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Cosmic Origins Spectrograph Instrument Handbook for Cycle 17

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COS Handbook History

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Acknowledgments

The technical and operational information contained in this Handbook is the summary of the experience gained by members of the STScI COS Team and by the COS IDT at the University of Colorado in Boulder.

Current and former members of the STScI COS Team include Alessandra Aloisi (lead), Tom Ake, Tom Donaldson, Linda Dressel, Scott Friedman, Phil Hodge, Mary Beth Kaiser, Tony Keyes, Claus Leitherer, Matt McMaster, Melissa McGrath, Cristina Oliveira, David Sahnow, Ken Sembach, Brittany Shaw, David Soderblom, and Alan Welty. All of these individuals contributed to this volume, as did Russ Makidon and Brittany Shaw.

The COS IDT includes James Green (Principal Investigator), Cynthia Froning (Project Scientist), Steven Penton, Steven Osterman (Instrument Scientist), Stéphane Béland, and Matthew Beasley, all of whom provided information and assistance. COS co-investigators are Dennis Ebbets (Ball Aerospace), Sara R. Heap (GSFC), Claus Leitherer (STScI), Jeffrey Linsky (University of Colorado), Blair D. Savage (University of Wisconsin-Madison), J. Michael Shull (University of Colorado), Oswald Siegmund (University of California, Berkeley), Theodore P. Snow (University of Colorado), John Spencer (Southwest Research Institute), and John T. Stocke (University of Colorado). K. Brownsberger, J. Morse, and E. Wilkinson have also been part of the COS IDT and have made significant contributions.

The prime contractor for COS is Ball Aerospace, Boulder CO. The XDL detector was built at UC Berkeley by O. Siegmund, J. McPhate, J. Vallerga, and B. Welsh.

The Editor thanks Susan Rose for her contributions to the production of this *Handbook*.

References and Additional Information

This document has relied heavily on the information provided by the COS team in Boulder. The primary documents used are:

Morse, J. 2003, Cosmic Origins Spectrograph Science Operations Requirements Document, rev. 23 (referred to as OP-01).

Wilkinson, E. 2002, COS Calibration Requirements and Procedures, rev. B. (referred to as AV-03).

Wilkinson, E. 2004, COS Prelaunch Calibration Data, initial release (referred to as AV-04).

We also used the *STIS Instrument Handbook* (Kim Ouijano et al. 2003, v7.0).

CHAPTER 1:

Introduction

In this chapter…

1.1 Purpose of This Handbook

This *COS Instrument Handbook* is meant to be the basic reference manual for observers who wish to use the Cosmic Origins Spectrograph, and it describes the design, performance, operations, and calibration of COS. This *Handbook* is written and maintained at STScI. We have attempted to incorporate the best available information, but as this is written COS is not yet installed in HST and therefore its performance parameters are inevitably based on data obtained during tests on the ground.

There are three occasions upon which a reader would consult this Handbook:

- To obtain the instrument-specific information needed to prepare a Phase I proposal for HST time;
- To obtain more detailed usage information when writing a Phase II program once a proposal has been accepted; or
- To find the information about the performance and operation of COS to help in understanding and interpreting observations that have already been made.

This *Handbook* is ***not*** meant as a reference for COS data reduction or analysis; that is provided in a chapter in the *COS Data Handbook*. However, because the *COS Data Handbook* has not yet been prepared, we have added a chapter on COS data products as an initial guide. See Chapter 12.

1.1.1 Document Conventions

This document follows the usual STScI conventions:

- Terms, words, or phrases which are to be entered by the user in a literal way in an HST proposal are shown in a typewriter or Courier font, such as "`COS/FUV`" or "`TIME-TAG`."
- Names of software packages or commands (such as **calcos**) are shown in boldface.
- Wavelengths in this Handbook and in COS data products are always as measured in vacuum and are in Ångstroms (Å).

1.1.2 FEFU: Femto-erg Flux Unit

To simplify the text and to avoid typographical errors, particularly in exponents, in this *Handbook* we introduce and use a unit for fluxes: a FEFU, or "femto-erg flux unit."

$$1 \text{ FEFU} = 10^{-15} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ Å}^{-1}$$

This unit makes it possible to write most fluxes without needing exponents. This convention also helps to reduce confusion from sometimes illegible exponents in figure legends.

1.2 Preparing Proposals and Observing with COS

1.2.1 The STScI Help Desk

Observers are encouraged to direct questions to the Help Desk at STScI. To contact the Help Desk,

- Send e-mail to: help@stsci.edu
- Phone: 410-338-1082
- Inside the USA you may call toll free: 1-800-544-8125.

1.2.2 COS Web Pages and Supporting Information

Resources used in the preparation of this document are listed in the "Acknowledgments". Additional COS information and planning tools, including a link to a preliminary spectrum simulator, can be found on the COS Web page at:

`http://www.stsci.edu/hst/cos`

CHAPTER 2:

Special Considerations for Cycle 17

In this chapter…

2.1 SM4 and the Installation of COS

COS will be installed into HST during Servicing Mission 4 (SM4), now scheduled for launch in August, 2008.

There are some critical aspects of the performance of COS that will not be known in detail until COS is installed into HST and fully calibrated. The information presented in this *Handbook* (sensitivities, for example), is based on data from tests performed on the ground and represents our current best understanding of COS. Proposers for Cycle 17 are unlikely to receive updated information before the proposal deadline, but they are urged to check the STScI Web pages before submission. Any such updates should be posted no later than one month before the proposal deadline.

Once executed, SM4 will be followed by a period of Servicing Mission Observatory Verification (SMOV), during which HST's science instruments are activated, tested, and characterized. The successful conclusion of critical SMOV tests leads to an instrument being available for science observations. Because of its detectors, COS needs several weeks to outgas before high voltages can be turned on (in order to avoid arcing), followed by several additional weeks of engineering activities.

We cannot predict exactly when COS will start to be available to General Observers in Cycle 17 because of uncertainty in the launch date for SM4 and in the activities needed to certify COS for science use. For planning purposes we are assuming that COS will be available for all of Cycle 17, once it has completed initial turn-on and SMOV.

2.2 Observing Considerations for Cycle 17

2.2.1 The COS GTO Program

The COS Investigation Definition Team (IDT) is responsible for the development, management, and scientific oversight of COS prior to launch. As Guaranteed Time Observers (GTOs) the COS IDT has 555 orbits of guaranteed observing time with the instrument. The IDT observing time will occur primarily in Cycle 17, with a portion of the time remaining for observations in Cycles 18 and 19. The members of the COS IDT are listed in "Acknowledgments".

As GTOs, the COS IDT is permitted to have exclusive access to the targets they will observe for the science they proposed. The COS GTO target list may be found at:

`http://www.stsci.edu/hst/proposing/docs/COS-GTO`

GTO target protection policy is more fully explained in the HST *Call for Proposals*.

2.2.2 Survey and SNAP Programs with COS

The detectors in COS are photon counters and can be harmed by exposure to bright light. All COS observations must be checked at STScI by an Instrument Scientist to confirm both that the intended target is within safe limits for brightness and that no potentially too-bright objects exist nearby. Because of this, the combined total number of targets accepted from all Survey and SNAP programs for COS and STIS/MAMA will not exceed 300. For more information on this and other policies pertaining to HST observing, please see the *Call for Proposals*.

2.2.3 Non-point Sources Uses of COS

COS offers dramatic improvement in sensitivity to faint objects compared to previous UV spectroscopic instruments flown aboard HST. COS achieves high sensitivity, particularly in the FUV, by minimizing the number of reflections, which leads to an inherently simple design. Accordingly, COS was optimized for observing faint point sources (objects less than 0.1 arcsec in diameter), for which it delivers full throughput and spectral resolution performance. Observations of extended sources will result in degraded spectral resolution, although COS can be used to detect faint, diffuse sources.

2.2.4 Three-Gyro Observing with HST

We anticipate that all observations in Cycle 17 will be done in 3-gyro science mode, providing greater scheduling flexibility and greater sky coverage (at a given time) than in recent Cycles. Proposers should plan their observations accordingly, using information in the HST Primer and visibility tools on-line at:
http://apst.stsci.edu/apt/external/help/roadmap1.html

2.3 Should I Use COS or STIS?

Current plans for SM4 include both the installation of COS and the repair of STIS. While the success of these operations and the actual performance of each instrument during Cycle 17 cannot be known in advance, proposers should assume that both instruments will be available, and that HST will thus have two spectrographs with significant overlap in spectral range and resolving power. However, despite these similarities, each instrument has its unique strengths and the decision about which to use will be driven by science goals of the program and the nature of the target to be observed.

The primary design goal of COS is to improve the sensitivity to point sources in the far-UV (from about 1100 to 1800 Å). In this wavelength range the throughput of the COS FUV channel exceeds that of the STIS FUV-MAMA by factors of 10 to 30, and the combination of the spectroscopic resolving power (~ 20,000) and wavelength coverage (300 to 370 Å per setting) of the medium resolution COS FUV modes results in a discovery space (throughput times wavelength coverage) for observations of faint FUV point sources that is at least 10 times larger for most targets than that of STIS modes with comparable resolution, and is as much as 70 times greater for faint background-limited point sources.

In the near-UV (approximately 1700 - 3200 Å), COS and STIS have complementary capabilities, and the choice of instrument should be guided by the specific science requirements of an individual program. To accommodate the NUV detector format, the NUV spectrum of COS is split into three non-contiguous sub-spectra, each of which covers a relatively small range in wavelength. Obtaining a full spectrum of an object in the near-UV requires several separate set-ups and exposures (6 or more for the medium-resolution gratings and 4 for G230L). When broad near-UV wavelength coverage is needed, there will be circumstances when obtaining a single STIS spectrum is more efficient than taking separate COS spectra. However, the background count rate for COS/NUV is expected to be substantially lower than for STIS (by a factor of about four) so that COS will often be superior for very faint sources, even when more exposures are required. Observers are advised to perform detailed calculations using both the COS and STIS ETCs and to carefully consider the relative instrument overheads in order to decide which combination of instruments and modes is best for their particular science program.

In deciding which instrument to use to observe extended sources, the spatial resolution offered by STIS must be weighed against the superior sensitivity of COS. One of the primary design goals of STIS was to provide spatially-resolved spectra in the UV, optical, and near-IR. The STIS long slits, when used with the 1st order gratings, allow spatially-resolved observations that exploit the intrinsically high resolution of HST over the full width of the detectors (approximately 0.05 arcsec per 2-pixel spatial resolution element over a length of 25 arcsec with the NUV and FUV MAMAs, and ~ 0.1 arcsec per 2-pixel spatial resolution element over a length of 52 arcsec with the CCD). COS was optimized for point-source observations, and this results in some compromises when observing extended sources. COS has relatively large entrance apertures (2.5 arcsec diameter), which are significantly vignetted for any flux off-center by more than 0.5 arcsec. These large apertures also mean that objects extended in the dispersion direction will result in degraded spectral resolution. In addition, the optical design of the FUV channel provides intrinsic limits to the achievable spatial resolution, making it impossible to separate multiple point sources in the aperture unless they are separated by about 1 arcsec in the cross dispersion direction. The COS NUV channel uses a different optical design, and has spatial resolution comparable to that of STIS first-order NUV modes (~ 0.05 arcsec), with somewhat better sampling; however, for sources more than 1 arcsec in extent in the spatial direction, the different NUV spectral segments will begin to overlap.

Both COS detectors and the STIS MAMA detectors are prohibited from observing objects that exceed specific brightness levels (see Section 11.5 in this handbook and Sections 13.8 and 14.8 of the STIS Instrument Handbook). Some brightness limits have been established for the health and safety of the instrument, while others are practical limits that are set to ensure good data quality. Because STIS is less sensitive than COS the brightness limits for STIS tend to be significantly less stringent. In the NUV range, the STIS G230LB and G230MB gratings can also be used with the STIS CCD, which has no bright object limitations. STIS also has a number of small and neutral density apertures that can be used with the MAMA detectors to attenuate the light of a too-bright object. COS has only a single neutral density filter which attenuates by a factor of about 200, but which also degrades the spectral resolution by a factor of 3 to 5. In most cases, some combination of STIS gratings and apertures will be a better choice for observing a UV-bright object than using COS with its neutral density aperture would be. Users are advised to compare results from the COS and STIS ETCs to decide on an appropriate strategy for their target.

The STIS high dispersion echelle modes E140H and E230H have resolving powers of ~114,000, significantly higher than the best COS resolution. Also, STIS can obtain spectra in the optical and near-IR at wavelengths up to 10,200 Å, while the maximum wavelength observable by COS is about 3,200 Å.

Both STIS and COS can perform observations in `TIME-TAG` mode, where the time of each photon's arrival is recorded. STIS is capable of a much finer time resolution (125 microseconds vs. 32 milliseconds for COS), although few programs are expected to require such a high sampling rate. Due to its lower sensitivity, STIS may also sometimes be able to observe a target in TIME-TAG mode that is too bright for TIME-TAG observations with COS. Also, the TIME-TAG data acquired with COS includes information on the pulse-height distribution, while STIS NUV MAMA and COS NUV MAMA observations do not. The pulse-height information can be valuable in identifying and rejecting background counts in faint source spectra.

CHAPTER 3:

A Tour Through COS

In this chapter…

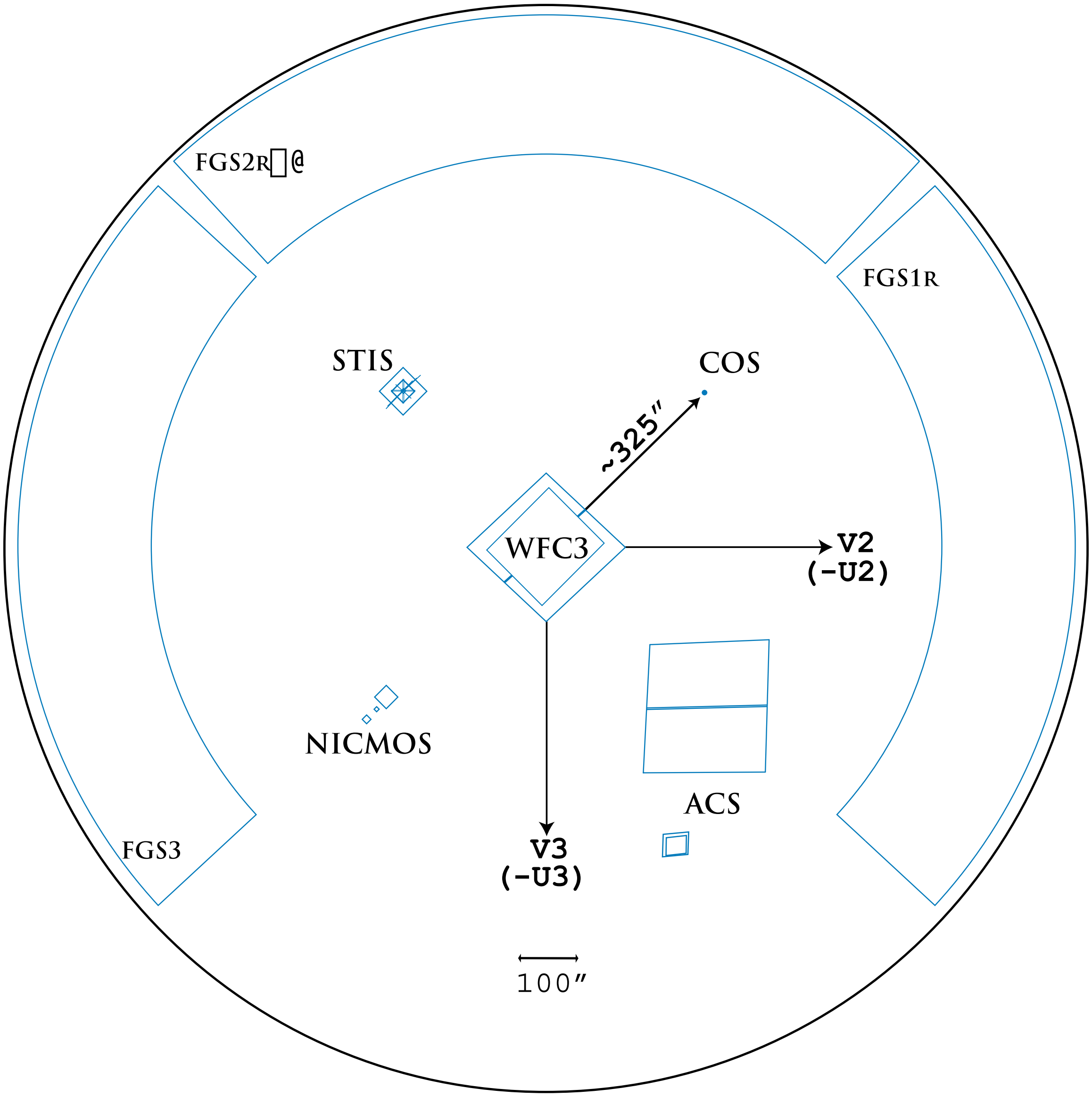
3.1 The Location of COS in the HST Focal Plane

COS will be installed in one of the axial instrument bays near the rear of HST. It will replace COSTAR, which was installed in the first servicing mission, in 1993, to provide correcting optics for the other axial instruments that were in HST at the time (FOC, FOS, and GHRS).

The location of the COS aperture in the HST focal plane is shown in Figure 3.1. Note the relative orientation of the HST V_2 and V_3 axes (the V_1 axis is along HST's optical axis), as well as the relative locations and orientations of the other instruments. Note that the COS aperture is 325 arcsec from the V_1 axis, and that COS is located in the $+V_2$, $-V_3$ quadrant. Also note that the direction along the dispersion of a COS spectrum corresponds to motion equally in V_2 and V_3 in a direction along a radius of the HST field of view. Specifically, increasing wavelength is in the direction of $+V_2$ and $-V_3$ for both the FUV and NUV (see Figure 3.2). Full information on the locations of all HST's instruments may be found at:

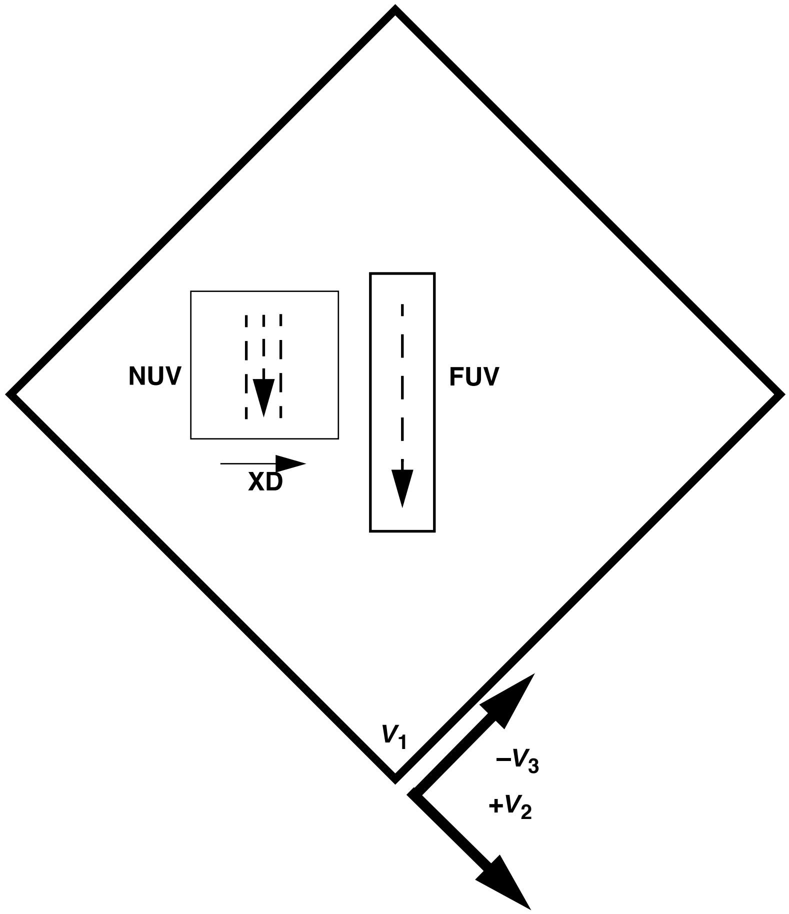
http://www.stsci.edu/hst/observatory/apertures/siaf.html

Figure 3.1: A Schematic View of the HST Focal Plane.



This drawing shows the entire HST focal plane and the apertures of the scientific instruments as it will appear after SM4. Note that this view is from the rear of the telescope looking forward toward the sky, the opposite of the sense of Figure 3.2.

Figure 3.2: Schematic Layout of the COS Detectors.

