Instrument Science Report COS 2023-26

Monitoring COS Spectral Placement after an OSM1 Home Position Move

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ABSTRACT

In ISR 2023-24 Hasselquist et al. (2023) described systematic trends and offsets with spectrum placement on the detector due to the Optics Select Mechanism 1 (OSM1) during Lifetime Position 4 (LP4) operations and after the start of operations at LP5. While these trends are within the requirements for COS and are usually corrected by internal WAVECALs, shifting the position on which Lyman-α falls has a potential impact on detector lifetime. These trends correlate with historical moves to the STScI Home Position for OSM1. To mitigate the observed behavior, the COS team, in consultation with NASA/Goddard Space Flight Center, Ball Aerospace, and the Hubble Space Telescope Mission Office, reverted the STScI home position for OSM1 back to G130M/1291 on 25 July 2022 from G130M/1222. Concurrent with this move, the special calibration program 17229, "COS Spectral Shift Monitor" was executed. The goal of the program was to monitor the location of the spectrum positioning after the home position move in order to better understand the physical origins of the behavior seen. This ISR describes the structure of the special calibration program and the resulting evolution in OSM1 positioning. We find that the choice of home position can impact the repeatability and average placement of spectra on the detector by the OSM1, potentially due to redistribution of lubricant from changes in mechanism motion patterns. In Program 17229, we find that a trend of increasing placement along the dispersion direction for G130M/1222 reversed and eventually flattened. For G130M/1291, the scatter in placements and offsets between small OSM1 moves and

larger OSM1 moves is reduced by tens of pixels. The changes in behavior with home position generally supports the theory that lubrication may be a cause for what has been observed.

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1. Introduction

The Optics Select Mechanism 1 (OSM1) returns to the same position after a sequence of observations, denoted the STScI Home Position. The STScI Home position was originally located at G130M/1309 during operations at Lifetime Positions 1, 2, and 3 (LP1, LP2, LP3). Concurrent with the start of LP4 operations, the STScI Home Position was moved to G130M/1291. At the start of LP5 operations, the home position was moved to G130M/1222. The move to G130M/1222 was for the purpose of retaining a highly used mode that didn't include geocoronal Lyman-α in the event of an OSM1 failure.

It was discovered during LP5 operations that certain grating/central wavelength (CENWAVE) combinations were undergoing systematic changes in the positioning of FUV spectra on the COS FUV detector in the dispersion direction. This motivated the COS team to carefully consider returning the STScI home position for the OSM1 to G130M/1291 in order to mitigate the trends (Hasselquist et al., 2023; hereafter H23). We briefly summarize that investigation here.

When a COS/FUV observation executes, CalCOS records the offset between the expected spectrum location in the dispersion direction and that observed in WAVECAL spectra in the SHIFT1A and B header keywords representing the measured shift for both the FUVA and FUVB detector. H23 discovered that these values are nearly identical for the two detectors and do not account for slight offsets in spectrum placement between LPs. The corrected values are represented in this ISR as the variable SHIFT1, which denotes the FUV spectral placement in the dispersion direction relative to FP-POS=3 for a given CENWAVE. Thus, SHIFT1 for FP-POS=3 should be ~0 pixels and successive FP-POS values should be ~250*(FP-POS-3) pixels away from 0. The requirements for spectral positioning accuracy are half an FP-POS, or roughly 125 pixels.

Routine monitoring of science observations during operations at LP5 revealed systematic trends in SHIFT1, that if they continued, would violate these requirements. First, within the G130M grating positions at the 1291 CENWAVE, small OSM1 motions (1 motor step) to the FP-POS = 3 and FP-POS = 4 locations were offset (~120 pixels) and more scattered (25 pixels to 40 pixels) in SHIFT1 values than large OSM1 motions (>200 motor steps) to these locations. Second, at the 1222 CENWAVE, the FP-POS=2 and 4 locations showed a significant positive trend with time in SHIFT1 of 0.5 pixels/day for close to six months before flattening out. This behavior was directly correlated with a change in OSM1 home position and the COS team hypothesized that the change in OSM1 usage could be the cause of a significant fraction of the behavior.

The science impact to these trends is relatively subtle, since WAVECALs generally correct systematic offsets between a spectrum placement of an observation and the nominal spectrum placement. However, these trends would mean that some sections of wavelength coverage may be slightly different than expected when the observation was planned and result in the loss of wavelength coverage. Additionally, the non-repeatability and trends in G130M/1291 affect where the geocoronal Lyman-α falls on the detector, impacting where gain sag occurs and also impacting wavelength coverage near these areas of the detector. H23 found that while the region is 50% wider where G130M/1291 falls on LP4 and LP5, the affected region in terms of wavelength coverage amounts to a difference of 1-2 Å.

When a spectrum is placed in a more positive direction than expected, the motor has not stopped as soon as expected. Conversely, if spectrum placement is in a more negative direction, the motor has stopped too soon. The OSM1 motor relies on both magnetic forces and friction to ensure a repeatable spectral position for a given motor step. If we assume that friction is the dominant variable, more positive shifts equate to less friction in the system, while more negative shifts equate to enhanced friction. The mechanism is lubricated, and H23 noted that one possible cause would be the unequal distribution of lubrication in the mechanism causing variable friction in the system.

Based on the deviation of the average positions of SHIFT1 for G130M/1222 and G130M/1291 from historical means, the COS team predicted that reverting the home position to G130M/1291 would return the measured SHIFT1 behavior to what was seen after the beginning of LP4 operations (September 2017), when the home position was last at G130M/1291. On 25 July 2022, the home position for OSM1 reverted back to G130M/1291 from G130M/1222.

