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Cycle 26 COS FUV Wavelength Scale Monitor

William J. Fischer[1]

[1] Space Telescope Science Institute, Baltimore, MD

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ABSTRACT

We report on the monitoring of the zero points of the COS FUV dispersion solutions during Cycle 26 in program 15536. Select cenwaves were monitored for all FUV gratings. Comparisons to COS monitoring data obtained in previous cycles indicate internal stability within the allowed ranges. Comparisons to FUSE and STIS data indicate satisfactory absolute calibration. All measured offsets are within the established thresholds of 6 pixels for G130M/1096, 3 pixels for the other G130M and G160M cenwaves, and 9 pixels for the G140L cenwaves.

Contents

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1. Introduction

Analysis of data from thermal vacuum testing (TV03) indicates that grating-dependent offsets may develop in the dispersion solutions for the Cosmic Origins Spectrograph Far-Ultraviolet (COS FUV) channel (Oliveira et al. 2010). To determine whether any such changes are taking place, the COS FUV wavelength scale monitor obtains data annually for select cenwaves with gratings G130M, G160M, and G140L. The spectra are cross-correlated with COS spectra from the Cycle 22 iteration of this program and with FUSE or STIS data to measure any changes in the zero points of the dispersion solutions. The linear and, for G140L, quadratic terms in the solutions are not monitored.

We use a STIS E140M spectrum for comparison because of the superior wavelength accuracy of STIS relative to COS. The STIS E140M dispersion solutions have an absolute accuracy of 3.3 km s^{-1} (Riley et al. 2019). In contrast, the COS FUV dispersion solutions are accurate to 7.5 km s^{-1} for most M modes, 15 km s^{-1} for the G130M blue modes (cenwaves 1055 and 1096), and 150 km s^{-1} for the L modes (Plesha et al. 2019b; Dashtamirova et al. 2020). FUSE is accurate to 7 km s^{-1} (Dixon et al. 2007), similar to most of the COS M modes. Point sources observed with FUSE through the low-resolution (LWRS) aperture, the case for the spectrum discussed below, may suffer from a zero-point offset of up to 0.15 Å. We account for this possibility in the analysis. (Offsets are less than 0.02 Å for FUSE's medium-resolution aperture, or MDRS, and are negligible for the high-resolution aperture, or HIRS.)

2. Observations

The Cycle 26 FUV wavelength monitoring program (PID 15536, PI W. Fischer) consisted of one visit of three orbits to check the zero points of the dispersion solutions of the following gratings: G130M (cenwaves 1096, 1222, 1291, and 1327), G160M (cenwaves 1577 and 1623), and G140L (cenwaves 1105 and 1280). The target was AV 75, a star of spectral type O5.5I. Visit 01 failed on 2019 March 19 due to the failure to acquire a guide star. It was rescheduled as Visit 51, which executed successfully on 2019 June 25.

The acquisition sequence consisted of ACQ/SEARCH followed by ACQ/IMAGE using the Bright Object Aperture (BOA) and Mirror A. Because this is a crowded field, orient constraints were put in place to avoid field objects that are too bright for the Primary Science Aperture (PSA) when the BOA is being used for acquisition. To mitigate the effects of gain sag, two FP-POS settings were used for each G130M and G160M cenwave, cycling among all four FP-POS throughout the visit. For G140L, only FP-POS 3 was used. The monitored settings, segments, FP-POS, and exposure times are listed in Table 1. When two FP-POS were observed, the listed exposure time was split equally between them.

The Cycle 26 program was identical to its Cycle 25 predecessor (PID 15385, PI W. Fischer), which was summarized by Fischer (2019). Beginning with Cycle 25 and

Table 1. Settings Monitored in PID 15536

Grating	Cenwave	Segments	FP-POS	Total Time (s)
G130M	1096	BOTH	2, 4	1240
G130M	1222	BOTH	1, 3	452
G130M	1291	BOTH	3, 4[1]	382
G130M	1327	FUVA[2]	1, 3	384
G160M	1577	BOTH	2, 4	610
G160M	1623	BOTH	1, 3	738
G140L	1105	FUVA	3	80
G140L	1280	BOTH	3	80

[1]When both segments are on for G130M/1291, only FP-POS 3 and 4 are allowed by the COS2025 rules designed to prolong the detector lifetime (Oliveira et al. 2018).