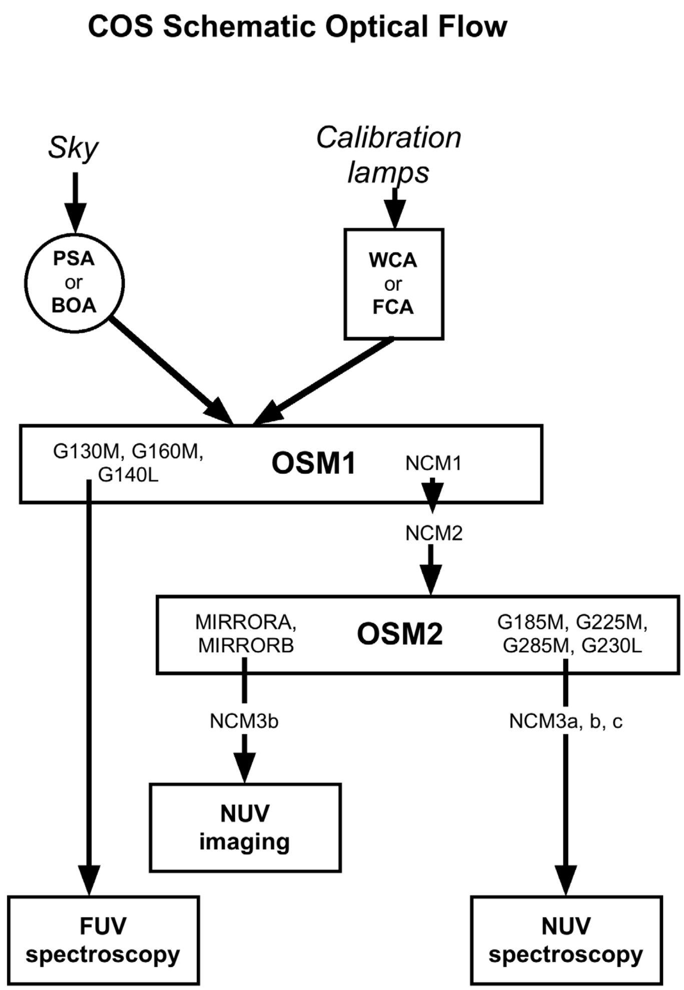


This view is from the front of the telescope looking aft, with the V_1 axis being at the bottom tip of the square. The dashed arrows show the direction of increasing wavelength for the two detectors, and "XD" shows the increasing wavelength for the NUV cross-dispersion direction. For both the FUV and NUV, increasing wavelength is in the ($+V_2$, $-V_3$) direction. Note that this diagram is purely schematic and it is intended to show relative directions. This diagram does **not** show the locations of apertures. As seen in Figure 3.1, the bottom corner of this square (at V_1) is where the WFC3 camera is located.

3.2 The Optical Design of COS

In this section the light from HST is followed as it progresses through COS to each optical element and mechanism. This path and its alternatives are shown schematically in Figure 3.3. In this chapter only a brief overview is provided to avoid unnecessary complication; the details of the optics, mechanisms, and so on are in Chapter 13.

Figure 3.3: Schematic of the Light Flow Through COS.



3.2.1 External Shutter

The external shutter is located at the front of the COS enclosure in the optical path before the aperture mechanism. When closed, the shutter blocks all external light from entering the COS instrument and prevents light from the COS internal lamps from exiting the instrument. The opening and closing of the external shutter is **not** used to determine the duration of an exposure. The external shutter will only be opened by a command at the beginning of every external exposure and is closed at the end of every external exposure, with the possible exception of one or more phases of target acquisition. The external shutter will be closed autonomously by the COS flight software whenever any over-light condition is triggered by an external or internal source or when the HST take-data-flag goes down indicating loss of fine lock; see Section 11.5.2.

For more on the external shutter, see Section 13.2.3.

3.2.2 The Apertures and Aperture Mechanism

After passing the focal plane, the light from HST first encounters the COS entrance apertures, which are mounted on the Aperture Mechanism.

In most spectrographs, the light from the telescope is focused on a slit, and the instrument's optics then re-image the slit onto the detector. In such a design, the slit width and how the slit is illuminated determine the resolving power and line spread function (LSF). COS is different: it is essentially a slitless spectrograph with an extremely small field of view.

There are four apertures: two look at the sky for science exposures, and two are for calibration. Selecting among these apertures can involve movement of the Aperture Mechanism. The two science apertures are the Primary Science Aperture (PSA) and the Bright Object Aperture (BOA).

Primary Science Aperture

The Primary Science Aperture (PSA) is a 2.5 arcsec (700 μm) diameter field stop located behind the HST focal surface near the point of the circle of least confusion. This aperture transmits ≥ 95% of the light from a well-centered, aberrated point-source image delivered by the HST optics. The PSA is expected to be used for observing in almost all instances. The PSA is in place, ready to use, at the start of a new visit. Note that when the PSA is in place the WCA (see below) is also in place and available for use.

Note also that the BOA is open to light from the sky when the PSA is being used for science (and vice versa); therefore bright object screening for the field-of-view must include both apertures.

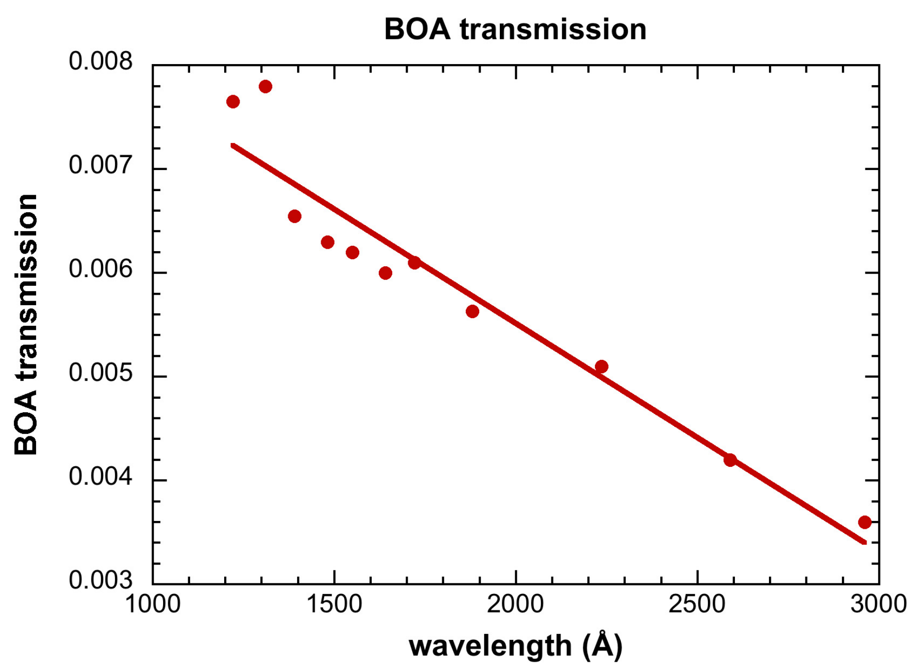
Bright Object Aperture

The Bright Object Aperture (BOA) is also 2.5 arcsec (700 μm) in diameter with a neutral density (ND2) filter immediately behind it. The transmission of the BOA is wavelength dependent, and is shown in Figure 3.4. The straight line fit is given by *transmission* = [0.99 – λ(Å)/4500]/100. The BOA attenuates by about a factor of 200 at 2000 Å.

The BOA material has a slight wedge shape so that the front and back surfaces differ from one another by about 15 arcmin. This wedge is sufficient to degrade the spectroscopic resolution realized when the BOA is used. In fact, a secondary peak in the image is formed; see Section 7.5.3.

The BOA must be moved into place with the Aperture Mechanism to replace the PSA for science observations. Thus, science spectra obtained through either the PSA or BOA will use the same optical path and detector region (for a given channel), and so may employ the same flat-field calibrations. At the same time, the BOA is open to light from the sky when the PSA is being used for science (and vice versa); therefore bright object screening for the field-of-view must include both apertures. Moving the BOA into place for science use precludes using the WCA for a wavelength calibration exposure, and so an additional movement of the Aperture Mechanism is needed to obtain a wavecal when the BOA is used. For this reason the BOA may not be used with TAGFLASH exposures (see Section 5.5.1).

Figure 3.4: Measured Transmission of the COS BOA as a Function of Wavelength.



Wavelength Calibration Aperture

The Wavelength Calibration Aperture (WCA) is offset from the PSA by 2.5 mm (about 9 arcsec) in the cross-dispersion direction, on the opposite side of the PSA from the BOA (this is illustrated in Figure 13.2). Light from external sources cannot illuminate the detector through the WCA; instead the WCA is illuminated by one of two Pt-Ne wavelength calibration lamps. The wavelength calibration spectrum can be used to assign wavelengths to the locations of detected photons for science spectra obtained through either the PSA or BOA. As noted, both the PSA and WCA are available for use at the same time and no additional motion of the Aperture Mechanism is needed.

Flat-field Calibration Aperture

The Flat-field Calibration Aperture (FCA) is used only for calibration and it is not available to observers. For more information, see Section 13.1.6. The FCA is used to obtain flat-field exposures using one of the two deuterium lamps.

3.2.3 Gratings and Mirrors: The Optics Select Mechanisms

After passing through either the PSA or BOA, light next encounters Optics Select Mechanism 1 (OSM1). OSM1 is a rotating mechanism that can bring one of four optical elements into the beam. These four optical elements are located at 90 degree intervals around OSM1. One of these, mirror NCM1, is a flat mirror that directs the beam to the NUV channel. The other three elements are gratings for the FUV channel.

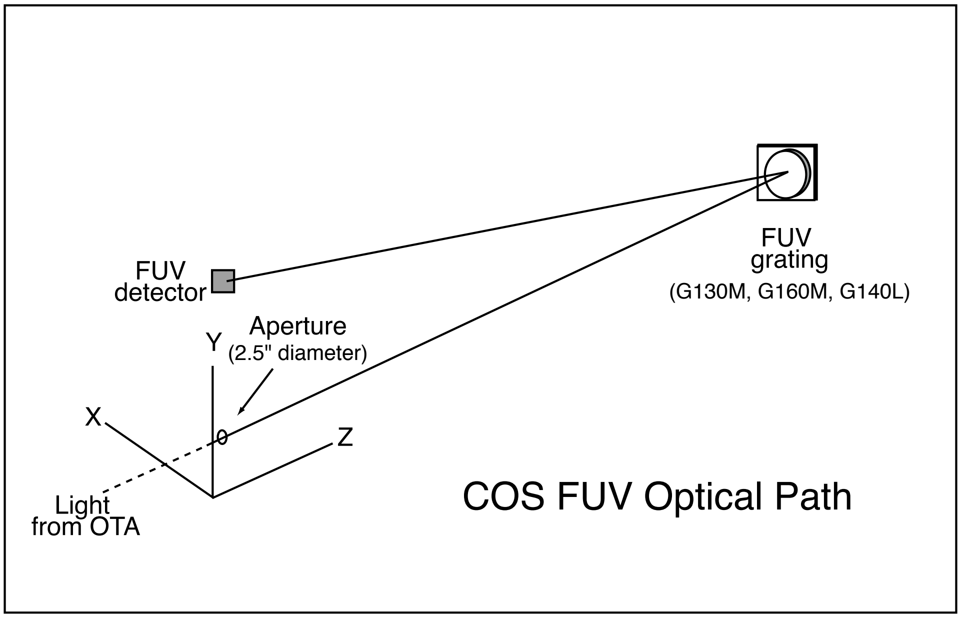
FUV Channel Optical Design

The COS FUV optical path is illustrated schematically in Figure 3.5. The FUV channel of COS uses only a single optical element to image the sky onto the XDL detector (described in Chapter 4). Each of the three FUV gratings is holographically ruled to disperse the light and to focus it onto the detector. The gratings also have optical surfaces configured to remove the spherical aberration produced by the HST primary mirror. Given the location of OSM1 in the HST optical chain, and given the several requirements placed on the FUV gratings (to disperse, focus, and correct), it is not possible to do all of these completely except for a point source that is centered in the aperture. In other words, the design of the FUV channel of COS has been optimized for high throughput and good spectrum resolution on centered point sources, but performance is reduced under other circumstances, such as when the source is moved away from the aperture center. However, this degradation of resolution is low for displacements up to about 0.5 arcsec from the aperture center (see Section 7.4).

The COS FUV channel provides spectra that cover the wavelength range 1150 to 2050 Å at low- and moderate spectral resolution. The XDL detector is described fully in Chapter 4, but it is important to note that it consists of two independent segments with a small physical gap between them. This gap prevents a single continuous spectrum from being obtained in one setting, but it also enables geocoronal Lyman-α to be placed there in some set-ups, thereby eliminating the local high count rates that that emission line can cause. The gap can miss 14 to 18 Å of spectrum with G130M or G160M, but the missing wavelengths can be filled, as described in Section 5.6.

The nominal wavelength range for the G140L grating is 1230 to 2050 Å, and this spectrum takes up only part of one detector segment. G140L actually directs light out to 2400 Å onto this detector segment, but the XDL sensitivity to these longer wavelengths is extremely low. On the other detector segment, the G140L grating disperses light between ~100 - 1100 Å. Again the sensitivity to these wavelengths is very low, limited in this case by the reflectance of HST's mirrors and COS optics. Calculations predict that the effective area below 1150 Å plummets rapidly but is not zero. The sensitivity at these wavelengths will be measured once COS is installed in HST.

Figure 3.5: The COS FUV Optical Path.



OSM2 and the NUV Channel

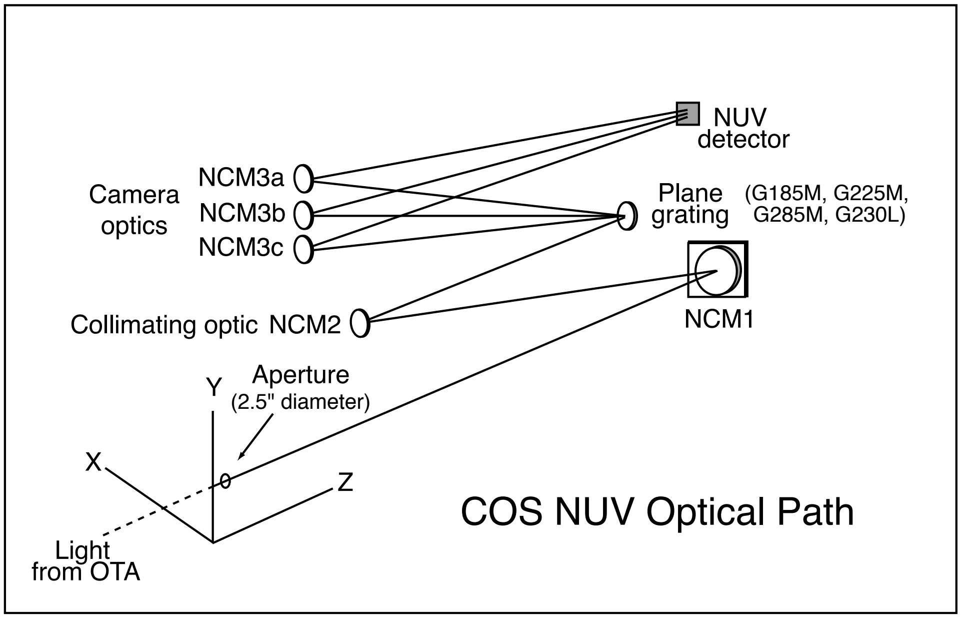
The COS NUV channel covers the wavelength range 1660 to 3200 Å at low- and moderate spectral resolution. If the NUV channel is to be used, first mirror NCM1 is placed into position on OSM1; that directs the beam to mirror NCM2 – which collimates the light – and then to Optics Select Mechanism 2 (OSM2). OSM2 holds five optical elements: four plane diffraction gratings plus a mirror for target acquisitions or imaging. These five optical elements are located at 72 degree intervals around OSM2.

Three of the gratings are medium-dispersion and deliver resolving powers of R = 20,000 to 24,000 (G225M and G285M) or R = 16,000 to 20,000 (G185M) over the wavelength range 1700 to 3200 Å. The dispersed light from the gratings is imaged onto a MAMA detector by three parallel camera optics (NCM3a, b, c). The spectra appear as three non-contiguous ~35-40 Å stripes on the MAMA detector, allowing ~105-120 Å wavelength coverage per exposure. The gratings can be scanned with slight rotations of OSM2 to cover the entire NUV wavelength band. The NCM3a,b,c mirrors are spaced such that several correctly chosen exposures will produce a continuous spectrum from the beginning of the short wavelength stripe in the first exposure to the end of the long wavelength stripe in the final exposure.

In addition, a low-dispersion grating, G230L, produces three stripes with ~400 Å coverage per stripe at a resolution of ~1.1 Å (R = 1550 - 2900). The first-order science spectrum from G230L over the 1700 to 3200 Å region is captured in four separate exposures.

The layout of the stripes is shown schematically in Figure 4.4.

Figure 3.6: The COS NUV Optical Path.



The plane mirror on OSM2 is designated as MIRRORA when used in direct specular reflection. MIRRORB refers to the arrangement in which OSM2 rotates the position of this mirror slightly so that the front surface of the order sorter filter on this mirror is used. This provides an attenuation factor of approximately 25 compared to MIRRORA. Because of the finite thickness of the order-sorting filter, MIRRORB produces an image with two peaks that may impede its use for imaging; see Section 7.5.3 for details. This doubled image is generally acceptable for acquisitions, however.

3.2.4 Detectors

The detectors in COS are described in Chapter 4.

3.2.5 On-board Calibration Lamps

Four calibration lamps are mounted on the calibration subsystem. Light is directed from the lamps to the aperture mechanism through a series of beam-splitters and fold mirrors.

Pt-Ne Wavelength Calibration Lamps

COS has two redundant Pt-Ne hollow-cathode wavelength calibration lamps on its internal calibration platform; their spectra contain emission lines suitable for determining the wavelength scale of any spectroscopic mode. Either lamp may be used for wavelength calibration exposures, but the choice is not user-selectable. We anticipate that one lamp will be used until it fails and then operations will be switched to the other.

The Pt-Ne lamps are used to obtain wavelength calibration ("wavecal") exposures, either as a separate wavecal for ACCUM exposures, or during a TIME-TAG exposure when FLASH=YES is specified ("TAGFLASH" mode). The light from the Pt-Ne lamp reaches the spectrograph through the WCA (wavelength calibration aperture). The WCA spectrum is displaced at an off-axis position relative to the PSA, projected 2.5 mm away from the PSA spectrum on the FUV detector. On the NUV detector, the corresponding WCA spectral stripe lies 9.3 mm away from the associated PSA science strip. This optical offset introduces a wavelength offset between the two sets of spectra, and this is compensated for during data reduction with **calcos**.

Note that the WCA and the PSA are available for use at the same time; this is what makes TAGFLASH mode possible. However, the Aperture Mechanism must be moved to bring the BOA into position and that makes it impossible to use TAGFLASH mode with the BOA; see Section 5.7.3.

The Pt-Ne lamps are also used during acquisitions to provide a reference point that will define the relationship between a known location at the aperture plane and the detector pixel coordinates in which the measurements are made.

Deuterium Flat-field Calibration Lamps

COS has two redundant deuterium hollow-cathode flat-field calibration lamps. The deuterium lamps may also be used interchangeably. Usage of these lamps for flat-field calibrations is restricted to observatory calibration programs. The light from these lamps enters the spectrograph through the FCA (flat-field calibration aperture).

3.3 Basic Instrument Operations

3.3.1 Target Acquisitions

The entrance apertures to COS are 2.5 arcsec in diameter. In order to ensure that the target is present and centered, a target acquisition procedure must be carried out.

The details of acquiring objects with COS are described in Chapter 7, but, in brief, the COS flight software provides two very different methods for acquiring and centering a target in the aperture. The simplest and fastest method uses the ACQ/IMAGE or ACQ/SEARCH commands to obtain a direct image of the aperture in the NUV and to then move the telescope to the centroid of the measured light. ACQ/IMAGE is the preferred method in most cases, but the object's coordinates have to be accurate enough to ensure that it falls within the aperture after the initial pointing of the telescope (this should be the case for accurate and precise coordinates provided in the GSC2 system). With less accurate coordinates one can still use ACQ/IMAGE if a spiral search is first done with ACQ/SEARCH. The other COS acquisition method uses dispersed light from the object to be observed, and can be performed with either the NUV or FUV detector. Acquisitions are described in Chapter 7.

3.3.2 Data Taking: TIME-TAG and ACCUM

Two modes are available to acquire spectra with COS.

In TIME-TAG mode, both the location on the detector and the time of arrival of individual photon events are recorded in the memory buffer. The location is recorded in pixel units, and the time to within 32 msec intervals. Having TIME-TAG data allows for more sophisticated data reduction if there is evidence after the fact for spectrum drift, say, or noise events. An observer can choose after the fact to compare, for instance, data from the night- and day sides of the orbit, or to obtain a continuous stream of data on an object with short-time-scale variability. Also, data from a TIME-TAG observation has individual events corrected for doppler displacement after the fact in **calcos**.

On the other hand, in TIME-TAG mode the maximum permissible count rate is more restrictive than for ACCUM mode, and this can prevent the observation of some bright objects (see Section 11.5.2 for information on rate limits). Also, for TIME-TAG mode the observer must provide a fairly accurate estimate of the BUFFER-TIME so that the memory buffer both does not overflow with too many events, and does not need to be read out too often either.

TIME-TAG mode includes an option (FLASH=YES) in which brief wavelength calibration spectra are obtained several times during the course of a long exposure. Doing this allows any drifts in the spectrum to be corrected; small motions of the optics selection mechanism have been seen during ground tests of COS. TIME-TAG is the preferred mode of use of COS in almost all cases.

The other mode option is ACCUM, which simply places photon events in their proper pixel location and integrates for a specified period of time.

Both TIME-TAG and ACCUM modes may be used with either the FUV or NUV channel. For more information comparing TIME-TAG to ACCUM, see Section 5.5.

3.3.3 Wavelength Calibration

The recommended mode of use of COS is TIME-TAG with FLASH=YES ("TAGFLASH" mode) in which case spectra are obtained concurrently with wavelength calibration information. As noted, Pt-Ne lamps provide the wavelength calibration spectra, and the reduction to wavelength is done automatically in **calcos**. ACCUM mode is sometimes to be preferred for brighter objects, and when used it too automatically causes wavecals to be taken, but as separate images. It is possible to completely suppress the wavelength calibration spectra taken by COS but doing so significantly lessens the archival quality of data and must be justified on a case-by-case basis.