In order to track whether the change in home position had the desired effect, the COS team designed and implemented a special calibration program that was intended to mimic likely mechanism moves during science exposures and to attempt to hasten changes in the spectral placement. While science observations can also be used to track spectrum placement, they are not scheduled often enough in each mode to provide the necessary coverage in time to look for small trends or correlated behaviors. This ISR describes the design of the special calibration program 17229 (PI: Debes) in Section 2 and the resulting behavior of spectral placement after the change in home position in Section 3. We summarize the results and remaining open questions in Section 4.

2. Special Calibration Program 17229

The primary goal of this program was to measure any systematic trends or changes in behavior with spectral placement after the change of home position. Based on the correlation between systematic SHIFT1 trends and the change in home position, we predicted that trends would revert to behavior and locations seen during LP4 operations. In order to do this, the monitoring program had to a) replicate an external science exposure while not impacting the science scheduling of the observatory, b) obtain data with a proper cadence and length to significantly detect trends with slopes equivalent to what was previously seen, c) probe the most highly impacted modes, and d) provide enough exposures to reverse the observed trends quickly to avoid widening of gain sag holes due to geocoronal Lyman α.

The COS team requested and was approved to use a total of 165 internal orbits to complete the monitoring, and by the end of the program had used 144 internal orbits. This resulted in 75 individual exposures for each FP-POS of G130M/1222, and 68 individual exposures for each FP-POS of G130M/1291. We further discuss our choice of monitoring cadence in Section 2.2.

2.1 Program Design

The primary measurable for the monitoring is the value of SHIFT1 for each exposure as this encodes the differential position on the detector of a flashed WAVECAL during a science observation relative to the lamp templates. It was also found that the trend in SHIFT1 values was created through the act of moving the mechanism, rather than a systematic drift during an observation. Our calibration program is thus designed to simulate the same SHIFT1 offsets by taking internal WAVECALS that move the mechanisms in a controlled manner rather than relying on science observations of external targets as part of normal operations.

We created visits for monitoring G130M/1222 and G130M/1291 by simulating a large OSM1 motor move from the NUV position to the first default FP-POS location followed by at least one small OSM1 motor move to subsequent FP-POS locations, mimicking an NUV acquisition followed by an observation with an FUV grating. For G130M/1222 we used the shortest exposure time NUV WAVECAL available with G230L/2635 at FP-POS=3, then executed four FUV WAVECALs for the cenwave at FP-POS=1, 2, 3, and 4. Additionally this would help to redistribute lubrication within OSM1 if that was the physical cause of the trends seen. For G130M/1291, he first exposure included a WAVECAL at G230L/2635 followed by additional WAVECALs at G130M/1291 FP-POS=3 and 4. This was followed by a move back to G230L/2635 and moves to FP-POS=1 and FP-POS=2. We wished to track these positions even though they have been infrequently used after the implementation of the COS2025 rules (Oliveira et al., 2018).

A comparison of FP-POS=1 and 2 to FP-POS=3 and 4 could reflect any differences caused by frequency of usage. Figure 1 shows a simple schematic of the observation structures for both CENWAVEs. These visits each took less than a single internal orbit, with ~1600s used in total with overheads for G130M/1291, and ~1200s in total with overheads for G130M/1222.

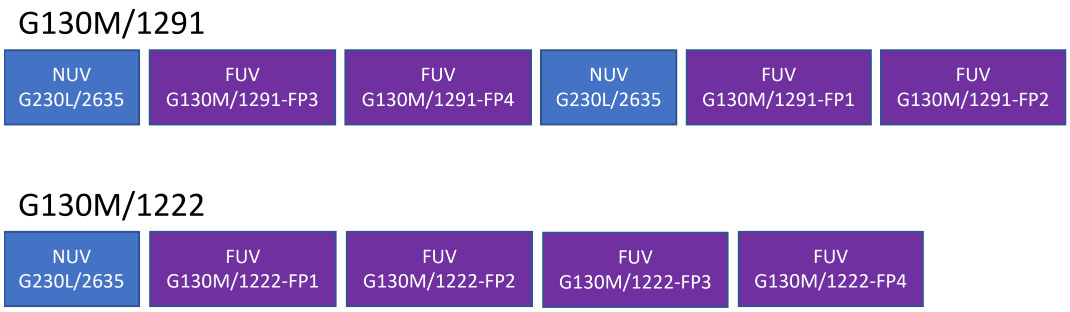

Figure 1: Schematic of the two types of visits executed in Program 17229. The top diagram denotes the sequence of WAVECAL exposures taken to simulate a science exposure with G130M/1291 FP-POS=3 and 4. First, a movement to an NUV position occurs to mimic a large motor move. There was evidence that showed a potential trend in the spectral offset based on FP-POS, so a second NUV WAVECAL was taken in this sequence to observe the behavior of FP-POS=1 and 2 after a simulated second NUV acquisition. This observation is not possible for CENWAVE G130M/1291 due to the COS2025 rules FP-POS restrictions (Olivera et. al). The bottom diagram denotes the sequence of WAVECAL exposures taken to track G130M/1222's behavior. Apart from G130M/1291, most science programs use all four FP-POS with the FUV.

