

Cosmic Origins Spectrograph : Target Acquisition Performance and Updated Guidelines

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Steven V. Penton¹, C. Keyes², S. Osterman¹, D. Sahnou³, COS IDT Team, & STScI COS Team

¹Univ. of Colorado, ²Space Telescope Science Institute, ³Johns Hopkins University.



Cosmic Origins Spectrograph (COS) is a slit-less spectrograph with a very small aperture (R=1.25"). To achieve the desired wavelength accuracies, HST+COS must center the target to within ~0.1" of the center of the aperture for FUV, and ~0.4" for NUV (the angle subtended by this poster when viewed from over 2800 miles away). During SMOV we fine-tuned the COS target acquisition (TA) procedures to exceed this accuracy for all three COS TA modes; NUV imaging, NUV spectroscopic, and FUV spectroscopic. We compare all COS TA modes in terms of centering accuracy, efficiency, and required signal-to-noise (S/N) for all targets suitable for use with COS. We also provide updated recommendations for the options of all TA modes. HST is providing a good, but not perfect, blind pointing accuracy in both the along-dispersion (AD) and cross-dispersion (XD) directions. We discuss the implications of this, and other lessons learned in SMOV, on Cycle 17 and 18 HST+COS TAs.

The Basics

There are four Target Acquisition (TA) modes:

- ACQ/SEARCH:** performs a search in a spiral pattern by executing individual exposures at each point in a square grid pattern. This mode can use either dispersed-light or imaging exposures.
- ACQ/IMAGE:** obtains an NUV image of the target field, moves the telescope to center the object, and secures a second NUV image as a confirmation.
- ACQ/PEAKXD:** determines the centroid of the dispersed-light spectrum in the direction perpendicular to dispersion and moves the telescope to center the object in the cross-dispersion direction.
- ACQ/PEAKD:** centers the target in the dispersion direction by executing individual exposures at each point in a linear pattern along the dispersion axis.

Coordinate accuracy and target brightness will determine your choice of TA strategy and optional parameters.

Centering Requirements

Wavelengths assigned to COS data are required to have an accuracy equivalent to an absolute uncertainty of less than ±15 km/s in the medium resolution modes, ±150 km/s in mode G140L and ±175 km/s in mode G230L. In the cross-dispersion (XD) direction, the requirement is to be centered to within ±0.3", however, our goal is ±0.1" for FUV flat-fielding purposes. Since the along-dispersion (AD) requirement is in units of km/s, it is detector and wavelength dependent as defined and shown below:

$$\Delta AD (\text{\AA}) = (\text{velocity requirement} \times \lambda) / (c \times \text{dispersion}(\text{\AA}/p) \times \text{platescale} (p''))$$