3.3.4 Typical Observing Sequences

For most observers in the majority of cases the following sequence of events will produce data of the desired high quality:

- Acquisition of the object using `ACQ/IMAGE`. This should take at most about ten minutes (see the examples in Chapter 9). This can be preceded by an `ACQ/SEARCH` if needed to scan a larger area of sky, but that should not ordinarily be necessary.
- Obtaining spectra in `TIME-TAG` mode with `FLASH=YES` so that the spectra can be corrected for any drifts. The COS Exposure Time Calculator (ETC) provides a means of calculating essential parameters such as `BUFFER-TIME`.
- Obtaining more spectra during additional orbits as needed for fainter targets to achieve a desired signal-to-noise.

3.3.5 Data Storage and Transfer

Effective use of COS requires awareness of the rate at which a given observation is acquiring data and the capacity of the data buffer and the manner in which those data are transferred within HST for downlink. This topic is covered in Section 5.5.1.

3.4 COS Illustrated

Figure 3.7: The various subassemblies of COS and how they fit in its enclosure.

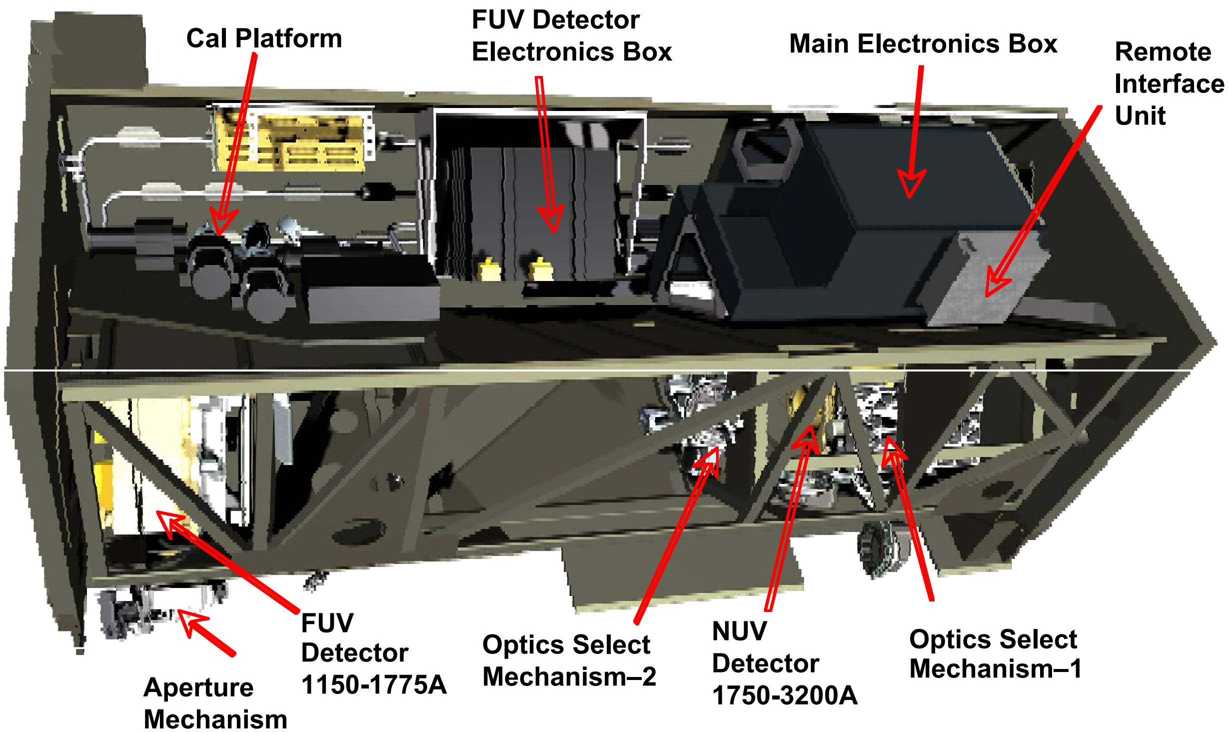
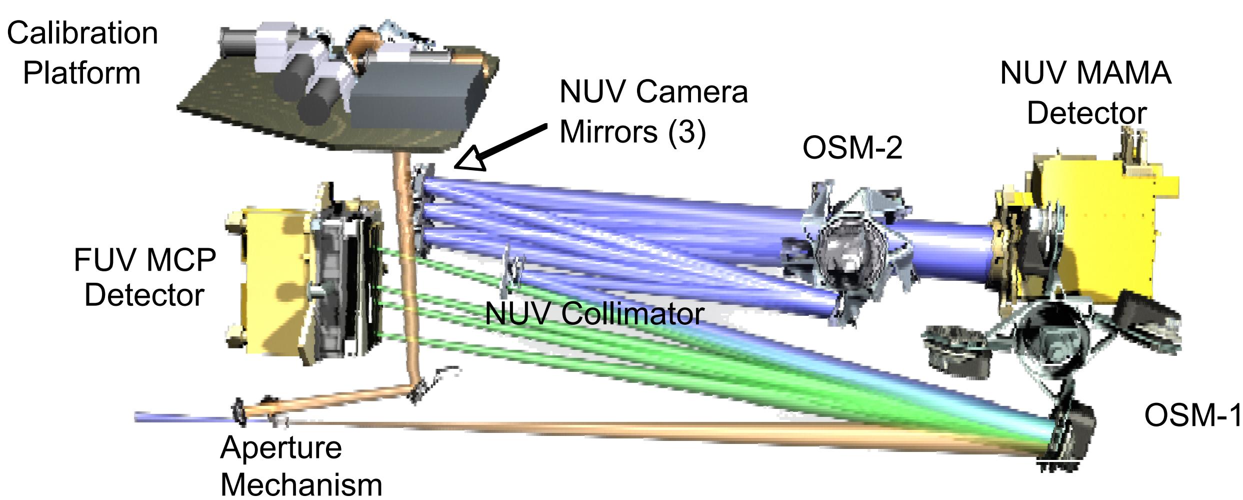


Figure 3.8: The COS optical path and the locations of the mechanisms.



This is drawn to scale, with all elements in proportion and in their correct relative locations.

Figure 3.9: The COS flight instrument in its test stand at Ball Aerospace.

3.5 COS Quick Reference Guide

Table 3.1: COS Instrument Characteristics

Property	FUV channel	NUV channel
Entrance aperture	2.5 arcsec round: clear (PSA) or attenuated (BOA)	
Detector plate scale (cross dispersion)	22.6 mas per pixel 136 mas per resel	23.6 mas per pixel 70.5 mas per resel

Table 3.2: COS Detector Characteristics

		FUV XDL	NUV MAMA
Photocathode		CsI (opaque)	Cs_2Te (semi-transparent)
Window		None	MgF_2 (re-entrant)
Wavelength range		1150 – 2050 Å	1700 – 3200 Å
Active area		85 × 10 mm (two)	25.6 × 25.6 mm
Pixel format (full detector)		16384 × 1024 (two)	1024 × 1024
Image size recorded per spectrum		16384 × 128 (two, `ACCUM`) 16384 × 1024 (two, `TIME-TAG`)	1024 × 1024
Pixel size		6 × 24 µm	25 × 25 µm
Spectral resolution element size (= "resel")		6 × 10 pix	3 × 3 pix
Quantum efficiency		~26% at 1335 Å ~12% at 1560 Å	~10% at 2200 Å ~8% at 2800 Å
Dark count rate		~0.5 cnt s^{-1} cm^{-2} ~7.2x10^{-7} cnt s^{-1} pix^{-1} ~4.3x10^{-5} cnt s^{-1} $resel^{-1}$	~60 cnt s^{-1} cm^{-2} ~3.7x10^{-4} cnt s^{-1} pix^{-1} ~3.3x10^{-3} cnt s^{-1} $resel^{-1}$
Detector global count rate limit	TIME-TAG mode	~21,000 cnt s^{-1}	~21,000 cnt s^{-1}
	ACCUM mode	~60,000 cnt s^{-1} per segment	~170,000 cnt s^{-1}
Local count rate limit		~100 cnt s^{-1} $resel^{-1}$ ~1.67 cnt s^{-1} pix^{-1}	~1800 cnt s^{-1} $resel^{-1}$ ~200 cnt s^{-1} pix^{-1}
Screening limits for bright objects		see Section 11.5.2	
Dead-time constant		7.4 µsec	280 nsec

Table 3.3: COS Predicted Calibration Accuracies

Property	FUV channel	NUV channel
Wavelength zero point: M gratings	15 km s^{-1}	15 km s^{-1}
Wavelength zero point: L gratings	150 km s^{-1}	175 km s^{-1}
Wavelength scale	15 km s^{-1}	15 km s^{-1}
Absolute photometry	5%	5%
Relative photometry (same object at a different time)	2%	2%
Flat field quality measured	62:1	100:1
Flat field quality goal	100:1	100:1

Table 3.4: Useful Figures and Tables

Topic	Source	Content
Usage planning	Table 5.1	Summary of COS spectroscopic modes
	Table 5.3	FUV grating wavelength ranges
	Table 5.4	NUV grating wavelength ranges
	Table 10.2	Earthshine and zodiacal light fluxes
	Table 10.3	Strengths of airglow lines
Aperture parameters and PSFs	Figure 3.1	HST focal plane and COS aperture
	Figure 3.4	BOA transmission
	Figure 13.5	Modeled HST PSF at COS PSA for 1450 Å
	Figure 13.6	Modeled HST PSF at COS PSA for 2550 Å
	Figure 13.7	Cross-section of the HST PSF at COS PSA at 2550 Å
	Figure 6.2	Two-dimensional NUV imaging COS PSF
	Figure 7.1	Relative transmission of the PSA
Sensitivity and throughput	Figure 5.2	FUV sensitivity curves
	Figure 5.3	NUV sensitivity curves for M gratings
	Figure 5.4	Sensitivity curve for G230L
Acquisitions	Figure 7.3	ACQ/IMAGE exposure times
	Figure 7.4	Cross section of image using `MIRRORB`
	Figure 7.5	Cross section of image using `MIRRORB` + `BOA`
	Figure 7.8	Spiral search pattern for 3 × 3
	Figure 7.9	Acquisition exposure times for FUV dispersed light

Topic	Source	Content
Detector characteristics	Figure 4.1	FUV XDL detector schematic layout
	Figure 4.4	NUV MAMA detector schematic layout
	Table 11.1	COS detector count rate limits
	Table 11.2	Local and global flux limits
	Table 10.1	Detector dark count rates
Overheads and observing parameters	Table 13.4	TAGFLASH exposure intervals
	Table 13.5	TAGFLASH exposure durations
	Table 9.1	Generic observatory overhead times
	Table 9.2	Overhead times for OSM1 movements
	Table 9.3	Overhead times for OSM2 movements
	Table 9.4	Science exposure overhead times
Celestial backgrounds	Figure 10.1	Sky background versus wavelength
	Figure 10.2	Moon and Earth background levels
	Figure 10.3	Galactic extinction model
Data quality	Figure 5.1	Scattered light in the FUV
	Figure 5.5	FUV flat-field example
	Figure 5.6	NUV flat-field example
	Figure 7.2	Resolving power vs. position in aperture

CHAPTER 4:

Detector Performance

In this chapter…

4.1 The FUV XDL

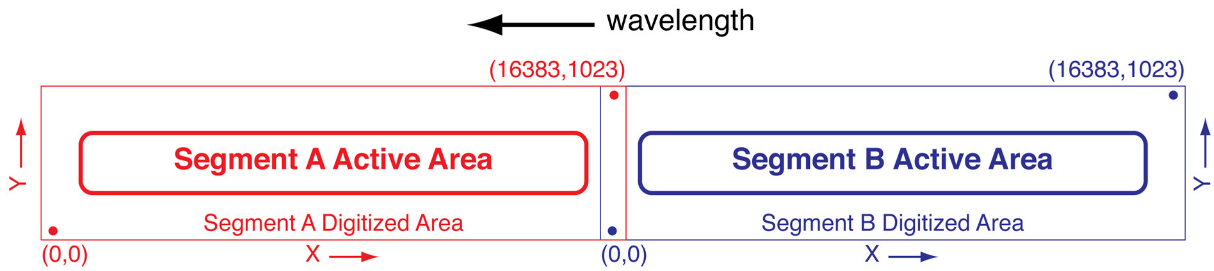
4.1.1 XDL Properties

The COS FUV detector is a windowless XDL (cross delay line) device that is similar to detectors used on the Far Ultraviolet Spectroscopic Explorer (FUSE). The XDL is a photon counter with two segments, with a gap of 9 mm between them. The two detector segments are independently operable to provide redundancy. Each segment has an active area of 85 × 10 mm. When the locations of detected photons are digitized, they are placed into an array of 16384 × 1024 pixels; however, the portion of that array used by the active area is less (see Figure 4.2). The long dimension of the array is in the direction of dispersion, and because of the orientation of the detector in COS, *increasing* pixel number (the detector's *x* axis) corresponds to *decreasing* wavelength. The XDL is shown schematically in Figure 4.1.

The locations of detected events are recorded in pixel units. However, the XDL does not have physical pixels in the usual sense, and the location of an event is determined by the analog electronics as they occur.

The FUV XDL is optimized for the 1150 to 1775 Å bandpass, with a cesium iodide photocathode. The front surface of the XDL is curved with a radius of 826 mm so as to match the curvature of the focal plane. When photons strike the photocathode they produce photoelectrons which are then amplified by micro-channel plates (MCPs). There are three curved MCP plates in a stack to go with each XDL segment.

Figure 4.1: The FUV XDL Detector.



This is drawn to scale, and the slight curvature at the corners is also present on the masks of the flight detectors. Note that wavelength increases in the direction opposite to the detector coordinate system. The red and blue dots show the approximate locations of the stim pulses. Note that the numbers in parentheses show the pixel coordinates at the corner of the segment's digitized area, and also note that the two digitized areas overlap in the region of the inter-segment gap.

The charge cloud that comes out of the micro-channel plates is several millimeters in diameter when it lands on the delay line anode. There is one such anode for each detector segment, and each anode has separate traces for the dispersion (x) and cross-dispersion (y) axes. The location of an event in each axis is determined by measuring the relative arrival times of the collected charge pulse at each end of the anode delay line for that axis.

The electronics that create the digitized time signals also generate pulses which emulate counts located near the edges of the anode, beyond the illuminated regions of the detector. These "stim pulses" (see Section 4.1.6) have several purposes. They provide a first-order means of tracking and correcting distortions. They are also used for determining dead-time corrections. The data reduction pipeline uses the locations of the stim pulses to assign wavelengths to pixels. **For this reason, comparisons of COS spectra taken at different times should be made in wavelength space, not in detector pixel coordinates.**

The XDL's quantum efficiency is improved with a grid of wires placed above the detector (i.e., in the light path). These wires create shadows in the spectrum that are removed during data reduction. The XDL also includes an ion repeller grid in addition to the DQE grid mentioned above. This reduces the background rate by preventing low-energy thermal ions from entering the open-faced detector. The grid wires cast out-of-focus shadows onto the detector; these are removed by flat-fielding.

4.1.2 XDL Spectrum Response

Initial measurements of the throughputs of the COS optical systems indicate that COS will be considerably more sensitive than STIS and earlier generation HST instruments at comparable spectral resolutions in the far-UV. The point source sensitivities for the COS FUV spectroscopic modes are shown in Figure 5.2.

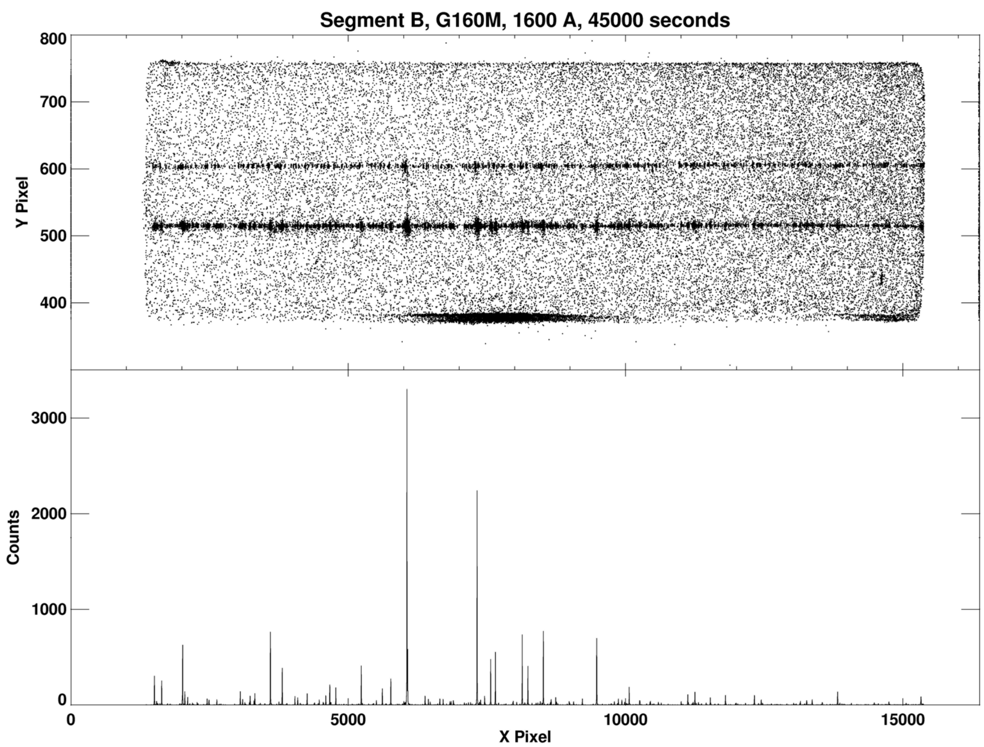
4.1.3 XDL Background Rates

The XDL detectors have extremely low dark rates, below 10^{-6} per pixel per second; see Section 10.3.1 in Chapter 10.

4.1.4 XDL Read-out Format

As noted, the FUV XDL detector actually consists of two separate and independent segments, each of which has an active area of 85 × 10 mm, with the long axis in the direction of dispersion. The physical devices are adjacent, but with a 9 mm gap between the active areas of the two segments. Although this gap prevents the recording of an uninterrupted spectrum, it also makes it possible to position spectra such that significant airglow features – Lyman-α, in particular, when G140L is used – fall on the gap. Without this feature, Lyman-α emission could sometimes trigger excessive count rates in the detector. For more about the gap, see Section 5.6.

Figure 4.2: Example of a COS FUV Spectrum.



Shown is a wavelength calibration spectrum obtained during ground testing. The internal wavelength calibration lamp spectrum is at the top, while the lower spectrum is from a lamp external to COS. Note the size of the active area compared to the overall digitized area. At the bottom is the extracted spectrum of the bottom trace. The bright streak at the bottom is due to an area of enhanced background on the detector segment.

Figure 4.2 shows an example of an FUV spectrum obtained during ground testing. Note the difference in *x* and *y* axis scales, and note that the image is for only one of the segments. The top portion shows the two-dimensional image, and the bottom shows the extracted wavelength calibration spectrum.

4.1.5 ACCUM and TIME-TAG Modes

As noted, each detected photon is assigned to a pixel. In ACCUM mode, the location in the buffer at those coordinates is then incremented by one. At the end of an ACCUM exposure, the buffer memory is read out and becomes an image of the detected photons.

In TIME-TAG mode, each photon is recorded as a separate event in a long list. Each entry in that list contains the (x, y) coordinates of the photon, together with the relative time it was detected and the pulse height. The time is binned into 32 msec increments, but multiple events can be recorded within a single 32 msec time interval. In almost all cases TIME-TAG is the preferred data-taking mode.

The dead time associated with the detection electronics of the XDL detector is 7.4 μsec. For more on non-linear effects, see Section 5.2.

4.1.6 Stim Pulses

The signals from the XDL anodes are processed by Time-to-Digital converters (TDCs). Each TDC contains a circuit which produces two alternating, periodic, negative polarity pulses which are capacitively coupled to both ends of the delay line anode. When active, these stim pulses emulate counts located near the edges of the anode, beyond the illuminated portions of the detector. While the stim pulses are primarily used as a detector health diagnostic and for calibration, they also provide observers a means to track changes in image shift and stretch during an exposure and provide a first-order check on the dead-time correction. The nominal location of these stim pulses in (x, y) coordinates are: (383, 33) and (15994, 984) but those locations change with temperature.

Four stim pulse rates are available: 0 (i.e., off), 2, 30, and 2000 Hz per segment; this is **not** user selectable. Exposures longer than 100 sec will use the 2 Hz rate, while exposures from 10 to 100 sec will use 30 Hz. The highest rate is only for calibration.

4.1.7 Pulse-height Distributions

The XDL detector will generate pulse-height distributions (PHDs) along with the science data. The PHD provides important information on the micro-channel plates. The PHD is a histogram of the amplitudes of the charge clouds (pulse heights) associated with all the events detected during an integration. The distribution of the pulse heights of photon events is peaked at the average gain of the MCPs with a width determined by MCP characteristics. Background events, both internal and cosmic-ray-induced, tend to have a falling exponential distribution in pulse height, with most events being at very low pulse heights. On-board charge threshold discriminators are used to preferentially filter out very large and small pulses to improve the achieved signal-to-noise. For the FUV XDL in TIME-TAG mode, the pulse height is recorded with each detected photon event and can be examined during data analysis. For the FUV XDL in ACCUM mode, only the overall pulse-height distribution is recorded.