2.2 Program Cadence

The original discovery of the long term SHIFT1 trends in G130M/1222 (H23) were observable within a short timescale due to a handful of science programs that executed observations on a near daily basis concurrently with the start of LP5 operations. This suggested that a daily cadence might be needed. Additionally, if motor movement patterns are responsible for trends, it was reasoned that more motor motions (i.e. with a higher monitoring cadence), could hasten the mitigation of the observed trends.

For a reasonably fixed uncertainty per SHIFT1 measurement, measuring slopes with significance requires a trade-off between the length of time one monitors for changes and the monitoring cadence. The timescale of changes previously seen was for 3-6 months, and the COS team decided that the length of time to monitor in total would be five months, which was roughly the timescale of the original trends.

To understand the cadence required to monitor the change in G130M/1222 behavior, we analyzed an ~85 day time period (59548 < MJD < 59634) over which observations occurred at an almost daily rate (PID 16196). Over this time period, we measured an average rate of change in SHIFT1 values of 0.38+/- 0.10 pixels/day for FP-POS = 2 and 0.49+/- 0.08 pixels/day for FP-POS = 4. We then subsampled the SHIFT1 values at decreasing sample size, including the first and last observation in each sample. For each of these subsamples, we calculated the fractional error on the slope as well as the deviation from the "true slopes" measured above.

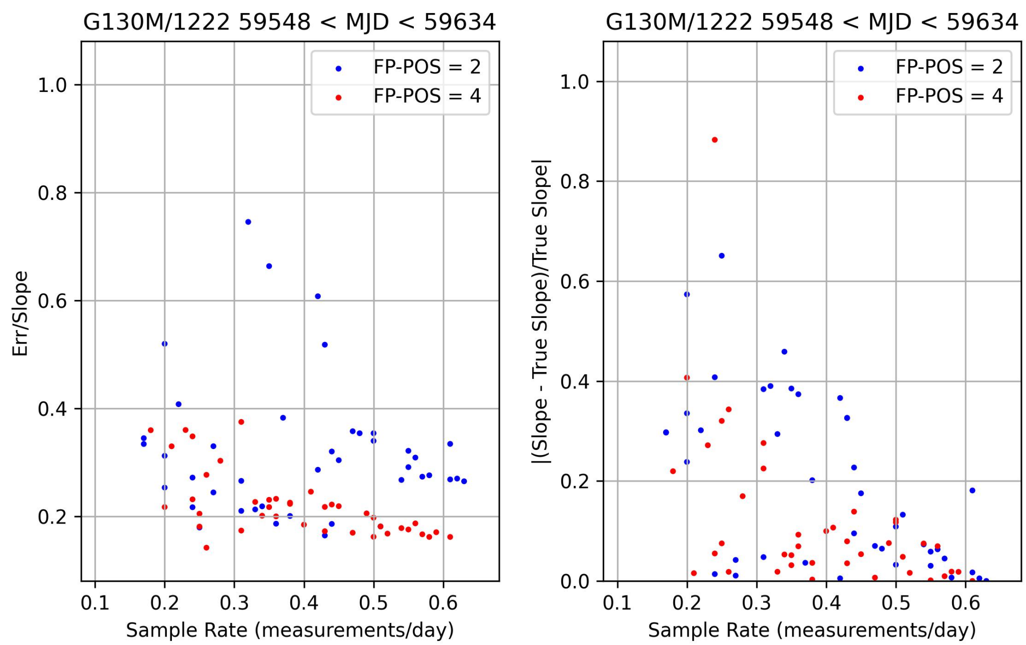

Figure 2. Investigations of different observing cadences to determine an optimal sampling of OSM1 SHIFT1 measurements over an 86 day period, roughly half the total time of the monitoring program. **Left:** the recovered error in slope divided by the slope as a function of cadence. The overall trend shows that decreasing the cadence degrades slope precision to high levels below ~0.3-0.5 measurements/day. **Right:** The fractional systematic uncertainty in the true slope as a function of cadence. Overall, lower cadences still recover the correct slope, but below ~0.3-0.5 measurements/day the risk of recovering an incorrect slope increases, and the best recovery occurs for cadences above 0.5 measurements/day.

These results are plotted against measurement cadence in the left and right panels of Figure 2, respectively. Downsampling to less than once per three days resulted in unsatisfactory uncertainties in the recovered slopes of the older trend.

The COS team also wished to be prepared to be sensitive to previously undetected short term behavior in case things evolved more quickly than what was implied by the previous change in home position. To that end, program 17229 sampled the shift behavior of both CENWAVEs on a daily basis for the first six weeks after the move of home position and then transitioned to a cadence of once every three days to follow the long term behavior of OSM1, with the transition occurring roughly on 4 September 2022. This added frequency also addressed the desire to accelerate the trend behavior compared to what was previously observed.

2.3 OSM1 Motor Temperature Considerations

The designed program executed several consecutive OSM1 moves in relatively short time periods compared to a median set of science observations. Because of this, and the possibility that the OSM1 motor could exceed its set upper limits, we investigated the historical behavior of the OSM1 motor temperature to determine if the proposed usage would cause excessive heating. In general, the motor temperature sharply increases by 4-6º C after a large motor move, dissipating to the baseline temperature with a half-life of roughly 20 minutes. The observed evolution meant that our proposed 1-2 large motor moves within ~30 minutes should not cause excessive heating. We reviewed the telemetry of the OSM1 motor temperature before, during, and after CAL/17229. We estimated the formal uncertainty in these averages to be ~0.1°. Overall, the average motor temperature did rise above the mean temperature during the special calibration program: the average motor temperature before our program was 25.6°, during the high cadence portion of the program it increased to 26.3°, lowered to 25.9° during the later phases of the program, and after the program ended the average motor temperature was slightly lower at 25.4°.

