired at LP2 during Cycles 19-21 (2012-2014). G130M/1096 spectra have continued to be acquired at LP2, while all other cenwaves were acquired at LP3 during Cycles 22-24 (2015-2017), and LP4 during Cycles 25-28 (2018-2021). Starting with Cycle 29, the COS2025 rules were put in place to prolong the lifetime of the detector to 2025 and beyond, resulting in spectra being acquired at different LPs depending on cenwave.[1] Table 1 lists the LP at which each exposure was obtained.

In 2018, the wavelength solutions for most G130M and G160M cenwaves were improved from their original accuracy goals of one resolution element. The solutions for the standard G130M cenwaves (1291, 1300, 1309, 1318, 1327) and G160M cenwaves (1577, 1589, 1600, 1611, 1623) were improved at LP1 (Plesha et al. 2018) and LP2 (Ake et al. 2019), and all of those modes plus G130M/1222 were improved at LP3 and LP4 (Plesha et al. 2019a,b). These modes are now accurate to approximately half a resolution element (3 pixels or $\sim 7.5\ \mathrm{km\,s^{-1}}$). In 2020, the solutions for G130M/1055 and G130M/1096 were also improved at LP2 (Kumari et al. 2020). They are now also accurate to approximately 3 pixels ($\sim 9\ \mathrm{km\,s^{-1}}$ at 1000 Å).

[1]See Oliveira et al. 2018 and the COS2025 webpage for details and current status: https://www.stsci.edu/hst/instrumentation/cos/proposing/cos2025-policies

Table 2. Residual COS-COS Pixel Shifts (Cycle 29 vs Cycle 22)[a]

Segment	G130M 1096	G130M 1222	G130M 1291	G130M 1327	G160M 1577	G160M 1623	G140L 1105	G140L 1280
A	– 0.4	– 2.2	+ 0.1	+ 0.7	– 1.6	– 2.3	+ 0.8	+ 0.1
B	– 0.2	– 1.7	– 0.8	...[b]	– 1.9	– 1.5	...[b]	+ 0.5

[a] Cross correlation shifts are the pixel offset required to bring Cycle 29 results into agreement with Cycle 22 data.

[b] Data are not collected in this mode.

We use Cycle 22 as the COS reference dataset because they were the first to be taken at LP3. Because LP3 was the first LP at which dedicated wavelength calibration spectra were obtained at commissioning, the dispersion solutions there are more accurate than earlier data. The LP3 wavelength calibration data were obtained in two separate programs that ran five days apart (PIDs 13931 and 13969; PIs J. Roman-Duval and P. Sonnentrucker, respectively). Table 2 shows the result of our cross-correlation analysis of Cycle 29 and Cycle 22 data. Figure 1 shows the shifts for each mode as a function of time back to Cycle 20. In each figure, the dashed lines indicate the wavelength accuracy requirements for that mode (3 pixels for all medium resolution cenwaves and 9 pixels for G140L cenwaves). All reported shifts are the median across all measurement windows for each mode. The Cycle 29 shifts are all found to be within the required specifications, and no long-term trends can be seen in Figure 1.

3.3 COS-STIS/FUSE Results

The Cycle 29 COS spectra are cross-correlated with STIS and FUSE reference spectra to monitor the external COS zero point stability. From STIS we use an E140M reference spectrum of AV 75 obtained in Cycle 7 (PID 7437; PI D. Lennon). Below 1090 Å we use a FUSE spectrum of the target from PID 115 (PI J.M. Shull). The FUSE and STIS spectra were cross-correlated by Plesha et al. 2019a, who found the FUSE spectrum to be shifted toward shorter wavelengths by 0.0106 Å. The FUSE reference spectrum used here has been corrected for this offset, which corresponds to 1.06 pixels for COS medium resolution modes and 0.13 for COS low resolution modes. The STIS and FUSE reference spectra are interpolated onto the COS wavelength scale and all data are boxcar smoothed before being cross-correlated.

The Cycle 29 median shift results are given in Table 3, and plotted as a function of observation time since Cycle 20 in Figure 2. All shifts are found to be within the required specifications, and no long-term trends are apparent. The persistent offsets noticed by Fischer (2022) in the G140L modes appear significantly reduced in these Cycle 29 data.