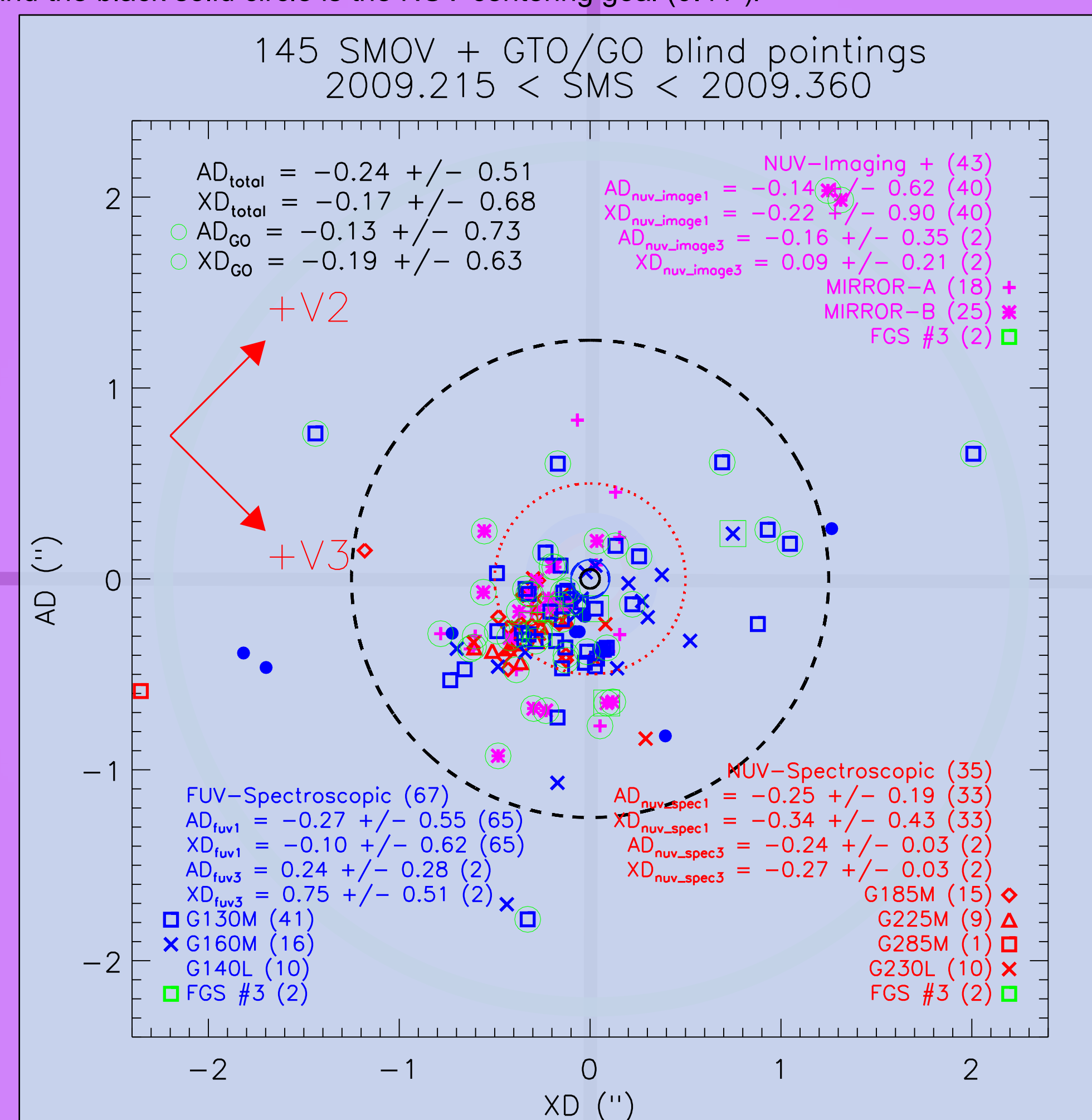
$\Delta AD(G185M@1825\text{\AA}) = \frac{15 \text{ km s}^{-1} \times 1825\text{\AA}}{c \times 0.037\text{\AA}/p \times 42.47p''} = 0.058''$
$\Delta AD(G225M@2250\text{\AA}) = \frac{15 \text{ km s}^{-1} \times 2250\text{\AA}}{c \times 0.035\text{\AA}/p \times 42.47p''} = 0.076''$
$\Delta AD(G285M@2850\text{\AA}) = \frac{15 \text{ km s}^{-1} \times 2850\text{\AA}}{c \times 0.040\text{\AA}/p \times 42.47p''} = 0.084''$
$\Delta AD(G230L@2450\text{\AA}) = \frac{175 \text{ km s}^{-1} \times 2450\text{\AA}}{c \times 0.390\text{\AA}/p \times 42.47p''} = 0.086''$
$\Delta AD(G130M@1300\text{\AA}) = \frac{15 \text{ km s}^{-1} \times 1300\text{\AA}}{c \times 0.00997\text{\AA}/p \times 43.5p''} = 0.150''$
$\Delta AD(G160M@1600\text{\AA}) = \frac{15 \text{ km s}^{-1} \times 1600\text{\AA}}{c \times 0.01223\text{\AA}/p \times 42.9p''} = 0.153''$
$\Delta AD(G140L@1800\text{\AA}) = \frac{150 \text{ km s}^{-1} \times 1800\text{\AA}}{c \times 0.08030\text{\AA}/p \times 45.4p''} = 0.247''$

Assuming that the wavelength error budget is split evenly between the COS TA and wavelength scale accuracy, the allowable TA centering errors, in arcseconds("), are given in the table below. The strictest requirement for each grating is highlighted in **RED**.