3. Results

CAL/17229 executed successfully, with the first set of observations occurring on 25 July 2022, the last G130M/1291 observation occurring on 16 November 2022, and the last G130M/1222 observation occurring on 22 December 2022. The COS team ended monitoring of G130M/1291 early due to a lack of significant slopes by November 2022. The COS team investigated the behavior of the SHIFT1 measurements as a function of time. For the purposes of this ISR, we correct the SHIFT1 measurements for small offsets between the LAMPTABs at different lifetime positions, detailed in H23. Figures 3-6 show the systematic SHIFT1 trends observed with the CAL/17229 data.

To help put our measurements in a broader context, we also measured the average SHIFT1 values for both modes in the last 90 days at the STScI Home Position at G130M/1291 (during LP4 operations) and at G130M/1222 and report the results in Table 1. A measure of success for the monitoring program would be if the average SHIFT1 measured during CAL/17229 matched the average position in the STScI Home Position G130M/1291 column. An example is FP-POS=2 of G130M/1222. When the home position was at G130M/1291 during LP4 operations, the average position was at -265 pixels. The ~0.5 pixel/day trend that occurred at the start of LP5 operations and the change in STScI Home Position to G130M/1222 showed an average position in early July 2022 of -168 pixels, a change of ~100 pixels. By the end of CAL/17229, the average position was back to -267 pixels and closer to its historical average position. The final column shows the estimated mean position of each mode as of mid-October 2023. All modes are within 20 pixels of the last measurements of 17229, implying that if any trends existed, they would be <0.06 pix/day.

Table 1. Average spectrum placements in science observations (SHIFT1) in the 90 days before the end of operations at the denoted home position (HP) compared to the average position of the last 5 measurements of CAL/17229, and to a median from science observations around Sep-Oct 2023. Insufficient data exists for G130M/1291 FP-POS=1,2 due to COS 2025 rules restricting their usage in science observations.

CENWAVE	FP-POS	HP=1291	HP=1222	17229	Oct 2023
1222	1	-503	-505	-540	-557
	2	-265	-168	-267	-275
	3	8	12	13	0
	4	236	301	242	246
1291	1	…	…	-529	…
	2	…	…	-146	…
	3	7.66	-3.6	-31	0.5
	4	369	382	346	366

3.1 G130M/1222

Plots of measured SHIFT1 position vs. time are shown in Figures 3 through 6 for all the FP-POS of G130M/1222. We model the full behavior of the trends as two discontinuous linear trends with a single breakpoint, shown as red lines in each plot. The breakpoints were selected by minimizing the residuals in the data. In particular, we identify MJD 59860 (8 October 2022) as the breakpoint for all FP-POS in G130M/1222. This date is very close to the start of operations at LP6 and 35 days later than the date when the cadence of our monitoring changed from both cenwaves/day to both cenwaves/three days (4 September 2022). This may indicate a correlation in the changes in behavior with changes in OSM1 usage.

The first few visits after the 25 July 2022 (MJD=59875) executed in this mode show a sharp drop of nearly 40 pixels in SHIFT1 location for FP-POS=2 and 4 relative to the average placement seen with the old home position (See Table 1; Figures 4 and 6), followed by a more gradual negative trend in spectrum placement for FP-POS=2 and 4 that eventually flattened out later in the program. These trends are punctuated by occasional discontinuous jumps in placement.

The slopes and their uncertainties are given in Table 2. Broadly speaking, FP-POS=1,2 and 4 had declining slopes early on that ranged from -0.2 pix/day to -0.6 pix/day (See Figures 3, 4, and 6), that after the breakpoint flattened to be consistent in all cases with nearly zero or slightly positive trends, although they are not statistically significant. The exception was FP-POS=3 (Figure 5) which had a nearly flat slope since the start of LP5 operations, then suffered a significant negative discontinuity followed by a positive slope until the end of monitoring, bringing it mostly back to the original spectrum placement location. The latest monitoring of science observations up until October 2023 is reported in Table 1 and shows that the positions have mostly stayed within 20 pixels of the end of our monitoring program.

Table 2. Spectrum placement trends for G130M/1222 and G130M/1291

CENWAVE	FP-POS	Slope 1 (pix/d)	Slope 2 (pix/d)	Breakpoint (MJD-59000)
1222	1	-0.3±0.1	+0.1±0.1	860
	2	-0.6±0.1	+0.2±0.1	
	3	-0.1±0.1	+0.4±0.1	
	4	-0.3±0.1	+0.2±0.1	
1291	1	+0.02±0.05	…	815
	2	-1.5±0.1	-0.1±0.1	
	3	-0.04±0.05	..	
	4	-2.9±0.3	-0.2±0.1	