[2]For G130M/1327, FUVB is disallowed by the COS2025 rules.

going forward, changes described by Fischer (2019) were made to align the program with the COS2025 rules designed to prolong the detector lifetime (Oliveira et al. 2018).

3. Analysis and Results

3.1 Window Selection

The cross-correlation analysis was performed in distinct windows featuring absorption lines formed along the line of sight to the target. The windows were identical to those tabulated in the Cycle 25 report for this program (Fischer 2019). Below 1090 Å, they were selected with the aid of a FUSE spectrum of the target (PID P115, PI J. M. Shull). Above 1090 Å, windows were based on those used for the 2018 improvements to the dispersion solutions of the G130M and G160M modes (Plesha et al. 2019b). Above 1300 Å, this list is fairly sparse, so it was supplemented with select windows used for the analysis of dispersion solutions by Sonnentrucker et al. (2013). For the low-resolution cenwaves, the suitability of each medium-resolution window was evaluated and a subset were selected for use. These windows were widened and combined if necessary to accommodate the broader lines. Each segment contains from three to fourteen windows, with the number typically decreasing toward longer wavelengths.

3.2 Comparison to Previous COS Spectra

To check the internal stability of the zero points, the Cycle 26 COS spectra were cross-correlated with COS spectra of the same star obtained with the same settings in the Cycle 22 instance of the FUV wavelength monitoring program. In the FUV, the lifetime position (LP) at which the spectra are acquired is relevant, because each has its own wavelength calibration. (The LP refers to the detector region on which COS spectra fall, which is updated every few years to mitigate the effects of declining gain.) AV 75 has been used as a wavelength monitoring target since Cycle 20 (2013), when LP2 was in use for all cenwaves. G130M/1096 spectra have continued to be acquired at LP2, while those for all other monitored cenwaves were acquired at LP2 in Cycle 21 (2014), at LP3 in Cycles 22 through 24 (2015–2017), and at LP4 in Cycles 25 and 26 (2018–2019).

In 2018 the wavelength solutions for most of the G130M and G160M cenwaves were improved. They are now accurate to 7.5 km s^{-1} instead of the original 15 km s^{-1}. Of the cenwaves monitored here, G130M/1291, G130M/1327, G160M/1577, and G160M/1623 were updated at LP2 (Ake et al. 2019), and all of these cenwaves plus G130M/1222 were updated at LP3 and LP4 (Plesha et al. 2019a,b).

We compare COS spectra to those obtained in Cycle 22, the first to take place at LP3, because the updating of the dispersion solutions is less complete in earlier datasets. As a consequence of LP3 commissioning, these spectra were obtained in two programs that ran five days apart (PIDs 13931 and 13969, PIs J. Roman-Duval and P. Sonnentrucker, respectively). The results of the Cycle 26 COS-COS analysis appear in Table 2. In all tables and figures, the reported shifts are the medians of those measured in all windows considered for each segment.

The available shifts for all cycles since Cycle 20 are plotted in Figure 1. Those for Cycle 22 (2015) are zero by definition, since it is the basis for comparison. The dashed lines in each panel show the error goals. These are 6 pixels for G130M/1096 because its solution was not recently updated, 3 pixels for the other medium-resolution modes, and 9 pixels for G140L. All shifts are within the specifications.

3.3 Comparison to FUSE and STIS Spectra

To check the external stability of the zero points, the Cycle 26 COS spectra were also cross-correlated with FUSE and STIS spectra of the same star. The FUSE spectrum is the one mentioned above for window selection. For STIS we use an E140M spectrum acquired in Cycle 7 (PID 7437, PI D. Lennon). We cross-correlated the FUSE spectrum with the STIS spectrum in the region where they overlap and found that the FUSE spectrum is shifted to shorter wavelengths by 0.0106 Å. The FUSE wavelength scale was corrected by this offset, which corresponds to 1.06 pixels for the COS M modes and 0.13 pixels for the COS L modes. The results of the Cycle 26 analysis appear in Table 3.