Grating	Total Error Budget	TA Requirement
G185M	0.058"	0.041"
G225M	0.076"	0.054"
G285M	0.084"	0.059"
G230L	0.086"	0.061"
G130M	0.150"	0.106"
G160M	0.153"	0.108"
G140L	0.247"	0.175"

HST Blind Pointing

By reverse engineering the actions performed by COS TAs, we have been able to approximate the blind pointing accuracy of HST+COS. The mean blind pointing offset in [AD,XD] coordinates was [-0.24±0.51, -0.17±0.68]", indicating a possible offset in the FGS to COS alignment. The outer black dashed circle in the figure below represents the R=1.25" aperture, the red dotted circle is the centering limit to transmit maximum flux, the blue dashed circle is the FUV centering goal (0.106"), and the black solid circle is the NUV centering goal (0.41").



GO observations are highlighted by green circles. If the dominant FGS was #3 a green box is added.

Conclusions & Recommendations

By evaluating the actions performed by the TA steps we have been able to monitor the performance of COS TA during early operations. During SMOV we adjusted many COS TA parameters to our best determinations of the values for early operations. In early 2010, we will be making a series of minor adjustments to further enhance the performance of COS TA based upon the performance of GTO and GO TAs under on-orbit usage. Our preliminary updated recommendations are:

➔ All TA modes are providing good centering. If you need maximum wavelength accuracy, use NUV imaging mode, otherwise use the mode that is fastest based upon STScI ETC simulation.

➔ 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.

➔ There is currently a small systematic blind pointing FGS to COS offset. Once this systematic offset has been corrected, future COS ACQ/SEARCHs will have relaxed requirements to allow faster target centering. The currently recommended ACQ/SEARCH SCAN-SIZE parameters, given below, are based primarily upon the confidence the observer has in their target coordinates. Spending extra time to validate target coordinates is the best way save TA time.

Scan-size	Uncertainty (")
2	$\sigma < 0.4''$
3	$0.4 < \sigma < 1.0''$
4	$1.0 < \sigma < 1.3''$
5	$1.3 < \sigma < 1.6''$

➔ Use STRIPE=B if at all possible for NUV spectroscopic ACQ/PEAKXD.

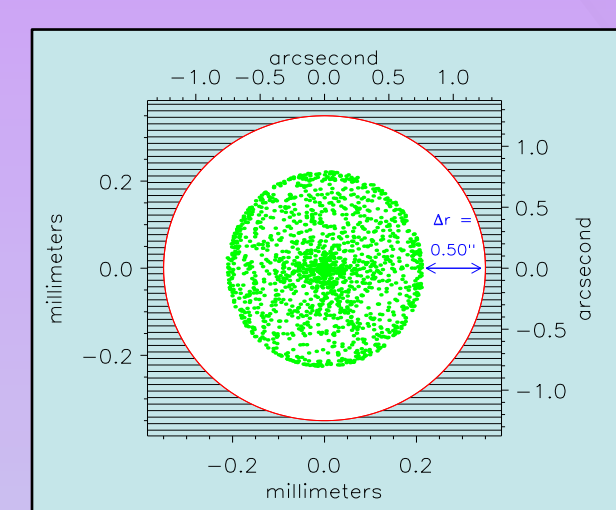
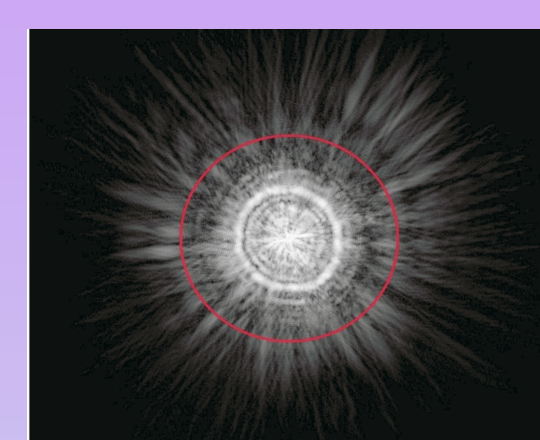
➔ Use SCAN-SIZE=5, STEP-SIZE=1.1, & CENTER=FLUXFLR for most ACQ/PEAKD centerings. For the most accurate AD centering possible, use SCANSIZE=9, STEP-SIZE=0.7, & CENTER=FLUXFLR. Where minimal TA time is required, use SCAN-SIZE=3, STEP-SIZE=1.4, & CENTER=FLUXWT.