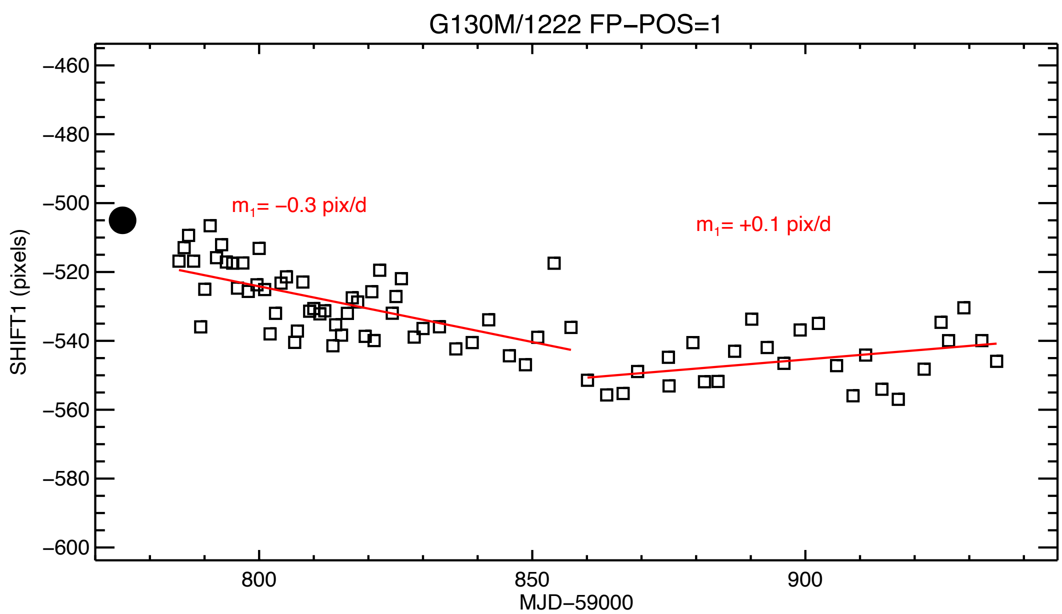

Figure 3. Measurements of SHIFT1 for G130M/1222 FP-POS=1 from Program 17229. Black squares are the measured spectrum placements, while the red lines denote the linear trends fit between the breakpoint at MJD 59860 (8 October 2022). The slope for each line segment is reported near the linear fit and in Table 2. The filled circle denotes the average SHIFT1 prior to the monitoring program start and corresponding to the value in the fourth column of Table 1.

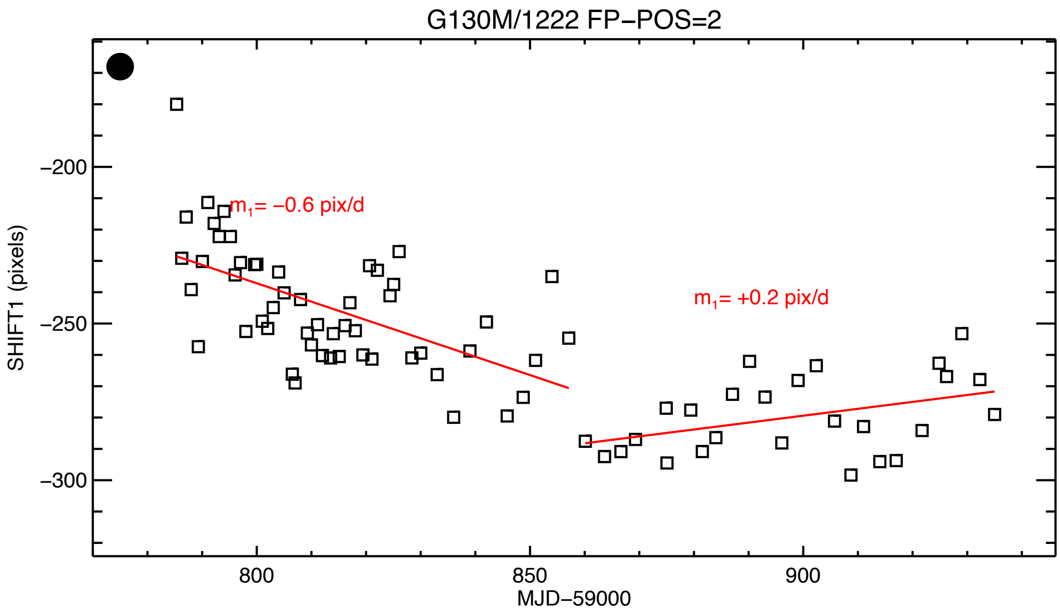

Figure 4. Same as Figure 3 but for G130M/1222 FP-POS=2.

