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Second COS FUV Lifetime Position: Verification of FUV Bright Object Aperture (BOA) Operations (FCAL4)

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ABSTRACT

As part of the calibration of the second lifetime position on the Cosmic Origins Spectrograph (COS) far-ultraviolet (FUV) detectors, observations of the external target, G191-B2B, were obtained with the G130M, G160M, and G140L gratings in combination with the Bright Object Aperture. The observations were designed to verify the performance of these spectroscopic modes by reproducing similar observations taken during the SM4 Servicing Mission Observatory Verification (SMOV) of COS. These observations allowed for a detailed determination of the spatial location and profile of the spectra from the three gratings, as well as a determination of the spectral resolution of the G130M grating prior to and after the lifetime move. In general, the negligible differences which exist between the two lifetime positions can be attributed to slight differences in the optical path. In particular, the spectral resolution appears to be slightly improved. The stability of the absolute and relative flux calibration was investigated for G130M as well using STIS echelle data of G191-B2B. We determine that the COS absolute flux calibration with the BOA is accurate to ∼10%, and flux calibrated data are reproducible at the 1-2% level since SMOV.

Contents

1. Introduction

The move to the new COS-FUV lifetime position consisted of moving the aperture by +3.5” in the cross-dispersion direction along with a -0.05” move in the dispersion direction. The lifetime move required verification of several observational modes, one of which is spectral observations of an external target with the BOA aperture. The BOA aperture is a 2.5″ diameter neutral density-2 (ND2) filter with the same size as the Point Source Aperture (PSA) and a transmission of roughly 0.6% relative to the PSA. Due to the MgF composition of the BOA, below about 1190 Å, the throughput of the window decreases rapidly. The filter wedge of the BOA degrades spatial resolution relative to the PSA due to additional coma in the resulting image. This degradation also translates to a degradation of spectral resolution by roughly a factor of two.

Characterization of the BOA spectroscopic performance at the first lifetime position is documented in ISR 2010-09(v1). Here we reproduce many of the same BOA measurements and compare our observations of the external target G191-B2B at the new lifetime position to data of the same target obtained during SMOV.

2. Observations

2.1 Data Obtained at the New Lifetime Position

G191-B2B is a hot, metal-line white dwarf that is an HST flux standard and is bright enough to be observed with the BOA efficiently. The second lifetime calibration program 12807 (FCAL4) was designed to observe the three modes of COS within a single external orbit. This was achieved by observing all three gratings at a single central wavelength and FP-POS (G140L/1280, G130M/1291, and G160M/1623, FP-POS = 3), with the exception of G130M which was observed at all four FP-POS locations.

A single WAVECAL was obtained for the FP-POS=4 position in G130M/1291, followed by two non-contemporaneous WAVECALS for the G160M/1623 and G140L/1280 modes during occultation of HST. Consequently, the wavelength solution for the remaining FP-POS observations of the G130M/1291 mode, the G160M/1623 mode, and the G140L/1280 mode are inaccurate due to unknown zeropoint shifts. Since the G140L/1280 and G160M/1623 modes have lower signal-to-noise, they will primarily be used to determine the spectrum location, cross-dispersion profile, and relative continuum flux compared to previous BOA observations of G191-B2B. For G140L/1280, Segment A had little usable data, and so measurements were done on Segment B only. Spectral