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

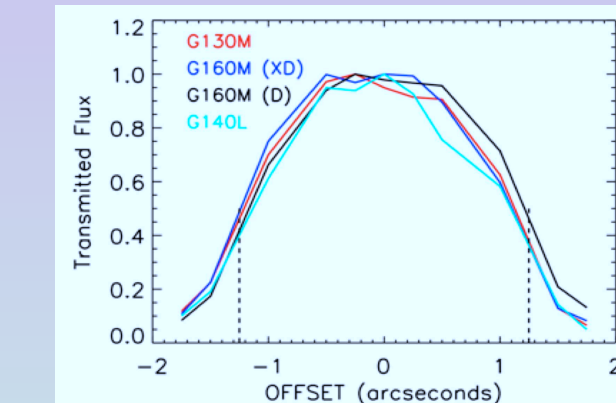
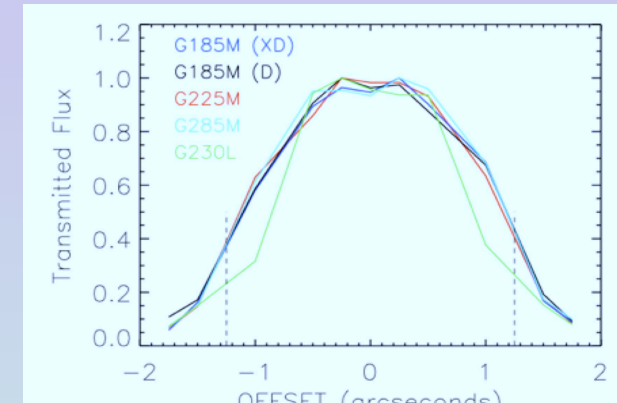
A complete summary of early COS TA analysis and Cycle 18 recommendations will be released in early 2010 as an STScI Instrument Science Report available at <http://www.stsci.edu>.

ACQ/SEARCH

Ray-tracing and computer simulations predict that properly designed ACQ/SEARCHs in all modes should center the target to within 0.1-0.2" in both AD and XD given that the target was within the box on the sky contained by the outer dwell points. These simulations were based upon the predicted, and not the observed PSF (see below). The observed PSF is noticeably asymmetric and contains a much larger percentage of the light in the extended wings (see below). The PSF asymmetries and extended wings, along with the extended transmission function of the aperture tend to feed incorrect information into the centering algorithm. On-orbit, a single ACQ/SEARCH should be expected to center the target to no better than 0.3" in either AD and XD, and depending on where the target falls in the pattern, it could easily be 0.4" off-center. This is why we recommend that all COS TAs follow up their initial ACQ/SEARCH with either an ACQ/IMAGE, ACQ/PEAKXD+PEAKD, or a second 2x2 ACQ/SEARCH. Further statistics on the on-orbit performance of ACQ/SEARCH are based upon analysis of the TA steps following the ACQ/SEARCHs, and are given in the other panels and the summary.