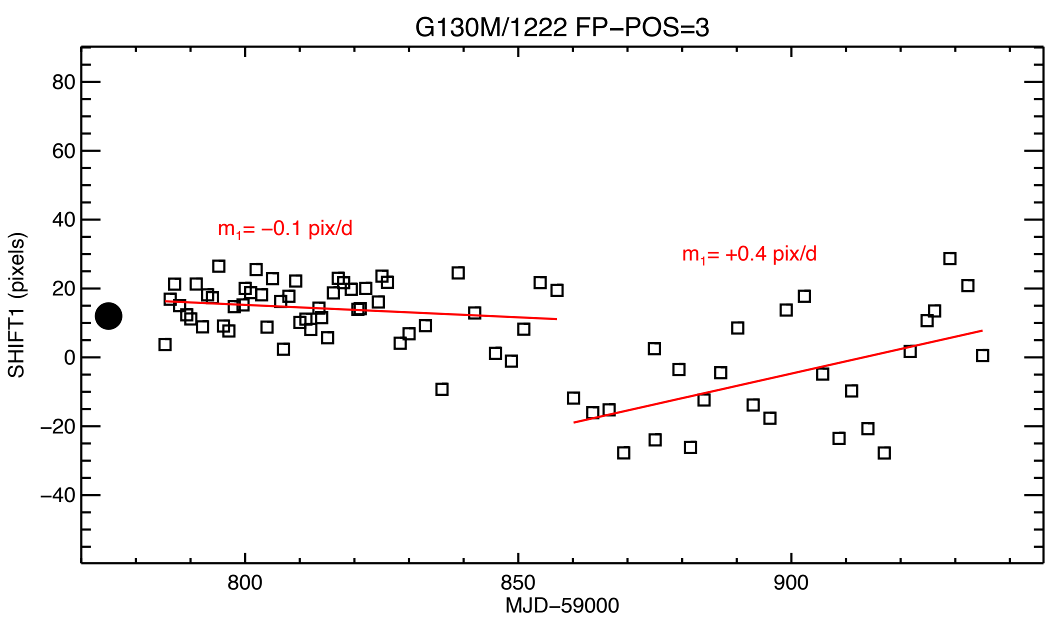

Figure 5. Same as Figure 3, but for G130M/1222 FP-POS=3

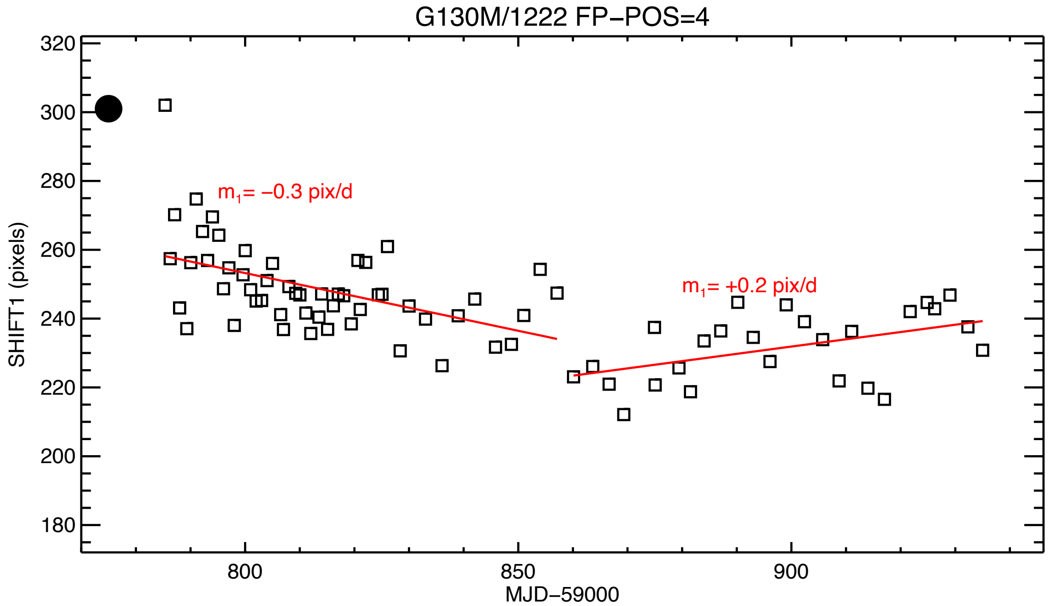

Figure 6. Same as for Figure 3 but for G130M/1222 FP-POS=4.

3.2 G130M/1291

The 1291 CENWAVE had slightly different behaviors. Figures 7 and 9 show that FP-POS=1 and FP-POS=3 both showed no significant trends or break points, while FP-POS=2 and FP-POS=4 (Figures 8 and 10) showed sharp declines until 24 August 2022 at which point the trends flattened. The COS team decided that monitoring would stop in mid-November 2022.

There is evidence that frequency of usage impacts the speed at which trends in spectral position may evolve. While FP-POS=2 and 4 both had steep negative trends shortly after the home position change in July 2022, the magnitude of the trends measured in Table 2 differ by a factor of 1.9 ±0.2. This could be due to the fact that there were science observations obtained during this time at FP-POS=4 while FP-POS=2 FUVB is no longer used in science observations due to the COS 2025 rules. However, further work would be needed to solidify this possible connection to frequency of usage and how quickly a trend evolves. We also note that the slopes seen in G130M/1291 are significantly steeper than those seen in G130M/1222. The 1222 CENWAVE was not frequently used for science over the monitoring period, while the 1291 CENWAVE had 63 science exposures at FP-POS=3 and 68 at FP-POS=4.

Despite some improvements, the change in home position has not completely resolved the non-repeatability for G130M/1291 noted in Hasselquist et al. (2023). As stated in Section 2.1, our program had a large motor move to FP-POS=3 and then a small motor move to FP-POS=4, followed by a large motor move to FP-POS=1 and a small motor move to FP-POS=2. Most science observations show that G130M/1291 FP-POS=4 spectrum placements after a small motor move are divergent from those motions occurring after a large motor move. While G130M/1222 was the home position, a small motor move to FP-POS=4 resulted in a median location as high as ~400 pixels compared to a location of ~230 pixels after a large motor move—the median of all moves is listed in Table 1. In our measurements, the small motor move to FP-POS=4 settled to an average position at pixel 346. If we compare to the median position of small motor moves during LP5 operations this is an improvement of 54 pixels. Currently, the average postion of all motor moves has nearly returned to the historical location seen when the HP was last at 1291.