4.1.8 FUV Detector Lifetime Sensitivity Adjustments

The FUV XDL MCPs are subject to gradual gain degradation due to charge extraction over their lifetimes which reduces their effective sensitivity. The effect is small, but can be important in a localized region where the lifetime fluence is high, e.g. where a strong spectrum feature such as geocoronal Lyman-α falls on the detector.

The requirement for COS is for the effect to be no more than a 1% loss in quantum efficiency after 10^9 events mm^{-2} have occurred. Estimates of COS usage show that the total number of events detected in the FUV channel over a seven-year mission would be a few times this value. The net effect is thus likely to be negligible, but nevertheless STScI will monitor any degradation of the XDL detector. There is a provision to move the location of the spectrum imaged onto the XDL detector in the cross-dispersion direction onto a previously-unused portion of the detector by offsetting the aperture mechanism. This can be done up to four times.

4.2 The NUV MAMA

4.2.1 MAMA Properties

The COS NUV detector is a MAMA (Multi-Anode Micro-channel Array) that is essentially identical to that used for the NUV in STIS (it is, in fact, the STIS NUV flight spare). The COS MAMA has a semi-transparent cesium telluride photocathode on a magnesium fluoride window; this allows detection of photons with wavelengths from 1150 to 3200 Å. The background achieved with this MAMA is about 25% of the level seen with the STIS NUV MAMA.

The NUV optics focus light through the MgF_2 window onto the Cs_2Te photocathode. A photoelectron generated by the photocathode then falls onto a curved-channel micro-channel plate (MCP) and the MCP then generates a cloud of about 700,000 electrons. A single MCP manufactured by Litton Electro-Optical Systems is used to multiply photoelectrons generated by the photocathode into this charge pulse. The active area of the coded anode array is 25.6 mm square and is divided into 1024 × 1024 pixels on 25 μm centers.

The window is stepped since the photocathode must protrude into the tube body to within 0.25 mm of the MCP. At this spacing and with a photocathode-to-MCP gap potential of 800 volts, the spatial resolution at 2500 Å is 35 μm FWHM.

4.2.2 MAMA Spectrum Response

The inherent spectral response of the COS NUV MAMA is essentially identical to that of the STIS NUV MAMA. However, the overall optical train of COS differs from STIS, so that the COS throughputs are different.

4.2.3 MAMA Non-linearity

As noted in Section 5.2, the MAMA detector is expected to be essentially linear over the count rate range permissible. For count rate limits, see Section 11.5.

4.2.4 Detector Format

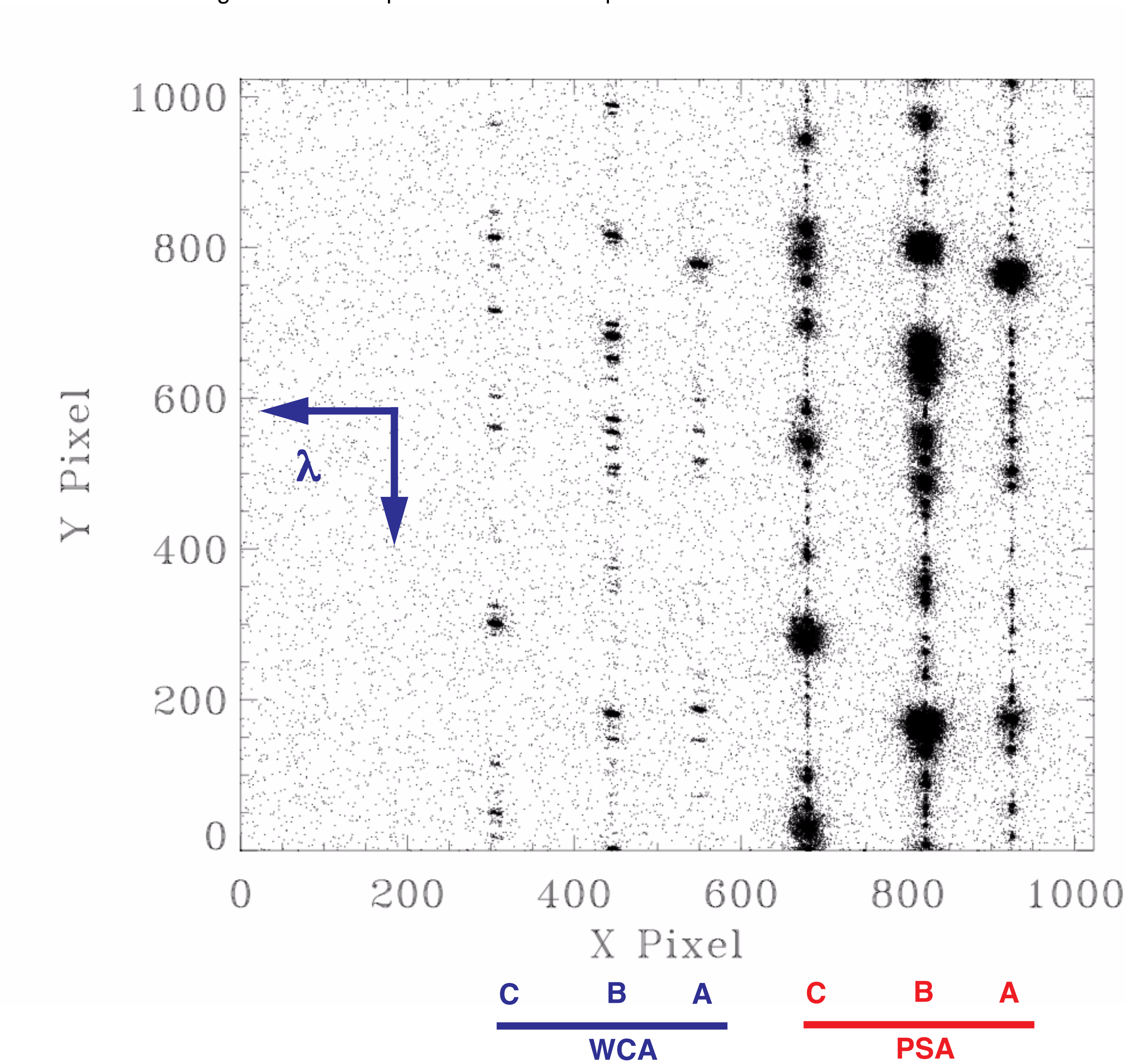
As noted in the instrument description, the NUV channel creates three spectrum stripes on the MAMA detector, and there are three separate stripes for the science data and three for the wavelength calibration data. This is shown schematically in Figure 4.4. Note that each stripe is separated by 2.80 mm center-to-center from its neighbor, and there is a gap of 3.70 mm between the reddest science stripe and the bluest calibration stripe.

Shown in Figure 4.3 is an example of an NUV spectrum (the two-dimensional image) obtained during ground testing in TAGFLASH mode.

4.2.5 Pulse-height Distributions

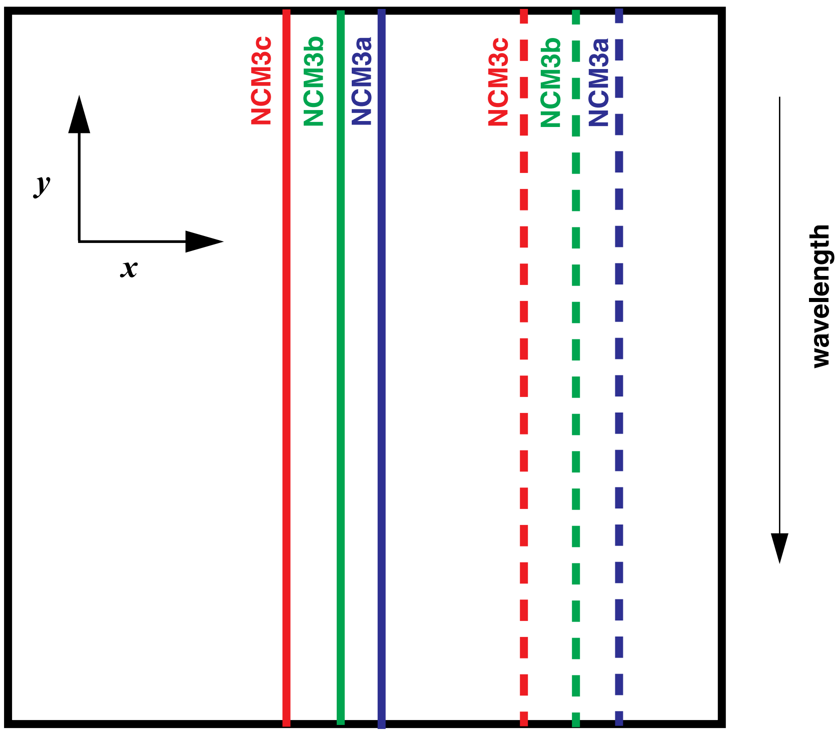
For the MAMA detector no pulse-height information is available.

Figure 4.3: Example of a COS NUV Spectrum.



Shown is a wavelength calibration spectrum, with both the WCA and the PSA illuminated by separate lamps in this set-up. Note the "science" spectrum on the right and the wavelength calibration spectrum (on the left); each have three stripes. These stripes are designated A, B, and C, in going from right to left in this illustration. Wavelength increases going down, opposite to the sense of the *y* axis.

Figure 4.4: Schematic spectrum layout for the COS MAMA.



The blue, and red stripes correspond to the shortest- and longest wavelengths, with green being intermediate. The stripes on the left are the wavelength calibration spectra and those on the right are the science spectra. The sense of x and y is the same as in Figure 4.3.

4.2.6 Read-out Format, A-to-D Conversion, etc.

The COS NUV MAMA is read out as a 1024 × 1024 array, but in all other respects the data are handled in the same way as for the FUV detector. As noted, no pulse-height information is provided with MAMA data.

CHAPTER 5:

Spectroscopy with COS

In this chapter…

5.1 The Capabilities of COS

COS has two channels, one for the Far Ultraviolet (FUV), and one for the Near Ultraviolet (NUV). Both channels use photon-counting detectors, but those detectors are very different, and in many other ways as well the two channels of COS are used in substantially different ways. Both channels also offer a selection of diffraction gratings that you may use to choose either medium- or low resolving power, with good throughput at any ultraviolet wavelength. Only one of the two channels may be in use at any one time.

This section starts with an outline of the spectroscopic capabilities and expected data quality for COS.

Table 5.1: COS Spectroscopic Modes

Grating	Useful wavelength range (Å)[1]	Bandpass per exposure (Å)	Resolving Power[2] $R = \lambda/\Delta\lambda$	Dispersion (mÅ $pixel^{-1}$)
FUV Channel				
G130M	1150 –1450	292[3]	20,000 – 24,000	9.97
G160M	1405 – 1775	360[4]	20,000 – 24,000	12.23
G140L	1230 – 2050	>820	2,000 – 5,000	80.3
NUV Channel				
G185M	1700 – 2100	3 × 35	16,000 – 20,000	37
G225M	2100 – 2500	3 × 35	20,000 – 24,000	33
G285M	2500 – 3200	3 × 41	20,000 – 24,000	40
G230L	1650 – 3200[5]	(1 or 2) × 398	1,550 – 2,900	390

1. The useful wavelength range is the expected usable range realized in each grating mode. Note that G140L is set so that Lyman-α falls in the gap between the two micro-channel plates to minimize the effects of geocoronal glow. With G140L, one half records 1230 – 2050 Å. The other half records whatever spectrum is detected below 1100 Å, but that is expected to be very little in most cases, hence the 820 Å nominal bandpass. The response of COS below Lyman-α will be evaluated after launch.
2. The lesser value of *R* is realized for the low-wavelength end of the useful range, and *R* increases roughly linearly with wavelength.
3. The inter-segment gap misses 14.3 Å.
4. The inter-segment gap misses 18.1 Å.
5. Some shorter wavelengths are recorded in second-order light. These are listed in Table 5.4.

COS also incorporates an imaging capability in its NUV channel (see Chapter 6 and Chapter 7).

5.1.1 Signal-to-noise Considerations

In ground testing, the COS FUV channel was capable of routinely delivering fully reduced spectra with a photon-noise-limited signal-to-noise (S/N) ratio of ~18 per resolution element in a single exposure. In order to achieve higher S/N, COS can move the spectrum in small amounts so that it falls on different parts of the detector. The use of this `FP-POS` option (see Section 5.8) at four positions can improve the S/N to 35. Photon-limited S/N values as high as 62 have been demonstrated during ground testing for wavelength regions in which good calibrations were available. The COS calibration program will test and confirm these results after installation in HST, with a goal of achieving S/N = 100 by using astrophysical flat-field sources.

In the NUV channel, we expect to achieve S/N comparable to what has been possible with STIS, namely 100:1 or better.

For more about signal-to-noise, see Section 5.8.

5.1.2 Photometric (Flux) Precision

The limits on the precision and accuracy of fluxes measured with COS are expected to be the same as for STIS. COS has the advantage of a fairly large aperture so that there are only small aperture losses (at most 5%; see Section 13.4). The photometric capabilities of COS will be tested after it is installed, but for now we take them to be the same as STIS, namely 5% accuracy on absolute fluxes and 2% on relative fluxes (within a single exposure). The experience with the NUV MAMA of STIS shows that the repeatability of a flux is good to well under 0.5%. The level of repeatability for the FUV detector is not yet known.

5.1.3 Spatial Resolution and Field of View

The spatial resolution of COS is inherently limited by the aberrated Point Spread Function of HST. Ground tests show that COS can separate spectra of two equally bright objects that are 1 arcsec apart in the cross-dispersion direction for either the FUV or NUV channel. The NUV channel's optics can correct the aberrations so that the NUV imaging capability is diffraction limited (see Chapter 6).

The field of view of COS is obviously determined by the entrance apertures that are 2.5 arcsec in diameter, but the aberrated light entering the aperture means that objects up to 2 arcsec from the center of the aperture will be visible in the recorded spectra.

5.1.4 Wavelength Accuracy

The COS specifications for absolute wavelength uncertainties within an exposure are:

- 15 km s^{-1} for medium-resolution spectra (the "M" gratings),
- 150 km s^{-1} for G140L, and
- 175 km s^{-1} for G230L.

The error budget for wavelength accuracy for the various gratings then breaks down as shown in Table 5.2. Note that all quantities are 1σ. To arrive at the last two columns, the error budget has been divided equally between internal and external sources. The internal sources include the accuracy of the wavelength scale, the dispersion relation, aperture offsets, distortions, and drifts. The external tolerance budget is dominated by target mis-centering in the aperture. For more on this subject, see Section 7.4.3.

Table 5.2: Wavelength Calibration Uncertainties.

Grating	Error goal (1σ)		Internal error (1σ)	External error (1σ)	Plate scale[1]
	km s^{-1}	pixels	pixels	arcsec	pixel $arcsec^{-1}$
G130M	15	5.7 – 7.5	3.0 – 4.0	0.09 – 0.12	45.1
G160M	15	5.8 – 7.2	3.1 – 3.8	0.10 – 0.12	44.6
G140L	150	7.5 – 12.5	4.0 – 6.6	0.12 – 0.21	47.1
G185M	15	7.2 – 10.0	1.2 – 1.7	0.03 – 0.04	41.85
G225M	15	9.7 – 13.3	1.6 – 2.3	0.04 – 0.06	41.89
G285M	15	9.7 – 14.7	1.6 – 2.6	0.05 – 0.07	41.80
G230L	175	8.3 – 15.5	1.4 – 2.6	0.03 – 0.07	42.27

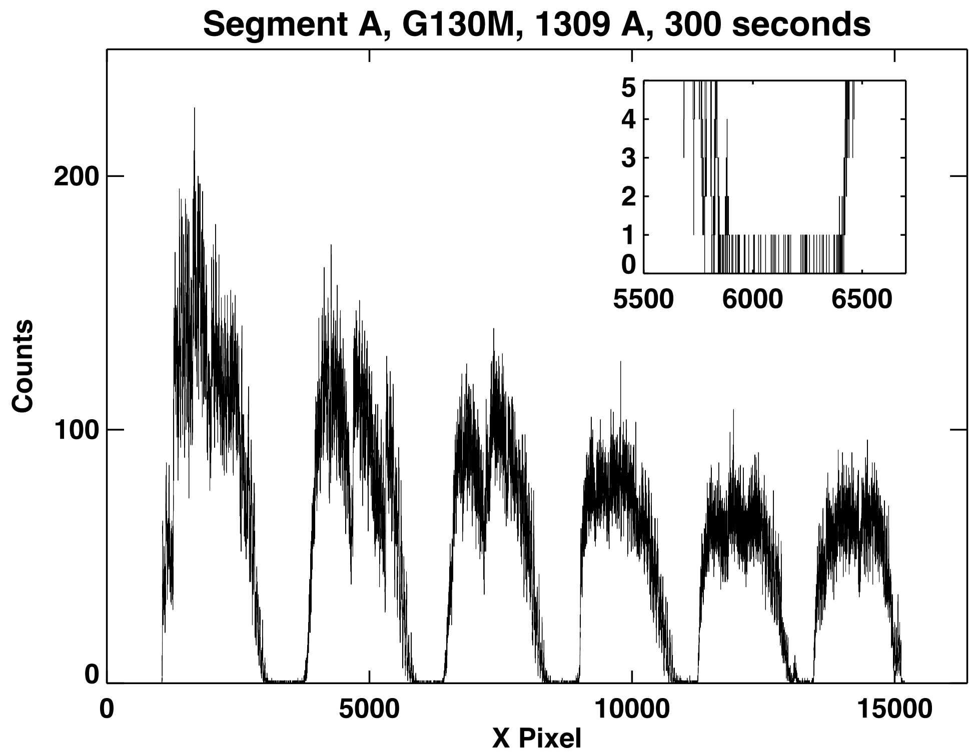
1. The plate scale is shown to indicate the centering precision needed during acquisition. The values are for the along-dispersion direction.

Tests of COS on the ground before flight showed some motion of the grating mechanisms (OSM1 and OSM2) after they were stopped in their nominal positions. This drift is small but significant enough for the first few minutes to potentially degrade a spectrum in wavelength. It is to properly calibrate this effect that the "TAGFLASH" operating mode was designed. TAGFLASH mode means using `TIME-TAG` observations with Optional Parameter `FLASH=YES` (the default), and in this mode the wavelength calibration lamp is exposed periodically during science observations so that any drift can later be removed. Because the wavelength calibration spectra are recorded on the detector well away from the science spectrum, one does not contaminate the other. TAGFLASH is described further in Section 5.7.1.

5.1.5 Scattered Light in COS Spectra

Figure 5.1 shows an example of an observation obtained during ground testing. A CO absorption cell was placed into the input beam while observing in the FUV with a continuum source. The inset shows an enlargement in the bottom of one of the absorption troughs, showing that any light scattered along the dispersion direction is well under 1% of the nearby continuum.

Figure 5.1: Scattered light in the FUV.



Shown is a test exposure obtained during ground calibrations using a CO absorption cell. The inset shows an enlargement of the bottom of one of the absorption troughs.

5.1.6 Spectroscopic Resolving Power

The available spectroscopic resolving powers (*R*) available to observers with COS were listed in Table 5.1. Note that no single value of *R* applies to any one grating, instead it depends on wavelength, with $R \propto \lambda$.

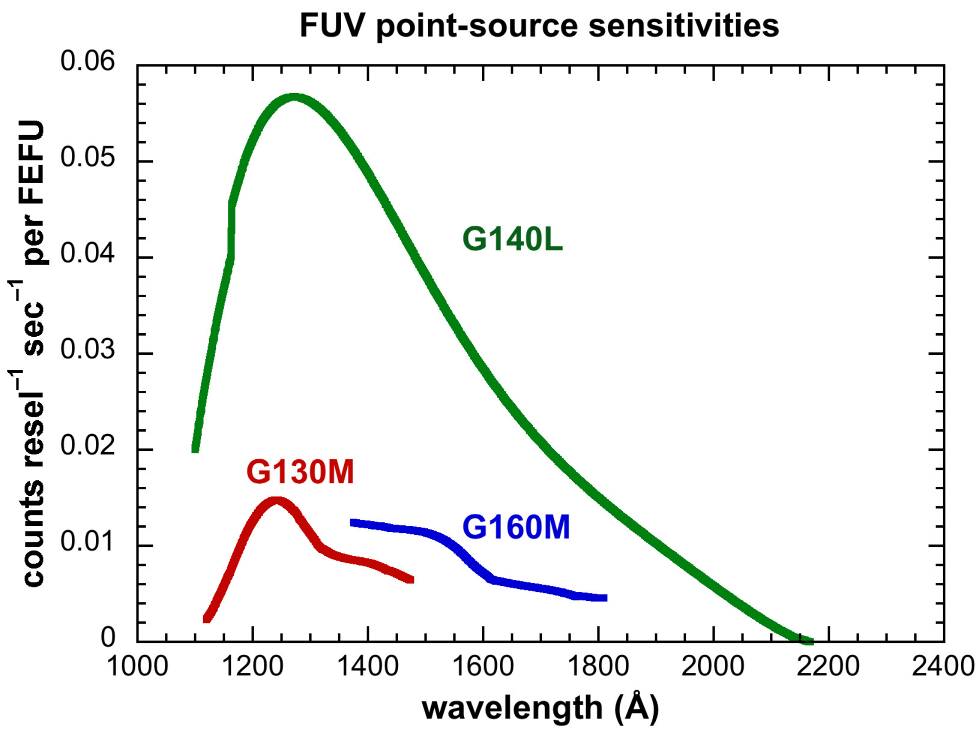
R also depends on the position of the source in the COS aperture; this is shown in Figure 7.2.

Use of the BOA leads to a degradation of *R* by factors of 3 to 5; see Section 13.1.3 for more information.