Table 2. Pixel Shifts from COS-COS Cross-Correlation (Cycle 26 vs. Cycle 22)[1]

Seg.	G130M 1096	G130M 1222	G130M 1291	G130M 1327	G160M 1577	G160M 1623	G140L 1105	G140L 1280
A	−0.3	−0.8	+0.4	+0.5	−0.8	−2.1	−0.4	−0.2
B	−0.5	−1.4	−0.3	... [2]	−1.4	−1.4	... [2]	−0.3

[1]Shifts are those required to bring the Cycle 26 data into agreement with the Cycle 22 data.

[2]Data are not collected at this setting.

Table 3. Pixel Shifts from COS-FUSE/STIS Cross-Correlation[1]

Seg.	G130M 1096	G130M 1222	G130M 1291	G130M 1327	G160M 1577	G160M 1623	G140L 1105	G140L 1280
A	−2.9	+0.6	+0.6	+1.2	−0.2	... [2]	−3.1	−0.9
B	+5.3	−0.3	+0.4	... [3]	−0.4	+1.0	... [3]	−3.0

[1]Shifts are those required to bring the COS data into agreement with the FUSE data (for G130M/1096, G130M/1222/B, and G140L/1280/B) or STIS data (all other settings).

[2]No FUSE or STIS data are available for this setting.

[3]Data are not collected at this setting.

The available shifts for all cycles since Cycle 20 are plotted in Figure 2. The dashed lines in each panel show the same error goals as before; all shifts are within them. For the modes with updated dispersion solutions, recent spectra have excellent agreement with spectra from other instruments. For modes that were not updated (G130M/1096 and both G140L cenwaves), there are persistent offsets of a few pixels, but the shifts are still within the specifications. The dispersion solutions for the G130M blue modes (cenwaves 1055 and 1096) are currently being updated.

4. Continuation Plan

This program continues in Cycle 27 as PID 15774 and is identical to the Cycle 26 version.

