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Characterizing the COS OSM1 Drift in the Dispersion Direction

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ABSTRACT

The Optics Select Mechanism 1 (OSM 1) is used to switch between the three FUV gratings (G130M, G160M, and G140L) or NUV Collimating Mirror 1 (NCM1) (Debes et al. 2014). The movement of OSM1 is not perfectly controlled and can continue through exposures which in turn moves the spectra across the detector in an effect referred to as OSM drift. In some cases, this OSM drift can be larger than one resolution element or ~6 pixels for COS (Fox et al. 2015). OSM drift over whole exposures is currently corrected in the instrument calibration pipeline, CalCOS, by applying measurements of the OSM drift obtained during TAGFLASH exposures along with linearly interpolated values between those measurements. In this ISR, we analyze the OSM drift on finer time-scales than the TAGFLASH intervals to determine if the current CalCOS correction is sufficient.

Contents

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1. Introduction

TAGFLASH is a setting for COS TIME-TAG exposures in which a PtNe lamp is used to take wavelength calibration spectra through the WCA (which then lands on a different part of the detector) concurrently with the science target spectra (through the PSA) at intervals during the exposure (Debes et al. 2014). This is the only way to correct for OSM drift.

After an initial flash at the beginning of the exposure that occurs for each COS exposure, the number of consecutive flashes and the flash interval are determined by the length of the exposure and bay the elapsed time since the last optical element to optical element OSM move. Smaller adjustments of the OSM such as changes in CENWAVE or FP-POS have a negligable effect (Keyes 2011). The number of flashes and the flash interval follow rules stated in COS ISR 2011-04, and a consequence of these rules is that as exposure time increases, the frequency of flashes decreases. In this way, the exponential shape of the OSM drift is approximated by a linear interpolation between the drift determined from TAGFLASH measurements (referred to hereafter as lampshifts). In Section 2 we describe the data we use for testing and their selection criteria. We test the OSM drift CalCOS correction as described in Section 3 by measuring the shift of spectra at different points in time and the calculating the residuals between them and the interpolated and measured lampshifts, while in Section 4 and 5 we discuss the results and conclusions respectively of these comparisons.

2. Data

We use TIME-TAG data from HST programs 13650 and 12022.

Table 1a. Program 13650; Target V-EPS-ERI; Observation Date: 2015 (Cycle 22)

Dataset	Cenwave	Grating	Exposure Time
lck102010	1577	G160M	1000.192
lck102020	1611	G160M	1045.184
lck103010	1291	G130M	4987.360
lck103020	1318	G130M	8136.512

Table 1b. Program 12022; Target MRK-509; Observation Date: 2009 (Cycle 17)

Dataset	Cenwave	Grating	Exposure Time
lbdh01030	1577	G160M	5484.384
lbdh01040	1589	G160M	2742.208
lbdh01010	1309	G130M	1993.216
lbdh01020	1327	G130M	2742.208

We choose these data for their high signal-to-noise (SN) of ~10 or greater, long exposure times (greater than 1000s), and deep, sharp spectral features that are at least twice as deep as they are wide and located near the center of the detector. These criteria are necessary to maintain high SN as we look at samller and smaller time-scales (using the TIME-TAG features as described in Section 3) to achieve accurate measurements on those time scales

We use the intermediate data from *corrtag* files instead of the fully calibrated data from *x1d* files for this anaysis. From the associated *corrtag* files, we use XDOPP and YCORR columns for our measurements because XDOPP data are corrected for geometric, thermal, and doppler distortions, but they are not drift corrected (Fox et al. 2015). From the associated *lampflash* files we use the SHIFT_DISP column which contains the CalCOS calculated shifts from the TAGFLASH measurements to compare to our measurements.

3. Analysis

To measure the OSM drift on finer time-scales than those determinded from the TAGFLASH measurements, we monitor the position of either an individual line or complex of lines (where available) at multiple time-slices (Δt_n, where n= 1, 2, 3… N; N is the total number of slices). N and therefore the number of shift measurements depends greatly on the SN of the data being studied. We assume that for each time-sliced window the noise is dominated by Poisson noise since we are working with partially calibrated counts, and therefore, $SN \approx \sqrt{M}$, where M is the average number of counts in the window being observed. A SN of ~6 in the region of interest is generally the limit at which four or more measurements can be obtained with this method accurately.