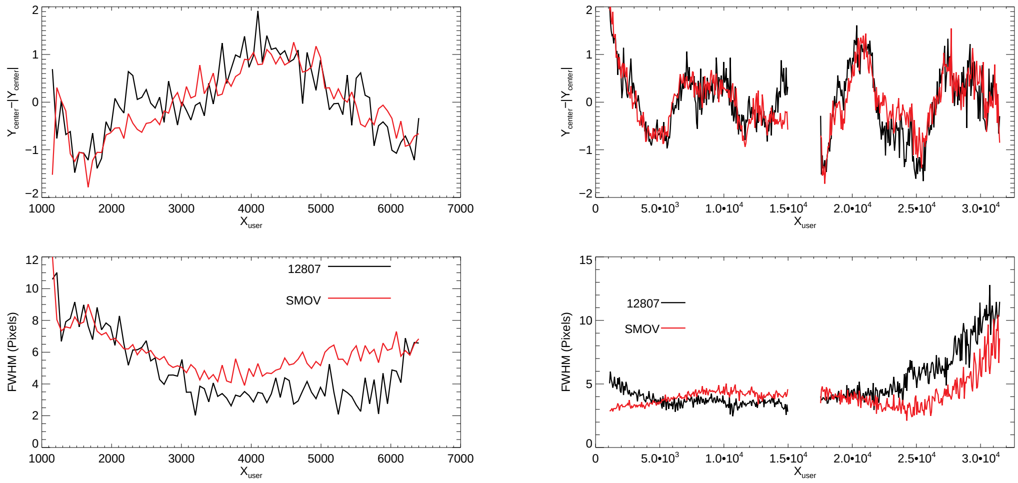

Figure 1. (left) Spectrum location and spatial profile FWHM for the G140L grating at FP-POS=3. (right) Spectrum location and spatial profile FWHM for the G160M grating at FP-POS=3.

lines present within the spectrum of G191-B2B were used to determine the zero-point offsets of the G130M/1291 FP-POS that did not have WAVECALS, thus allowing the spectral resolution at the second lifetime position to be investigated for this mode. Table 1 lists the datasets obtained for program 12807.

2.2 Data Obtained during SMOV

G191-B2B was originally observed during the SMOV program 11489, "COS FUV External Spectroscopic Performance - Part 1", with the goal of measuring the resolution of the BOA modes. The gratings and cenwaves were identical with the exception of the G140L observations, which used the obsolete 1230 Å cenwave. For the G130M/1291 and G160M/1623 modes, spectra were obtained at all FP-POS locations while the G140L data was taken at FP-POS 1,2, and 3. Table 1 lists the datasets obtained for program 11489.

3. Analysis

The primary goal of the G191-B2B observations was the spot-checking of the spectrum's position, its spatial profile, and the spectral resolution. Additionally, overall flux levels relative to the past observations provide an independent check of the measured throughput of the BOA (ISR 2010-09) and the long term validity of the time dependent sensitivity (TDS) corrections.

3.1 Spectrum Location and Spatial Profiles

The location of the spectrum on the detector and its deviations from the average position would demonstrate any additional geometric distortions that may be present at the new lifetime position. Measuring the spectral location is also important for verifying the target acquisition parameters that are used to search for the spectrum and is important for verifying that calcos can reliably extract spectral information from data taken with the BOA aperture. Measuring spatial profiles determines the spatial resolution of the spectra, usually defined as the full width at half-maximum (FWHM) of the cross-dispersion profile.

To determine the spectral location, data from each segment on _flt corrected files were binned into arrays of 256×1024 pixels, corresponding to rebinning the spectra along the dispersion direction into ∼0.6 Å 0.7 Å, and 4.8 Å bins for the G130M, G160M, and G140L gratings respectively. The cross-dispersion profile from each column was fit with a Gaussian and the center and FWHM of the fitted profile was recorded, similar to the procedure documented in ISR 2010-09. Comparison of the new 12807 data with the previous SMOV program 11489 shows minor differences in the deviations of the spectral location between the original and new lifetime position.

Figures 1 and 2 show the resulting deviations from the median spectral location and the FWHM for the G140L, G130M, and G160M modes respectively. As mentioned in Section 2.1, Segment B only is presented for G140L/1280. In general, only small changes are apparent both in the deviations from median spectral location and in the cross-dispersion FWHM. In particular, the FWHM of the new data appears improved compared to the SMOV observations. It is important to reiterate that the cross dispersion profile is not strictly Gaussian as assumed in the previous analysis. Figure 3 demonstrates this fact for each of the gratings. For the G130M grating in particular, the BOA cross dispersion profile is nearly double peaked. However, the Gaussian fits in general still work to provide a reasonable approximation of both the FWHM and the spectrum center.

3.2 Spectral Resolution of the G130M Grating at both lifetime positions

The resolution of the BOA aperture has not been fully characterized, and so in this section an estimate on whether resolution has degraded, improved, or remained constant from the observations taken during SMOV has been performed.