5.1.7 Sensitivity

Measurements of the throughputs of the COS optical systems on the ground indicate that COS will be considerably more sensitive than STIS and earlier generation HST instruments at comparable spectral resolutions, particularly in the far ultraviolet. The point source sensitivities (S_λ) for the COS spectroscopic modes are shown in Figure 5.2, Figure 5.3, and Figure 5.4 Note that these are shown per resel, not per pixel. The reader is reminded that the definition of FEFU may be found at Section 1.1.2. A resel is a “resolution element,” which is 6 pixels wide for the FUV channel and 3 pixels for the NUV. Thus the per-pixel sensitivities are lower than shown by these factors.

Figure 5.2: Far-ultraviolet Sensitivity Curves for COS.

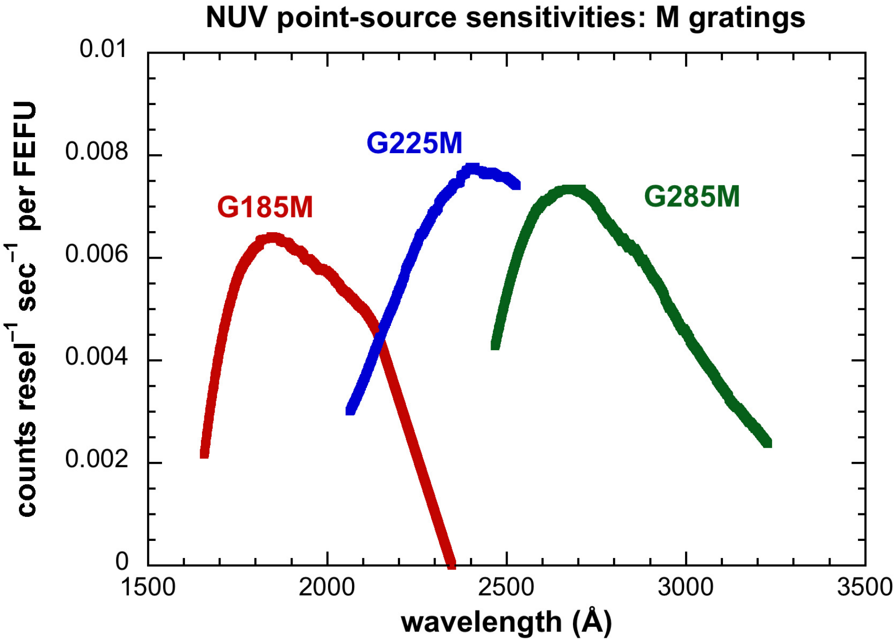


The values shown are counts per resel per second per FEFU, and are for point sources. Please note that these data are plotted for display purposes only and that those planning observations should use the ETC to get accurate estimates. Also note that these data are pre-flight measurements that will be verified after COS is installed. **An FUV resel is 6 pixels wide, so the sensitivity per pixel is 6 times lower than the value indicated here.**

An estimate of the number of counts (N) expected per resolution element in an amount of time (Δt) for a source flux (F_λ) is given by $N = S_\lambda F_\lambda \Delta t$. As an example, with the COS G130M grating at 1300 Å an exposure time of approximately 1900 seconds is required to reach S/N = 15 per 0.066 Å resolution element ($R \sim 20{,}000$) for an object with $F_{1300} \approx 10$ FEFU.

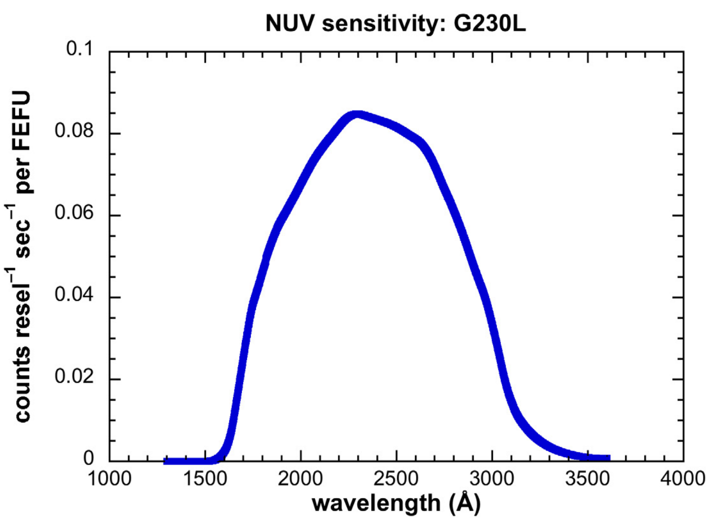
The sensitivities illustrated here are based on a preliminary analysis of pre-flight test data. Proposers are urged to use the facilities in the COS ETC when planning observations because the ETC uses the most up-to-date information available.

Figure 5.3: Near-ultraviolet sensitivity curves for COS medium-resolution gratings.



The values shown are in counts per resel per second per unit FEFU, and are for point sources. The data shown are pre-flight measurements from ground tests. **An NUV resel is 3 pixels wide, so the sensitivity per pixel is 3 times lower than the value indicated here.**

Figure 5.4: Sensitivity Curve for Grating G230L.



The values shown are in counts per resel per second per unit FEFU, and are for point sources. NUV resels are 3 pixels wide. The data shown are pre-flight measurements from ground tests. **An NUV resel is 3 pixels wide, so the sensitivity per pixel is 3 times lower than the value indicated here.**

5.1.8 Sensitivity to second-order spectra

COS has been designed to avoid contamination of the first-order spectra by any second-order light. In the FUV channel, second-order light is suppressed by the three reflections from optics coated with Al and MgF_2 (two in the HST OTA plus the COS FUV optical element that is chosen). The NUV channel is susceptible, however, because the MAMA detector is sensitive to light down to 1150 Å. This means that NUV settings above about 2300 Å may be vulnerable.

To mitigate this problem, the NUV optics in COS are optimized for NUV wavelengths to provide peak reflectivities between 1600 and 2000 Å. In addition, two of the NUV gratings (G225M and G285M) have bare aluminum surfaces which has poor FUV reflectivity. Given four such reflections, light from below 1250 Å is reduced by 99%. A 2 mm thick fused silica order-sorting filter was placed in front of two of the NUV gratings (G225M and G285M) as well as in front of MIRRORA/MIRRORB so that light passes through it twice, reducing second-order light to very low levels.

The result from ground tests is that only G225M shows measurable second-order throughput, but even then the second-order light was suppressed by factors of 3,000 to 10,000. Because most astrophysical sources decline in flux in going to shorter wavelengths, it is expected that second-order contamination in COS will be insignificant.

5.2 Non-linear Photon Counting Effects (Dead-time Correction)

The electronics that handle the COS detectors have a finite response time, and that limits the rate at which they can detect photons. This effect of non-linearity is sometimes known as the dead-time correction.

For the FUV channel, there are three factors that influence the detected count rate. The first is a Fast Event Counter (FEC) for each segment that has a dead time of 300 nsec. The FECs only matter at count rates well above what is usable, amounting to a 1% effect at a count rate of 33,500 per segment per second.

The second effect is due to digitization of the detected events, and that has been measured for the FUV XDL detector, with a dead-time constant of 7.4 μsec. For a given true count rate C, the detected count rate is given by:

$$D = \frac{C}{1 + C \cdot t}$$

where D is the detected count rate and t is the dead-time constant. For $t = 7.4$ μsec, the apparent count rate deviates from the true count rate by 1% when $C = 1{,}350$ counts sec^{-1}, and by 10% when $C = 15{,}000$ counts sec^{-1}. Note that when the effect is near the 10% level, then the FUV detector is near its global count rate limit (see Section 11.5) and so non-linear effects are small for the FUV detector.

Finally, for the FUV channel the count streams for the two separate segments must be combined in a single "round robin" Detector Interface Board (DIB) that takes signals from both the A and B segments and then stores them in the data buffer. The DIB interrogates the A and B segments alternately, and, because of this, a high count rate in one segment but not the other could lead to an additional effect. The DIB is limited to processing about 250,000 events sec^{-1} in ACCUM mode and only 30,000 counts sec^{-1} in `TIME-TAG` mode. Tests have shown that the DIB is lossless up to a combined rate for both segments of 20,000 sec^{-1}, and the loss is 100 sec^{-1} at a rate of 40,000 sec^{-1}. Thus this effect is less than 0.3% at the highest allowable rates, and there is information in the engineering data that characterizes this effect.

For the NUV MAMA on COS, the dead-time is the same as for the STIS NUV MAMA, which is 280 nsec. Note that for the STIS MAMAs the 1% level of non-linearity is reached for C = 36,000 counts sec^{-1}. The MAMAs also show a local non-linear effect that is small and will be calibrated on orbit.

Dead-time corrections are automatically made in the **calcos** pipeline.

5.3 Exposure Time Considerations

All COS exposure times must be an integer multiple of 0.1 seconds. If the observer specifies an exposure time that is not a multiple of 0.1 sec, its value is rounded down to the next lower integral multiple of 0.1 sec, (or set to 0.1 seconds if a smaller value is specified). The minimum COS exposure time duration is 0.1 seconds (but `FLASH=YES TIME-TAG` exposures impose a longer minimum; see FLASH section below). The maximum COS exposure time is 6,500 seconds. Bear in mind that exposure time values much larger than about 3,000 seconds are normally appropriate only for visits with the CVZ special requirement because the visibility period of a single orbit is ~50 minutes. See the *HST Primer* for information about HST’s orbit and visibility periods.

If an exposure specifies `FP-POS=AUTO`, then the valid range for the exposure time is 0.4 to 26,000.0 seconds. This is because the exposure time you enter specifies the total time, and the exposure time for each individual sub-exposure of the four implied by `FP-POS=AUTO` must be at least 0.1 sec. In other words, if `FP-POS=AUTO`, the specified Time_per_Exposure is divided equally among the four `FP-POS` offset exposures.

For `TIME-TAG` exposures with `BUFFER-TIME` < 110 seconds, photon events may be generated faster than data can be transferred out of the buffer during the exposure. In this case, Time_Per_Exposure should be less than or equal to 2 × `BUFFER-TIME` so that the exposure can complete before data transfer is necessary. A `BUFFER-TIME` of 110 seconds corresponds to an average count rate of ~21,000 counts/sec. For more on `BUFFER-TIME`, see Section 5.5.1.

For target=`WAVE` exposures, `DEF` must be entered as the exposure time and the appropriate value for the optical configuration will be chosen from a table that is established at STScI for best performance.

5.4 Apertures

The PSA aperture will be used for most COS targets. The BOA aperture should be used only for those targets too bright to be observed with the PSA aperture. The BOA aperture degrades the spectral resolution by a factor of three or more from nominal design levels. The WCA aperture is used only for user-specified target=WAVE wavelength calibration observations. Also note that the BOA cannot be used for TIME-TAG mode observations with FLASH=YES ("TAGFLASH" mode) because the WCA is blocked when the BOA is in position.

See Section 3.2.2 for more information.

5.5 TIME-TAG or ACCUM?

COS exposures may be obtained in either a time-tagged photon address mode (TIME-TAG), in which the position, time, and pulse height of each detected photon are saved in an event stream, or in accumulation (ACCUM) mode in which the positions, but not the times, of the photon events are recorded. The TIME-TAG mode of recording events allows the post-observation pipeline processing system to screen the data as a function of time, if desired, and to make other corrections. The COS TIME-TAG mode has a time resolution of 32 ms.

Some pulse-height information is available for all COS FUV science exposures. (No pulse height information is available for COS NUV science exposures.) The pulse height distribution (PHD) is an important diagnostic of the quality of any spectrum obtained with micro-channel plate detectors:

1. In FUV ACCUM mode, the global PHD is accumulated on-board as a separate data product along with the photon events.
2. In FUV TIME-TAG mode, the individual pulse height amplitudes are recorded along with the position and time information of the photon events, so the PHD can be screened by time or position on the detector if desired during the calibration process. Post-observation pulse height screening is useful for reducing unwanted background events, and can often improve the signal-to-noise ratio in the extracted science spectrum.

5.5.1 TIME-TAG Mode

TIME-TAG should be used for COS observations whenever possible because it provides significant post-pipeline advantages for temporal sampling, exclusion of poor quality data, and, for the FUV, improved thermal correction and better background removal (by using the pulse-height information). TIME-TAG should always be used for exposures that will generate count-rates of 21,000 counts sec^{-1} or less from the entire detector (including both detector segments for the FUV). In the 21,000-30,000 counts sec^{-1} range, TIME-TAG may be used to obtain properly flux-calibrated data, but loss of some continuous time-periods within extended exposures will occur (see the discussion under BUFFER-TIME below). At present, TIME-TAG should not be used for count-rates greater than 30,000 counts-sec^{-1}. ACCUM mode should be used only when absolutely necessary, such as for high count-rate targets.

We also recommend that TIME-TAG mode always be used with FLASH=YES (the so-called TAGFLASH mode) unless circumstances prevent that.

Important Considerations for BUFFER-TIME

All external TIME-TAG observations (i.e., all except wavecals) must have a specified BUFFER-TIME (equal to 80 or more integer seconds), which specifies the estimated minimum time in which 2.35×10^6 photon events (half of the COS data buffer capacity) will be accumulated during the exposure. BUFFER-TIME is a required parameter if the target is not WAVE. If the target is WAVE, then BUFFER-TIME may not be specified.

It is important for you to actually calculate an accurate value of BUFFER-TIME using the COS ETC. Do not simply specify the minimum BUFFER-TIME in your proposal! Observations that fail to deliver all the potential data because of observer error of this kind will not be repeated.

If the predicted total number of events from a TIME-TAG exposure exceeds the total COS data buffer capacity of 4.7×10^6 photon events, data must be transferred to the HST on-board science recorder during the exposure. Transfers of data from the COS buffer during an exposure will be made in 9-MByte blocks (half the buffer capacity). The value of BUFFER-TIME should be the half-buffer capacity (2.35×10^6 counts) divided by the anticipated maximum sustained count rate in photons per second.

We recommend that you give yourself a margin of error of about 50% if at all possible; i.e., to take the BUFFER-TIME just estimated and multiply by 2/3. Note that the BUFFER-TIME values returned by the COS ETC should also be reduced by 2/3.

Note that BUFFER-TIME should include expected counts from the detector dark current and stim pulses as well as the detected photon events, factoring in the instrument quantum efficiency (the COS ETC includes these effects). On-board commanding utilizes the predicted buffer-time to establish the pattern and timing of memory dumps during the exposure.

During the first BUFFER-TIME of an exposure, counts are recorded in one of the two 9-Mbyte buffers of memory. After that first BUFFER-TIME is completed, data recording switches to the second of the two memory buffers, and the first buffer is read out concurrently. No data will be recorded in a buffer until it has been read out completely. Therefore, if the second buffer fills before the first has read out, all subsequently arriving counts will be lost until the first buffer is read out completely and again available for data-taking.

If BUFFER-TIME is incorrectly overestimated, the on-board data buffer may fill before the scheduled memory dump. Subsequently arriving photons will not be counted; they will not overwrite earlier recorded events. Therefore, a gap in recorded data will occur. NOTE: the pipeline will correct actual exposure times for any such gaps, so flux calibrations will be correct, although the overall S/N will be lower.

The absolute minimum BUFFER-TIME of 80 seconds corresponds to a maximum average count rate of ~30,000 counts sec^{-1} over the entire detector, which is the maximum rate at which the flight software is capable of processing counts. Note that the first buffer readout of an exposure requires 110 seconds to complete; this means that the maximum average count rate that will always produce no gaps in the recorded data is ~21,000 counts sec^{-1}.

If BUFFER-TIME < 110 seconds, Time_Per_Exposure should be less than or equal to 2 × BUFFER-TIME so that the exposure can complete before data transfer is necessary.

Note that TIME-TAG exposures of high data-rate targets have the potential to rapidly use up the HST on-board storage capacity. Caution is advised on any exposure with an exposure time greater than 25 × BUFFER-TIME, which corresponds to ~6 × 10^7 counts, or about 2 GBits (close to 20% of the solid-state recorder capacity).

The software and parameters that control dumps of the data buffer have been set to avoid any loss of data from an observation. The duration and timing of data dumps depend on several factors, and observers are urged to use APT for observation planning in order to get accurate and complete determinations of how these occur.

Doppler Correction for TIME-TAG Mode

No on-board corrections are made for shifts in the spectrum from orbital motion while in TIME-TAG mode; this is done later in pipeline processing.

Pulse-height Data for TIME-TAG

The FUV detector provides five bits of pulse-height information with every photon event. These data are down-linked with the science data and are used later during data processing. See also Section 4.1.7.

5.5.2 ACCUM Mode

ACCUM mode should be used primarily for brighter targets, where the high count rate would fill the on-board buffer memory too rapidly if the data were taken in TIME-TAG mode. In some instances it may be possible to observe a relatively bright object in TIME-TAG mode if the BOA is used instead of the PSA, but using the BOA degrades the spectroscopic resolution. Observers wishing to use ACCUM mode will be asked to justify doing so when submitting their Phase II program.

Observing Efficiencies with ACCUM

In certain cases on-board readout overheads can be minimized with ACCUM mode. This will typically be of interest for very bright targets that must be observed with ACCUM anyway.

Two ACCUM FUV images may be placed into on-board memory as ACCUM exposures read out only that portion actually illuminated by the target (1/8 of the full detector area, or 128 pixels high). FUV ACCUM image readouts require one-half of the total COS memory so it is possible to acquire two FUV images before dumping the on-board buffer. Similarly, for the NUV detector, up to nine ACCUM images can be placed in memory.

If multiple exposures with the same setup configuration are required in ACCUM mode, (e.g., a time-series of observations on a bright target), then utilization of the Number_Of_Iterations Optional Parameter can be useful (the “repeatobs” option). Unlike the TIME-TAG case, no data may be acquired during an ACCUM readout, so the NUV detector is more efficient for repeatobs observing as more images can be placed in memory prior to pausing for readout.

If FP-POS=AUTO is specified with NUMBER_OF_ITERATIONS > 1, the exposures will be obtained in the order Number_Of_Iterations of exposures at each FP-POS position between moves of the grating.

Doppler Correction for ACCUM Mode

In ACCUM mode, the COS flight software adjusts detected events for the orbital motion of HST. The doppler correction is updated whenever HST’s motion changes enough to cause the spectrum to cross a pixel boundary. This is done via a small table of values computed at the start of each exposure based on the orbital motion and the dispersion of the grating in use.

Doppler- or other corrections for ACCUM mode observations cannot be performed in the post-observation pipeline as the identity of individual photons is lost in the ACCUM process. The on-board flight software will adjust for the doppler shift of the spectrum due to the orbital motion of HST when observing in ACCUM mode. The doppler correction is updated whenever the HST orbital motion shifts the spectrum across a pixel boundary.

Note that ACCUM mode exposures longer than 900 seconds that use the G130M or G160M gratings may blur the FUV spectra by 1 to 2 pixels (about 1/6 to 1/3 of a resolution element) due to wavelength-dependent deviations from the mean doppler correction.

Pulse-Height Distribution Data for ACCUM Mode Observations

Some limited pulse-height information is also available for FUV ACCUM observations. A PHD histogram is dumped for every ACCUM mode image with the FUV detector, consisting of 256 bins (128 bins for each segment) of 32 bits each. Pulse-height data are not provided for NUV exposures.

5.6 FUV Gap Coverage and Single Segment Usage

The FUV detector contains two segments whose active areas are separated by a gap approximately 9 mm wide. The optical image of the spectrum is continuous, but the wavelengths that fall on the gap are not recorded. The area between the two segments of the FUV detector causes a 14.3 Å gap in the wavelength coverage for the G130M grating, and 18.1 Å for G160M. Depending upon the science requirements of the observation, these wavelengths can be brought onto the active area of the detector by choosing one of the alternate central wavelength settings. Each FUV “M” grating has five central wavelength settings and the G140L has two. Wavelengths that fall on the gap with one of the settings are visible with at least one of the other settings.

The 9 mm gap between the FUV segments corresponds to about 1500 FUV pixels. Note that one step of OSM1 motion (such as occurs between individual `FP-POS` settings) gives rise to a displacement of 240 pixels. **Thus just executing a full set of `FP-POS` settings is not sufficient to provide full wavelength coverage of the gap.**

Single Segment Usage

The COS FUV detector consists of two distinct segments which are, at the lowest commanding level, operated and read out independently. Normally, both detector segments are utilized for a science exposure, however, there are circumstances where operating with one detector segment at the nominal high voltage and the other effectively turned off may be beneficial. The `SEGMENT` Optional Parameter allows this choice. STScI strongly recommends usage of both segments (the default for all but the G140L 1105 Å setting) unless very special circumstances exist. Such circumstances include, but are not limited to:

- Sources with unusual spectral energy distributions at FUV wavelengths (bright emission lines or rapidly increasing/decreasing continuum slopes), where the count rate on one detector segment may exceed the bright object protection limit, but the other segment would be safe for observing.
- Other sources with unusual spectral energy distributions, where the count rate on one detector segment would be high but safe, and the other segment would have a relatively low count rate. In this case, if the science to be done were on the low count-rate segment, operating just that segment may result in a substantially reduced dead-time correction.

Wavelength and flat-field calibration procedures will remain the same for a particular segment whether the other segment is operating or not.

The Optional Parameter `SEGMENT` (`=BOTH` (default), `A`, or `B`) specifies which segment of the FUV detector to use for an observation. A value of `BOTH` will activate both segments. If `A` is selected, only segment A of the detector will be activated for photon detection, and the spectrum will contain data from only the long-wavelength half of the detector. If `B` is selected, only the short-wavelength segment B of the detector will be activated and used to generate data.