First, we create 2D images from the XDOPP and YCORR data of the *corrtag* files. We then collapse these images in the cross-dispersion direction within the appropriate BOXCAR extraction region (specific to each cenwave; found in the XTRACTAB) to produce a 1D spectra in units of counts vs. XDOPP position in pixels. We use this integrated exposure to select a line or complex of lines towards the center of the detector to avoid edge effects (we define a conservative range of 4,000 to 12,000 pixels for most observations, but lines can be selected as low as the 2,000 pixel range and high as 14,000 pixels with no significant impact to the measurements). We then slice the targeted region in time according to the XDOPP/YCORR event's corresponding time value (from the TIME column in the *corrtag* files) and Δt, which is determined by: $\Delta t= T/N$, where T is the exposure time and N is the number of slices, and $\Delta t_n= [t_{n-1}, t_n]$. For this analysis we use N= 5, 10, 15, and 20.

From these time-sliced spectra, we choose the first time slice (Δt_1) as the reference (S_o) starting from the beginning of the exposure (t= 0). The counts for S_o and each consecutive time-sliced spectra, S_n, are then subsampled by a factor of 2 with linear interpolation to increase the number of data points available for cross-correlation. S_o is then cross-correlated with S_n for each slice. We build the cross-correlation array by taking the inverse Fourier Transform of the element-wise product of the Fourier Transform of S_o with the complex-conjugate of the Fourier Transform of S_n:

$$(1) \qquad C= F^{-1}\{ F\{ S_o\} \circ (F\{ S_n\})^* \}$$

We recover the shift by selecting the location (or lag) of the maximum argument in the correlation array, C, which is then scaled back to the original, subsampled coordinates of S_o and S_n. Alternatively, the shift could be calculated more accurately by fitting the correlation array near the peak and calculating the maximum of the fit. However, using the maximum of the correlation array produces shift measurements that are accurate enough for our purposes. The zero points of the measured shifts are adjusted to the match the lampflash shift zero points, and the direction of the measured shift is reversed by multiplying by -1 to match the directions of the measurements.

4. Results

We compare the CalCOS TAGFLASH determined shifts to our measured shifts by plotting them together with the residuals in Figure 1. The differences between the lampshifts and our measured shifts are generally less than 2 pixels, and more often less than 1 pixel (within errors) for 23 individual exposures between program 12022 and 13650. In comparing data from 2009 to data from 2015, we find no noticeable change in behavior of the OSM drift. Figure 1 a) and b) includes examples of the shifts determined from our analysis compared to the CalCOS determined shifts and the difference between the two.

