TAACOS: Target Acquisition Analysis for the Cosmic Origins Spectrograph

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1. SCOPE

The purpose of the Target Acquisition Analysis for the Cosmic Origins Spectrograph (TAACOS) is to ensure that the algorithms and procedures defined in COS OP-01, IN0090-619, IN0090-623 and COS-FSW-001 are sufficient to accurately place a science target of interest at a proper location in the aperture in a timely and efficient fashion.

1.1 PROJECT OVERVIEW

The TAACOS will be performed in two phases. Phase I of the Target Acquisition (TA) analysis will provide a ``quick-look" evaluation for all TA steps to determine if the proposed algorithms are viable. Phase I will test both the near ultraviolet (NUV) and far ultraviolet (FUV) detectors for a limited set of targets and gratings. Phase II of TAACOS will expand the targets tested, and will include all COS gratings.

For both phases, the FUV channel TA will be evaluated for the G160M grating and the NUV channel will be evaluated for the G225M grating. For Phase I of this evaluation, we will restrict our analysis to the acquisition of an isolated z=1 quasi-stellar object (QSO) with $F_\lambda = 10^{-15}$ ergs/cm^2/s/Å. Only the 2.5" diameter primary science aperture (PSA) will be tested in Phase I. Phase II will test stellar targets of varying type and magnitude, QSO targets with varying spectral index, redshift, and flux, crowded fields, and extended targets. The Phase II analysis will be performed using the PSA and the bright object aperture (BOA) at all planned aperture locations.

1.2 SCOPE

Since all Hubble Space Telescope (HST)/COS TA is performed spectroscopically, this task will require the creation of a COS simulator which will produce a NUV or FUV detector image for any grating configuration, target location, and target spectra. This effort will rely heavily on ground-based estimations of the COS in-orbit performance. This analysis will be performed using ray-tracing and other software developed within the Interactive Data Language (IDL) environment at the Center for Space Astronomy/University (CASA/CU). Some simplifications will be required, however TAACOS should be sufficient to predict if the proposed TA algorithms are adequate, and to provide alternative strategies where deficiencies are identified. The TAACOS efforts will lead to accurate science exposure and target acquisition temporal simulators. Final algorithms will be tested during the integration and testing (I&T) phase of the COS development. This analysis and simulation will be performed for all four stages of the TA process, Calibrate Aperture Location (CAL), Target Search (TS), Peakup in the Cross-Dispersion Direction (PCD), and Peakup in the Dispersion Direction (PD).

2. APPLICABLE DOCUMENTS

The following documentation describes the algorithms and procedures proposed for HST/COS target acquisition.

COS OP-01	COS Science Operations Requirement Document (CASA)
IN0090-619	Control Section Flight Software Requirements Document for the COS (BATC)
IN0090-623	Software Design Document for the Control Section Flight Software for the COS (BATC)
COS-FSW-001	Target Acquisition Concepts for COS (BATC)

3. LIST OF ACRONYMS AND ABBREVIATIONS

BATC	Ball Aerospace & Technologies Corp.
BOA	Bright Object Aperture
CAL	Calibrate Aperture Location
CASA	Center for Astrophysics and Space Astronomy
COS	Cosmic Origins Spectrograph
CU	University of Colorado
FUV	Far UltraViolet
HST	Hubble Space Telescope
IDL	Interactive Data Language
I&T	Integration and Testing
NUV	Near UltraViolet
PCD	Peakup in the Cross-Dispersion Direction
PD	Peakup in the Dispersion Direction
PtNe	Platinum-Neon
PSA	Primary Science Aperture
QSO	Quasi-Stellar Object
TA	Target Acquisition
TAACOS	TA Analysis for COS
TS	(Spiral) Target Search