Please note: if grating G140L is specified with the 1105 Å wavelength setting, then the value must be SEGMENT=A. Bear in mind that segment A detects the longer wavelength light and segment B the shortest wavelengths, and this is true for all FUV settings. Switching from two-segment to single-segment operation (or back again) incurs a substantial overhead time; see Table 9.4.

5.7 Internal Wavelength Calibration Exposures

Three types of internal wavelength calibration exposures may be inserted in the observation sequence by the scheduling system or by the observer:

1. FLASH=YES (so-called TAGFLASH) lamp flashes (TIME-TAG observing only),
2. AUTO wavecals, and
3. User-specified wavecals.

Note that all wavelength calibration exposures are taken in TIME-TAG mode. Wavelength calibration exposure overheads are higher when the BOA is used for science observation as the aperture mechanism must be moved farther to place the WCA in the wavelength calibration beam.

For TIME-TAG observing, we strongly recommend use of the default FLASH=YES mode of wavelength calibration.

5.7.1 Concurrent Wavelength Calibration with TAGFLASH

Optional Parameter FLASH (=YES (default), NO) indicates whether or not to “flash” the wavelength calibration lamp during TIME-TAG exposures. These flashes are needed to provide information used by the **calcos** pipeline to compensate for the effect of post-move drift of the Optic Select Mechanisms. The default behavior will be that when the external shutter is open, the wavecal lamp is turned on briefly at the start of an externally targeted exposure, and at intervals later in the exposure. In this mode, photons from the external science target and the internal wavelength calibration source are recorded simultaneously on different portions of the detector. Other than the flash at the start of each exposure, the actual timing of flashes is automatically determined by the elapsed time since the last OSM move has occurred. As a result, flashes may occur at different time-points in different exposures. The grating-dependent “flash” durations (discussed below) and the time-since-last-OSM-move-dependent flash intervals will be defined and updated as necessary by STScI. Observers may not specify either flash duration or flash interval. We strongly recommend use of Optional Parameter FLASH=YES with all TIME-TAG observations.

FLASH=YES TIME-TAG sequences provide the highest on-target exposure time per orbital visibility as no on-target time is lost due to required instrumental calibration exposures.

When flashing is enabled, the exposure time must be at least as long as a single flash. FLASH may not be specified, and defaults to NO, when aperture BOA is selected. FLASH also may not be specified for ACCUM mode.

Additional information on how TAGFLASH works may be found in Section 13.5.

5.7.2 AUTO Wavecals (When TAGFLASH is not Used)

For TIME-TAG exposures, specifying FLASH=NO disables automatic flashing for the current exposure. Also, flashes are not performed in ACCUM exposures.

In these cases, unless specifically requested in the Exposure Specification, a separate wavelength calibration exposure will be automatically performed (AUTO wavecal) for each set of external spectrographic science exposures using the same spectral element, central wavelength, and FP-POS value, including each sub-exposure of an exposure specification with Optional Parameter FP-POS=AUTO. These AUTO wavecals are always obtained in TIME-TAG mode with the external shutter closed. This automatic wavelength calibration exposure will be added prior to the first such science exposure and after each subsequent science exposure if more than 40 minutes of visibility time has elapsed since the previous wavelength calibration exposure and if the same spectrograph set-up has been in use over that time. The calibration exposure will often use some science target orbital visibility. The calibration lamp configuration and exposure time will be based on the grating and central wavelength of the science exposure. Utilization of a GO wavecal (see below) resets the 40 minute interval timer. Insertion of a FLASH=YES exposure in the time-line does not affect the 40-minute clock.

For TIME-TAG FLASH=NO and for ACCUM observations, AUTO wavecals may not be turned off by the observer. If there is a science requirement to turn off AUTO wavecals, specific permission must be sought from the STScI Contact Scientist.

ACCUM and TIME-TAG observations with FLASH=NO will be less efficient than with FLASH=YES observations in terms of on-target utilization of orbital visibility and in terms of resultant wavelength calibration due to possible OSM residual motions.

5.7.3 Wavelength Calibration Exposures with the BOA

If the BOA is moved into position for science observations, the WCA is no longer available and light from the Pt-Ne lamps cannot reach the detector. As a result FLASH=YES may not be used when the BOA is specified. If TIME-TAG mode is specified with the BOA as the aperture then separate wavecals will automatically be obtained in the same way as for an ACCUM mode exposure and subject to the same rules. Such wavecals will also be obtained if ACCUM mode exposures are obtained with the BOA as aperture.

5.7.4 User-specified Wavelength Calibration Exposures (GO Wavecals)

Observers may insert additional wavelength calibration observations in the visit by specifying target=WAVE (so-called GO wavecal exposures). Note that the default modes of operation (TIME-TAG, ordinarily, or ACCUM) automatically secure needed wavelength calibration information to go with your science data, and so the need for user-specified wavecals should be rare. Exposure time must be set to DEF for these exposures, TIME-TAG must be used, and FLASH=NO should be explicitly selected. Exposures specified with the WAVE internal target will use the same calibration lamp configuration and exposure time as the automatic wave calibrations discussed above. Initially, lamp flash durations are identical to the required default wavelength calibration exposure times, however this identity may be changed.

5.8 Achieving Higher Signal-to-noise using FP-POS

5.8.1 Use of Optional Parameter FP-POS

Special "central-wavelength dithers" (for STIS and GHRS known as FP-SPLITs) may be used to enhance signal-to-noise in spectroscopic data or to correct for fixed pattern detector features through a sequence of exposures taken at slight offsets in the dispersion direction. For COS, these motions are specified by the FP-POS Optional Parameter.

The full automatic wavelength dithering pattern uses four FP-POS positions: a nominal position ("0"), 2 positions toward shorter wavelengths (–2 and –1), and 1 position toward longer wavelengths (+1). The ordering of the four when FP-POS=AUTO is used is –2, –1, 0, and +1; i.e., in order of increasing wavelength. These four positions are designated respectively as FP-POS=1, FP-POS=2, FP-POS=3, or FP-POS=4 if a specific setting is desired. Note that FP-POS=3 is the default if no specific value is chosen.

The number of steps to rotate the optical mechanisms is one for each adjacent FP-POS position. The amount that a particular wavelength moves in the dispersion direction on the detector due to one rotation step of the appropriate mechanism is 240 pixels for the FUV channel and 49 pixels for the NUV. The subsequent spectra will be aligned and co-added by **calcos** in pipeline processing. Wavelength calibration spectra will automatically be obtained for each FP-POS position.

Note that FP-POS indicates the relative position of an exposure, not the number of separate exposures. The one exception is FP-POS=AUTO, which takes four exposures in the order of 1, 2, 3, 4. FP-POS=4, for example, takes a single spectrum at position number 4 for the specified exposure time. FP-POS=AUTO indicates that the specified exposure time will be divided evenly among four sub-exposures, and each sub-exposure will be obtained at a different predetermined offset from the specified central wavelength. Note that there is a preferred direction to move the grating mechanism and so overheads are reduced in some FP-POS scenarios compared to others (see Section 9.3). We ordinarily recommend use of FP-POS=AUTO. The default value (FP-POS=3), or if FP-POS is not specified on the exposure, will result in the exposure being obtained at the nominal central wavelength (i.e., at a zero) offset and the exposure will be for the specified exposure duration. Note that utilization of FP-POS=AUTO at two consecutive central wavelength settings allows complete filling of the FUV detector gap, but that FP-POS=AUTO by itself at a single wavelength setting is not sufficient to cover the gap.

Wavelength calibrations will be obtained each time the FP-POS changes. For FLASH=YES exposures, the time-since-grating-move clock is not reset by an FP-POS movement, however there will always be at least one lamp flash during each individual FP-POS exposure. For FLASH=NO exposures, a separate wavelength calibration exposure will be taken for each FP-POS position change. Note for internal targets: FP-POS is not allowed for internal targets except Target=WAVE. Allowed values for exposures with Target=WAVE are FP-POS=1, 2, 3 (or not specified), or 4; FP-POS=AUTO is not allowed.

To summarize, users may specify the full range of FP-POS sampling by using AUTO, or may design wavelength-dither pattern sequences of their choosing. Note that an explicit specification of exposure sequences FP-POS=1, FP-POS=2, FP-POS=3, and FP-POS=4 is marginally more efficient (by a few seconds) than using FP-POS=AUTO, but the explicit specification allows for greater flexibility in using your orbits in Phase II.

5.8.2 FUV Signal-to-noise

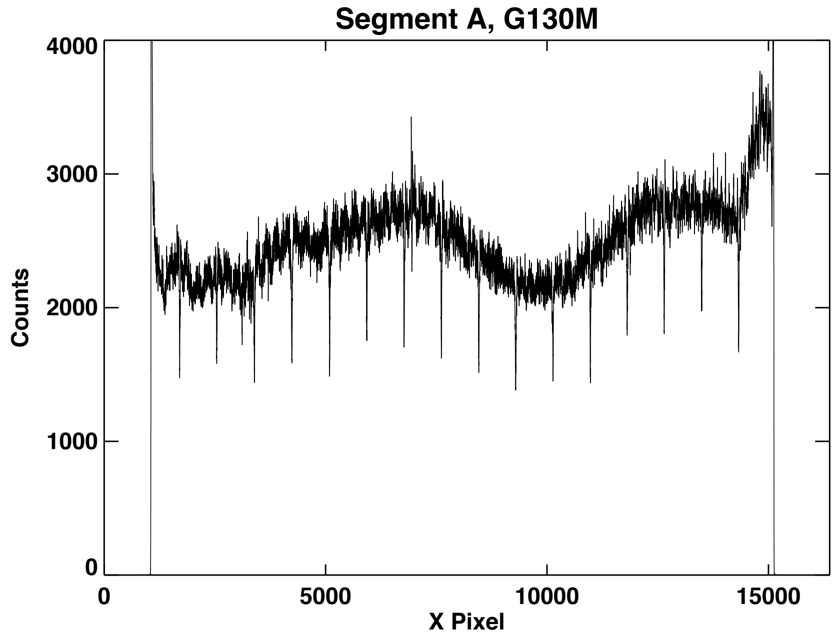
The FUV XDL detector has been shown to achieve S/N up to about 18 based just on photon statistics, without use of a flat field. By using FP-POS as well it is possible to reach S/N = 35. By also using a flat-field exposure, S/N up to 62 has been demonstrated during pre-flight ground tests. The best achievable S/N will be determined once COS is on orbit and it is possible to use astrophysical objects as flat-field sources. It is believed that S/N up to 100 is achievable in the FUV channel.

An example of an FUV flat-field exposure is shown in Figure 5.5. The regularly-spaced features are artifacts of the shadows of the wire grid over the detector. Although significant structure is present in this exposure, it is reproducible and therefore can be calibrated.

5.8.3 NUV Signal-to-noise

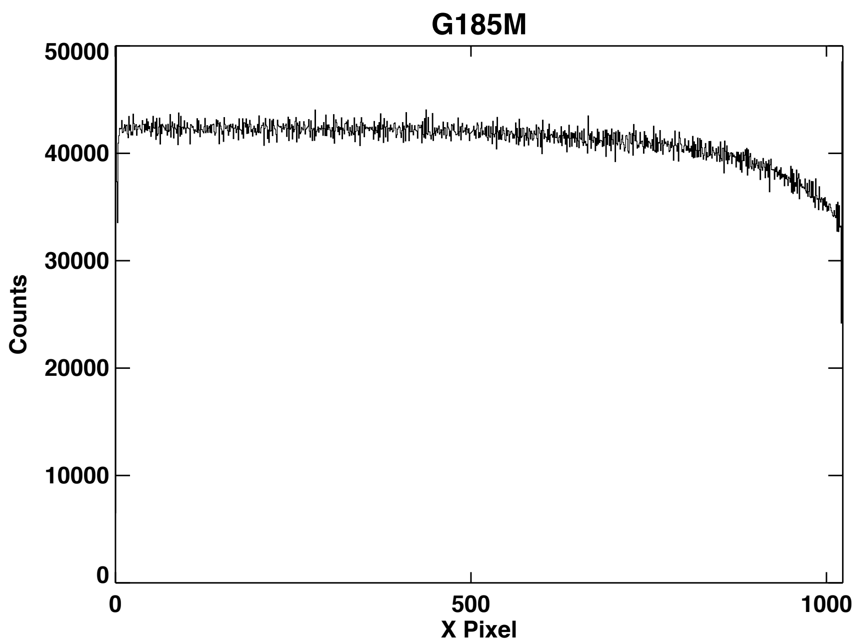
The NUV MAMA in COS is expected to behave very much like its STIS cousin, and observers may wish to consult STIS documents to see how its MAMA has performed in orbit. Pre-flight ground tests with COS show that the NUV MAMA can deliver S/N up to about 50 without using a flat field, just based on photon statistics. By using flat-field exposures, S/N up to 100 or more per resolution element should be routinely achievable. An example of a NUV flat-field exposure is shown in Figure 5.6.

Figure 5.5: Example of a flat-field exposure for the FUV XDL.



The regularly-spaced features are due to grid wires in front of the detector that cast shadows.

Figure 5.6: Example of a flat-field exposure for the NUV MAMA.



5.9 EXTENDED Optional Parameter

Optional Parameter EXTENDED (NO (the default), or YES) populates a science header keyword with this information to inform the **calcos** pipeline that the target is an extended source. The keyword may be used to activate special data reduction procedures, although none are currently in the pipeline. No aspect of on-board data-taking is affected by this parameter.

As noted several times in this document, observing extended objects with COS will produce a spectrum with degradation in spectral resolution. For example, consider a source that fills the COS aperture. The FUV channel has a magnification of about 0.8, so the 700 micron PSA is reduced to a spot 560 microns across, and that covers about 90 pixels on the detector. Those 90 pixels correspond to about 0.9 Å with G140L, meaning R = 1400. For the NUV, the situation is much worse because a source that fully fills the COS aperture will lead to cross-contamination among the three spectrum stripes on the MAMA detector.

A similar, but more favorable situation arises in the case of multiple point sources that fall within the aperture. COS was designed to resolve two point sources that are one arcsec apart in the cross-dispersion direction, and ground tests confirm that is possible. However, note that a point source that is 0.5 arcsec from the center of the PSA will not have all of its light transmitted; see Figure 7.1.

5.10 Calibrations

This section discusses calibration data that can be obtained in orbit to support routine reduction of science observations.

5.10.1 Internal Calibrations

COS internal exposures for wavelength, flat-field, and dark calibration will be incorporated in routine STScI calibration programs. Internal wavelength, flat-field, and dark calibration data will be obtained in TIME-TAG mode to maximize the scientific content. Doppler corrections will not be made to any internal calibration target data. GO users are not allowed to perform either internal flat-field or dark exposures.

Wavelengths

Wavelength calibration exposures will be routinely obtained with all science exposures (TAGFLASH and AUTO wavecals) and observers also may specify their own additional wavelength calibration exposures (GO wavecals).

Flat Fielding

On-orbit flat-fielding using either of the two redundant COS flat-field lamps may only be performed by STScI calibration programs. Basic flat-field calibrations have been obtained during the ground-based calibration of COS. These data should be applicable to either single exposures or multiple exposures made with the `FP-POS` procedure. We will acquire additional information after COS is installed in HST.

Observations of the lamp will be used to monitor changes in the detector flat-field response, and to derive updates to keep the calibration data in the pipeline database relevant and useful. We expect that these updates will be infrequent.

Additionally, flat-fields will be determined on-orbit with the use of external targets.

Sensitivity

The sensitivity calibration provides a relationship between observed count rates and astrophysical flux. Initial estimates were obtained during pre-launch testing, and will be updated after launch using HST flux-standard stars. The sensitivity of COS will be regularly monitored and the calibration updated. There are provisions for time-variability in COS sensitivity built into the **calcos** procedures, if the sensitivity changes with time.

Detector Background Rates

Background dark counts will be subtracted from every observation during the reduction process. The dark count rate can be estimated from a region of the detector far from the optical spectrum in the cross-dispersion direction, Additionally, dark count observations will be a routine part of science cycle calibration programs. GOs may not select target=`DARK`.

5.10.2 External Calibrations

Flat Fielding

Astrophysical objects such as white dwarfs will be used to obtain improved flat fields once COS is installed.

Sensitivity

Standard stars will be used to evaluate the sensitivity of COS once it is on orbit. One reason for including the BOA in COS is to be able to observe some of the same brighter standards that are used for STIS, to provide an accurate cross-calibration.

5.11 Wavelength Settings and Ranges

The following tables show the expected wavelength ranges recorded on the detectors for each valid combination of grating and setting. Note that the FUV settings do not record the central-most wavelengths that fall into the gap between the detector segments. The nominal wavelength setting has been chosen to be the shortest wavelength that is adjacent to the gap on segment A so that the indicated wavelength is an actually recorded one.

Table 5.3: Wavelength Ranges for FUV Gratings

Grating	Nominal wavelength setting (Å)[1]	Recorded wavelengths	
		Segment B	Segment A
G130M	1291	1132 – 1274	1291 – 1433
	1300	1141 – 1283	1300 – 1442
	1309	1150 – 1292	1309 – 1451
	1318	1159 – 1301	1318 – 1460
	1327	1168 – 1310	1327 – 1469
G160M	1577	1382 – 1556	1577 – 1752
	1589	1394 – 1568	1589 – 1764
	1600	1405 – 1579	1600 – 1775
	1611	1416 – 1590	1611 – 1786
	1623	1428 – 1602	1623 – 1798
G140L	1105	<300 – 970	1105 – 2253
	1230	<300 – 1095	1230 – 2378

1. The nominal wavelength setting has been chosen to be the shortest wavelength that is adjacent to the gap on segment A so that the indicated wavelength is an actually recorded one.

5.11.1 “Painting” a Complete NUV Spectrum

From the table that follows (Table 5.4) an observer can plan a set of observations that best meets the needs of his or her science goals. To acquire a complete medium-resolution spectrum of an object in the NUV with COS requires 6 settings with G185M, 6 with G225M, and 8 with G285M. A full spectrum with G230L requires all four central wavelength settings. Such a complete spectrum can probably be acquired more efficiently with STIS, but COS may be more advantageous when a limited number of specific wavelengths is desired.

Table 5.4: Wavelength ranges for NUV gratings

Grating	Nominal wavelength setting (Å)	Recorded wavelengths		
		Stripe A	Stripe B	Stripe C
G185M	1786	1670 – 1705	1769 – 1804	1868 – 1903
	1817	1701 – 1736	1800 – 1835	1899 – 1934
	1835	1719 – 1754	1818 – 1853	1916 – 1951
	1850	1734 – 1769	1833 – 1868	1931 – 1966
	1864	1748 – 1783	1847 – 1882	1945 – 1980
	1882	1766 – 1801	1865 – 1900	1964 – 1999
	1890	1774 – 1809	1872 – 1907	1971 – 2006
	1900	1783 – 1818	1882 – 1917	1981 – 2016
	1913	1796 – 1831	1895 – 1930	1993 – 2028
	1921	1804 – 1839	1903 – 1938	2002 – 2037
	1941	1825 – 1860	1924 – 1959	2023 – 2058
	1953	1837 – 1872	1936 – 1971	2034 – 2069
	1971	1854 – 1889	1953 – 1988	2052 – 2087
	1986	1870 – 1905	1969 – 2004	2068 – 2103
	2010	1894 – 1929	1993 – 2028	2092 – 2127
G225M	2186	2070 – 2105	2169 – 2204	2268 – 2303
	2217	2101 – 2136	2200 – 2235	2299 – 2334
	2233	2117 – 2152	2215 – 2250	2314 – 2349
	2250	2134 – 2169	2233 – 2268	2332 – 2367
	2268	2152 – 2187	2251 – 2286	2350 – 2385
	2283	2167 – 2202	2266 – 2301	2364 – 2399
	2306	2190 – 2225	2288 – 2323	2387 – 2422
	2325	2208 – 2243	2307 – 2342	2406 – 2441
	2339	2223 – 2258	2322 – 2357	2421 – 2456
	2357	2241 – 2276	2340 – 2375	2439 – 2474
	2373	2256 – 2291	2355 – 2390	2454 – 2489
	2390	2274 – 2309	2373 – 2408	2472 – 2507
	2410	2294 – 2329	2393 – 2428	2492 – 2527

Grating	Nominal wavelength setting (Å)	Recorded wavelengths		
		Stripe A	Stripe B	Stripe C
G285M	2617	2480 – 2521	2596 – 2637	2711 – 2752
	2637	2500 – 2541	2616 – 2657	2731 – 2772
	2657	2520 – 2561	2636 – 2677	2751 – 2792
	2676	2539 – 2580	2655 – 2696	2770 – 2811
	2695	2558 – 2599	2674 – 2715	2789 – 2830
	2709	2572 – 2613	2688 – 2729	2803 – 2844
	2719	2582 – 2623	2698 – 2739	2813 – 2854
	2739	2602 – 2643	2718 – 2763	2837 – 2878
	2850	2714 – 2755	2829 – 2870	2945 – 2986
	2952	2815 – 2856	2931 – 2972	3046 – 3087
	2979	2842 – 2883	2958 – 2999	3073 – 3114
	2996	2859 – 2900	2975 – 3016	3090 – 3131
	3018	2881 – 2922	2997 – 3038	3112 – 3153
	3035	2898 – 2939	3014 – 3055	3129 – 3170
	3057	2920 – 2961	3036 – 3077	3151 – 3192
	3074	2937 – 2978	3053 – 3094	3168 – 3209
	3094	2957 – 2998	3073 – 3114	3188 – 3229
G230L	2635	1334 – 1733[1]	2435 – 2834	**1768 – 1967**[2]
	2950	1650 – 2050	2750 – 3150	**1900 – 2100**[2]
	3000	1700 – 2100	2800 – 3200	**1950 – 2150**[2]
	3360	2059 – 2458	3161 – 3560	**2164 – 2361**[2]

1. The wavelengths listed for central wavelength 2635 Å in stripe A are listed for completeness only and also in case a bright emission line falls onto the detector. Note that the NUV detector's sensitivity at these wavelengths is extremely low. To obtain a low-resolution spectrum at wavelengths below about 1700 Å we recommend G140L and the FUV channel.
2. The values in shaded cells are wavelength ranges as seen in second-order light. In these cases the achieved dispersion is twice that for first-order mode.