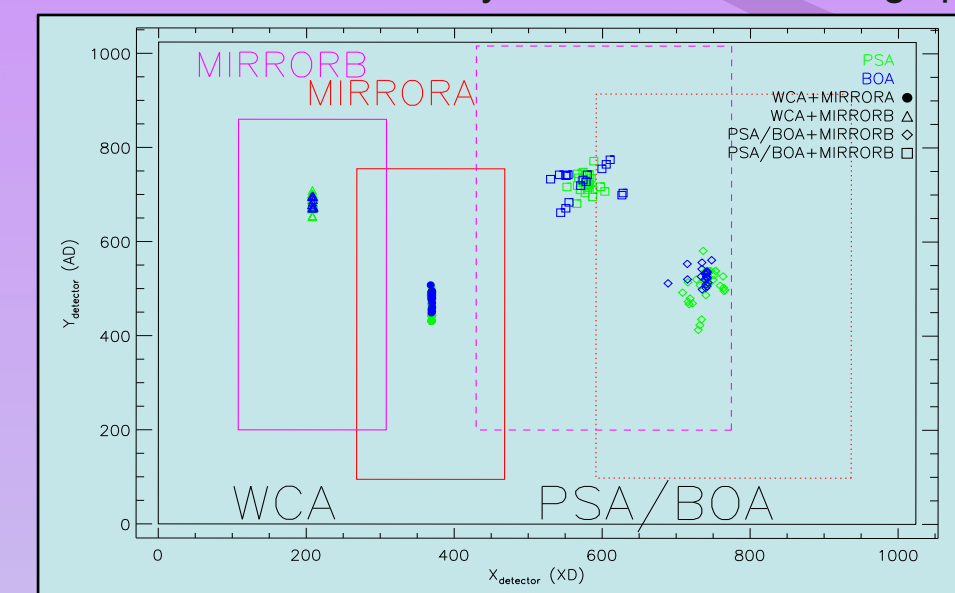
The left figure shows the on-orbit PSF at the COS aperture, the pre-launch estimate is on the right. The red circles are the size of the aperture. The pre-launch PSF has central peak and a symmetric outer ring of radius 0.75". The on-orbit PSF is not symmetric, and has considerable power (> 5%) in extended wings and rings.



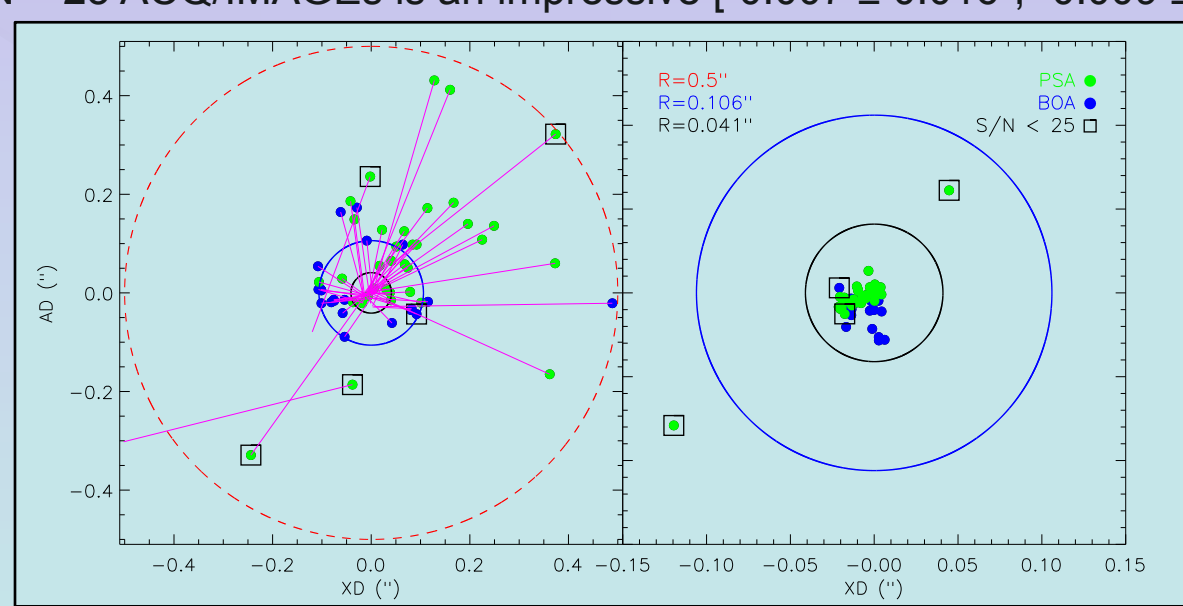
The left figure shows the relative COS aperture throughput as a function of XD or AD (D in figure) offset from the center of the aperture for all NUV gratings. The right figure is for the FUV.

ACQ/IMAGE

Wavelength calibration lamp (WCA) flashes first determine the location of the aperture block on the NUV detector, then an image of the sky is taken. After measuring the positions of the target and the WCA, the slew required to center the target is determined and performed. Depending on target flux, this can be performed with (PSA or BOA) + (MIRRORA or MIRRORB). PSA/BOA images land on about the same location on the detector, but MIRRORA and MIRRORB (a reflection off the order sorter in front of MIRRORA) images land at different locations. The figure below shows the on-orbit WCA, initial target locations, and the TA subarrays used in determining spot locations.

