Instrument Science Report COS ISR 2018-YYY

FENA4: FUV Target Acquisition at the 2^{nd} Lifetime Position (LP2)

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COS is a slit-less spectrograph with a pair of circular apertures with radii of 1.25″. The Primary Science Aperture (PSA) is placed at the location of the minimum beam waist, with the instrument focused on the sky. The Bright Object Aperture (BOA) is identical to the PSA except that the aperture is filled with an ∼ND2 filter. To achieve our FUV centering goals, we need to center a point source to within 0.3″ in the cross-dispersion (XD) direction and 0.106″ in the along-dispersion (AD) direction.

In this ISR we will discuss the performance of the COS FUV spectroscopic on-board target acquisition (TA) modes at the second lifetime position (LP2). Except for the obvious displacement of the TA sub-arrays is the Y direction, the only upadates required are to the grating specific plate scales and the WCA-to-PSA/BOA offsets.

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1 Introduction

This ISR details the execution of HST COS Program 12797 - Second COS FUV Lifetime Position: FUV Target Acquisition Parameter Update (FENA4). This ISR is designed to supplement information about COS FUV spectroscopic Target Acqusitions (TAs) contained in the Instrument Handbook (IHB(v5), Holland 2012) , COS ISR 2010-014(v1) (Keyes & Penton, "COS Target Acquisition Guidelines, Recommendations, and Interpretation", 2010), and COS TIR 2010-03(v1) (Penton & Keyes, "On-Orbit Target Acquisitions with HST+COS", 2010).

FENA4, was the last of a series of programs allowing COS to be moved to its second lifetime position (LP2). These other programs, and what they contributed to this program, were;

- 12793 - FUV Detector High Voltage Sweep (FENA1)
  - Determines the initial FUV Detector High Voltage Setting for LP2.
- 12795 - Verification of Aperture and FUV Spectrum Placement (FENA2)
  - Provides the cross-dispersion (XD) spectral locations for each grating.
  - Provides the initial estimate for the WCA-to-PSA offsets for each grating.
  - Provides the inital estimate for the XD plate scales.
- 12796 - Focus Sweep Enabling Program (FENA3)
  - Determines the FUV focus settings for use during FUV spectroscopic TA.

bout performing FUV Spectroscopic Target Acquisitions (TAs) with the Cosmic Origins Spectrograph (COS).

1.1 Document Structure

After establishing some naming conventions in §**??** we begin by reviewing the required accuracy of COS FUV Target Acquisitions (TAs) in § 2. In § **??** we will review all of the TA parameters that need to be modified for TA at LP3. This includes items in the flight software (FSW) and in the ground system (GS) commanding. In § **??**, we will review the actions required to locate the FUV spectra at the desired location on the detector for lifetime position three (LP3). In § **??**, we detail the TA subarrays, and in § **??** we discuss the focus values to be used for COS FUV observations at LP3.

We will then step through the observations of each of the five LENA3 (13636) visits used to determine the TA parameters needed for operations at LP3. In § **??**, we discuss Visit 01, which was designed to test the `ACQ/SEARCH` TA algorithm at LP3. In § **??**, we discuss Visit 02, which was designed to test the `ACQ/PEAKD` TA procedure at LP3, and also determines the WCA-to-SA offsets needed for the `ACQ/PEAKXD` procedure. In § **??**, § **??**, and § **??**, we will review the `ACQ/PEAKXD` procedure testing and plate scale determination for the G140L, G130M, and G160M gratings, respectively. Visit 05 also contains the first on-orbit "proof of concept" `NUM_POS` >1 `ACQ/PEAKXD` exposures. These will be discussed in § **??**.

2 Required Accuracy of COS FUV TA

The original Contract End Item (CEI) requirement (STE-63) for COS TA is

```
During the target acquisition process, it shall be possible to calibrate the location
of the science aperture in detector pixel coordinates in order to compute a maneuver
of HST needed to improve the centering of the target within the aperture.  The measurement
shall be made using COS internal sources.  The measurement calibration process shall
allow the target to be centered in the science aperture with an accuracy of 0.3″.
```

There is the additional FUV requirement that

Wavelengths assigned to data points in the fully reduced and calibrated COS spectra shall have an accuracy equivalent to an absolute uncertainty of less than $\pm 15\ \mathrm{km\,s^{-1}}$ in the $R = 20,000$ modes, $\pm$ 150 $\mathrm{km\,s^{-1}}$ in mode G140L

For COS TA, we take the CEI spec (0.3″) to refer to the required centering accuracy in the XD, and the wavelength requirements to apply to the TA accuracy required in the AD direction. Since the AD requirement is in units of $\mathrm{km\ s^{-1}}$, it is detector and wavelength dependent as defined in equations 2–4. Assuming that the wavelength error budget is split evenly between the COS TA and wavelength scale accuracies, the error budgets for the COS gratings, in arc-seconds (″), are given in Table 1. By "evenly" we mean that when added in quadrature the total error budget is that given by the second column of Table 1. Setting the TA error budget equal to the wavelength scale accuracy, the AD TA requirement given in the third column is the second column divided by $\sqrt{2}$.

$$\Delta\ AD(G130M@1300\mathring{A}) = \frac{15\ \mathrm{km\ s^{-1}}\ \times 1300\mathring{A}}{c \times 0.00997\mathring{A}/p \times 43.5p/''} = 0.150'' \tag{1}$$

$$\Delta\ AD(G160M@1600\mathring{A}) = \frac{15\ \mathrm{km\ s^{-1}}\ \times 1600\mathring{A}}{c \times 0.01223\mathring{A}/p \times 42.9p/''} = 0.153'' \tag{2}$$

$$\Delta\ AD(G140L@1800\mathring{A}) = \frac{150\ \mathrm{km\ s^{-1}}\ \times 1800\mathring{A}}{c \times 0.08030\mathring{A}/p \times 45.4p/''} = 0.247'' \tag{3}$$

Table 1. COS Along-Dispersion (AD) Centering Requirements.

COS Grating	Total Error Budget	AD TA Requirement
G130M	0.150″	0.106″
G160M	0.153″	0.108″
G140L	0.247″	0.175″

Note. — Assuming the total error budget (column 2) is split equally between TA AD centering and wavelength scale accuracy, the AD TA requirements (column 3) are $1/\sqrt{2}$ of the total error budget (equations 2–4).