CHAPTER 6:

NUV Imaging

In this chapter…

6.1 Essential Facts About COS Imaging

- Imaging with COS may only be done with the NUV channel.
- It is not necessary to use imaging mode if what is desired is a confirmation of an acquisition. Use of `ACQ/IMAGE` mode automatically records and downlinks an image taken after the centroid is determined and HST is moved to that position. See Chapter 7 for a description of acquisitions.
- The COS field of view is very small, but because the optics image the sky onto the detector – not the aperture – the image records some of the light from sources out to a radius of about 2 arcsec. However, only point sources within about 0.5 arcsec of the aperture center have essentially all their light imaged (see Figure 7.1), and so the photometric interpretation of a COS image can be inherently complex.
- COS is very sensitive and there is a limit on the maximum count rate per pixel (75 counts per second for the NUV). The imaging mode of COS concentrates an object's entire NUV flux into a diffraction-limited image, and so that limiting count rate can be exceeded easily.
- MIRRORB and/or the BOA can be used to obtain images of brighter objects, but MIRRORB produces a secondary image and the BOA produces an image with coma that degrades resolution; see Chapter 7.

6.2 Configurations and Imaging Quality

COS includes an NUV imaging mode; no FUV imaging is possible. It is anticipated that the greatest use of this imaging capability will be for target acquisition (see Chapter 7), but science exposures may be obtained as well. With OSM1 set to mirror NCM1 (which occurs automatically when any NUV mode is selected), and with OSM2 set to MIRRORA, an image of the sky is formed on the NUV MAMA detector. The plate scale on the detector is 23.6 mas per pixel. Because the entrance aperture is out of focus at the detector, the image receives light out to a radius of about 2 arcsec. However, as can be seen from Figure 7.1, once a point source is more than about 0.5 arcsec from the aperture center its light is diminished.

The NUV imaging mode requires the observer to make only two optical element selections. First, either the PSA or BOA is selected as the aperture. The BOA (see Figure 3.4) provides an attenuation factor of approximately 200 compared to the PSA (which is completely open and provides maximum transmission through the aperture). The second selection required is `MIRRORA` or `MIRRORB`. `MIRRORA` refers to the usual position of the TA1 mirror on OSM2. `MIRRORB` refers to the arrangement in which OSM2 rotates the position of this mirror slightly so that the front surface of the order sorter filter on this mirror is used. This provides an attenuation factor of approximately 25 compared to `MIRRORA`. Because of the finite thickness of the order-sorting filter, `MIRRORB` produces a doubled peak in the image that may impede its use for imaging; see Section 7.5.3 for details. Ground testing shows that the secondary peak will contain ~1/2 the flux of the primary image (see Figure 7.4). The secondary peak is located ~20 pixels in the $-y$ direction on the MAMA detector from the primary image. This is easily separable for an isolated point source but may present difficulties for extended sources or crowded fields. Similarly, the BOA includes a neutral density filter and the optical properties of that filter degrade the image compared to what is possible with the PSA (see Figure 7.5, Figure 7.6, and Figure 7.7).

To record an image, Config = `COS/NUV` is used, together with Mode = `ACCUM` or `TIME-TAG`. If `TIME-TAG` mode is selected, the minimum allowable `BUFFER-TIME` is 80 seconds, which may be longer than the expected exposure time. `ACCUM` mode is recommended for short exposures.

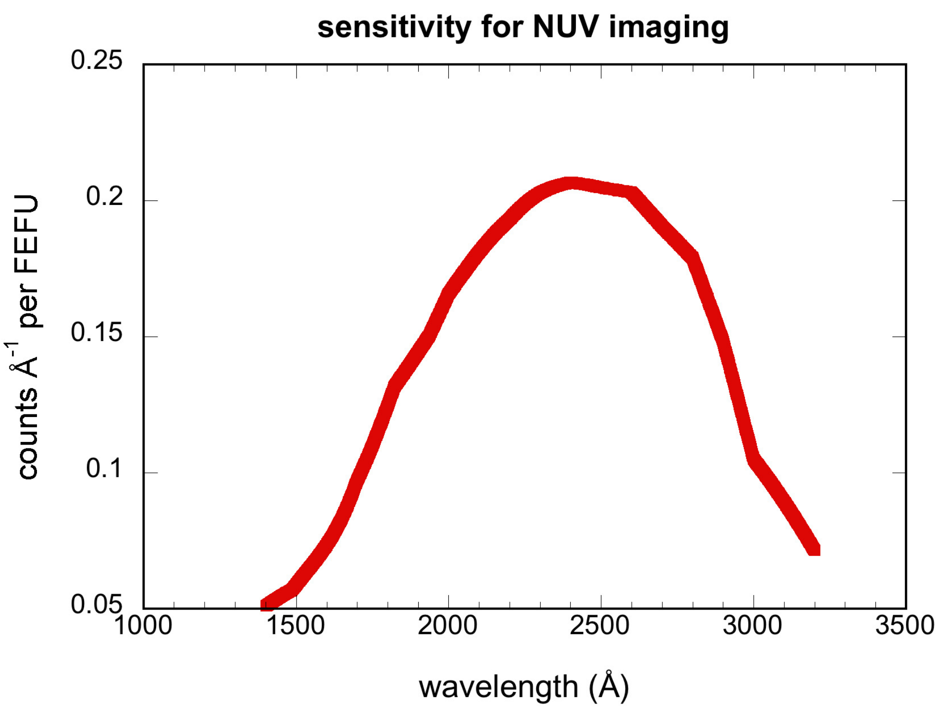
All COS exposure times must be an integer multiple of 0.1 seconds. If the observer specifies an exposure time that is not a multiple of 0.1 sec, its value is rounded down to the next lower integral multiple of 0.1 sec, (or set to 0.1 seconds if a smaller value is specified). The minimum COS exposure time duration is 0.1 seconds. The maximum COS exposure time is 6,500 seconds. Bear in mind that exposure time values much larger than 3,000 seconds are normally appropriate only for visits with the CVZ Special Requirement.

6.3 Sensitivity

Figure 6.1 shows the sensitivity of COS for NUV imaging. Please note the following:

- The flux over all wavelengths must be integrated to get the total number of counts per second.
- That total count rate is for the entire image; the PSF shown in Figure 6.2 indicates how much ends up in the peak pixel (about 14%).

Figure 6.1: Sensitivity Curve for COS NUV Imaging with the PSA.



COS is very sensitive, and the imaging mode concentrates an object's NUV flux into a diffraction-limited image rather than dispersing the light. The local count rate limit for COS/NUV is 75 counts per pixel per second, and that limit is easily reached, even for fairly faint objects. Observers should use the COS ETC (see Chapter 10) to get an accurate estimate of expected count rates, but the following values will provide a guide. These have been calculated for a flat-spectrum source (flux independent of wavelength), and the limiting count rate is reached for the following approximate flux levels:

- PSA + MIRRORA: 2 FEFU;
- BOA + MIRRORA: 400 FEFU;
- PSA + MIRRORB: 30 FEFU;
- BOA + MIRRORB: 6,000 FEFU.

6.4 Image Characteristics

Figure 6.2 shows an image of a point source obtained in ground testing as seen on the NUV MAMA (i.e., fully corrected for HST's aberrations). A 2-dimensional Gaussian fit to this PSF has the following characteristics:

FWHM: 1.93 pixels = 45.5 mas

Fraction of light in brightest pixel: 14.3%.

Figure 6.2: Two-dimensional PSF for COS in imaging mode.

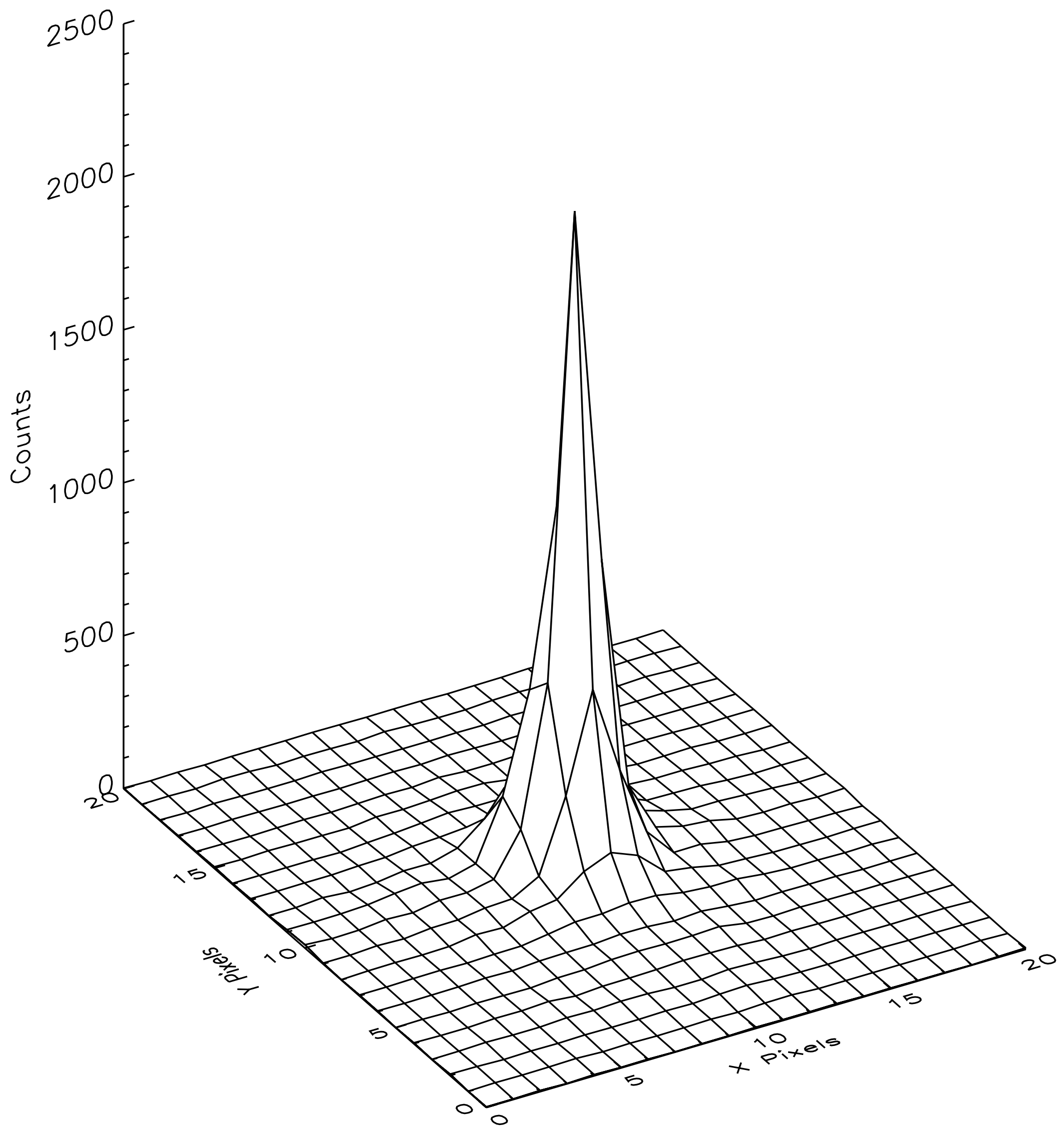
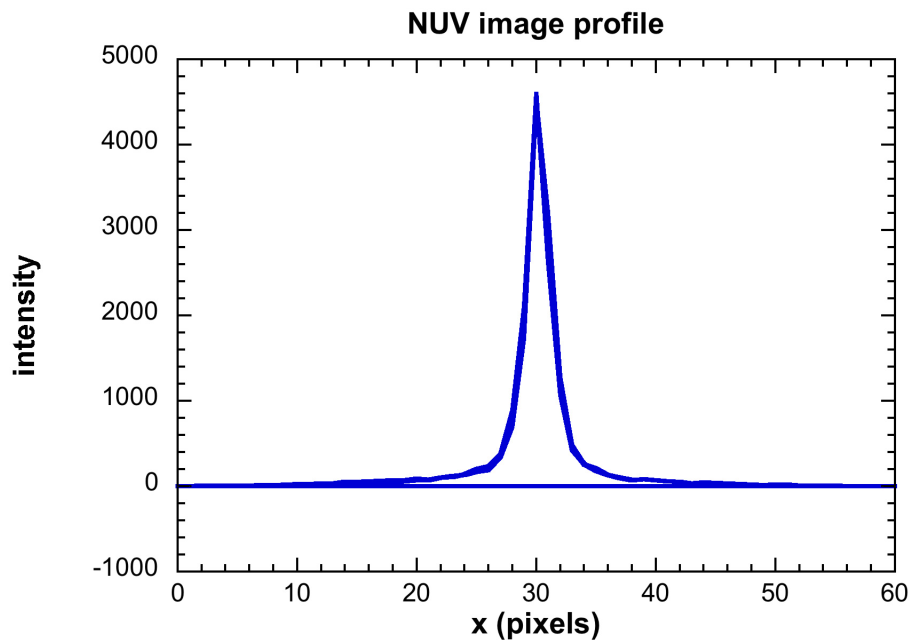


Figure 6.3 shows the profile through the PSF of Figure 6.2 in the *x* direction.

Figure 6.3: Profile through COS imaging PSF in the x direction.



This is a slice through the center of the profile.

CHAPTER 7:

Target Acquisitions

In this chapter…

7.1 The Need for Target Acquisition

The COS apertures are 2.5 arcsec in diameter. The success of an observation requires being certain that the object is in the aperture. More than that, several aspects of data quality are improved when the source is properly centered in the aperture. This discussion of target acquisition starts with an overview of COS acquisition methods, considers the initial pointing of HST, shows how data quality is affected, and explains the available acquisition methods in detail.

Bright Object Protection

The COS detectors are vulnerable to damage or performance degradation if exposed to too much light. Imaging acquisitions are a special risk because they concentrate the light of an object on a small area of the detector.

Users of COS must demonstrate that their targets are safe for the detectors of COS. Information on bright-object protection and screening is in Section 11.5.

7.2 Initial HST Pointing and Coordinate Accuracy

The strategy you choose for your COS acquisition will depend on the accuracy of your target coordinates, and also on the target's brightness. Given uncertainties in the initial pointing of HST and uncertainties in the alignments between COS and the FGSs, errors in your coordinates must be well under 1 arcsec if the target is going to reliably fall within the aperture. It is also necessary that target coordinates be compliant with the GSC2 system.

If you are less certain of coordinates, or wish to be more conservative, you should start with an acquisition in `ACQ/SEARCH` mode. In `ACQ/SEARCH` mode you can command the COS aperture to be swept in a square pattern up to 5 × 5 steps in size. With a `STEP-SIZE` of 1.767 arcsec (the recommended and default value), and a 2 × 2 search pattern, your target will be found if it is within about 3 arcsec of the initial pointing.

After the initial `ACQ/SEARCH`, the next step depends on the brightness of the target. The most efficient option is `ACQ/IMAGE` with the NUV channel, using either `MIRRORA` or `MIRRORB` plus your choice of `PSA` or `BOA`. For targets that are too bright for `ACQ/IMAGE`, a sequence of `ACQ/PEAKXD` followed by `ACQ/PEAKD` is recommended.

There is more on `ACQ/SEARCH` below in Section 7.5.2.

7.3 A Quick Guide to COS Acquisitions

COS has four acquisition modes or exposure types that you may use:

- **`ACQ/IMAGE`** obtains an NUV image of the field after the initial HST pointing, determines the telescope offset needed to center the object, and secures a second identical NUV image as a confirmation after the telescope movement (details are in Section 7.5). This is generally the fastest method of COS target acquisition. This is the recommended acquisition mode for most observations, but some targets may be too bright.
- **`ACQ/SEARCH`** performs a search in a spiral pattern by executing individual exposures at each point in a square grid pattern (details are in Section 7.6.1). This mode can use either dispersed light or imaging exposures.
- **`ACQ/PEAKXD`** determines the centroid of the dispersed-light spectrum in the direction perpendicular to dispersion (details are in Section 7.6.3).
- **`ACQ/PEAKD`** centers the target along dispersion by executing individual exposures at each point in a closely-spaced linear pattern along dispersion (details are in Section 7.6.4).

ACQ/PEAKXD should always precede ACQ/PEAKD and the two should always be performed together in sequence. Typically ACQ/PEAKXD and ACQ/PEAKD sequences should be preceded by ACQ/SEARCH.

These acquisition modes are used in several different ways that depend on the accuracy of the target coordinates and whether or not the target may safely be observed with either MIRRORA or MIRRORB. These scenarios are described in detail below and Table 7.1 presents a summary of recommended target acquisition exposure sequences for these possible scenarios.

1. The most favorable case is when accurate GSC2 coordinates (to better than 1 arcsec on the GSC2 system) are available and MIRRORA or MIRRORB may be used safely. In this case ACQ/IMAGE may be employed and will result in the most efficient COS acquisition strategy. No peakups are required after an ACQ/IMAGE.

2. In the next case, scenario 1 applies, but a conservative approach concerning target coordinates is desired. An ACQ/SEARCH should be inserted prior to the ACQ/IMAGE.

3. In case 3, accurate GSC2 coordinates are available but neither MIRRORA nor MIRRORB may be used because the predicted count rates exceed the screening limits. In this instance a sequence of an ACQ/SEARCH (in dispersed light) followed by ACQ/PEAKXD and ACQ/PEAKD must be employed.

4. In case 4, the target coordinates are not accurate (i.e., coordinate uncertainties exceed 1 arcsec) but MIRRORA or MIRRORB may be used safely. If the GSC2 coordinates are not sufficiently accurate for the target to fall within the COS PSA or BOA upon the initial HST pointing but the object is safe to observe with MIRRORA or MIRRORB, then the target acquisition sequence should begin with ACQ/SEARCH and be completed with an ACQ/IMAGE (this is a variation on scenario 2).

5. In this last scenario, the target coordinates are not accurate (uncertainties exceed 1 arcsec) and neither MIRRORA nor MIRRORB may be used. If the GSC2 coordinates are not sufficiently accurate for the target to fall within the COS PSA or BOA upon initial HST pointing and the object is not safe to observe with a MIRROR configuration, then the target acquisition sequence should begin with ACQ/SEARCH and be completed with an ACQ/PEAKXD and ACQ/PEAKD sequence.

Table 7.1: Target acquisition scenarios.

	Coordinate quality	Target brightness	Step 1	Step 2	Step 3
1	Good (error < 1 arcsec)	Safe to use MIRRORA or MIRRORB	ACQ/IMAGE	none	none
2	Good, but conservative approach desired	Safe to use MIRRORA or MIRRORB	ACQ/SEARCH	ACQ/IMAGE	none
3	Good	Not safe to use mirrors	ACQ/SEARCH	ACQ/PEAKXD	ACQ/PEAKD
4	Poor (errors > 1 arcsec)	Safe to use MIRRORA or MIRRORB	ACQ/SEARCH	ACQ/IMAGE	none
5	Poor (errors > 1 arcsec)	Not safe to use mirrors	ACQ/SEARCH	ACQ/PEAKXD	ACQ/PEAKD

ACQ/IMAGE is the preferred COS acquisition mode as long as the predicted count rate for the target does not exceed screening limits (see Section 11.5). ACQ/IMAGE is the fastest acquisition method.

7.4 Acquisition Effects on Data Quality

7.4.1 The HST PSF at the COS Aperture

The HST Point Spread Function (PSF) has been modeled at the nominal position of the COS Primary Science Aperture (PSA) - see detailed discussion in Section 13.4. These calculated PSFs are based on the known aberrations present in the HST optical design and the surface errors present in the HST primary and secondary mirrors. While the HST primary and secondary mirrors are among the most precise mirrors ever produced, these optics still exhibit a number of zonal surface errors that limit the quality of the PSF, especially at ultraviolet wavelengths.

The models predict that at least 95% of the energy in the HST PSF is contained within the 2.5 arcsec diameter COS PSA at both 1450 and 2550 Å. The contributions of the PSF that fall outside of the PSA are primarily due to the surface errors in the HST optics themselves, not to the low-order aberrations present in the HST optical design.