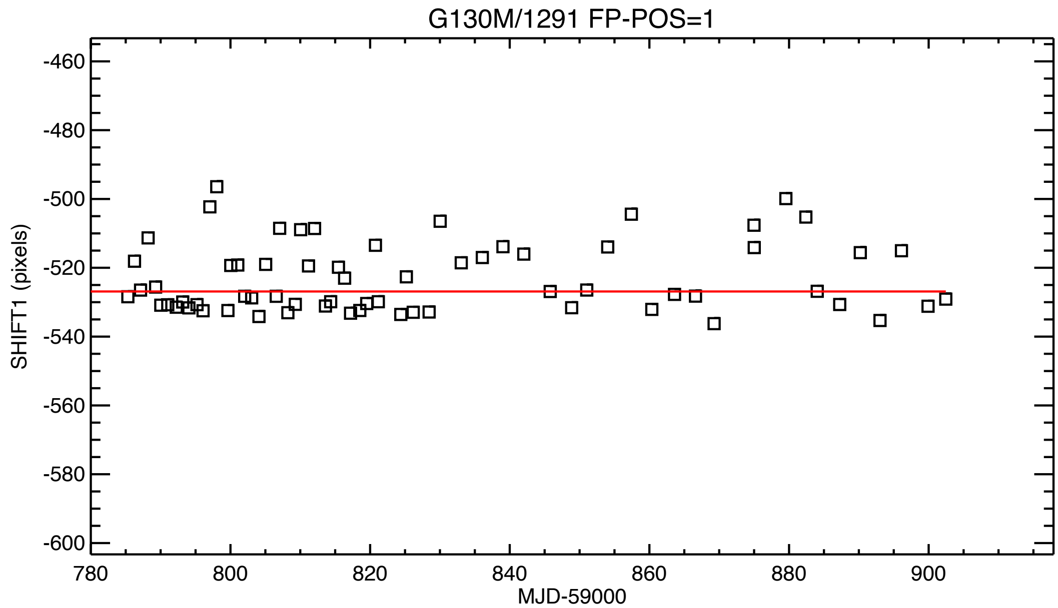

Figure 7. Same as for Figure 3 but for G130M/1291 FP-POS=1. No significant trend was seen, so instead of a linear fit we show the median position over the lifetime of the program. Due to COS 2025 rules we do not have a measure of the average placement just prior to CAL/17229.

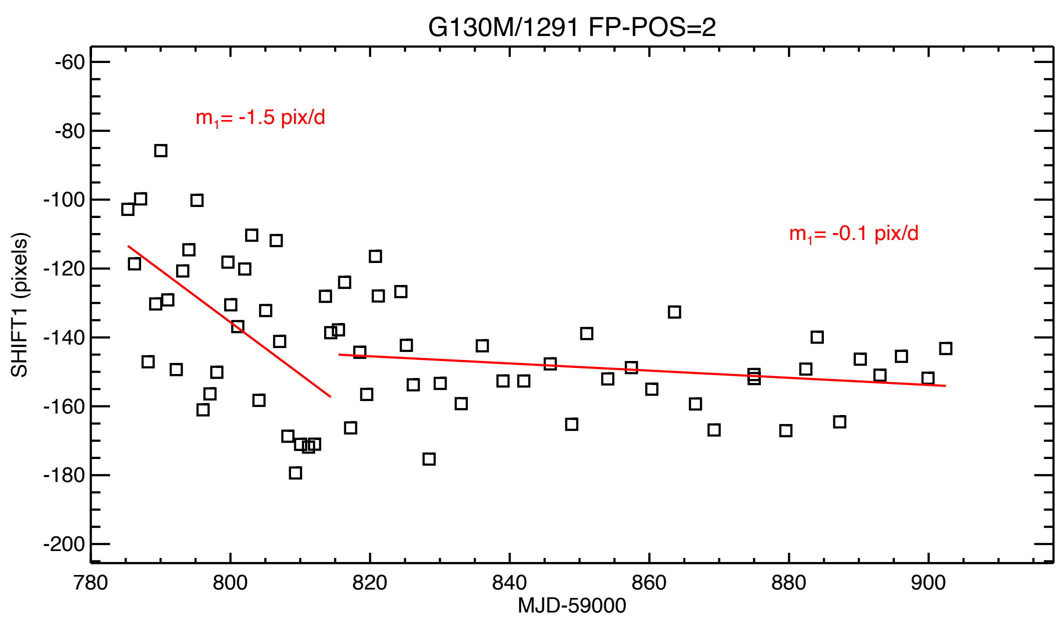

Figure 8. Same as for Figure 3 but for G130M/1291 FP-POS=2. For this grating we find a breakpoint in the linear trends at MJD 59815 (24 August 2022). Due to COS 2025 rules we do not have a measure of the average placement just prior to CAL/17229.