3 Initial "Blind" Pointing of HST

We can estimate the initial (blind) pointing accuracy of HST+COS observations by reverse engineering all of the TAs of the SMOV plus early GTO and GO observations. Figure **??** shows the observed blind-pointing results for the three COS TA modes: NUV imaging, NUV spectroscopic, and FUV spectroscopic. Overall, we observe an initial pointing bias of [AD,XD] = [-0.XX±0.YY,-0.18±0.68]″. In general, the 1σ accuracy of guide stars in the GSC2 is ∼0.4″ so the standard deviation of our blind pointing is slighter higher than the guide star accuracy due to target coordinate uncertainties. The initial pointing bias of [-0.23,-0.18]″ was, however, not expected and was the result of a minor FGS-to-COS misalignment (see COS ISR 2018-XXX.

4 COS Target Acquisition Modes

In the next four sections, we will examine each of these modes in detail, particularly when the TA centering accuracy depends upon the proper choice of TA mode option. A summary of the recommended values of all TA mode options is given in § **??** (Table **??**). Each TA modes uses TA flight software (FSW) parameters which are not specifiable by the user. A description of each of these parameters is given in Appendix **??**, and the current and past values of the important TA FSW parameters are given in Appendix **??**.

4.1 Using `ACQ/SEARCH`

An `ACQ/SEARCH` is fully defined by specifying the three TA parameters `SCAN-SIZE`, `STEP-SIZE`, and the `CENTER` method and can be performed in imaging or spectroscopic made. `SCAN-SIZE` can be 2, 3, 4, or 5 (the upper limit is set by the TA parameter PCTA_MAXSCANSIZE). `STEP-SIZE` can range from 0.001″ to 2.0″ (the FSW parameters PCTA_MINSTEPSIZE and PCTA_MAXSTEPSIZE). The recommended value of `STEP-SIZE` is the default (1.767″). This is the largest `STEP-SIZE` that covers the sky without internal gaps or holes in on-sky coverage, and should be used in almost all cases. The `CENTER` method can be `FWF` (Flux-Weighted-Floor), `FW` (Flux-Weighted), or `RTB` (Return to Brightest). `CENTER=FWF` is recommended for `SCAN-SIZE`=3 or larger, while `CENTER=FW` is recommended for `SCAN-SIZE`=2. Use of `CENTER=FWF` with `SCAN-SIZE`=2 produces an asymmetric pattern that pulls the target away from proper centering. `CENTER=FWF` centers better than `CENTER=FW` because it subtracts the lowest counts in any dwell point from all counts, which acts as a crude background removal. A simple schematic of `STEP-SIZE`=2–5, `SCAN-SIZE`=1.767″ `ACQ/SEARCH`s are given in Figure **??**. The red circle here has a radius of 3″, and is useful in comparing the area on the sky covered by the available patterns. Blue numbers show the order of the dwells in the pattern, and the pre-launch PSF is shown in the center for comparison.

Ray-tracing and computer simulations for the NUV (COS-11-0024A) and FUV (COS-11-0016A) predict that properly designed `ACQ/SEARCH`s should center the target to within 0.1–0.2″ in all modes in both AD and XD, if the target was within the box on the sky contained by the outer dwell points. These simulations were based upon the predicted, not the observed PSF, (see Figure **??** and COS ISR 2010-01). The observed PSF is noticeably asymmetric and contains a much larger percentage of the light in the extended wings. The PSF asymmetries and extended wings, along with the extended transmission function of the aperture (Figure **??**), tend to feed incorrect information into the `ACQ/SEARCH` centering algorithm. For these reasons, a single `ACQ/SEARCH` should be not expected to center the target to better than 0.3″ in either AD and XD. Depending on where the target falls in the `ACQ/SEARCH` pattern, it could be as much as 0.5″ off-center. This is why we recommend that all TAs follow up their initial `ACQ/SEARCH` with either an `ACQ/IMAGE`, `ACQ/PEAKXD`+`PEAKD`, or a second 2x2 `ACQ/SEARCH`.

The NUV detector background has risen from about 60 counts/s to 400 counts/s since May 2009, with an annual rate of increase of ∼226 counts/year (see § **??**). The original NUV imaging and spectroscopic TA subarrays comprised ∼13% of the NUV detector and are were counting 31–46 counts/s of detector background as of mid-2010. Under the simplifying assumption that during an `ACQ/SEARCH` the weakest background counts will be 1σ low and the brightest will be 1σ high, when using `CENTER=FWF` the target should be brighter than $2 \times \sqrt{(}$maximum background rate) to avoid significant pointing error due to background contamination. For normally distributed background events and observations away from the SAA, this is $\sim$14 counts/s, or ACQ/SEARCH dwells times of greater than $\sim$120s for target equal to S/N=40 TAs. For cases using CENTER=FW, the target should be brighter than or equal to the maximum expected background rate to provide adequate centering (count rates greater than 50 counts/s and dwell times less than 35s). In cases where the target does not meet these criteria, other COS TA strategies should be employed.

As discussed in § **??**, NUV imaging ACQ/SEARCH TA subarrays were optimized (reduced) during mid-2010, and the above warning about NUV ACQ/SEARCHs now only apply to spectroscopic TAs.

4.2 ACQ/IMAGE

When mirrors are selected on both Optics Select Mechanisms (OSMs), COS can be used in NUV imaging mode. ACQ/IMAGE uses this mode to center a point-source, or the brightest point in an extended object, in the aperture. All COS apertures are on a common aperture plate, and therefore have a fixed physical offset. Flashing the on-board Pt-Ne wavelength calibration lamp allows the determination of the position of the wavelength calibration aperture (WCA) on the NUV detector. COS has two Pt-Ne lamps; **P2** is used exclusively for TA and **P1** is used for wavelength calibration. Once the position of the WCA is known, the center of the other apertures can be precisely calculated. NUV ACQ/IMAGE observations can use either the PSA or BOA aperture and either MIRRORA or MIRRORB modes. MIRRORA mode is simply using a flat mirror on OSM2. This mirror has 2mm thick UV grade fused silica 'order sorter' on the front which suppresses light at $\lambda < 1600\AA$.

The order-sorter was placed in front of the gratings, so that the light makes two passes through the filter before reaching the detector. UV grade fused silica transmits well for $\lambda > 1700\AA$, but is almost totally opaque for λ ¡ $1600\AA$. while MIRRORB is a slight rotation of OSM2 so that light reflects off the order-sorting filter in front of the mirror. The TA order sorter has a slight wedge of $\sim 30''$in the AD. This produces two images, one from the front surface reflection off of the order sorter, and a second reflecting off of the back surface of the order sorter. The second reflection is dimmer by a factor of ~ 0.48[1], therefore MIRRORB produces two target images in a $\sim$ 2:1 intensity ratio. Each of these modes has different WCA-to-aperture offsets that are stored in the COS FSW as the parameter PCTA_CALTARGETOFFSET (Table **??**). Details of this TA step, known as LTAIMCAL, are given in § **??**.