Figure 1a

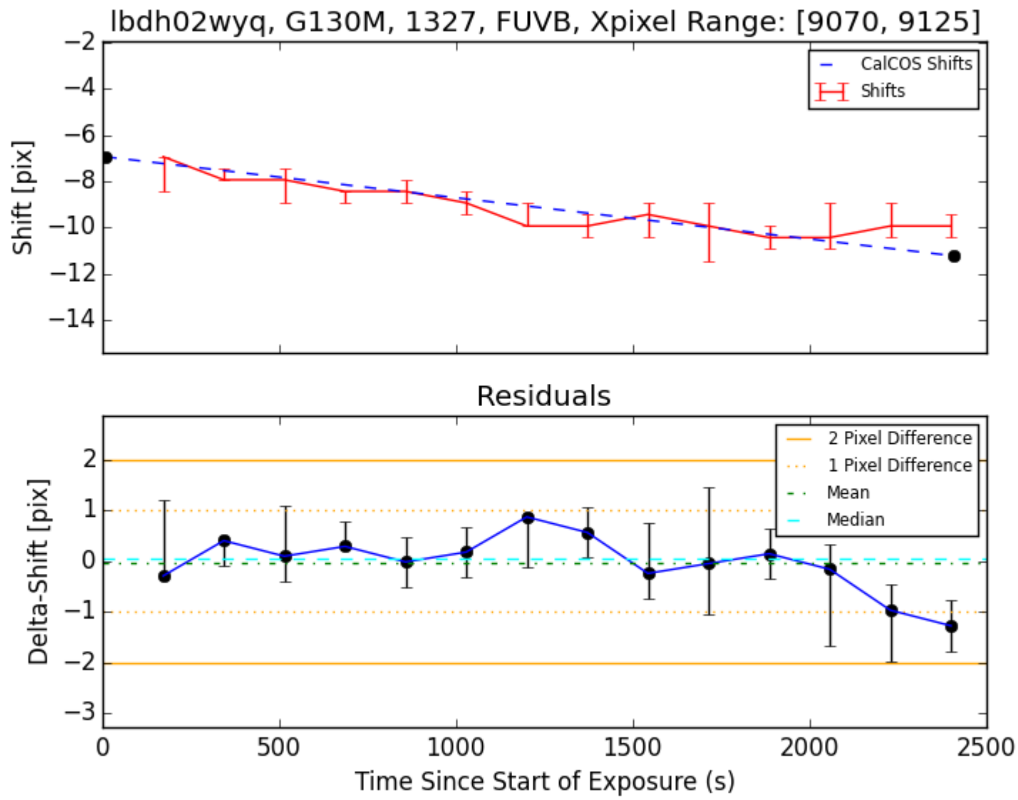

Figure 1b

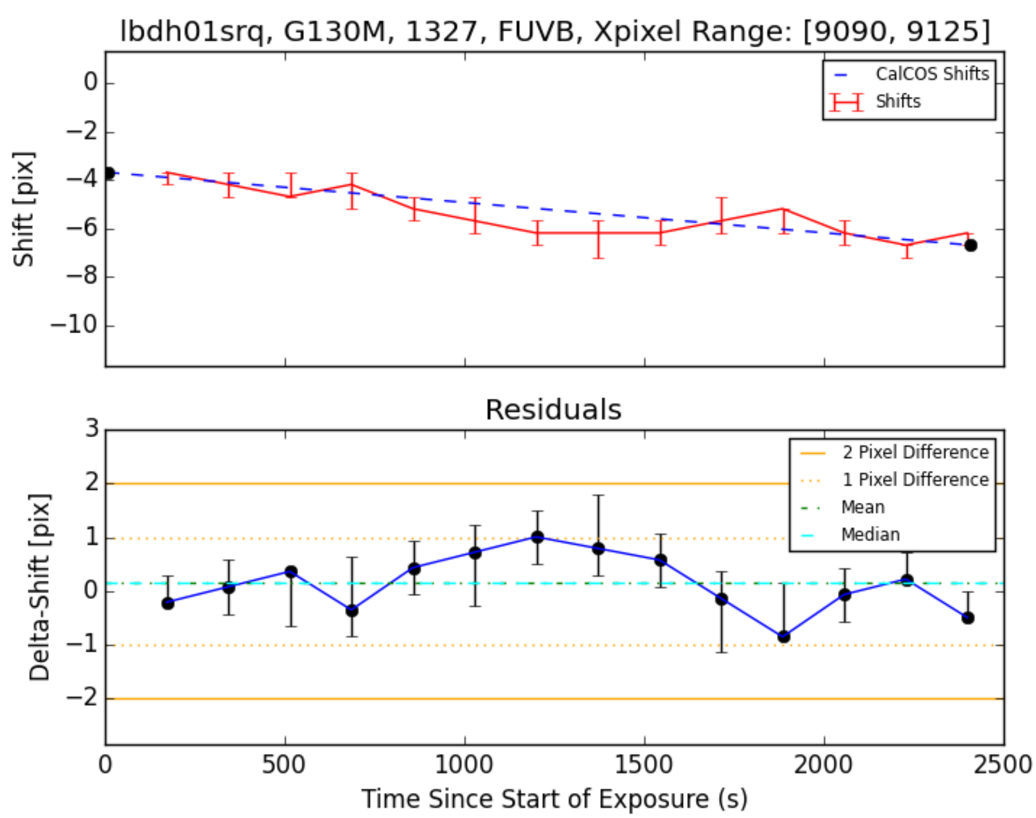

Figure 1c

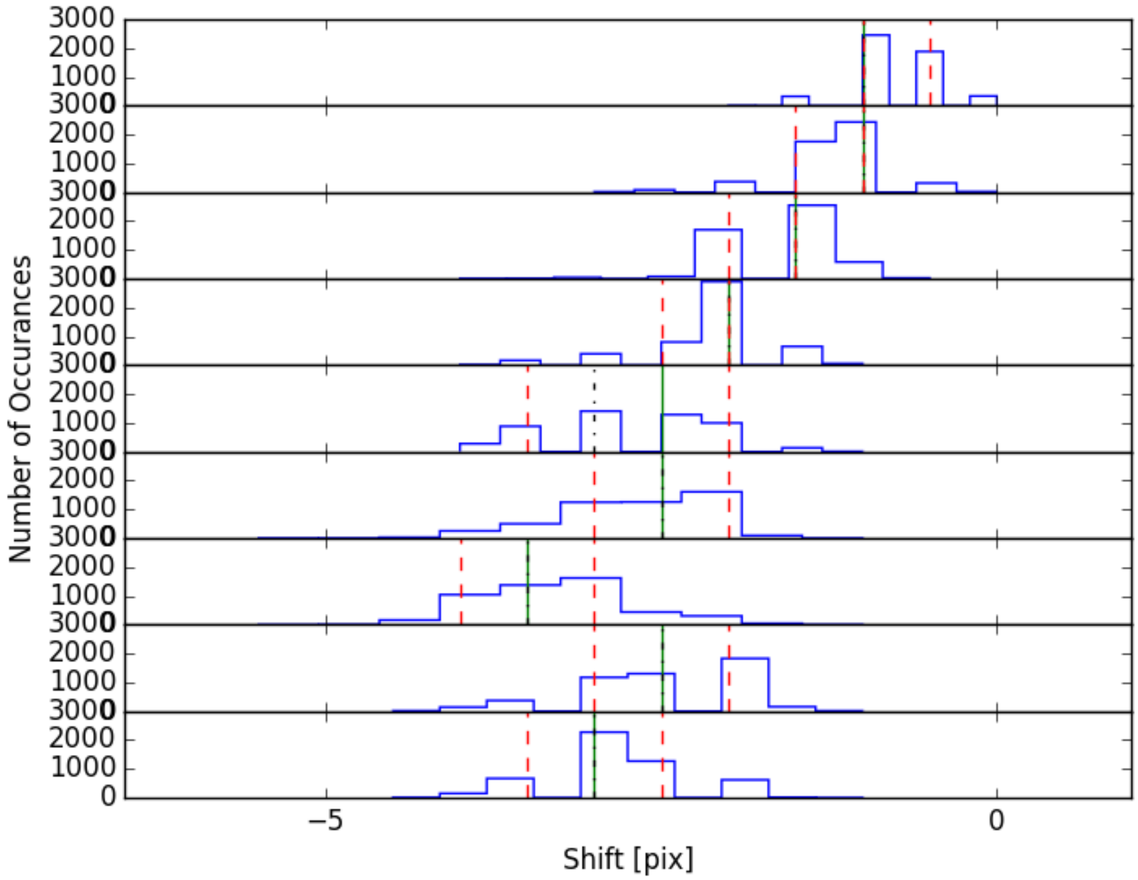

Figure 1. a) and b): CalCOS shifts plotted as black points with a blue dashed line and measured shifts are plotted in red with errorbars in the top plot. Residuals are plotted with error bars in the bottom plot. In c): distributions are plotted in blue with the 16th and 84th percentiles (red, dashed), median (black, dot-dashed), and original measurement (green) marked.

Figure 1c shows an example of the stacked distributions for each shift measurement with time proceeding in the downward direction. We see from the examples in Figure 1 that the drift remains non-linear which is easiest to see in Figure 1c.

To estimate the error of the cross-correlation calculation, we use a numerical approach. For both S_o and S_n, we randomize the counts according to a Poisson distribution with a mean equal to the detected number of counts. We generate 5,000 different realizations of S_o and S_n in this way, and for each realization a shift is measured using the same method as with the original estimate to create a distribution of shift values. As a 1σ confidence level, we report the 16th and 84th percentile of the cumulative distribution with respect to the original shift measurement as an estimation of the errors (Figure 2).

