**Instrument Science Report COS 2023-25(v1)**

# Overview of COS Lifetime Position 6 Calibration

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**Abstract**

*The Cosmic Origins Spectrograph (COS) Far-Ultraviolet (FUV) modes G160M/1533, 1577, 1589, 1600, 1611 and 1623 moved from Lifetime Position 4 (LP4) to the new Lifetime Position 6 (LP6) on October 3, 2022 at the beginning of Cycle 30 operations. The procedures for calibrating these modes at LP6 followed those used for previous LPs. A number of observing programs were implemented, and the data analyzed to obtain calibration parameters, which were then incorporated into the reference files used by the COS pipeline. We present an overview of the LP6 calibration activities, brief descriptions of the individual observing programs, and a list of the output products. A series of Instrument Science Reports (ISRs) present the details of the calibration activities described here.*

## Contents

## 1. Introduction

The Far-Ultraviolet (FUV) detector used by the Cosmic Origins Spectrograph (COS) records photon events by creating a cascade of electrons when a UV photon strikes it. The "modal gain" is a measure of the number of electrons generated for every photon detected. With use, the detector becomes less efficient at converting photons to electrons in a phenomenon termed "gain-sag". When the modal gain of a pixel falls to a value of 3, it implies that about 5% of the incident photons remain undetected there (Sahnow et al. 2011).

The COS FUV detector segments (FUVB and FUVA) are two-dimensional arrays, and spectra lie along the dispersion (X) direction and span a band, about 10% of the detector width, in the cross-dispersion (Y) direction. The Y-locations where spectra are obtained correspond to COS Lifetime Positions (LPs). When the detector modal gain falls below 3 in the inner extraction region of a given LP at the highest allowed high-voltage (HV) level, then the default position for spectra are offset to a pristine portion of the detector. The maximum allowed HV values are 175 for FUVB and 178 for FUVA, and LP changes are typically triggered by FUVB reaching its limiting HV. The Y-locations of the LPs are measured as offsets from the original LP1. The dates of LP moves up to LP6 (the most recent) and their cross-dispersion locations are given in Table 1 of Fischer et al. (2022).

At a given LP, the three COS FUV gratings project to slightly different Y-locations. The previous LP move, from LP4 to LP5 (Fischer et al. 2022) could not accomodate grating G160M, as that would have overlapped regions already gain-sagged by usage at LP2. It was therefore decided to move only G130M modes to LP5 and place G160M observations about 1.1" higher at a new position, LP6, located at $+6.5$" from LP1 (James et al. 2023a).

One major difference between operation at LP6 and all previous LPs is the need for split WAVECAL exposures. Due to the light leak of the wavelength calibration lamp through the Flat-field Calibration Aperture (FCA), TAGFLASH exposures for wavelength calibration have to be taken at a different aperture block position (James et al. 2023a,b, Rowlands et al. 2023, in prep). The requirement to obtain Pt-Ne calibration spectra via split WAVECAL exposures before and after each science exposure – rather than concurrently with science exposures as was standard at previous LPs – adds to the overheads for external target observations, and can increase the number of orbits required for any given calibration program.

Through experience gained with the commissioning of each new LP, the COS team has developed a set of tasks and best practices to be employed during the process (Plesha et al. 2022). The preparation for a move to a new LP starts with an exploratory phase during which various studies are done primarily to decide on its location, and also to determine whether there are any other special considerations that have to be taken into account during the remaining phases. This is followed by the enabling phase during which the target placement is verified, and the focus values for each mode moving to the new LP are determined. The calibration is the last phase in commissioning the new LP. During this phase a number of observation programs are executed to obtain the required calibration data. The calibration parameters derived from these data are incorporated into several reference file tables used by the COS calibration pipeline, and these reference files are technically and scientifically validated in preparation for routine observations at the new LP. Additionally, the spectral and spatial resolutions at the new LP are determined from these data and included in documents such as the COS Instrument Handbook (Soderblom et al. 2023). The LP6 Calibration phase started in late January 2022 with the preparation of the draft Phase II proposals for the observing programs, and ended in mid-September 2022 with the delivery of the reference files to CRDS, ahead of the start of HST Cycle 30 observations at the beginning of October.

The LP6 exploratory phase is described in James et al. (2023b) and the enabling phase in Rowlands et al. (2023, in prep). This document contains an overview of the LP6 calibration phase activities. Section 2 presents a brief timeline of the calibration activities and short descriptions of the calibration programs, and Section 3 is a summary of the results, including a table of the reference files delivered. Details about the individual programs, their results, and the validation of reference files are provided in a series of COS Instrument Science Reports (ISRs).