Once the desired position of the aperture+MIRROR center has been determined, an image of the sky is taken to determine the initial target position. Using the plate scale parameters stored in the FSW constants PCTA_NUVMILLIARCSECSPERPIXELX and PCTA_NUVMILLIARCSECSPERPIXELY (Table **??**), the calculated target motion required to center the target in pixels is converted to arcseconds ($''$) and HST is commanded to slew the required amount to center the target in the aperture. Details of this TA step, known as LTAIMAGE are given in § **??**.

After slewing to the desired location, ACQ/IMAGE takes a second image of the sky to verify that the target was centered as desired. The two images, and the results of the WCA target location, are returned in the IPPPSSOOT_rawacq.fits file. In § **??**, we evaluate the performance of the four APERTURE+MIRROR ACQ/IMAGE modes and compare them to our centering requirements.

The average number of counts in the WCA LTAIMCAL MIRRORA images was 3233±68 (a 7-second exposure with **P2** at low current). The average number of counts in the WCA LTAIMCAL MIRRORB images was 798±153 (a 30-second exposure with **P2** at low current). The average number of counts in the primary MIRRORB image was 2/3 of this value (~ 535). As discussed in § **??**, the COS dark rate is currently ∼220–330 counts/s over the entire detector, or ∼31–46 counts/s in the WCA subarray. The WCA MIRRORB exposures are currently 30 seconds in duration, so the total background in the subarray is ~ 930 counts, comparable to the counts in the lamp images.

Figure **??** shows the LTAIMCAL counts as a function of time. The solid crosses indicate the total number of accumulated counts during the MIRRORA and MIRRORB LTAIMCAL. The solid lines give the moving average of the measured counts. There is significant scatter in the

[1] Since the primary reflection does not pass through the order sorter, but the secondary image dose, this ratio is target SED dependent.

Table 2. On-Orbit LTIMCAL Measurements.

Aperture	MIRROR	AD Position	XD Position	# of LTAIMCALs
PSA	MIRRORA	474.0 ± 15.5	370.0 ± 0.6	80
PSA	MIRRORB	689.0 ± 11.9	209.0 ± 0.8	116
BOA	MIRRORA	474.0 ± 15.0	370.0 ± 0.8	46
BOA	MIRRORB	684.0 ± 8.8	208.0 ± 0.8	6
ALL	MIRRORA	474.0 ± 15.3	370.0 ± 0.6	126
ALL	MIRRORB	689.0 ± 11.8	209.0 ± 0.8	122

Note. — The reported positions are the median detector coordinates. The proposed subarrays shown in Figure **??** are derived from these measurements.

total LTAIMCAL counts due to detector background which is related to the temperature of the NUV MAMA tube (LNTUBET). As discussed in Pascucci et al. 2010, this relationship has been estimated as :

$$\text{NUV Dark Rate} = 1.1 \times\ 10^9\ \ exp(\frac{-8791}{T_c + 273.16})\ (\frac{(t - t_0)}{163} + 1.5) \tag{4}$$

where t_0 is the modified Julian date of 55100.0 (2009.269) and T_c is the MAMA tube temperature tracked by the COS keyword LNTUBET.

4.3 **ACQ/PEAKXD**

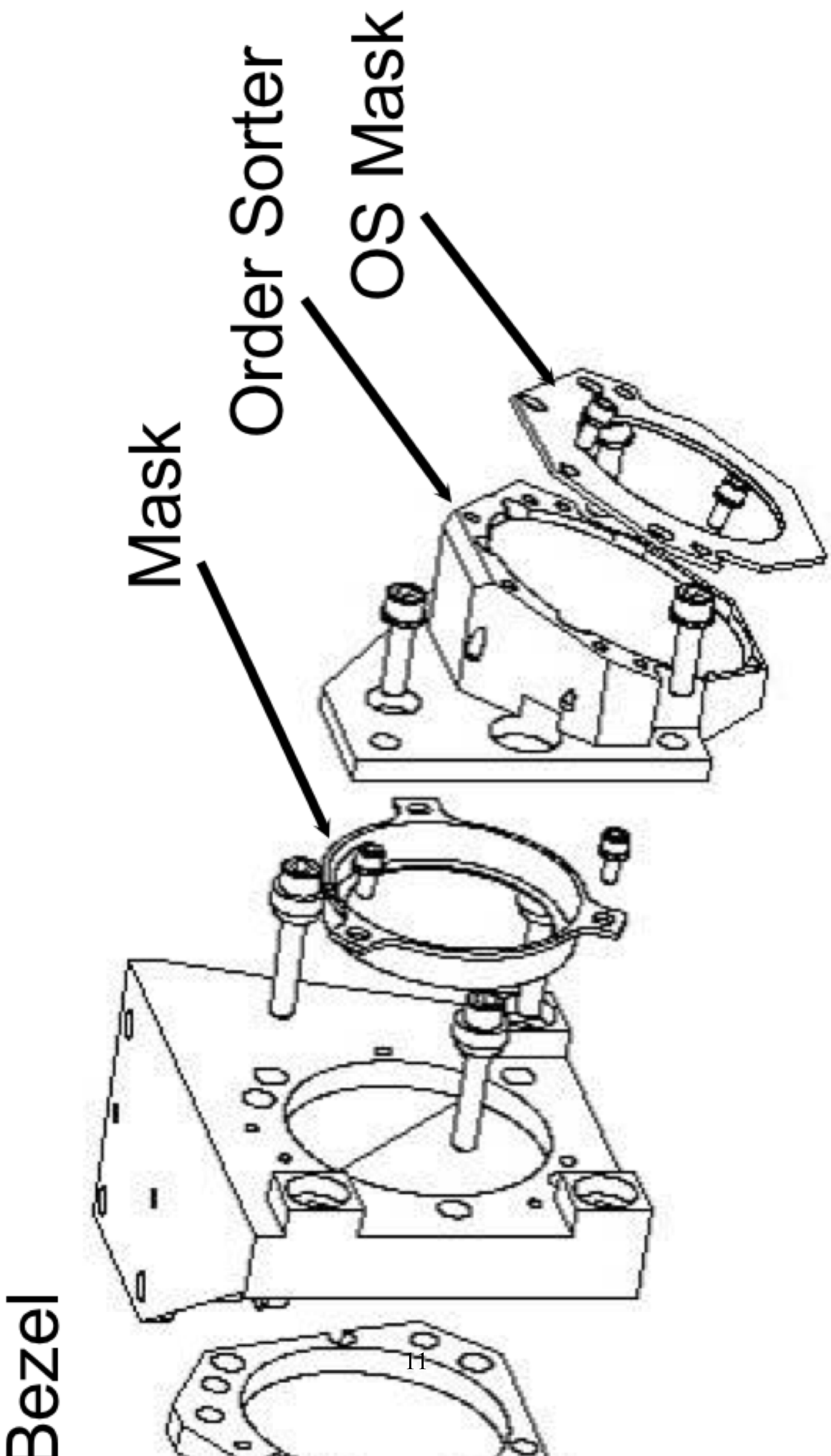
ACQ/PEAKXD sequences start with a 17-second flash of **P2** at medium current to locate the wavelength calibration spectrum (WCS, or WCA spectrum) in dispersed light on the detector. For NUV TAs, one must specify the stripe to be used in centering. The optional parameter is *STRIPE=A, B* (DEFAULT), or *C*, or in APT, *STRIPE=SHORT, MEDIUM, LONG*. For FUV TAs, one must specify which segment(s) to use (*SEGMENT=A* (DEFAULT for G140L)*, B* or *BOTH* (DEFAULT for G130M, G160M). To limit the amount of detector background contributing to the WCS location, a single subarray is used for the NUV detector and one for each of the FUV segments (if applicable). The values of these WCS ACQ/PEAKXD TA subarrays are given for the NUV and FUV in Tables **??** and **??** for the FUV channel.