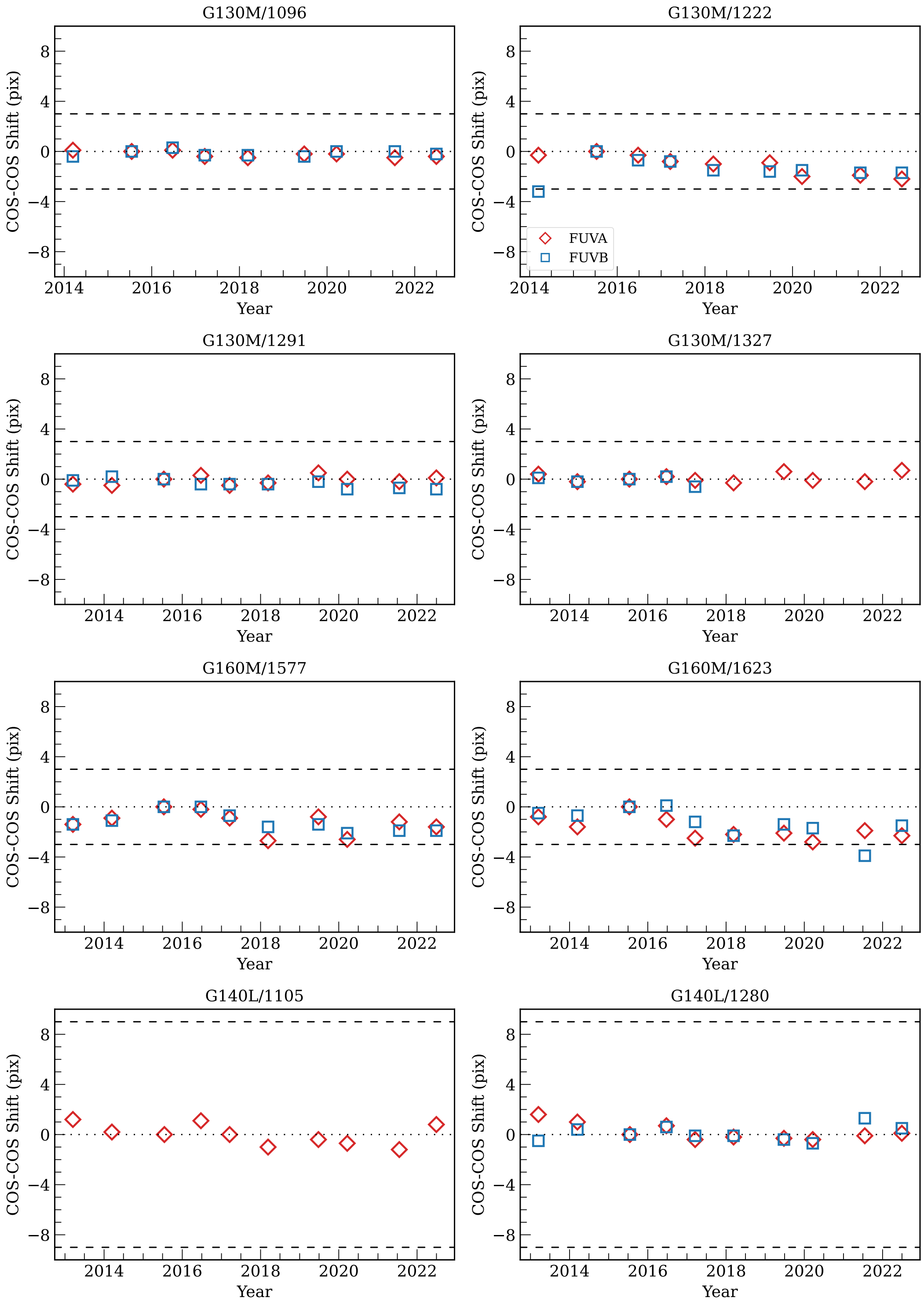

Figure 1. Plots of the measured pixel shifts between the COS Cycle 22 reference spectra and COS Cycle 20-29 data as a function of observation date for each monitored mode. Results from segments FUVA and FUVB are shown as red diamonds and blue squares, respectively. Wavelength accuracy requirements are indicated by dashed lines.