4. REQUIREMENTS BY TA STEP

4.1 CALIBRATE APERTURE LOCATION

The Calibrate Aperture Location (CAL) procedure locates the cross-dispersion spectral location of the Platinum-Neon (PtNe) calibration lamp on the detector. Photons from the calibration lamp follow the same optical path as those of a science observation, but are directed through a different aperture than science targets. The known offset between the calibration and science apertures allows one to determine the optimum location of the science target in the science aperture based upon the location of the calibration spectrum on the detector. Due to variations in the mechanical position of the grating and the conversion of photons into digitized pixels, it is expected that this procedure will be required for each target acquisition. If the spectrum is symmetric in the cross-dispersion direction, determining the mean cross-dispersion location is sufficient to identify the position of the CAL spectrum. If the CAL spectrum is asymmetric in the cross-dispersion profile, or if the CAL spectrum is rotated with respect to the detector, an alternate algorithm may be required. The wavelength dependence of the cross-dispersion profile will also be examined. Phase I of this analysis will determine if a more sophisticated algorithm is required, and if so, recommend alternate strategies. Phase I will evaluate the cross-dispersion profile of the CAL spectrum and predict the elapsed time[1] required to properly determine the location of the calibration spectrum on the detector. Information required before the Phase I simulation can begin are:

1. The expected location of the calibration spectrum, in detector coordinates, for both detectors. For the FUV detector, the G160M grating will be used, while the G225M grating will be used for the NUV detector.
2. The expected offset, in detector pixels, between the calibration spectrum and a properly positioned target in PSA for both the FUV/G160M and NUV/G225M configurations.

The Phase I FUV analysis will be performed using each of the FUV detector segments, separately and together. Elapsed time estimates will be provided for all configurations. Phase II will test the CAL procedure for the remaining gratings, including elapsed time estimates. The above constants for these configurations will be required at that time. For each configuration, the symmetry of the cross-dispersion profile will be evaluated.

4.2 TARGET SEARCH

The spiral Target Search (TS) procedure is used to ensure that the science target is in the science aperture. The mandatory TS centering accuracy is determined by requiring that the target spectrum is on the detector and is within some known detector subarray appropriate for the subsequent cross-dispersion peakup (PCD) and dispersion peakup (PD) TA steps. This accuracy (and the subarray sizes) will not be known until the completion of Phase I of the TAACOS analysis, and is dependent upon the robustness and subarray sizes of the subsequent TA steps (PCD and PD). For example, the FUV

[1] The elapsed time calculations will include both exposure and computation time, including local rate check exposures.

detector segments are composed of ~6x10μm pixels, and a 1" cross-dispersion TS centering error corresponds to a ~250μm displacement on the detector, or approximately 42 dispersion or 25 cross-dispersion pixels. The Phase I evaluation of the proposed subsequent PCD and PD TA algorithms will determine if they can implement displacements of this magnitude. This evaluation will allow requirements to be established for the accuracy of the TS centering. It is possible that merely ensuring that the target is in the aperture will be sufficient for subsequent PCD and PD processing.

For the simulation, it is assumed that the initial HST centers the target with a 1σ accuracy of 1". This is consistent with GHRS, FOS, and STIS acquisition histories. Given the initial HST centering accuracy, and the 2.5" diameter circular PSA, there is no guarantee that the target will be in the aperture. Therefore, a spiral search pattern of specified size, with specified distance between each dwell point, will be performed during TS to ensure that the target is in the aperture. The analysis of the TS procedure will determine the required accuracy of the TS centering, thereby determining the number and offset of the dwell points. In Phase I, the 2.5" diameter circular PSA using 3x3 and 5x5 grids will be considered. For the 3x3 search offsets between 1.250" and 1.767" will be tested, while for the 5x5 search offsets between 0.625" and 0.884" will be tested. These grids are displayed in Figure 1, and are compared to the 3σ HST initial centering accuracy. The Phase I evaluation will be performed only for an isolated z=1 QSO with $F_\lambda = 10^{-15}$ ergs/cm^2/s/Å. TS accuracies and elapsed time estimates will be evaluated for the FUV/G160M and NUV/G225M configurations.