## 2. The LP6 Calibration Programs

The set of observing programs developed to calibrate COS at LP6 were based on similar programs conducted in previous LP moves (e.g. see Fischer et al. 2022 for LP5). The list of programs, along with the targets, orbits used, program IDs (PIDs) and PI names are given in Table 1. The individual programs were developed in January 2022, and collectively approved by the HST Mission Office in February. The Phase II proposals prepared by the PIs and CoIs were checked by members of the Commanding, Scheduling and the Flight Software groups, and subsequently finalized by the end of February. In parallel, interim reference files for LP6 were prepared in order to enable the raw data to be processed through the standard pipeline and for the products to be made available in the archive like any routinely obtained COS data. The LP6 calibration programs were executed between March 7 and May 14, 2022. The final reference files were prepared by August 2022 and delivered for implementation by mid-September. Once these reference files were delivered, all the data obtained in LP6 calibration programs were reprocessed and are available in the archive.

Brief summaries of each of the LP6 Calibration programs are given below. Details about the reference files or calibration steps mentioned in these summaries may be found in the COS Data Handbook (Soderblom et al. 2022).

**Table 1.**: LP6 Calibration Programs

| Title[a] | Target(s) | Orbits | PID | PI |
|---|---|---|---|---|
| Profiles, Traces, Sensitivities, Flat Fields and Spatial Resolution | WD0308-565, GD71 | 20 | 16906 | E. Frazer |
| Spectral Resolution | AV75 | 3 | 16907 | N. Kerman |
| Dispersion Solution | $\epsilon$ Eri | 6 | 16908 | W. Fischer |
| Lamp Templates | LINE1 Pt-Ne Lamp | 2[b] | 16909 | N. Indriolo |
| Gain Maps | Deuterium Lamp | 1[b] | 16910[c] | C. Johnson |

[a] The formal titles are "COS FUV LP6 Calibration:" followed by these entries.
[b] Internal orbits.
[c] This program was withdrawn, and the required data were obtained as part of an existing program (PID:16829; PI:D. Sahnow) for LP5. See Johnson & Sahnow (2023) for details.

### *2.1 Spectral extraction, flux calibration, spatial resolution*

The program, "COS FUV LP6 Calibration: Profiles, Traces, Sensitivities, Flat Fields and Spatial Resolution" (PID:16906; PI: E. Frazer) observed two HST flux-standard white dwarf (WD) stars, GD71 and WD0308-565. The data were used to derive the spectral extraction parameters, which specify the locations and shapes of the 2D spectra for each mode in the thermally and geometrically corrected detector images. These parameters are used in the XTRACTAB reference file for BOXCAR extraction, and in the TRACETAB, PROFTAB and TWOZXTAB reference files for TWOZONE extraction. Furthermore, the parameters in the XTRACTAB are used in the wavelength correction (WAVECORR) step to perform the "CORR" to "FULL" coordinate conversion for both BOXCAR and TWOZONE extraction. In addition to specifying the location of the spectral extraction region, these data are used to determine the optimal background regions on the detectors. Details about the program, and about how spectral extraction parameters were derived are provided in Frazer et al. (2023, in prep).

In order to obtain accurate 2D profiles of a point source, the required signal-to-noise (S/N) is about 50 per resolution element (resel) in the combined spectrum from all four FP-POS exposures. GD71 is much brighter than WD0308-565, and it was observed with detector segment FUVA only, with FUVB turned off to prevent the COS bright-object limit from being exceeded. WD0308-565 data were used for obtaining the extraction parameters for segment FUVB, and GD71 data for FUVA, where the throughput is lower compared to FUVB.

The data from program 16906 were also used in deriving the low spatial frequency flat-fields (L-flats) and sensitivities at LP6. The L-flats depend on LP, grating and detector segment, and for each combination of these are functions of XCORR, i.e. fixed in detector space. The sensitivities depend on LP, grating, detector segment and cenwave, and for each combination of these are functions of wavelength. The 1D L-flats and sensitivities are derived simultaneously. The L-flats are converted to 2D arrays and incorporated into the FLATFILE. The time-dependent sensitivity (TDS) models are applied to the derived sensitivity curves to back out their values at the reference time in the TDSTAB reference files, and the resulting senstivities are used in the FLUXTAB reference file for LP6.

The derivation of accurate throughputs requires a S/N of about 30 per resel, and therefore used the WD0308-565 data for both segments FUVB and FUVA. In order to minimize the effects of the time-dependent sensitivity (TDS) on the flux calibration, all visits were planned to be within a four-week time window, and also close in time to the LP4-LP6 connection visits in the FUV TDS monitor program (PID:16830; PI: K. Rowlands). These connection visits are used to provide the scaling between count-rates at different LPs, which is necessary for deriving the TDS slopes (Rowlands et al. in prep). The details of the flux calibration analysis and results are provided in Miller et al. (2023, in prep).

Further, the high S/N data from this program are used to measure the spatial resolution at LP6, which is essentially the FWHM of the 2D spectra in the cross-dispersion direction. An account of these measurements is given in Kerman et al. (2023b).

### *2.2 Spectral resolution*

The program, "COS FUV LP6 Calibration: Spectral Resolution" (PID:16907; PI: N. Kerman) observed AV75, a blue supergiant in the Small Magellanic Cloud. The spectral resolution of COS depends on the cross-dispersion location of the spectrum on the detector, and was one of the factors considered in deciding where to place LP6 (James et al. 2023b). There are a number of interstellar absorption lines along the line of sight to AV75, which makes it a suitable target for measuring spectral resolution, and it has been used for that purpose at other LPs. The extreme cenwaves 1533 and 1623 were targeted to cover the entire spectral range and all FP-POS were used to achieve an S/N of about 60 per resel, which is required to measure the spectral resolution to within about 7%. The details about measuring the spectral resolution at LP6 are given in Kerman et al. (2023a).