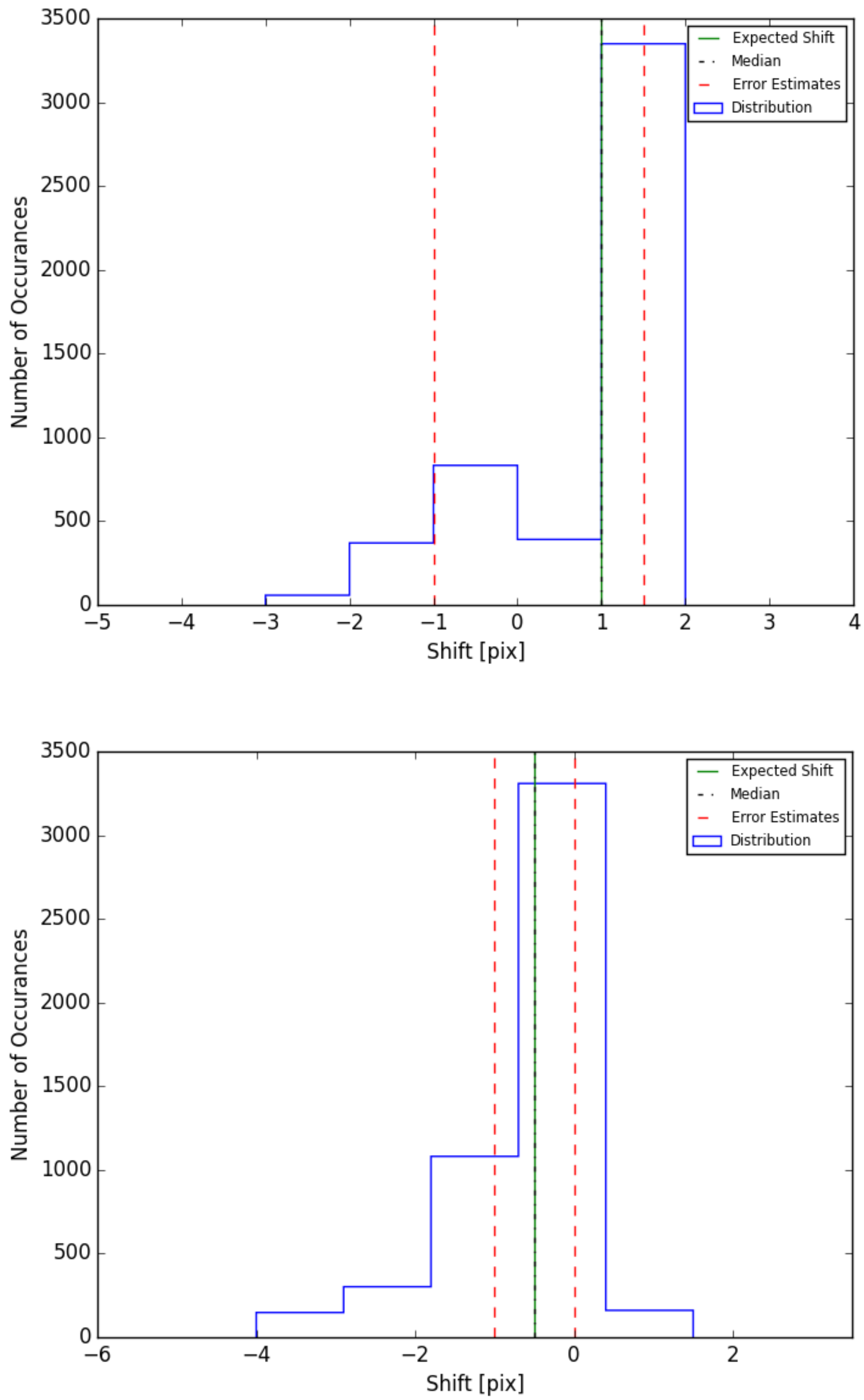

Figure 2. Examples of distributions (blue) of shift values with 16th and 84th percentiles (red dashed lines), original estimate (green), and median (black dash-dotted line) marked. The top pannel is an example of when the distribution of shifts is asymmetric—caused by noise that affects the accuracy of the cross correlation—while the bottom pannel is an example of a symmetric shift distribution.

The distributions are generally asymmetric and heavily influced by the noise of the selected spectral feature.

We also perform a visual inspection of the alignment after correcting for the shift as shown in Figure 3.