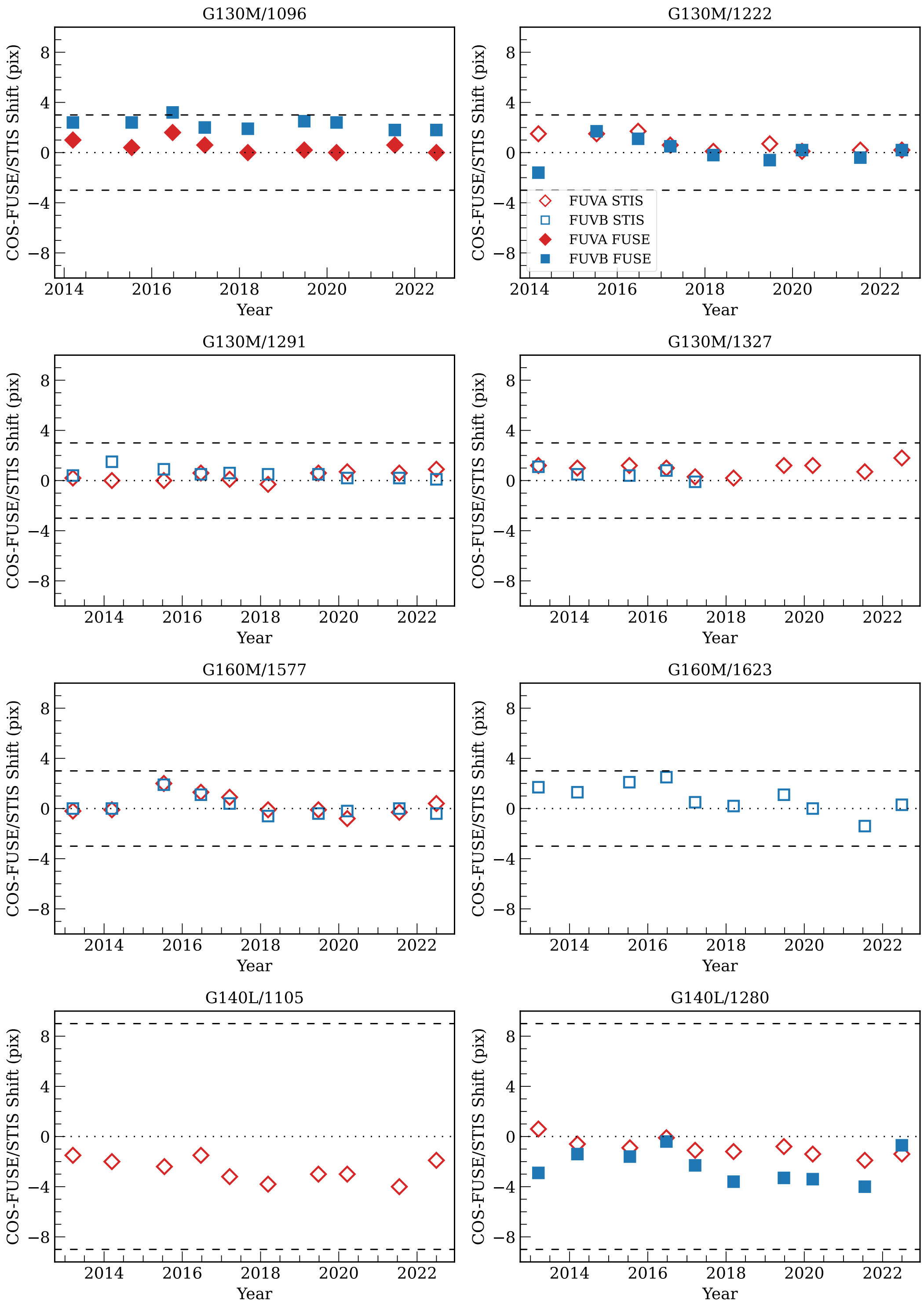

Figure 2. Plots of the measured pixel shifts between the STIS/FUSE reference spectra and COS Cycle 20-29 data as a function of observation date for each monitored mode. Wavelength accuracy requirements are indicated by dashed lines. Results from segments FUVA and FUVB are shown as red diamonds and blue squares, respectively. Filled symbols indicate FUSE provided the reference spectrum instead of STIS.

Table 3. Residual COS-FUSE/STIS Pixel Shifts[a]

Segment	G130M 1096	G130M 1222	G130M 1291	G130M 1327	G160M 1577	G160M 1623	G140L 1105	G140L 1280
A	0.0	+ 0.2	+ 0.9	+ 1.8	+ 0.4	...[b]	– 1.9	– 1.4
B	+ 1.8	+ 0.2	+ 0.1	...[c]	– 0.4	+ 0.3	...[b]	– 0.7

[a] Cross correlation shifts are the pixel offset required to bring Cycle 29 results into agreement with FUSE or STIS reference spectra.

[b] No STIS or FUSE data are available for this mode.

[c] Data are not collected in this mode.

4. Program Continuation

This program continues into Cycle 30 as PID 17250 with one major change. The enabling of LP6 operations for Cycle 30 requires G160M spectra to be taken at both LP4 and LP6, which requires an additional orbit. Otherwise, the Cycle 30 program will be identical to this Cycle 29 version.

Change History for COS ISR 2024-02

Version 1: 31 January 2024 - Original Document

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