In order to estimate the resolution, a comparison was made between a high resolution STIS echelle spectrum convolved with Gaussian profiles of varying FWHM to both the SMOV G130M data and the G130M data taken at the new lifetime position. A χ^2 metric was calculated for each of 12 separate absorption features. In order to perform the comparison, we took archival STIS echelle spectroscopy of G191-B2B obtained from StarCat (Ayres et al., 2010), a high-level science product that includes STIS UV spectra of many different stars. The combined spectra included observations of G191-B2B from several central wavelengths of the E140H and E230H gratings that span roughly three years starting in late 1998, with a S/N that is ≈40-50/resel. The final spectrum extends from 1150 Å-3160 Å, providing a spectral template of the G130M data. The StarCat STIS spectrum was resampled and convolved with Gaussian model LSFs. The LSFs ranged in FWHM from 0.09-0.23 Å, spanning possible resolutions of between

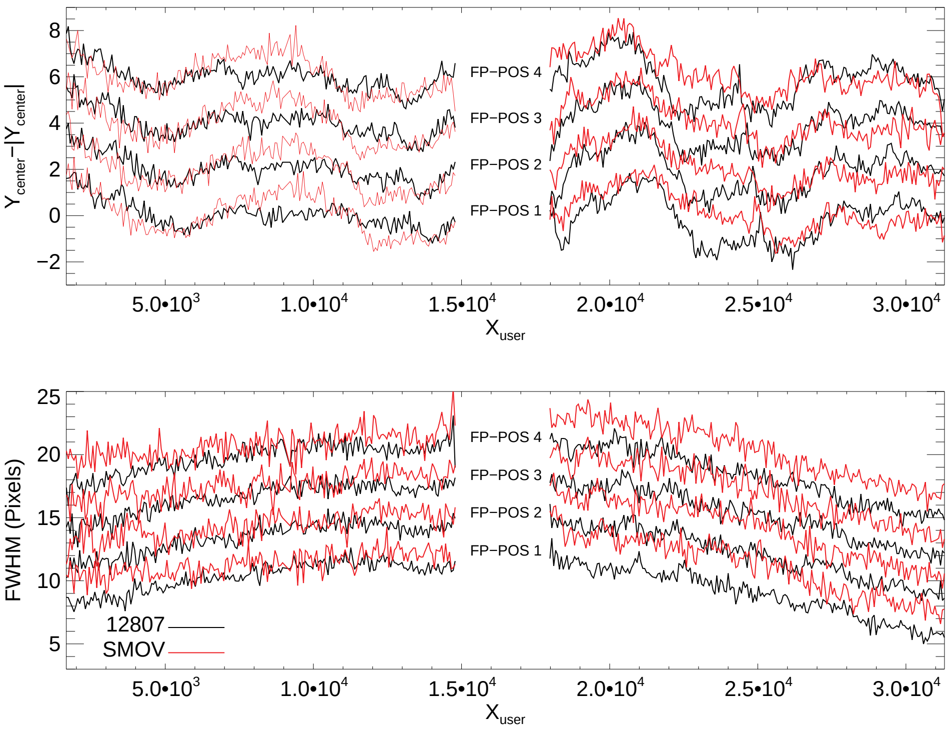

Figure 2. Spectrum location and spatial profile FWHM as a function of FP-POS for the G130M grating.

5000-16000. Inspection of some lines, such as those shown in Figure 4, suggests that the resolution has slightly improved with the BOA since the move to the new lifetime position.

The resulting median best fit to the effective FWHM of the spectral lines is 0.14 Å, with a possible degradation of the resolution at the longest wavelengths. This is compared to the SMOV data, which has a median best fit of 0.17 Å. However, given the relatively small number of lines fit and the possible non-Gaussian nature of the G130M+BOA LSF, it is only possible to give an estimated resolution for the BOA of between 8400 at 1190 Å and 10000 at 1400 Å, compared to resolutions of 7000-8300 over the same wavelength range at the old lifetime position. A more rigorous analysis may need to be performed if the BOA becomes more heavily used by the scientific community.

The BOA is a wedge of MgF glass, which creates significant coma structure to the focal plane point spread function, thus degrading spectral resolution. The improvement in the spectral resolution is thus probably due to light from the source traveling through a thinner part of the BOA aperture.