Once the XD location of the NUV WCS for the *STRIPE* selected is determined (using a median, PCTA_USEMEDIAN4CAL4NUV=TRUE), the expected location of the median (PCTA_USEMEDIAN4PKXD4NU of the spectral stripe (BOA or PSA) is calculated using the grating and aperture specific parameter CALTARGETOFFSET given in Table **??**.

The ACQ/PEAKXD target exposure is then taken and the slew required to center the target is calculated and performed. For NUV TAs, the FSW always uses the XD separation between the WCA and the target aperture for STRIPE=B. As a result, NUV ACQ/PEAKXD exposures taken with stripes other than STRIPE=B will be mis-centered in the XD direction by as much as 2.5p (0.06″). In addition, due to the slope of NUV spectra on the detector, targets with different spectral energy distributions will center slightly differently ($\leq 2p = 0.05''$). In the COS FSW, a single NUV parameter is used for the XD plate scale for all gratings (PCTA_NUVMILLIARCSECSPERPIXELXDISP). This value of this parameter was set in SMOV to 0.02384 mas/p. The actual NUV plate scale is, however, grating dependent. The estimates in Table **??** were derived in COS 2010-08 (Ghavamian, 2010). The maximum difference from the FSW value is the G285M value, with a difference of $24.4 - 23.84 = 0.56$ mas/p. This is a XD displacement of 2p (0.05″) in XD for a 1.1″ G285M/`ACQ/PEAKXD` adjustment. For the FUV channel, the differences in XD plate scale are much larger and each grating uses its own grating specific value of (PCTA_FUVMILLIARCSECSPERPIXELXDISP) as given in Table **??**.

There is one additional complication due to the off-axis alignment of the COS NUV channel. The act of centering an NUV target in the XD direction moves the target in the AD direction as given by the α_{yx} column in Table **??**. This parameter has units of p/″ of motion. In the worst case (G225M), a 1.25″ PEAKXD centering will move the target 8.4p (0.20″) in the AD. For this reason, NUV `ACQ/PEAKXD`s should always precede `ACQ/PEAKD`s. Also given in Table **??** is the amount of motion in the XD direction for NUV AD motion (α_{xy}). A 1.25″ NUV `ACQ/PEAKD` TA will move the target in the XD by a much smaller amount, at most 0.4p (0.01″) for G185M.

Because of cross-contamination between the spectral stripes, NUV `ACQ/PEAKXD`s will not work properly for extended sources, and should be avoided.


