ABSTRACT
We report on the monitoring of the zero points of the COS FUV dispersion solutions during Cycle 27 in program 15774. 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 3 pixels for the G130M and G160M cenwaves and 9 pixels for the G140L cenwaves.

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1. Introduction

Analysis of data from thermal vacuum testing in 2003 (TV03) indicated 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\(^{-1}\) (Branton et al. 2021). In contrast, the COS FUV dispersion solutions are accurate to 7.5 km s\(^{-1}\) for the M modes and 150 km s\(^{-1}\) for the L modes (Plesha et al. 2019b; Kumari et al. 2020; Hirschauer et al. 2021). FUSE is accurate to 7 km s\(^{-1}\) (Dixon et al. 2007), similar to 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 27 FUV wavelength monitoring program (PID 15774, 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 ran successfully on 2020 March 20.

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 per grating. For G140L, only FP-POS 3 was used. The monitored settings, segments, FP-POS, and exposure times are listed in Table I. When two FP-POS were observed, the listed exposure time was split equally between them.

The Cycle 27 program was identical to its Cycle 26 predecessor (PID 15536, PI W. Fischer), which was summarized by Fischer (2020). Beginning with Cycle 25 and going forward, changes described by Fischer (2019) were made to align the program.
Table 1. Settings Monitored in PID 15774

<table>
<thead>
<tr>
<th>Grating</th>
<th>Cenwave</th>
<th>Segments</th>
<th>FP-POS</th>
<th>Total Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G130M</td>
<td>1096</td>
<td>BOTH</td>
<td>2, 4</td>
<td>1240</td>
</tr>
<tr>
<td>G130M</td>
<td>1222</td>
<td>BOTH</td>
<td>1, 3</td>
<td>452</td>
</tr>
<tr>
<td>G130M</td>
<td>1291</td>
<td>BOTH</td>
<td>3, 4(^1)</td>
<td>382</td>
</tr>
<tr>
<td>G130M</td>
<td>1327</td>
<td>FUVA(^2)</td>
<td>1, 3</td>
<td>384</td>
</tr>
<tr>
<td>G160M</td>
<td>1577</td>
<td>BOTH</td>
<td>2, 4</td>
<td>610</td>
</tr>
<tr>
<td>G160M</td>
<td>1623</td>
<td>BOTH</td>
<td>1, 3</td>
<td>738</td>
</tr>
<tr>
<td>G140L</td>
<td>1105</td>
<td>FUVA</td>
<td>3</td>
<td>80</td>
</tr>
<tr>
<td>G140L</td>
<td>1280</td>
<td>BOTH</td>
<td>3</td>
<td>80</td>
</tr>
</tbody>
</table>

\(^1\)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.

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 27 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 through 27 (2018–2020).

In 2018 the wavelength solutions for most of the G130M and G160M cenwaves were improved. They are now accurate to half a resolution element (3 pixels or \(\sim 7.5 \text{ km} \text{s}^{-1}\)) instead of the original one resolution element. The solutions for G130M cenwaves \(\geq 1291\) and all G160M cenwaves 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). In 2020 the wavelength solutions for G130M/1055 and G130M/1096 at LP2 were improved (Kumari et al. 2020). They are also now accurate to half a resolution element (3 pixels or \(\sim 9 \text{ km} \text{s}^{-1}\) at these shorter wavelengths) instead of the original one resolution element.

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 27 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 I. 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 3 pixels for the G130M and G160M cenwaves and 9 pixels for the G140L cenwaves. 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 27 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.
Table 2. Pixel Shifts from COS-COS Cross-Correlation (Cycle 27 vs. Cycle 22)¹

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>−0.5</td>
<td>−2.0</td>
<td>0.0</td>
<td>−0.1</td>
<td>−2.5</td>
<td>−2.6</td>
<td>−0.7</td>
<td>−0.3</td>
</tr>
<tr>
<td>B</td>
<td>−0.1</td>
<td>−1.5</td>
<td>−0.8</td>
<td>···²</td>
<td>−2.1</td>
<td>−1.9</td>
<td>···²</td>
<td>−0.7</td>
</tr>
</tbody>
</table>

¹Shifts are those required to bring the Cycle 27 data into agreement with the Cycle 22 data.
²Data are not collected at this setting.

Table 3. Pixel Shifts from COS-FUSE/STIS Cross-Correlation¹

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+0.4</td>
<td>+0.1</td>
<td>+0.8</td>
<td>+1.2</td>
<td>−0.6</td>
<td>···²</td>
<td>−3.1</td>
<td>−1.4</td>
</tr>
<tr>
<td>B</td>
<td>+2.4</td>
<td>+0.2</td>
<td>+0.1</td>
<td>···³</td>
<td>−0.3</td>
<td>0.0</td>
<td>···³</td>
<td>−4.7</td>
</tr>
</tbody>
</table>

¹Shifts 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).
²No FUSE or STIS data are available for this setting.
³Data are not collected at this setting.

and 0.13 pixels for the COS L modes. The results of the Cycle 27 analysis appear in Table 3.

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 (G140L cenwaves), there are persistent offsets of a few pixels, but the shifts are still within the specifications.

4. Continuation Plan

This program continues in Cycle 28 as PID 16325 and is identical to the Cycle 27 version except that exposure times have been slightly adjusted to better fill the orbits.
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 cemwaves 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 2021-10

Version 1: 15 December 2021 – Original Document

References