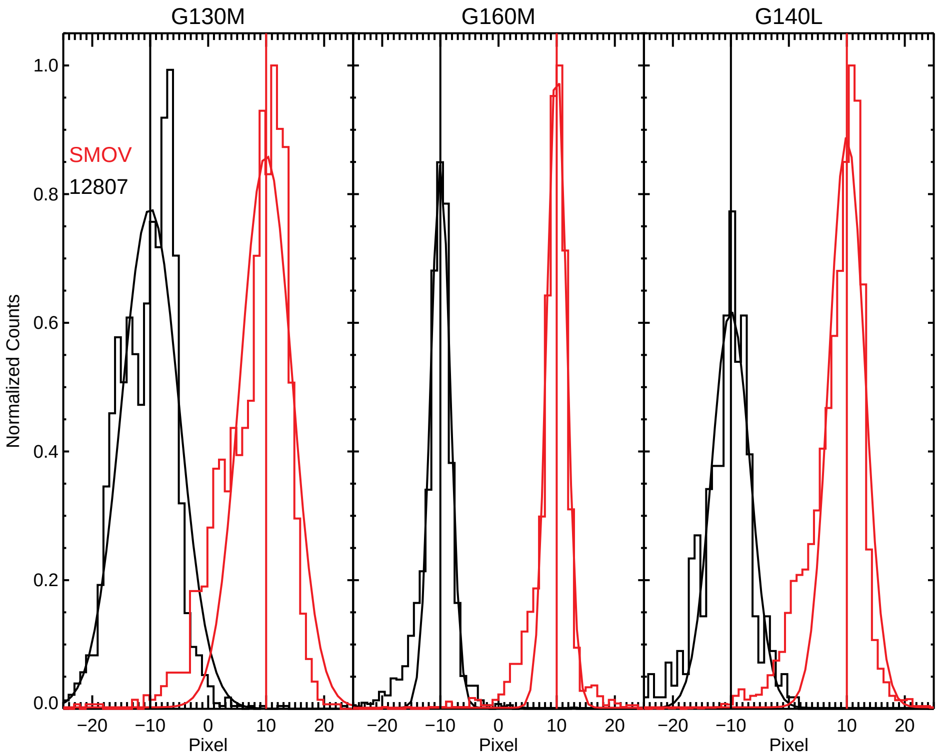

Figure 3. Cross dispersion profiles for the different gratings with the BOA. Each cross-dispersion profile is offset from their relative centers by +10 pixels (SMOV) or -10 pixels (12807) to highlight the differing structures. Overplotted for each profile is a Gaussian fit to the distribution.

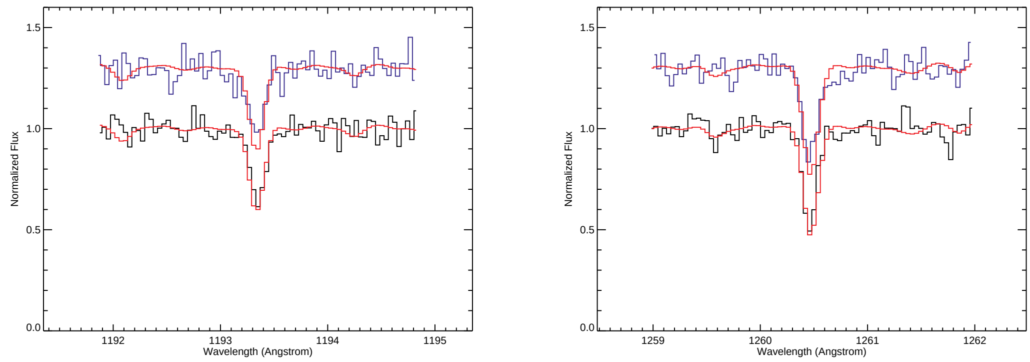

Figure 4. A marginally improved resolution for COS+BOA. Both figures show absorption lines detected in the photosphere of G191-B2B during SMOV (blue curve) and 12807 (black curve). The red curve overplotted is a STIS E140M spectrum of G191-B2B convolved with a Gaussian LSF using a best-fitting FWHM of 0.14 Å. This represents a 20% improvement relative to SMOV observations.

3.3 Flux Calibration at both Lifetime Positions

At the new lifetime position, there could be the concern that the absolute flux calibration has changed significantly, or the time dependent sensitivity might be dependent on the choice of high voltage for the FUV detector. The higher S/N data from the G130M grating were used to test for these potential issues.