OS Mask
Order Sorter
Mask
Bezel

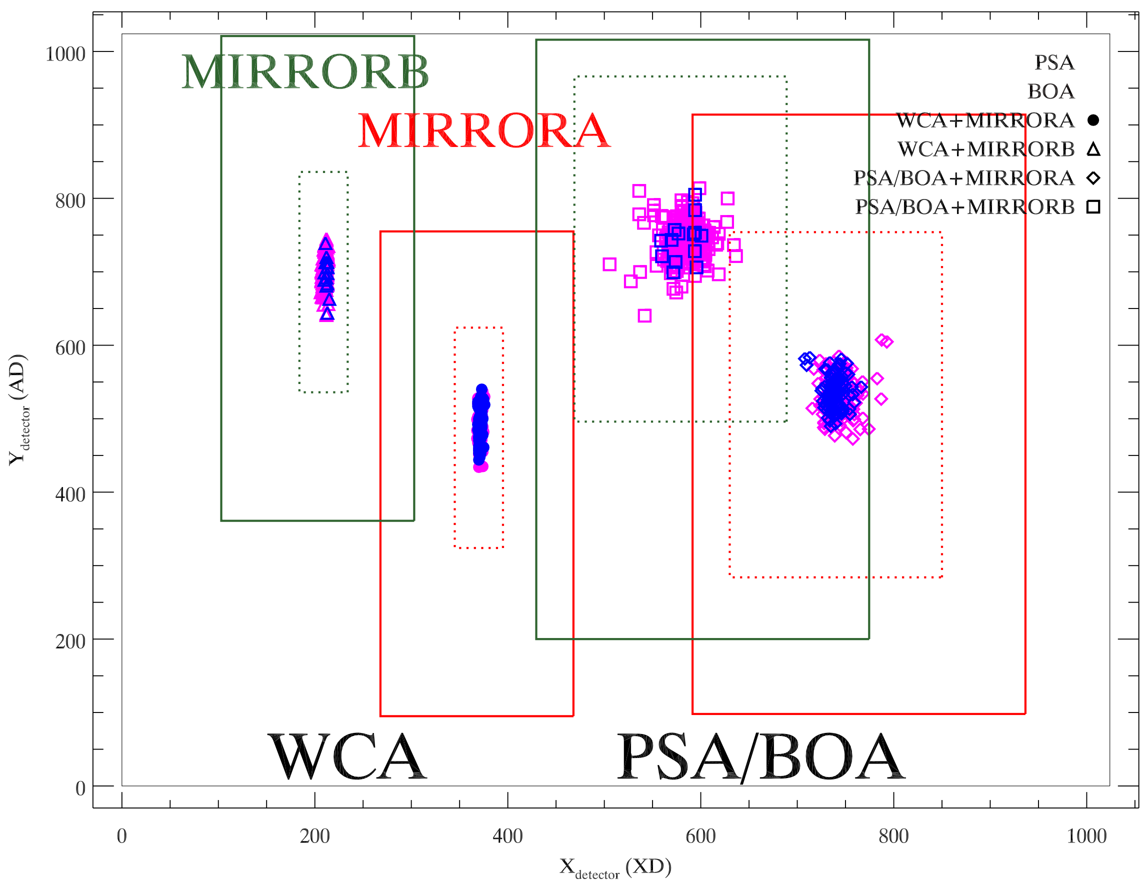


Figure 2 Representation of the NUV detector showing the locations of the wavelength calibration lamp images (WCA, `LTAIMCAL`) and the initial positions of the target images (PSA/BOA, `LTAIMAGE`). The two solid boxes on the left show the current MIRRORA and MIRRORB WCA TA subarrays capturing the WCA lamp locations for both PSA and BOA `ACQ/IMAGE`S. The two solid boxes on the right show the current MIRRORA and MIRRORB TA subarrays for PSA/BOA `LTAIMAGE`s. The initial target pointings are also shown for the PSA and BOA `ACQ/IMAGE`s. The dashed boxes are proposed updates to these subarrays as discussed in § **??** and shown in Table **??**. All coordinates are in detector coordinates.

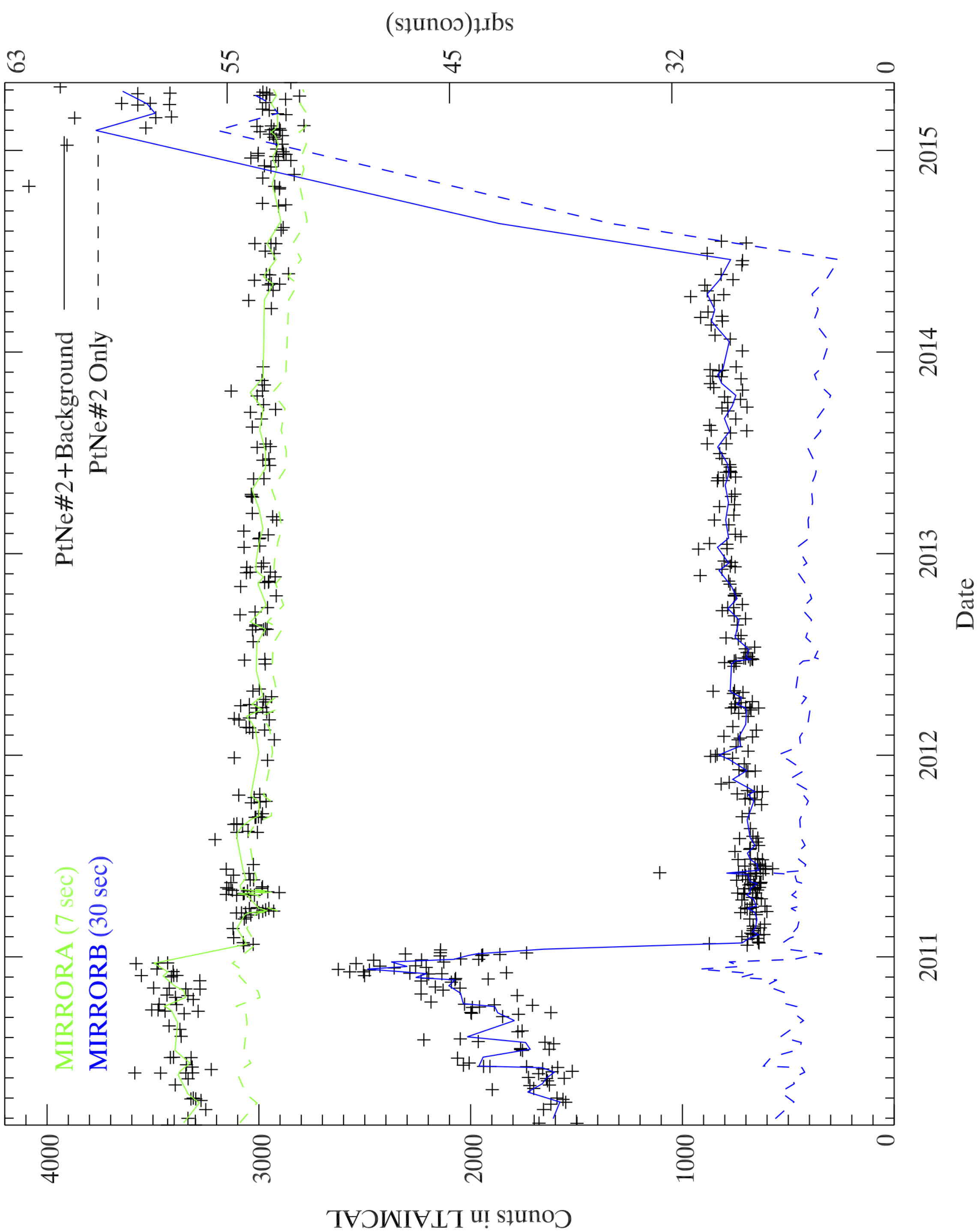


Figure 3 Count rates during the LTAIMCAL TA phase for MIRRORA and MIRRORB observations (crosses). The solid lines are a moving average of the calibration lamp plus the detector background counts. As explained in the text, from the date and the temperature of the NUV MAMA we can estimate the detector background present in the LTAIMCAL subarrays. After subtracting this estimate of the detector background, we determine the number of LTAIMCAL calibration lamp events as a function of date. The wavelength calibration lamp used during LTIMCAL appears to be stable over the sampled interval. The MIRRORA count rates are clearly adequate, but the MIRRORB count rates in the two MIRRORB images appear to be drop-

FUV ACQ/PEAKXDs are performed in "raw" coordinates and do not receive the thermal and geometric corrections of science data. The raw coordinate systems of each FUV segment are different. ACQ/PEAKXDs that use both segments must map the Segment-B detector "Y" (XD) positions to Segment-A coordinates before determining the combined Segment-A plus Segment-B WCS and PSA/BOA XD locations. The FUV mapping is determined by the grating specific parameters PCTA_XDISPINTERCEPTCOEFF and PCTA_XDISPSLOPECOEFF (Table **??**). Unlike the NUV, the FUV XD location determinations give better results when using a mean to determine the XD locations (PCTA_USEMEDIAN4CAL4FUV=FALSE, and PCTA_USEMEDIAN4PKXD4FUV=FALSE). Because of the thermal and geometric distortions present in raw FUV data, and the slight slope of FUV spectra on the detector, targets with different spectral energy distributions will center slightly differently during FUV ACQ/PEAKXDs. This effect has been measured as $\leq 2\ DE = 0.2''$, less than our centering goal of $\pm 0.3''$.