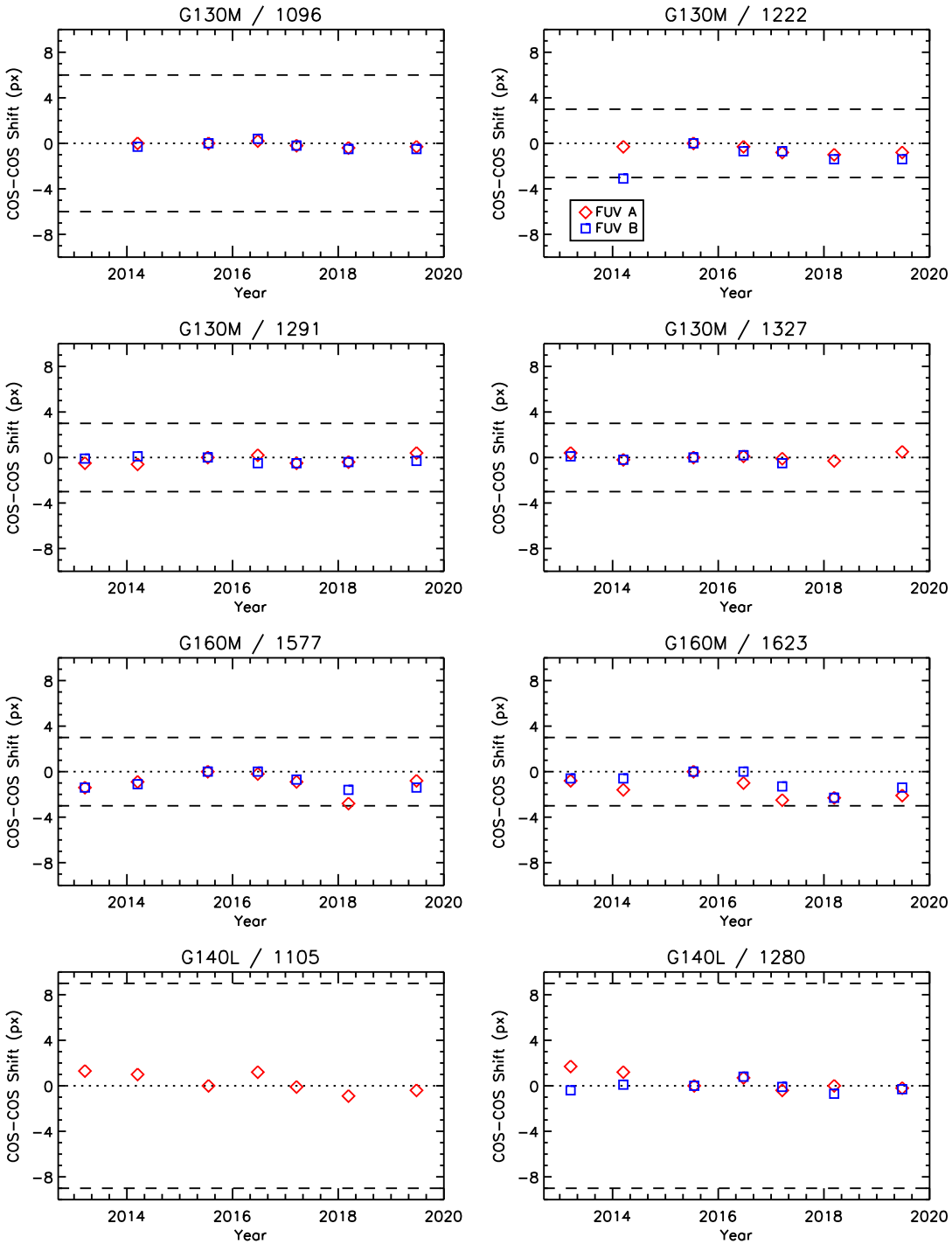

Figure 1. Plots of COS-COS shifts for the eight cenwaves monitored with AV 75 since Cycle 21 (2014) or before. Shifts are those required to bring each spectrum into agreement with the Cycle 22 data. Symbol types distinguish between segments. Dashed lines indicate the error goals.