The initial reduction of the datasets revealed that the throughput files for G130M did not incorporate the on-orbit throughput as measured in ISR 2010-02, but rather the pre-launch predicted throughputs. Once the on-orbit flux calibration was applied, the G130M spectra were binned and compared to the STIS calspec spectrum to investigate the absolute flux calibration. Figure 5 shows a comparison between the pre-launch flux calibration, the on-orbit flux calibration, and the STScI calibration spectrum of G191-B2B. In general, the match is reasonable, with significant variations between the calspec model and the on-orbit calibration occurring at wavelengths $<$1200 Å, where S/N was probably lowest when the BOA throughput was investigated during SMOV. The absolute flux calibration of STIS for this wavelength range is also somewhat uncertain. Over the G130M grating, the on-orbit absolute flux calibration of G191-B2B matches that of the STIS data on average by 1% over the 1200 Å-1430 Å wavelength region, with a per-pixel variation of $\sim$7%. Since the other gratings were at lower S/N, we did not investigate their absolute flux calibrations, but we expect similar agreement to within the uncertainties of the lower quality spectra. The COS/STIS Team plans to implement an improved calibration of the BOA throughputs as part of a larger flux calibration program of COS with new low order flat fields applied.

Another test is to compare the SMOV and 12807 data to each other, which determines the repeatability of the flux with respect to flux calibration at the new lifetime position and due to the time dependent sensitivity of the COS FUV gratings. Figure 6 shows the resulting ratio of the 12807 data to the SMOV data for G130M in 5 Å bins. A sigma-clipped mean of the unbinned (binned) ratios gives 0.98±0.001 (0.99±0.002) for Segment B and 1.00±0.001 (1.01±0.002) for Segment A in the G130M grating. There is minor structure at the 1-2% level, consistent with the expected uncertainties in the TDS slopes for the detectors as a function of wavelength.

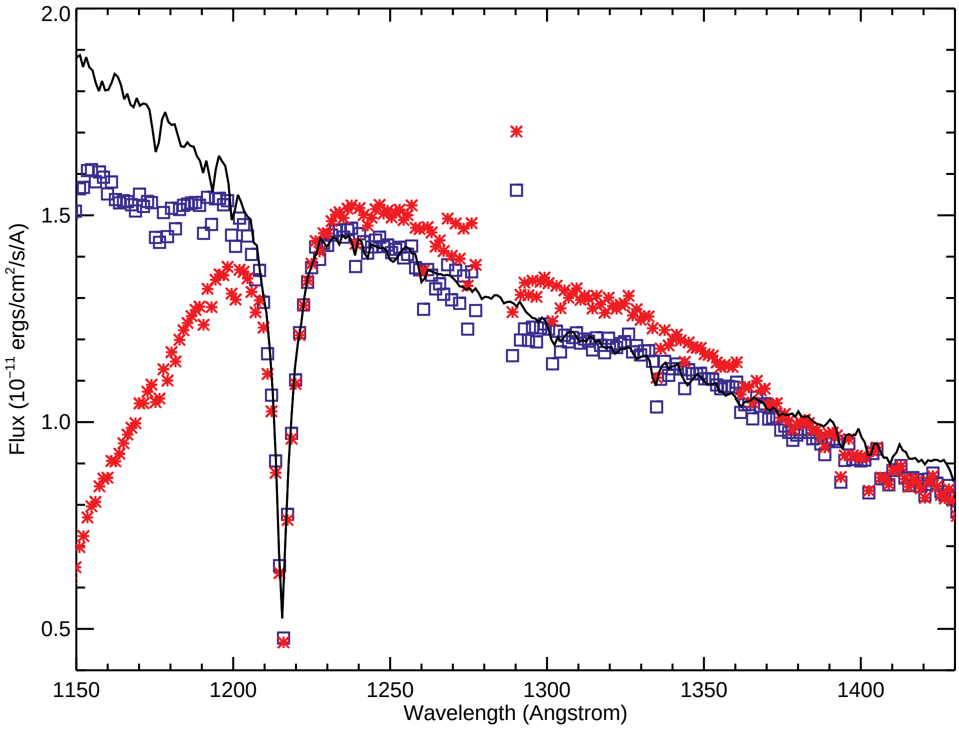

Figure 5. Comparison of G191-B2B's COS flux calibration to its calspec spectrum. The black curve is the calspec spectrum. The red curve is the COS G130M/1291 spectrum binned to the sampling of the calspec spectrum using the pre-launch predicted throughputs as currently implemented in calcos. The blue curve is with the on-orbit throughputs of the BOA calibrated with a different target as presented in ISR 2010-02.