For the NUV, TA extraction subarrays isolate the STRIPE in use. Table **??** gives the lower-left corner in $X_{detector}$ (XC) for all three stripes for each grating and the WCA and PSA/BOA. All NUV PEAKXD subarrays have YC=0, YS=1024, and XS=81.

FUV TA subarrays must also exclude the geocoronal emission lines for each SEGMENT. The subarrays described in the ACQ/SEARCH section (§ 4.1) and Appendix **??** are also used for ACQ/PEAKXD. The geocoronal lines excluded by the FUV TA subarrays are given in Table **??**. FUV TA subarrays exclude only those lines above the double line in Table **??** (Daytime > 0.2 kR). The observer should be aware of possible spectral contamination from the other lines, but these lines should not affect TA.

Since COS FUV TAs are done in raw coordinates (no thermal or geometric corrections), the temperature at the time of the TA affects the XD location of the WCA and PSA/BOA spectra on the detector. As outlined in COS-2010-13 (COS FUV and NUV On-Orbit Structural and Thermal Stability), these digital locations will experience virtual oscillations of up to $\pm$ 0.05$''$ in one orbit due to internal COS thermal instability. The XD components of the four FUV stim locations move approximately in step with orbital phase, but with varying magnitude As a result, the relative offset between the WCA and science aperture does not change as much as the absolute positions. The overall XD centering error in ACQ/PEAKXD due to thermal effects should be ≤ 0.25 DE (digital element), or $\leq 0.025''$. On the other hand, geometric distortions can affect overall XD centering by as much as 2 DE, or $0.2''$. Statistics on the effects of geometric distortion on FUV XD ACQ/PEAKXD centering are difficult to determine since the XD profiles are returned as a TA data product.

COS FUV on-orbit spectra are not perfectly aligned with the detector; there is a slight slope to both the WCA and PSA/BOA spectra (≈ -0.27 XD(DE) per 1000 AD(DE)). This slope equates to an ≈ 3.5 DE XD offset from the beginning to end of each segment. This obviously broadens the XD profiles of both the WCA and PSA/BOA spectra, making centroiding less precise and a function of the target spectral energy distribution (SED). Since COS TA spectra are not geometrically corrected either, the XD profiles are further broadened in non-linear fashion. FUV ACQ/PEAKXD centering accuracy is therefore mildly CENWAVE dependent, even for the same target.

On-orbit, we have observed the centerings listed in Table **??** with ACQ/PEAKXD between days 2009.215–2010.119. In all cases, the ACQ/PEAKXD is following a spectroscopic ACQ/SEARCH. Overall, ACQ/PEAKXD is correcting for ACQ/SEARCH errors by XX$\pm$YY$''$, clearly indicating its importance in properly centering targets in the XD. The 1σ standard deviation indicates that ACQ/SEARCH is centering the target in the XD direction to within $\pm$0.3$''$ about 90% of the time,

Table 3. Average On-Orbit `ACQ/PEAKXD` Centering Moves.

Grating/Channel	Aperture	|XD Offset|	$\sigma_{\|XD\ Offset\|}$	# of Centerings
G130M	PSA	-0.119″	0.168″	98
G160M	PSA	-0.224″	0.091″	30
G140L	PSA	-0.188″	0.094″	18
G130M	BOA	-0.208″	0.177″	4
G160M	BOA	...	...	0
G140L	BOA	...	...	0
FUV	PSA	-0.149”	0.153”	146
FUV	BOA	-0.208”	0.177”	4
PSA	ALL	-0.085″	0.157″	223
BOA	ALL	-0.179″	0.166″	5

Note. — Previous NUV+FUV PSA+BOA TA stages centered the target to within ±0.3″ prior to `ACQ/PEAKXD` 90% of the time, and within ±0.1″ only 50% of the time.

but to within our desired accuracy of ±0.1″only 50% of the time.

By examining COS spectra, we can directly measure the final XD accuracies achieved by `ACQ/PEAKXD` compared to the commanded XD positions. The results for the NUV observations are given in Table **??** and the FUV results are given in Table **??**. These results include all observations taken between 2009.215 and 2010.119. Due to incorrect WCA-to-PSA parameters, NUV BOA spectroscopic TAs will not correctly center the target in the aperture. No BOA spectroscopic TAs are scheduled for Cycle 17. A PR will be filed to correct this before Cycle 18.

COS observations begin to lose flux at an XD offset of ∼0.4″ due to aperture vignetting. As shown in Table **??**, the G160M `ACQ/PEAKXD` currently have a systematic offset of 2-3 XD DE (0.2–0.3″). This is most likely due to errors in the Segment B-to-A mapping parameters coupled with geometric distortion issues. Uncertainties in the plate scale would produce a centered XD distribution with a large scatter. An incorrect WCA-to-PSA offset would center the target incorrectly, but at the commanded position, not offset in a consistent direction.

In all cases, the `ACQ/PEAKDs` in Figure **??** followed spectroscopic `ACQ/SEARCH` and `ACQ/PEAKXDs`. `ACQ/PEAKD` is correcting for `ACQ/SEARCH` + `ACQ/PEAKXD` AD residual centering errors by an average of . Table **??** gives the average and 1σ standard deviations of all `ACQ/PEAKD` observations taken in the date range previously given, excluding all `CENTER=RTB ACQ/PEAKDs`. Results are given for all COS gratings, apertures, and channels. Some low signal-to-noise and high background (SAA) observations were removed in this analysis. For normal observations taken with the PSA, the NUV `ACQ/PEAKD` AD centerings averaged and for the FUV, the average AD centering was . The 1σ standard deviations on all SMOV + GTO + GO observations tested indicate after the initial spectroscopic `ACQ/SEARCHs`, NUV+PSA observations were already centered to the strictest NUV AD requirement of $< 0.041''$ 41% of the time. For the looser FUV requirement of $<$0.106″, COS TAs are already centered to the required AD accuracy 82% of the time.

Table 4. FUV/PSA On-Orbit `ACQ/PEAKXD` Accuracies.