Phase I evaluation should be sufficient to determine the optimum TS strategy and provide elapsed time[2] estimates for all strategies. The TS strategies to be considered are (1) return to the brightest pointing and (2) slew to the flux-weighted centroid (using only those pointings above a specified count rate threshold).

The FUV evaluation will be performed using each detector segment separately, and together to determine the optimum operating procedure. Phase II of the TS evaluation will repeat the Phase I analysis for the Phase II targets described in §6. Phase I and II testing will require the development of the COS simulator described in §7.

[2] [2] The elapsed time calculations will include exposure, slew, and computation time, including local rate check exposures.

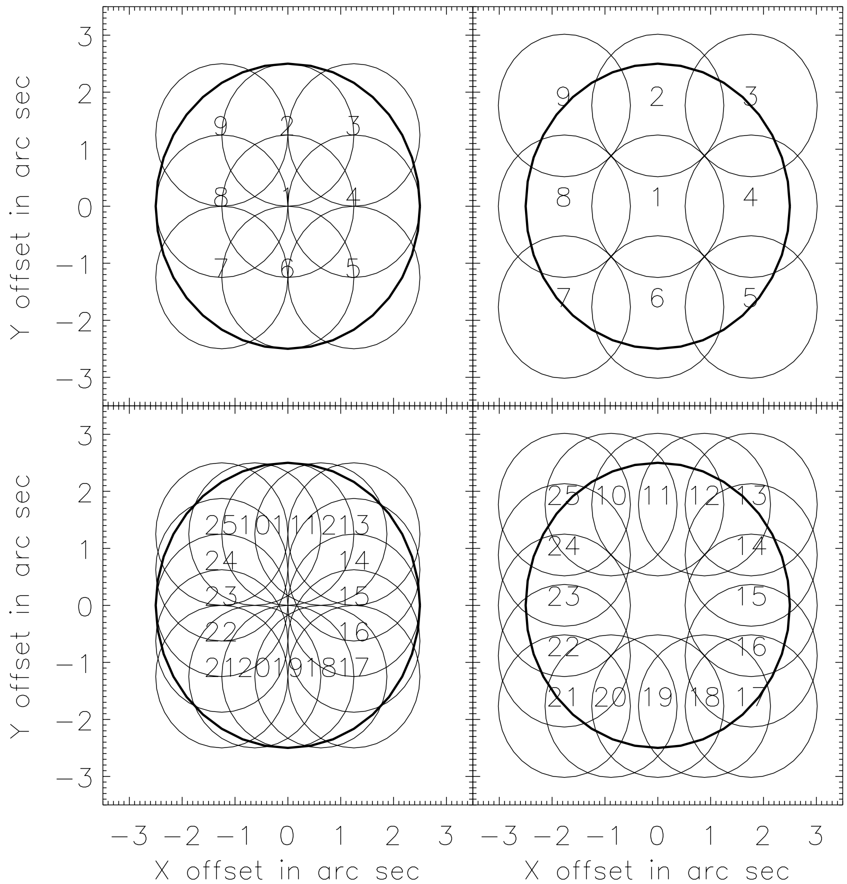

Figure 1: Aperture sky location extents of the TS analysis. The upper left panel shows the 3x3-spiral search for a 1.250" offset between dwell points for the 2.5" diameter circular PSA. The centered 5" diameter dark circle indicates the 3σ extent of the initial HST slew error. The upper right panel shows the 3x3 search for 1.767" offsets. The bottom panels indicate the search pattern for 5x5 grids with dwell point offsets of 0.625" (left) and 0.884" (right). For clarity, the first 9 dwell points are not indicated for the 5x5 grids.