4. Conclusions

As part of the move of COS to its second lifetime position on the FUV detector, we have investigated the impact this move might have on spectroscopic FUV modes used in concert with the BOA. We have verified that performance of the BOA has remained the same or slightly improved, especially for shorter wavelength spectroscopic resolution. Variations of the flux calibration, spatial profile, and spectrum center all are comparable in magnitude to the previous lifetime position.

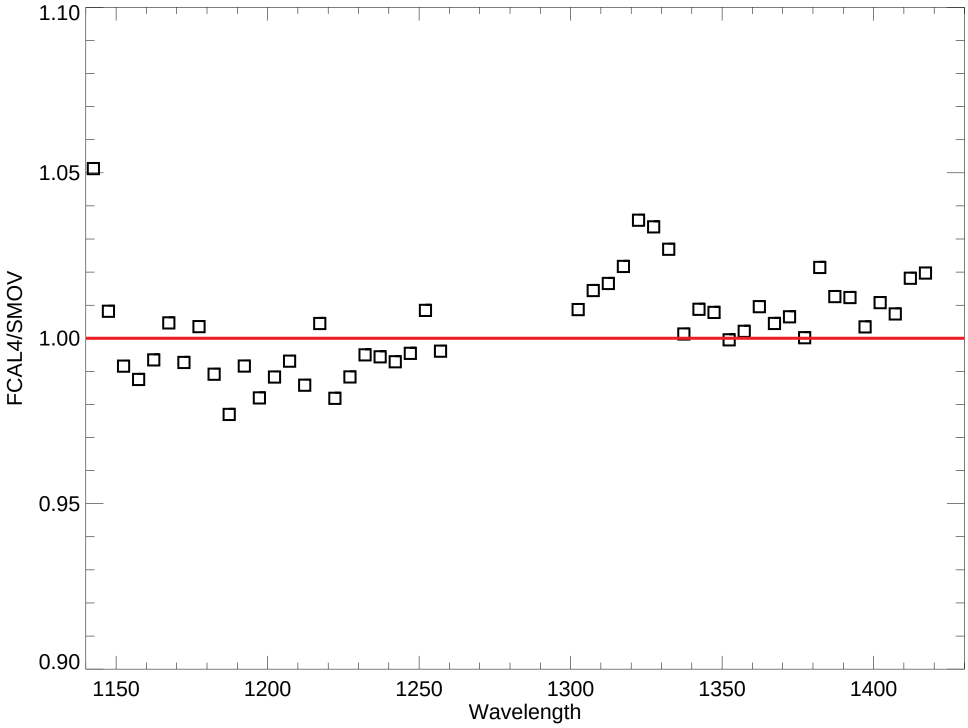

Figure 6. Comparison of G191-B2B's flux calibration during SMOV and in program 12807, binned to a width of 5 Å.

Acknowledgements

Change History for COS ISR 2013-05

Version 1: DD May 2013- Original Document

References

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Ghavamian, P., Froning, C., Osterman, S, Keyes, C. D., Sanhow, D., 2010, Instrument Science Report 2010-09
Massa, D., Keyes, C., Penton, S., Bohlin, R., Froning, C., 2010, Instrument Science Report 2010-02

File	Program	Grating	CENWAVE	FP-POS
laaf03hgq	11489	G130M	1291	1
laaf03hkq	11489	G130M	1291	2
laaf03hoq	11489	G130M	1291	3
laaf03hsq	11489	G130M	1291	4
laaf03hwq	11489	G160M	1623	1
laaf03i0q	11489	G160M	1623	2
laaf03i4q	11489	G160M	1623	3
laaf03i8q	11489	G160M	1623	4
laaf03icq	11489	G140L	1230	1
laaf03igq	11489	G140L	1230	2
laaf03ikq	11489	G140L	1230	3
lbxn01t2q	12807	G140L	1280	3
lbxn01t4q	12807	G160M	1623	3
lbxn01t6q	12807	G130M	1291	1
lbxn01t8q	12807	G130M	1291	2
lbxn01taq	12807	G130M	1291	3
lbxn01tcq	12807	G130M	1291	4

Table 1. List of COS observation files obtained during SMOV (Program 11489) and calibration of the new COS FUV lifetime position (Program 12807).