FUV Grating	Cenwave (Å)	$\Delta\mathrm{XD}_{measured}$ (PSA-WCA)	$\sigma_{measured}$ (PSA-WCA)	# of ACQ/ PEAKXDs[b]	$\Delta\mathrm{XD}_{commanded}$ (PSA-WCA)	$\delta\Delta\mathrm{XD}$ (measured-commanded)	FUV Segment
G130M	1291	-88.13	1.05	47	-87.80	0.33	FUVA
G130M	1291	-88.29	1.08	40	-87.80	0.49	FUVB
G130M	1291	-86.28	4.72	46	-87.80	-1.52	FUVAB
G130M	1300	-88.29	1.07	23	-87.80	0.49	FUVA
G130M	1300	-88.55	1.38	23	-87.80	0.75	FUVB
G130M	1300	-88.08	1.25	23	-87.80	0.28	FUVAB
G130M	1309	-88.29	2.85	45	-87.80	0.49	FUVA
G130M	1309	-88.67	3.88	41	-87.80	0.87	FUVB
G130M	1309	-87.93	3.58	41	-87.80	0.13	FUVAB
G130M	1318	-87.31	1.14	15	-87.80	-0.49	FUVA
G130M	1318	-88.45	1.32	15	-87.80	0.65	FUVB
G130M	1318	-87.60	1.18	15	-87.80	-0.20	FUVAB
G130M	1327	-88.43	1.01	9	-87.80	0.63	FUVA
G130M	1327	-89.10	1.13	7	-87.80	1.30	FUVB
G130M	1327	-88.70	1.00	8	-87.80	0.90	FUVAB
G130M	ALL	-88.01	1.28	135	-87.80	0.21	FUVA
G130M	ALL	-88.43	1.57	124	-87.80	0.63	FUVB
G130M	ALL	-87.79	1.44	124	-87.80	-0.01	FUVAB
G160M	1577	-88.28	1.07	5	-87.80	0.48	FUVA
G160M	1577	-89.28	1.54	6	-87.80	1.48	FUVB
G160M	1577	-89.06	1.43	6	-87.80	1.26	FUVAB
G160M	1589	-88.21	2.38	41	-87.80	0.41	FUVA
G160M	1589	-89.29	2.71	45	-87.80	1.49	FUVB
G160M	1589	-89.77	3.02	49	-87.80	1.97	FUVAB
G160M	1600	-87.66	1.16	48	-87.80	-0.14	FUVA
G160M	1600	-89.09	1.28	52	-87.80	1.29	FUVB
G160M	1600	-88.97	1.39	52	-87.80	1.17	FUVAB
G160M	1611	-88.99	1.07	26	-87.80	1.19	FUVA
G160M	1611	-89.35	1.20	24	-87.80	1.55	FUVB
G160M	1611	-89.42	1.31	24	-87.80	1.62	FUVAB
G160M	1623	-88.86	1.14	45	-87.80	1.06	FUVA
G160M	1623	-90.00	1.29	43	-87.80	2.20	FUVB
G160M	1623	-89.84	1.31	45	-87.80	2.04	FUVAB
G160M	ALL	-88.34	1.33	163	-87.80	0.54	FUVA
G160M	ALL	-89.37	1.41	167	-87.80	1.57	FUVB
G160M	ALL	-89.42	1.46	171	-87.80	1.62	FUVAB
G140L	1105	-86.61	1.41	8	-86.40	0.21	FUVA
G140L	1230	-86.89	3.11	46	-86.40	0.49	FUVA
G140L	ALL	-86.85	2.92	54	-86.40	0.45	FUVA

Note. — Offsets are broken down by segment; FUVA, FUVB, or both (FUVAB). Unless specified, `ACQ/PEAKXD` uses both; unless the grating is G140L (Segment-A only). Offsets and errors are in units of raw coordinate FUV Segment-A XD digital elements (DEs), which are $\sim 0.1''$. These results include all observations taken between 2009.215 and 2010.119.

[a]Only Segment-A is used for G140L TAs.

[b]Only XD profiles with a signal-to-noise ratio greater than 40 are considered.

Table 5. Average On-Orbit ACQ/PEAKD Centering Moves.

Grating or Channel	Aperture	|AD Offset|	$\sigma_{\|AD\ Offset\|}$	# of Centerings
G185M	PSA	0.001″	0.156″	16
G225M	PSA	0.060″	0.037″	9
G285M	PSA	-0.055″	0.000″	1
G230L	PSA	0.011″	0.054″	15
G185M	BOA	0.013″	···	1
G225M	BOA	-0.002″	···	1
G285M	BOA	-0.030″	0.072″	3
G230L	BOA	···	···	0
NUV	PSA	0.016″	0.105 ″	41
NUV	BOA	-0.016″	0.054 ″	5
G130M	PSA	0.007″	0.238 ″	46
G160M	PSA	0.017″	0.064 ″	17
G140L	PSA	0.053″	0.069 ″	9
G130M	BOA	0.081″	0.119″	3
G160M	BOA	···	···	0
G140L	BOA	···	···	0
FUV	PSA	0.015″	0.194 ″	72
FUV	BOA	0.081″	0.119 ″	3
ALL	PSA	0.015″	0.167″	113
ALL	BOA	0.021″	0.091″	8
ALL	ALL	0.016″	0.163″	121

Note. — Only ACQ/PEAKDs with SCAN−SIZE=5 and not CENTER=RTB, or SCAN−SIZE=3 and CENTER=FW taken between 2009.215–2010.119 are included. After the initial spectroscopic ACQ/SEARCHs, NUV+PSA were already centered to the strictest NUV requirement of $< 0.041''$ 41% of the time. For the looser FUV requirement of $< 0.106''$ observations were already centered to the required accuracy 79% of the time.

Note. — Some lower signal-to-noise and high background (SAA) observations were removed from the full sample to create this table.

To test the on-orbit performance of ACQ/PEAKD, a subsample of the aligned dwell points shown in the bottom panels of Figure **??** was created. The NUV and FUV PSA profiles appear to be similar enough to merge the results of all ACQ/PEAKD trials together. BOA, CENTER=RTB, low signal-to-noise, SAA impacted ACQ/PEAKDs, and ACQ/PEAKDs with SCAN-SIZE=3 were removed from the sample. All CENTER=FWF observations in the sample were converted back to detected counts on the sky by adding the subtracted background (floor) number of counts back into the dwell counts. The merged transmission versus AD profile is show in Figure **??**.