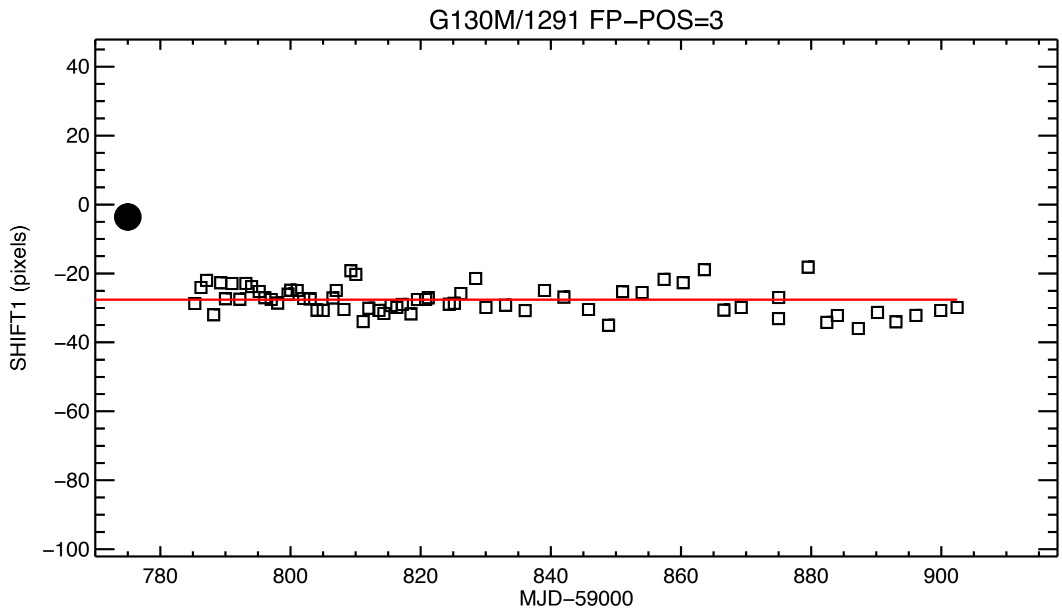

Figure 9. Same as for Figure 3 but for G130M/1291 FP-POS=3. As in Figure 8 no significant trends are measured and we overplot the median spectrum placement over the lifetime of the program.

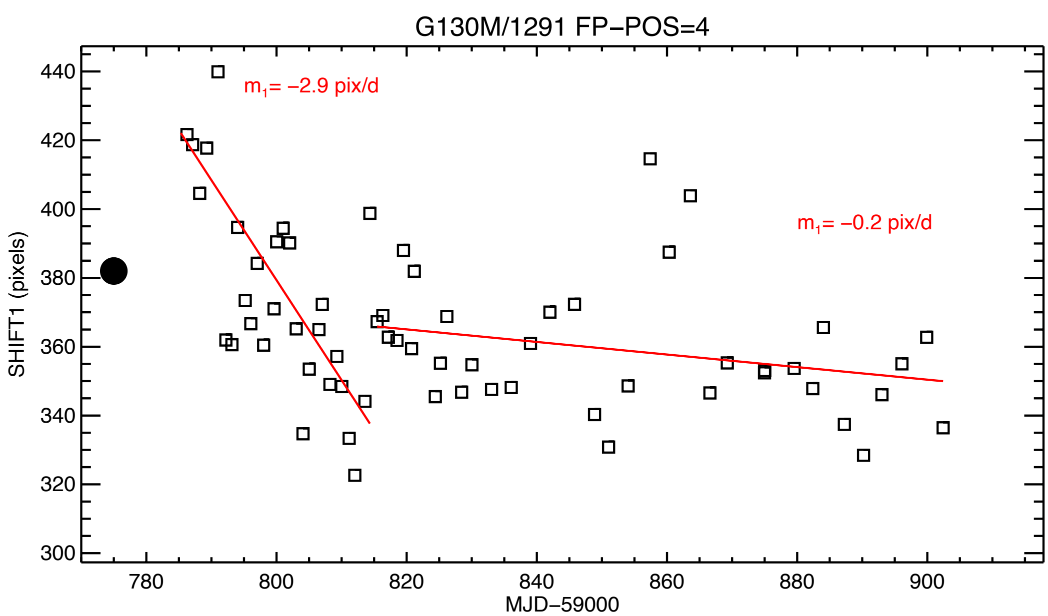

Figure 10. Same as for Figure 3 but for G130M/1291 FP-POS=4.

3.3 Updated behavior of OSM1 for G130M/1222 and G130M/1291

While the last monitoring of these modes for 17229 occurred in December 2022, science observations have routinely executed since that time and provide a coarser record of OSM1 behaviors. We report these updated values in the last column of Table 1. In general, most of the median positions for the FP-POS of G130M/1222 and G130M/1291 have returned to within 20 pixels of the median positions just before the start of LP5 operations when the HP was moved to 1222. The exception is FP-POS=1 of G130M/1222 which is currently at a location of -557 pixels, compared to the previous value of -503 pixels. The majority of this change occurred during our monitoring program, and confirming that any trends beyond Oc

4. Summary

The COS team implemented special calibration program 17229 to monitor the spectral placement behavior of the OSM1 mechanism after a change in STScI home position from G130M/1222 to G130M/1291. Even though the physical origin of the OSM1 repeatability trends and behaviors is not well known, it is clear that the change of home position back to G130M/1291 has reversed many of the trends seen with the previous home position, as evidenced by the measurements made with Program 17229 in Table 1 and in Figures 3-10. The reversals, and the apparent connection between the steepness of overall trends with mechanism usage, potentially point to unequal distribution of lubrication in the mechanism, which relies on friction to come to a repeatable stopping location.

OSM1 will likely continue to have an evolution in its behavior. Many smaller scale trends are noticeable across different CENWAVEs and FP-POS locations, suggesting that continued monitoring of the SHIFT1 derived from science observations is needed. Additionally, the 17229 measurements clearly show that we have not completely reversed the non-repeatability between small and large motor moves for G130M/1291 FP-POS=4, which launched our investigation into OSM1's behavior in the first place. That said, the magnitude of the non-repeatability is still largely within our requirements and does not have a significant impact on science exposures. The COS team has required all moves to FP-POS=4 to be large moves to help mitigate this issue.

Finally, the successful implementation of all-internal WAVECALs that efficiently measure spectrum location has utility for other calibration activities. For example, some modified form of this program can be utilized to monitor OSM1 small scale drifts that occur within the first several hundred seconds of an exposure after a large motor move.

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