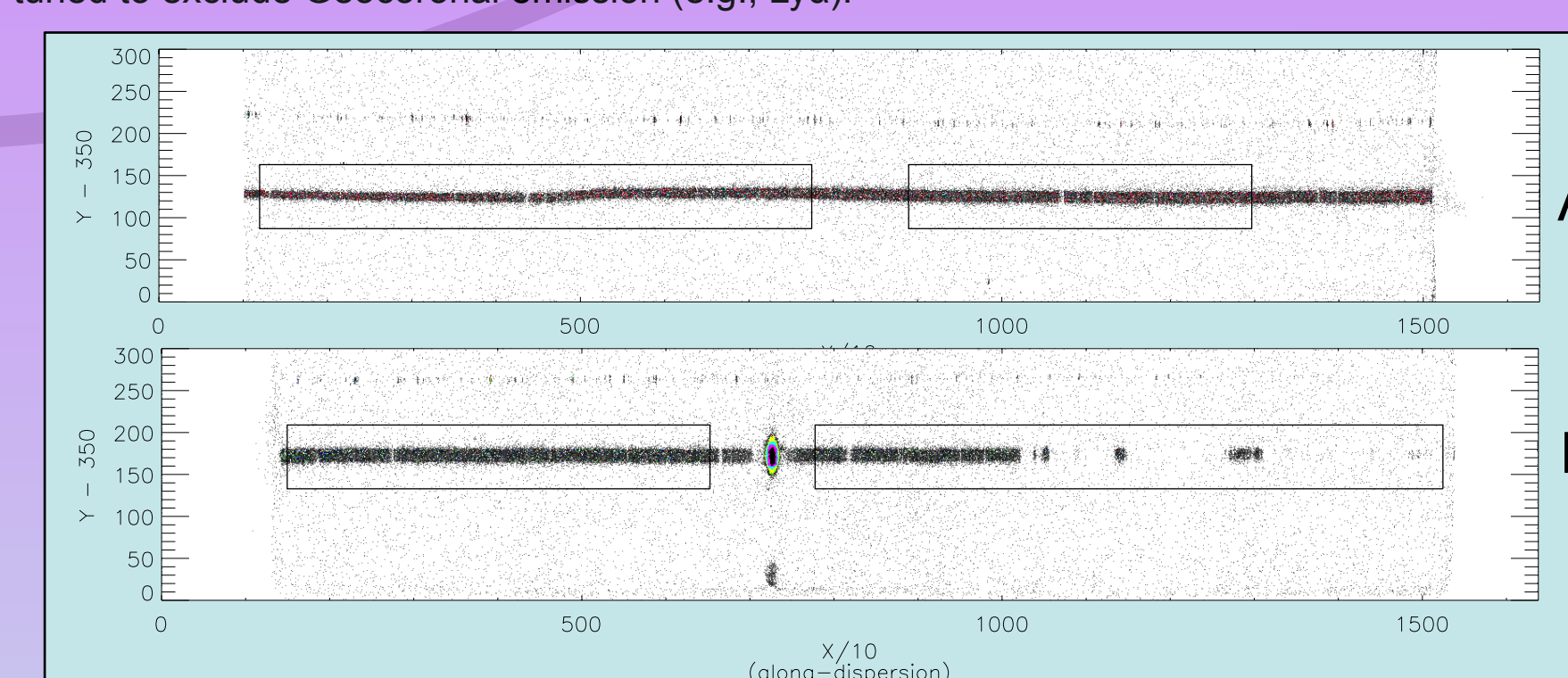


Comparing the initial target locations to those measured from the confirmation images, we can directly measure the centering accuracy of ACQ/IMAGE. The left figure below shows the above initial centerings compared to the circles denoting the required NUV, FUV, and full transmission centering accuracies. Also shown by the lines are the performed centerings. The right panel shows the final centerings. Boxes outline TAs taken with signal-to-noise (SN) < 25. The final [AD,XD] centering accuracy of all SN > 25 ACQ/IMAGEs is an impressive [-0.007 ± 0.016", -0.009 ± 0.012"].