4.3 PEAKUP IN THE CROSS-DISPERSION DIRECTION

The peakup in the cross-dispersion direction (PCD) is intended to improve the pointing of the science target in the direction perpendicular to the dispersion. If the TS step was previously executed, the target is ensured to be in the aperture. This should guarantee that the target spectrum will be within a known subarray on the detector, but it may not be in the optimum cross-dispersion location. The PCD will measure the cross-dispersion location of the spectrum and move the telescope to place the target spectrum at the desired cross-dispersion detector location. The initial approximate location of the spectrum is known from the CAL step. The same CAL algorithms for determining the mean cross-dispersion location of the CAL spectrum will be utilized and tested in locating the cross-dispersion center of the target spectrum during the PCD testing.

4.4 PEAKUP IN THE DISPERSION DIRECTION

The peakup in the dispersion direction (PD) is intended to improve the centering of the science target in the dispersion direction. This TA step is designed to maximize flux at the detector. This differs from the PCD step that positions the spectrum on the detector. In PD, HST is moved through a series of dwell points in the dispersion direction. The number and sky separations of dwell points are TBD (Phase I). In PD, only the total flux within a specified subarray is needed to determine the best telescope pointing. In Phase I of TAACOS, the PD algorithms to be tested are:

1. use the brightest dwell point,
2. use the flux-weighted centroid of the dwell points, or
3. use a quadratic fit of the three brightest dwell points[3].

In addition, Phase I of this analysis will estimate the elapsed time (including computational, exposure, and slewing times) required for PD, and recommend extraction subarrays for the FUV/G160M and NUV/G225M configurations for the Phase I targets. The FUV PD will be evaluated for 1 and 2 detector segment peakup strategies. Phase II will expand the PD testing to include the Phase II targets (§6), and all other COS gratings.

[3] This algorithm is no longer a flight software requirement. It will be evaluated only for comparison to the other algorithms.

5. POST TARGET ACQUISITION EVALUATION

Following the testing of the four steps of TA (CAL, TS, PCD, PD), an analysis of the accuracy of the HST/COS pointing will be performed. It is possible that a series of PCD and PD peakups will be required to center the target to the desired accuracy. The creation of the HST/COS simulator (§7) will allow a comparison between the autonomous positioning of the target to its actual location in the aperture. This analysis will be performed for both the Phase I and II targets and configurations.

6. PHASE II TAACOS EXTENSIONS

Phase II will expand the efforts by considering the following targets:

1. An object a fixed offset (>2") from a second, fainter, UV point source.
2. An object a fixed offset (>3") from a second, brighter, UV point source.
3. A small, but resolved, target smaller than the aperture size.
4. An extended object that is larger than the aperture, but which has a region of enhanced brightness for the target.
5. An extended diffuse object with no preferred target position.
6. Bright targets in a field crowded wither fainter UV point sources.
7. Two objects of equal intensity at various separations (< 3”).
8. Bright targets through the bright object aperture (BOA). Since the BOA and PSA are identical in diameter and location (the BOA is translated to the PSA location), TA evaluations using the BOA may prove unnecessary, except in predicted TA elapsed time.

In addition, Phase II will extend the input targets to include: QSO's of an array of redshifts (e.g., $z = 0.01, 0.05, 1.0, 3.0$), varying spectral indicies (e.g., $\alpha = -3, -1, 1, 3$ for a spectrum of the form $F_\lambda \sim F_0\, \lambda^\alpha$) and varying flux $F_0 = (0.25, 0.5, 5, 10)\ 10^{-15}$ ergs/cm^2/s/Å; and stellar targets of varying magnitude and type as derived from the COS science goals.

For the FUV detector, the location of the PSA and BOA are designed to be moved periodically to avoid localized gain deficiencies and the associated loss in detection quantum efficiency. Currently, four offset (off-axis) aperture locations of ±500μ and ±1mm are planned. Since off-axis aperture locations will affect the spectral location and cross-dispersion profile, phase II will explore the effects of off-axis aperture location on all FUV COS-TA steps.