Figure 3 a

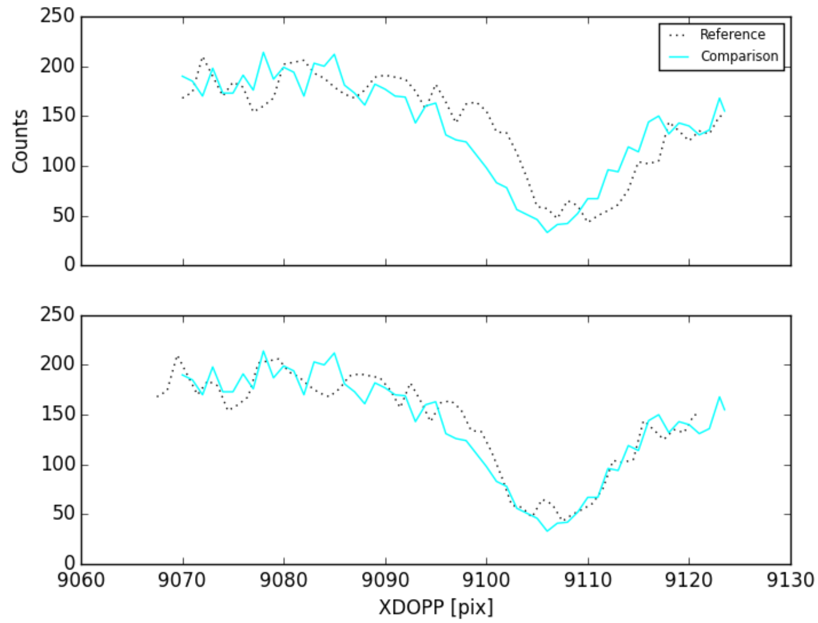

Figure 3 b

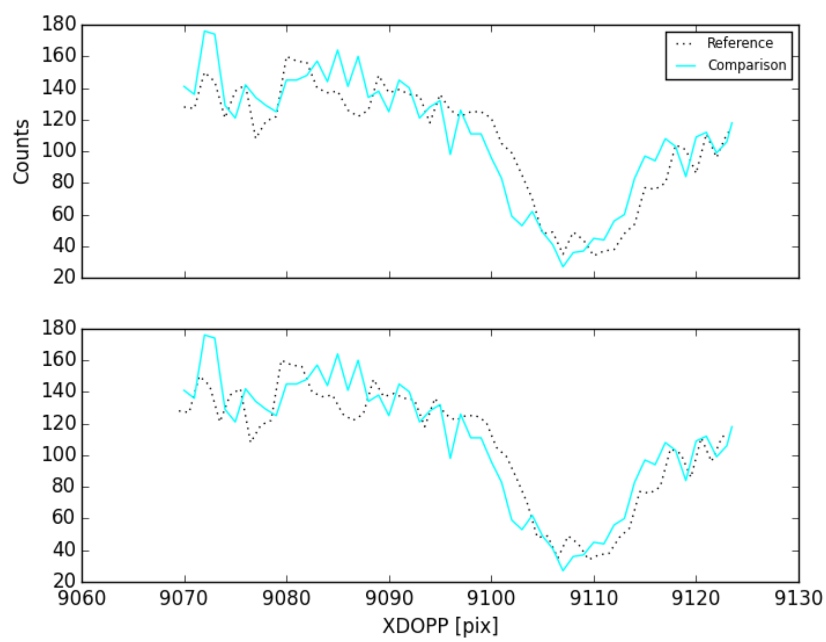

Figure 3. Comparison of S_n (comparison; cyan line) to S_o (reference; black dotted line) before and after correcting S_n relative to S_o with the measured shift of the selected region. Shifted spectra generally align well as in **a)**, but these plots can also

show the dependance of the cross-correlation on small fluctuations in shape of the spectral feature which can result in small miss-alignments as in **b)**.

Figure 3 is used to qualitatively check the shift measurements. Generally the alignment is good, but for some measurements such as those in Figure 3b, the small changes in flux from pixel to pixel can result in misalignments which then propogate into the error estimation process and result in asymmetric distributions.

5. Conclusions

For the data used in our analysis we find that the CalCOS pipeline correction adequately estimates the OSM drift to within 2 pixels. The differences between our measured shifts and CalCOS TAGFLASH shifts are on average 1 pixel (more extreme cases being 2 pixels) with errors of 0.5-1 pixel depending on the particular exposure.

6. Recommendations and Further Work

Our analysis indicates that the current correction does not require modifictation as our findings (within errors) do not differ significantly from the error for the OSM drift correction of ~ 0.5 pixels that is stated in the COS Instrument Handbook (Debes et al. 2014). Further work on improving the accuracy of our measurements could be done to better estimate the success of the current correction. For example, a more robust estimation of error may include bootstrapping the counts to counter the effects of the small flux variations on the cross-correlation, but this is currently not compatible with our method of computing the cross-correlation. The effect of subsampling is also not taken into account using this method and could affect our error estimations by a few percent.

Also, we recommend that this study be done on a broader range of data. This would allow for broad statistical studies of the OSM drift's behaviour over time as well as refine our current estimates. This analysis focused on a few data sets partially due to the selection criteria. Finding datasets that meet these criteria is difficult and time-consuming, but with work being done on an internal queriable database for COS by the COS team, this will soon be much faster and easier. The inclusion of NUV data in the analysis would also be beneficial in studying the combined drift of OSM1 and OSM2.

References

Fox, A., et al. 2015, "COS Data Handbook", Version 3.0, (Baltimore: STScI)

Debes, J., et al. 2015, Cosmic Origins Spectrograph Instrument Handbook, Version 7.0 (Batltimore: STScI)

Keyes, C., 2011, COS ISR 2011-04, "Details of COS TAGFLASH Execution"