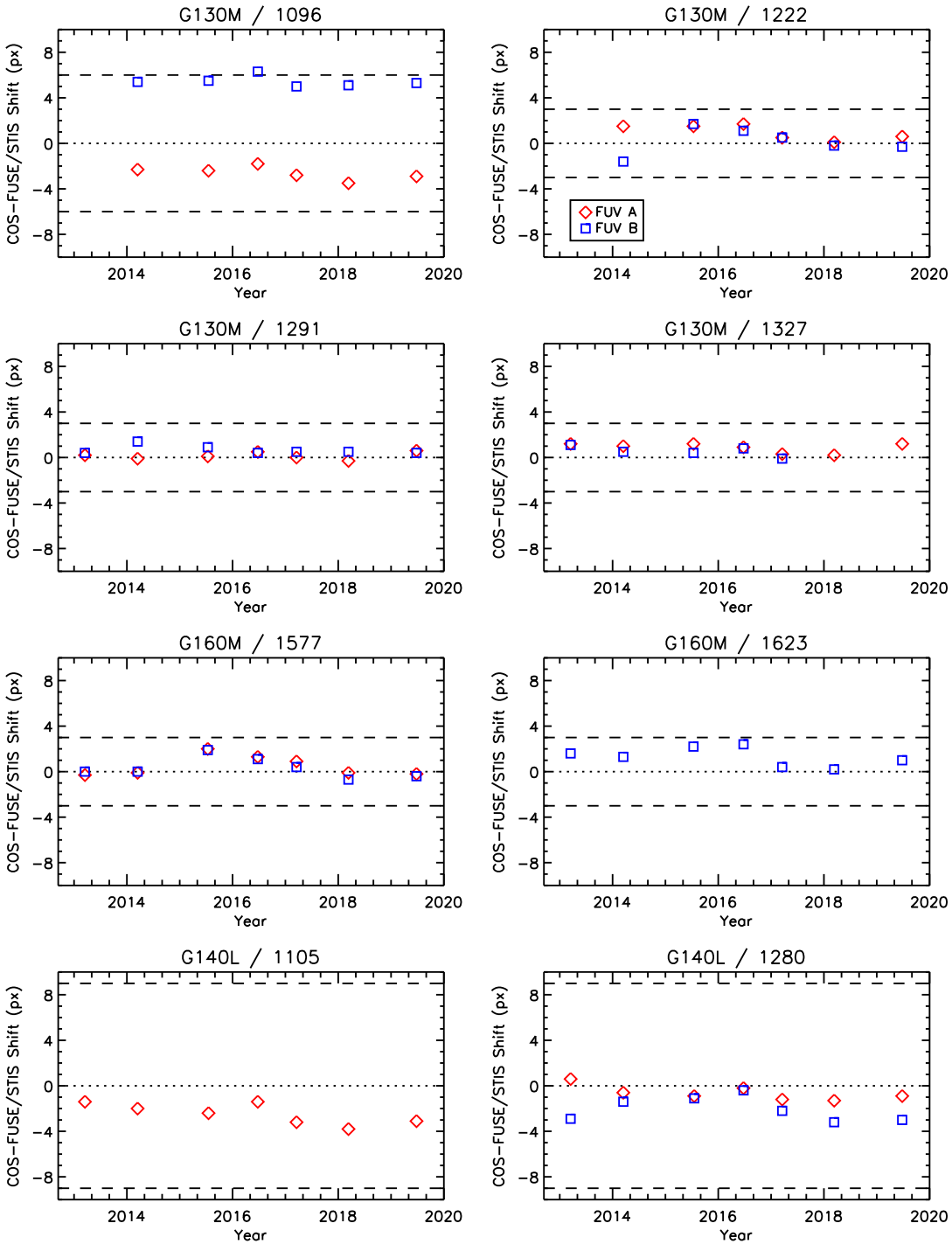

Figure 2. Plots of COS-FUSE/STIS shifts for the eight cenwaves monitored with AV 75 since Cycle 21 (2014) or before. Shifts are those required to bring each COS spectrum into agreement with the FUSE or STIS data. Symbol types distinguish between segments. Dashed lines indicate the error goals.

Change History for COS ISR 2020-03

Version 1: 8 June 2020 – Original Document

References

Ake, T., Plesha, R., De Rosa, G., et al. 2019, COS ISR 2018-23, "Improvements to the COS FUV G130M and G160M Wavelength Solutions at Lifetime Position 2"

Dashtamirova, D., Fischer, W. J., et al. 2020, *Cosmic Origins Spectrograph Instrument Handbook*, Version 12.1 (Baltimore: STScI)

Dixon, W. V., Sahnow, D. J., Barrett, P. E., et al. 2007, PASP, 119, 527

Fischer, W. J. 2019, COS ISR 2019-16, "Cycle 25 COS FUV Wavelength Scale Monitor"

Oliveira, C., Béland, S., Keyes, C., & Niemi, S. 2010, COS ISR 2010-06, "SMOV: COS FUV Wavelength Calibration"

Oliveira, C., De Rosa, G., Mackenty, J., et al. 2018, COS ISR 2018-16, "COS2025: A New Strategy to Prolong the Lifetime of the COS/FUV Detector to 2025"

Plesha, R., Ake, T., De Rosa, G., Oliveira, C., & Penton, S. 2019a, COS ISR 2018-24, "Improvements to the COS FUV G130M and G160M Wavelength Solutions at Lifetime Position 3"

Plesha, R., Ake, T., De Rosa, G., Oliveira, C., & Penton, S. 2019b, COS ISR 2018-25, "Improvements to the COS FUV G130M and G160M Wavelength Solutions at Lifetime Position 4"

Riley, A., et al. 2019, *Space Telescope Imaging Spectrograph Instrument Handbook*, Version 19.0 (Baltimore: STScI)

Sonnentrucker, P., Roman-Duval, J., Ely, J., et al. 2013, COS ISR 2013-06, "COS FUV Dispersion Solution Verification at the New Lifetime Position"