### *2.3 Wavelength calibration*

The program, "COS FUV LP6 Calibration: Dispersion Solution" (PID:16908; PI: W. Fischer) observed the chromospherically active K2V dwarf star $\epsilon$ Eri. The dispersion solution maps the corrected detector co-ordinate, XFULL (Oliveira et al. 2010) of a 1D spectrum along the dispersion direction to wavelength for each mode. For G160M, the mapping is a linear function whose co-efficients are stored in the DISPTAB reference file. The exposure times are driven by the need to achieve S/N of about 25 at the peak emission of weaker lines, which in turn is required to obain a wavelength solution with an accuracy of 0.5 resel, which is approximately 3 pixels for G160M modes. Obtaining the dispersion solution requires an accurate extraction of the 1D spectrum and therefore depends on the availability of the spectral extraction reference files described above. The details of the measurements and derivation are given in Fischer et al. (2023, in prep).

The program, “COS FUV LP6 Calibration: Lamp Templates” (PID:16909; PI: N. Indriolo) targeted the LINE1 Pt-Ne lamp that is part of the COS calibration platform. The aperture block was moved to the default location for LP6 split WAVECAL expoures, and the Pt-Ne lamp was turned on and observed through the Wavelength Calibration Aperture (WCA). Lamp spectra were obtained for all four FP-POS at each cenwave setting. Each exposure was processed to create a 1D spectrum of the Pt-Ne lamp in XCORR space that serves as a template, which is stored in the LAMPTAB reference file, and used during the wavelength calibration procedure. Note that while the LP6 Primary Science Aperture (PSA) projects above the LP5 PSA on the detector, the LP6 WCA in split WAVECAL exposures projects below the LP5 WCA to prevent the previously mentioned light leak. The shift between a Pt-Ne spectrum recorded during science observations and these templates is used to set the zero point of the wavelength calibration to within 3 pixels. Details about the observations, the analysis and the creation of the LAMPTAB reference file for LP6 are provided in Indriolo et al. (2023).

### *2.4 Gain maps*

The program, “COS FUV LP6 Calibration: Gain Maps” (PID:16910; PI: C. Johnson) was designed to observe the internal deuterium lamp within the first two weeks of operation at LP6 to verify the modal gain, and to have a set of reference gain maps for modeling detector behavior. Exposures in gain map programs are obtained through the FCA, which, due to the soft-stop limit, cannot project high enough on the detector to be centered at LP6. However, analysis of gain maps obtained at LP5 showed that there were sufficient counts in the LP6 rows to measure the modal gain there. Therefore, program 16910 was withdrawn, and instead the data from one of the visits of the on-going detector gain maps program (PID:16829; PI: D. Sahnow) obtained soon after the start of Cycle 30 were used to measure the gain at LP6. The gain map analysis details are given in Johnson & Sahnow (2023).

## 3. Results and Reference Files Delivered

The calibration parameters, such as the width of the extraction box and profiles, the L-flats, and the sensitivities for the G160M cenwaves at LP6 were found to be similar to those at LP4. The spectral resolution at LP6 is generally lower than at LP4, by up to 10–20% over significant portions of the bandpass, but is also found to be about 10% higher towards the long-wavelength end of cenwave 1533 FUVA and most of cenwave 1623 FUVB. The spatial resolution at LP6 is about the same as LP4, which is expected since

**Table 2.** LP6 Reference Files

| Type | LP6 File |
|---|---|
| XTRACTAB | 69d21095l_1dx.fits |
| TRACETAB | 69d21096l_trace.fits |
| PROFTAB | 69d21098l_profile.fits |
| TWOZXTAB | 69d2109gl_2zx.fits |
| FLATFILE | 69d21090l_flat.fits |
| FLUXTAB | 69d2108sl_phot.fits |
| DISPTAB | 69d2109fl_disp.fits |
| LAMPTAB | 69d21093l_lamp.fits |
| GSAGTAB | 71j1935gl_gsag.fits[a] |

[a] Activated on 2023-01-19.

they are about the same distance away from LP1 on opposite sides ($+6.5$" and $-5$", respectively). Overall, the performance of COS G160M modes at LP6 is comparable to LP4.

The reference files that were prepared incorporating the LP6 calibration parameters are listed Table 2. These files (except for the GSAGTAB file, which was delivered later) have an activation date of 2022-09-14 and were used at the start of Cycle 30 operations. They may be accessed at the HST Calibration Reference Data System page for context hst_1037.pmap[1]. Several of these calibration files have since been updated to include other refinements not directly related to the LP6 Calibration programs described here.

## Change History for COS ISR 2023-25

Version 1: 16 November 2023- Original Document

## References


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[1] https://hst-crds.stsci.edu/context_table/hst_1037.pmap

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