7. COS SIMULATOR

To produce the required TAACOS evaluations, it is necessary to simulate the HST and COS optics, including efficiencies. Figure 2 conceptually displays the COS simulator. The components within the bounding box of Figure 2 will be based upon ray-tracing code developed at CASA.

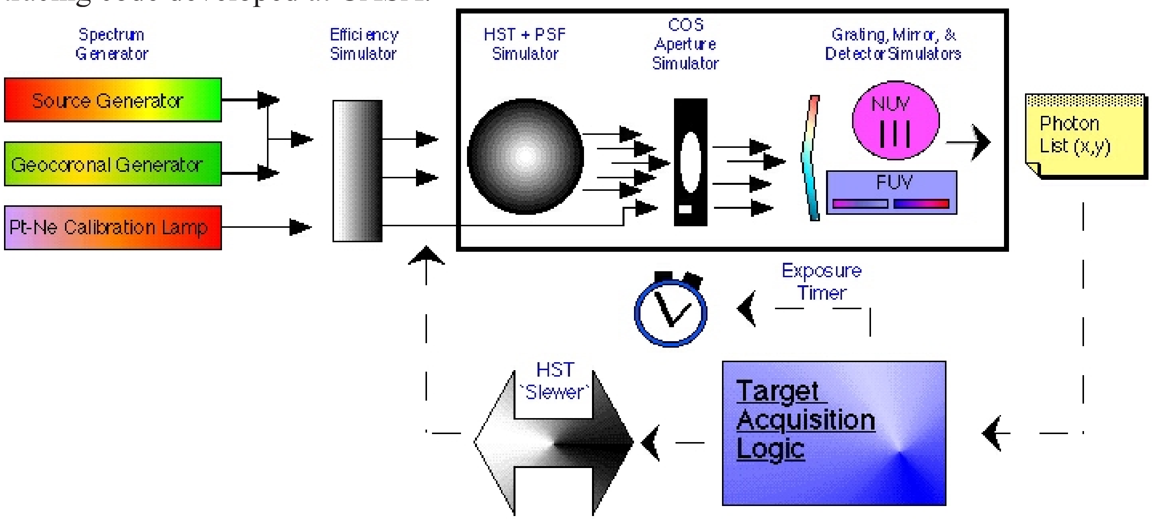

Figure 2: Target Acquistion Pipeline.

The main components of the HST/COS simulator are:

- Spectrum Generator - The spectrum generator produces photon events matching those expected from a target of given type, spectral index, and redshift. These events include geocoronal photons. Simulated spectra will uniformly illuminate the HST/COS simulator based upon target flux level and Poisson statistics. In addition, the Pt-Ne wavelength calibration lamp will be simulated to test the wavelength calibration procedures.

- Efficiency Simulator: Current estimates of the grating, mirror, aperture, and detectors efficiencies will be used to simulate detector spectra based upon the flux of the simulated target. The efficiency of each element will be a function of photon wavelength.

- HST PSF and COS Aperture Simulator: Ray-tracing code developed at CASA/CU will be used to model the spherically aberrated HST mirrors and the COS science apertures. The ray-tracing code will handle off-axis sources, as well as apertures of arbitrary size and location.

- Grating, Mirror, and Detector Simulators and Photon List: The photon events predicted by the ray-tracing code will be convolved with estimates of the detector characteristics to simulate the detection of individual photons. These events will be collected into the final photon list/detector image.

- Target Acquisition Logic (Exposure Timer): The algorithms to be tested by TAACOS will operate on the simulated spectra. This includes the estimation of the elapsed time for each step of the TA.

- HST 'Slewer': Once the desired detector motion for the next TA step has been determined, this motion must be propagated back to spacecraft motion. The ray-tracing code will be used to move the simulated target to the corresponding off-axis angle to simulate spacecraft motion. A set of constants for each detector that relates detector pixel (X, Y) to arcsecond (X, Y) on the sky will be required to complete the HST/COS TAACOS simulator.