ACQ/PEAKXD

ACQ/PEAKXD sequences start with a flash of the wavelength calibration lamp (WCA), followed by a brief spectrum. The measured WCA position allows one to calculate the desired XD location of the science spectrum. The slew required to put the spectrum at this location is calculated and performed. For NUV TAs, one must specify which stripe to center upon. The optional parameter is STRIPE=A, B, or C. For FUV TAs, one must specify which segment(s) to use SEGMENT=A,B, or BOTH. To limit the amount of detector background contributing to the WCA location, a single subarray is used for the NUV detector and one for each of the FUV segments (if applicable). As shown below, FUV subarrays are tuned to exclude Geocoronal emission (e.g., Ly α).



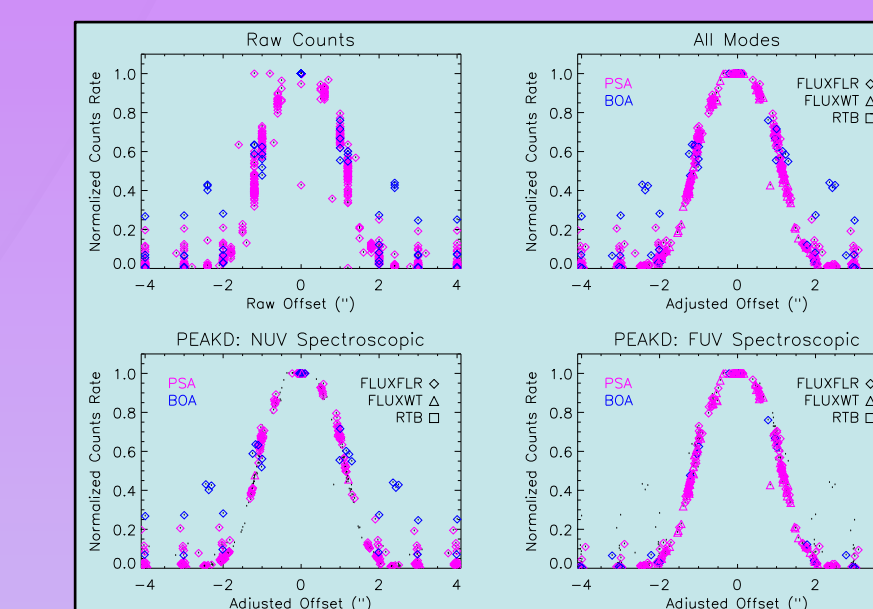
FUV ACQ/PEAKXDs are complicated by the:
 ✘ distortions present in the raw coordinate frame (no thermal or geometric correction),
 ✘ wavelength dependent XD profile of FUV spectra (different targets are centered differently)
 ✘ mapping of segment B spectra onto the segment A coordinate system (each segment has different raw digital element XD sizes and zero point offsets).

NUV ACQ/PEAKXDs are complicated by:
 ✘ an additional error is present if STRIPE is not equal to B,
 ✘ science stripes are tilted relative to the detector (different targets are centered differently),
 ✘ each grating has a unique plate scale, but the average is used for all NUV gratings.

The average ACQ/PEAKXD motions will tell us the accuracy of spectroscopic ACQ/SEARCHs.

ACQ/PEAKD

ACQ/PEAKD is a 1D along-dispersion (AD) version of ACQ/SEARCH. The transmission of the COS apertures is essentially flat within the central 0.5" then tails off in a non-linear, but approximately symmetric profile.



Upper left panel above shows the normalized ACQ/PEAKD results. The upper right panel shows the normalized counts after alignment based upon the chosen centering method. The lower left panel highlights the NUV results, while the lower right panel gives the FUV results. The centering results for all appropriate observations were merged to a composite profile representing the average on-orbit AD profile. The average correcting maneuver was $0.018 \pm 0.127''$. This profile was used to create simulations for all ranges of the parameters SCAN-SIZE and STEP-SIZE, with a background appropriate for a 15 second observation. As shown below, there are several centering options that are exceeding the FUV (0.106") and NUV (0.041") centering requirements.