This AD profile was used to evaluate the performance of trial ACQ/PEAKDs. SCAN-SIZEs of 0.2–2.0 and STEP-SIZEs of 3, 5, 7, and 9 were tested with all three CENTER options (FW, FWF, RTB). The input distribution was taken to be that reported in Table **??** ($1\sigma =$). A total of 30,000 normally distributed initial AD offset values were evaluated with simulated ACQ/PEAKDs. The results of these simulations are shown in Figure **??**. The different SCAN-SIZEs are shown in different colors, and the different CENTERs are in different panels. The abscissa is the SCAN-SIZEs, and the ordinate is the standard deviation of the simulated centering error. Horizontal lines indicate our strictest FUV (0.106″) and NUV (0.041″) centering requirements.

5 COS TA, Detector Backgrounds, and the SAA

As outlined in detail in the ISRs COS 2010-11 ("COS NUV Detector Rates During SMOV and Early Cycle 17") and COS 2010-12 ("COS NUV Detector Dark Rates During SMOV and Early Cycle 17"), the NUV and FUV detector backgrounds increase with proximity to the SAA, and the NUV count rate is slowly increasing with time. The detector background has no effect on normal FUV target acquisitions. NUV MIRRORB imaging TAs could be affected as outlined below.

Figure **??** shows the FUV dark count rate measured inside the G130M/1309Å FUV TA subarrays for Segment A (red upward triangles), Segment B (blue downward triangles), and both (green diamonds). Excepting the FUV dark count measurements taken between 2009.5–2009.7 (which included intentional excursions near the SAA during SMOV), the FUV dark count rate is constant for both segments at around 3 counts/second over the TA subarrays. Gaussian error bars ($\sqrt{counts}$) are included in the figure, but are smaller than the plotting symbols.

Discuss updated parameter table.

Table 6. Recommended TA Options

Acquisition Type	Description	SCAN-SIZE	STEP-SIZE (″)	Parameters	Recommendation	Required S/N
ACQ/SEARCH	Spiral pattern;	2	1.767	CENTER=FW,FWF,RTB	FW	40
	Multiple	3	1.767		FWF	40
	exposures	4	1.767		FWF	40
		5	1.767		FWF	40
ACQ/PEAKXD	One exposure	N/A	N/A	FUV: SEGMENT=A,B,BOTH	BOTH	40
		N/A	N/A	NUV: STRIPE=A,B,C	B (MED)	40 to 100
ACQ/PEAKD	Linear pattern;	3	1.5[a]	CENTER=FW,FWF,RTB	FW	40 to 100
	Multiple	5	1.1[a]		FWF	
	exposures	7	1.0		FWF	
		9	0.7[b]		FWF	
ACQ/IMAGE	Initial and	1	N/A	Aperture=PSA,BOA		40 (PSA)
	confirm images	1	N/A	Mirror=A,B		40 60 (BOA)

[a]The previously recommended value was 1.2″.

[b]The previously recommended value was 1.0″.

6 Summary

In 2010, a series of minor adjustments are planned to further enhance the performance of COS TA based upon the performance of GTO and GO TAs under on-orbit usage.

Our updated recommendations are:

1. All TA modes are providing good centering, although there is some room for improvement in certain modes.[2] If you need maximum wavelength accuracy, use NUV imaging mode, otherwise use the mode that is fastest based upon STScI ETC simulation.

2. A single `ACQ/SEARCH` is not sufficient to center a COS point-source target in the aperture; always follow up the first `ACQ/SEARCH` with an `ACQ/IMAGE`, `ACQ/PEAKXD`+`ACQ/PEAKD`, or a second 2x2 `ACQ/SEARCH`.

3. With the correction to the FGS-to-COS offset (the SIAF update), COS `ACQ/SEARCH` requirements can be relaxed to allow faster target centering. The recommended `ACQ/SEARCH` `SCAN-SIZE` parameters listed in Table **??**, are based primarily upon the confidence observers have in their target coordinates. Spending extra time to validate target coordinates is the best way save TA time.

4. Use `STRIPE`=B if at all possible for NUV spectroscopic `ACQ/PEAKXD`s.

5. Because of potential cross-contamination between stripes, NUV spectroscopic TAs should not be used with extended sources.

6. Use `SCAN-SIZE`=5, `STEP-SIZE`=0.9, and `CENTER`=FWF for most `ACQ/PEAKD` centerings. For the most accurate AD centering possible, use `SCANSIZE`=9, `STEP-SIZE`=0.6, and `CENTER`=FWF. Where minimal TA time is required, use `SCAN-SIZE`=3, `STEP-SIZE`=1.3, and `CENTER`=FW.

[2]See #8 and 10, which discuss known problems with FUV/G160M and NUV/BOA spectroscopic TAs.

7. Signal-to-noise (S/N) is important to an accurate TA; use S/N=40 for PSA TAs, and S/N=60 for BOA.

8. FUV spectroscopic TAs that require absolute photometric accuracy should avoid G160M `ACQ/PEAKXD`s as these can occasionally be partially vignetted. The `ACQ/PEAKXD` phase of FUV TA may not be able to properly center the target in the XD direction. This is partially due to errors in the Segment B-to-A mapping parameters, which should be updated.

9. The WCA+MIRRORB `LTAIMCAL` TA subarrays should be reduced to avoid contamination from the rising NUV detector background. The `LTAIMAGE` subarrays could also be reduced; this would not affect the quality of the TA, but would reduce processing time of the centering step.

10. The NUV imaging `ACQ/SEARCH` TA subarrays should be reduced to avoid contamination from the rising NUV detector background.

11. Due to incorrect WCA-to-PSA parameters, NUV BOA spectroscopic TAs will currently not correctly center the target in the aperture. No BOA spectroscopic TAs are scheduled for Cycle 17, and this will be corrected before Cycle 18.

12. The current COS SAA contours should be adjusted to prevent any COS TAs from occuring in the elevated background region that currently exists over South America. COS TAs that use `ACQ/SEARCH` and/or `ACQ/PEAKD` will not center the target correctly in this region.[3]

13. The number of counts in the primary spot from the wavelength calibration lamp in `LTAIMCAL` in `MIRRORB` mode has been decreasing since SMOV. Reducing the size of the `LTAIMCAL` subarrays is planned (**??**, above) and will help with signal-to-noise issues, but may not be enough to negatively impact `ACQ/IMAGE` + `MIRRORB` centering (one of the most used TA modes). The number of counts determined to have come from the wavelength calibration lamp during `LTAIMCAL` should be monitored, and the exposure time for `LTAIMCAL+` `MIRRORB` may need to be increased for Cycle 19 and beyond.

[3]COS SAA contours were adjusted in PRs# 65147, 65227, and 65188 on May 13–25, 2010