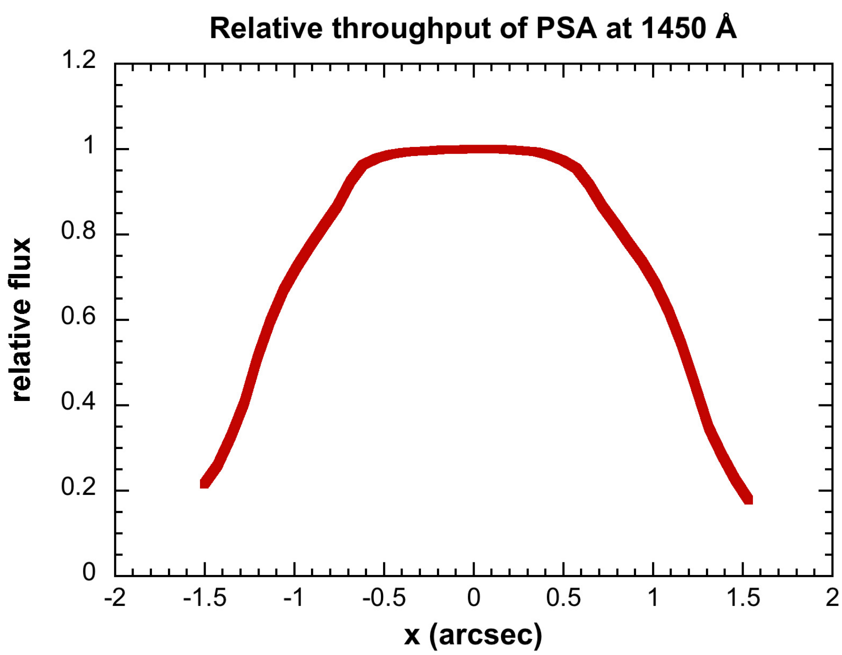
All of the light passing through the COS aperture is fully corrected for HST aberration by the downstream COS optics. NUV images and spectra are fully corrected for all optical effects. FUV spectra are fully corrected for aberration, but contain a small amount of astigmatism which does not affect spectral resolution or photometric quality. As verified in ground testing, the resultant PSF at the detector for

NUV imaging mode is characterized by a FWHM of approximately 2 pixels (~0.05 arcsec) as discussed in Section 6.4. Scattered light and spectral resolution at the FUV and NUV detectors are well within design specifications. The following sections use the results of this modeling to consider the ramifications of target acquisition centering accuracy upon various aspects of data quality.

7.4.2 Centering Accuracy and Photometric Precision

Figure 7.1 shows the relative transmission of the PSA as a function of displacement of a point source from the aperture center, computed using the modeled PSFs described in Section 13.4.2. Obviously any mis-centering of a source leads to some loss of throughput, but that loss is less than 1% if the source is within 0.4 arcsec of aperture center and is less than 5% if the displacement is less than 0.65 arcsec. In other words, the signal-to-noise achieved in an observation is little affected by small centering errors. This means that a target may be displaced by as much as 0.4 arcsec from the aperture center without a significant loss of throughput, and also that two sources separated by as much as ~1 arcsec (i.e., ±0.5 arcsec) will both have essentially full throughput.

Figure 7.1: Relative Transmission of the COS PSA at 1450Å



The transmission is shown as a function of displacement from aperture center. The calculation was done for a point source and for the HST PSF at 1450 Å. Note that the absolute transmission with a point source centered is at least 95%. The same curve for 2550 Å is essentially identical.

The spatial resolution of COS was measured during ground tests and is at least sufficient to separate spectra of equally bright objects that are 1 arcsec apart in the cross-dispersion direction; see Section 5.1.3.

7.4.3 Centering Accuracy and the Wavelength Scale

If an accurate wavelength-calibrated spectrum is desired, one wants the error contribution from mis-centering to be low compared to other sources of uncertainty. For NUV `ACQ/IMAGE` acquisitions, a *resel* (resolution element) is 3 × 3 pixels. In order to not contribute significantly to zero-point uncertainty, then, the centering should be good to about 0.1 resel. The NUV plate scale is 42.3 pixels per arcsec, so the goal for centering is about 0.01 to 0.02 arcsec. For the FUV channel, resels are 6 pixels wide but the plate scale is reduced, with the result that again the desired centering precision is 0.01 to 0.02 arcsec. Simulations of COS imaging acquisitions have been calculated that show that a centering precision of about 0.02 arcsec is, in fact, feasible.

Dispersed-light acquisitions, whether with the FUV or NUV detector, are unlikely to achieve such a high pointing precision without requiring additional peak-ups in both the cross-dispersion and along-dispersion directions. Dispersed-light acquisitions with COS are slower than an imaging acquisition because HST must be moved to get the information needed to determine the object's centroid. The procedure for dispersed-light acquisitions is discussed below.

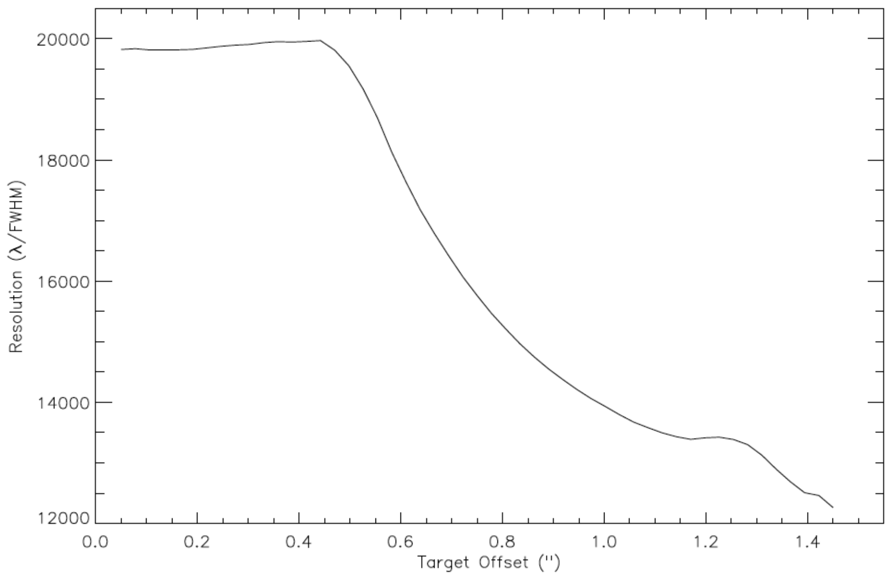
As just noted, the throughput of COS is little affected by mis-centering of the source, and so a very high centering precision is not necessary if your science goals do not require a good wavelength zero point. For example, the spectra of some objects may include foreground interstellar or inter-galactic absorption lines that can serve to establish relative velocities.

The plate scales for all the COS gratings along the direction of dispersion are listed in Table 5.2.

7.4.4 Centering Accuracy and Spectroscopic Resolution

Figure 7.2 shows the effect on spectroscopic resolving power of displacing a point source in the PSA. The measurements were calculated using ray tracing for grating G130M. The net effect is that there is no loss of spectroscopic resolution with a displacement as large as 0.5 arcsec.

Figure 7.2: Spectroscopic Resolving Power Versus Source Displacement in the Aperture for Grating G130M.



7.5 Imaging Acquisitions

Most of the time observers will wish to acquire their target using the COS/NUV configuration in ACQ/IMAGE mode. Ordinarily both COS detectors will be available for use, and so there is little time lost in switching from an NUV acquisition to an FUV spectrum (no more than about 2 minutes; see Chapter 9).

In ACQ/IMAGE mode the following steps occur:

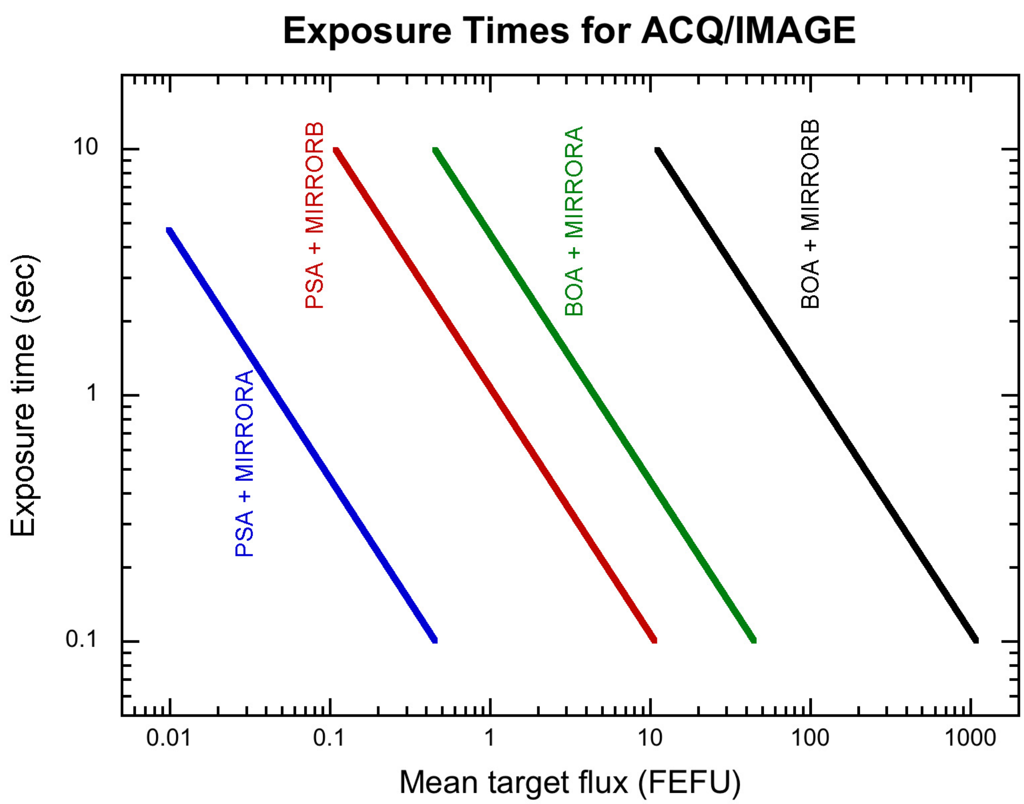
1. The shutter is opened and a target acquisition image is obtained. The telescope is not moved, meaning that an acquisition using ACQ/IMAGE will be successful only if the target lies within the aperture at this point. An area of 4 × 4 arcsec, centered on the aperture, is then read out. This image is recorded and downlinked, and becomes part of the data package that is archived. The plate scale in imaging mode is 23.6 mas per pixel, so 4 arcsec is 170 pixels.
2. A 9 × 9 pixel checkbox array is then passed over the 4 × 4 arcsec image. First, the pixel with the most counts is identified. In the unlikely instance that two pixels have equal counts, the first one encountered is used. The 9 × 9 array centered on that brightest pixel is then analyzed using a flux-weighted centroiding algorithm to calculate the expected target position.
3. Finally, HST is moved to place the calculated centroid at the center of the selected aperture. Another exposure is taken and recorded for later downlink as a verification of the centering. Both of the recorded acquisition images are 345 × 816 pixels, and are taken in TIME-TAG mode.

Note that NUV ACQ/IMAGE acquisitions require two minutes plus twice the exposure time specified for the S/N = 40 acquisition image. If the ACQ/IMAGE exposure is the first in a visit, then an additional five minutes of overhead are required as well. (Note that S/N = 40 is a standard value for HST acquisitions and is based on STIS experience.)

7.5.1 Exposure Times and Count Rates

The best way to determine actual count rates, exposure times, and the overall time needed for an acquisition is to use the COS acquisition ETC and APT. Here we provide less accurate information to give you a general idea of what happens.

Figure 7.3: Exposure Time Needed for ACQ/IMAGE Mode.



The time is given as a function of target flux. This calculation assumes a flat source spectrum.

Figure 7.3 shows acquisition exposure times needed to reach S/N = 40 for various combinations of mirrors and apertures. A flat source spectrum is assumed.

7.5.2 Imaging Acquisitions with Mediocre Coordinates

If you are less certain of your target coordinate accuracy, or wish to be more conservative, it is possible to scan a larger area of sky, also in undispersed light. The procedure is the same as for an NUV acquisition in dispersed light (see Section 7.7

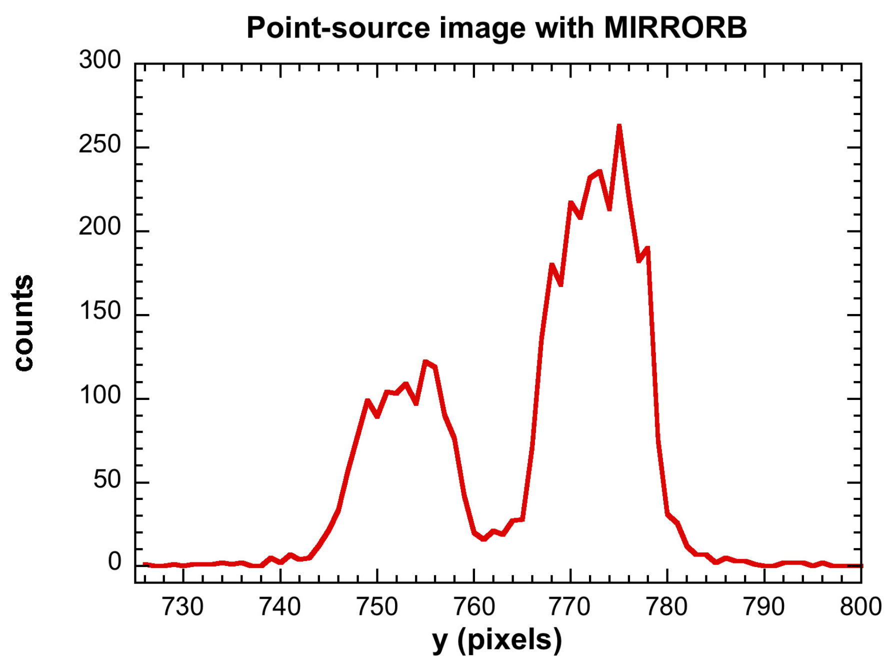
below), except that ACQ/SEARCH is used with the spectral element selected as MIRRORA or MIRRORB. Use of SCAN-SIZE=3, for example, should be adequate to find the object if it falls within 3 arcsec of the aperture center.

7.5.3 Imaging Acquisitions with MIRRORB or the BOA

Both MIRRORB and the BOA produce images that may affect an acquisition.

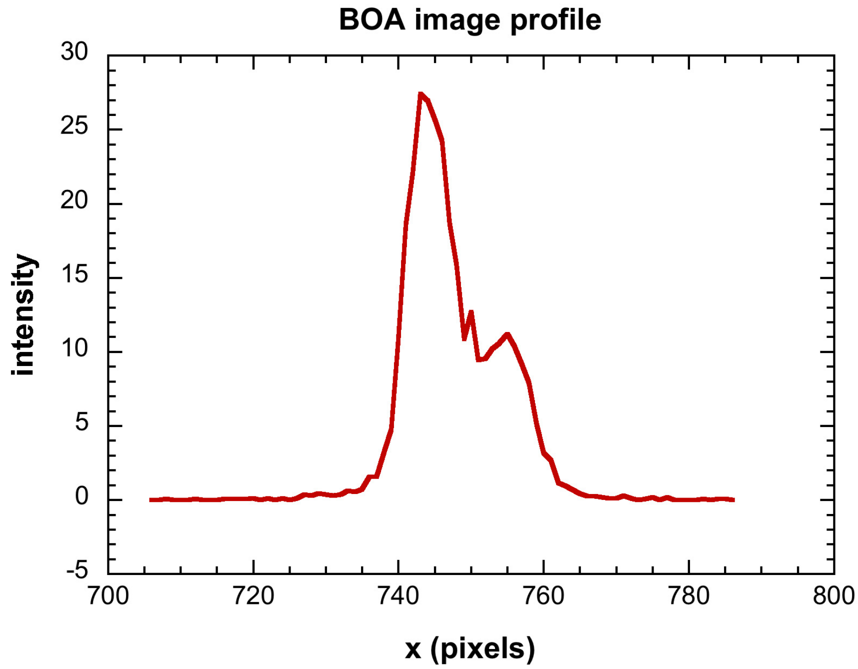
As noted elsewhere, what is termed "MIRRORB" is not a separate optical element but is instead MIRRORA oriented so that light is reflected from the order-sorting filter in front of MIRRORA. Because of the finite thickness of that filter, MIRRORB forms a secondary peak which has approximately half the intensity of the primary peak and is displaced by 20 pixels (about 0.5 arcsec) in the *y* direction. There is some overlap between the wings of the primary and secondary peaks, but they are well enough separated to lead to reliable acquisitions (see Figure 7.4).

Figure 7.4: Cross section through the center of an image obtained with MIRRORB.



Note the secondary peak, which has an amplitude of about half that of the primary peak and is displaced by 20 pixels (center to center) in the *y* direction.

Figure 7.5: Cross section through an image obtained with the BOA.



This is a slice through the center of the profile. Note the secondary peak, which has an amplitude of 44% relative to the primary peak and is displaced by 10 pixels (center to center) in the x direction.

In the case of the BOA, the slight wedge shape of the neutral density filter produces a comatic image with a secondary peak with an intensity 44% that of the main peak, displaced by 10 pixels (Figure 7.5). If both the BOA and MIRRORB are used then a series of 4 peaks is created, displaced in both x and y, although the fourth peak is very faint (Figure 7.6 and Figure 7.7). Note that these three illustrations have been made using images from test observations on the ground. These will be updated once COS is in orbit.

In each of these cases the primary peak in the image is significantly brighter than any secondary peak and is well removed from it, and so we anticipate successful acquisitions. Acquisitions using all of these attenuating options will be tested during SMOV.

Figure 7.6: A cross section in the x direction through the center of the image formed when both the BOA and MIRRORB are used.

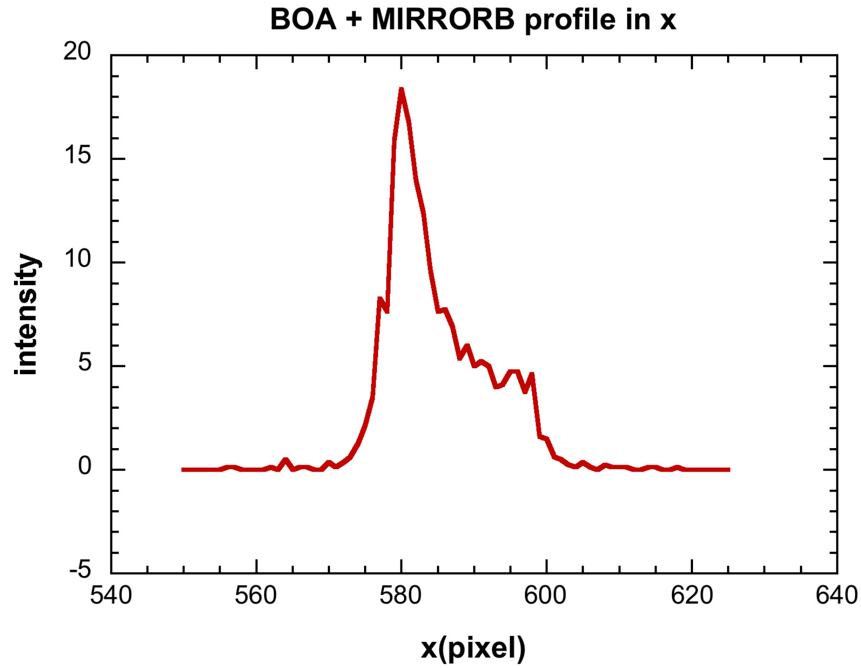
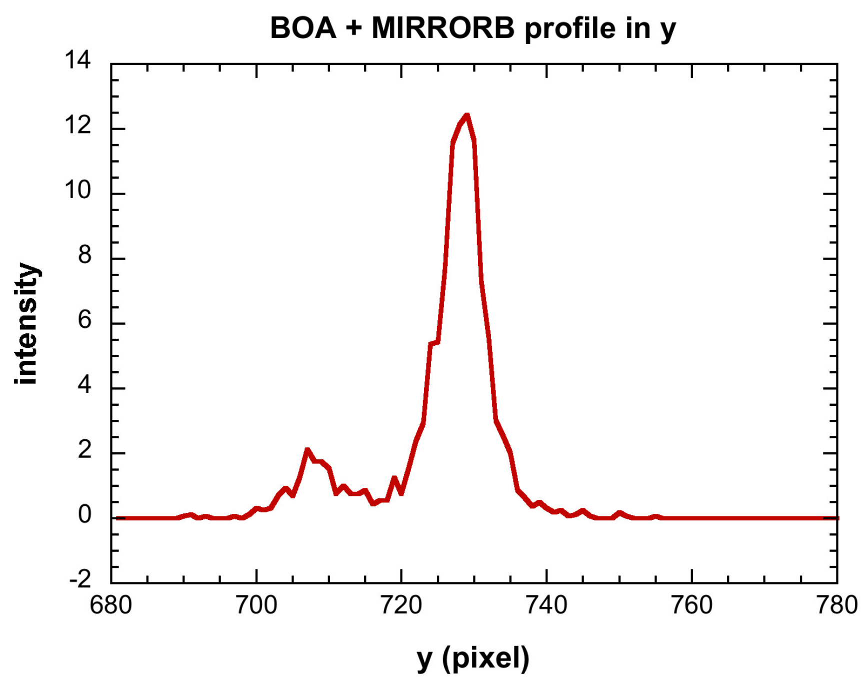


Figure 7.7: A cross section in the y direction through the center of the image formed when both the BOA and MIRRORB are used.



7.6 FUV Dispersed-Light Acquisitions

COS includes flight software that can find and center a source in the selected aperture by working with the dispersed spectrum. This can be done with either the FUV or NUV detector. A dispersed-light acquisition has the advantage of analyzing the same image that will then be integrated to form the science spectrum. However, there are some disadvantages to acquiring in dispersed light:

- Instead of obtaining only a single image that is then analyzed to determine a centroid (as in `ACQ/IMAGE` mode), in dispersed light the telescope is moved a number of times to create a spiral search pattern on the sky, and the accumulated counts are then analyzed. At each dwell point a separate exposure is needed, and then HST must be moved a small amount. Those exposures and motions are each fairly short, but they add up, resulting in a fairly slow acquisition.
- Mostly because of lower S/N, the initial dispersed-light acquisition achieves pointing precision of about 0.1 arcsec, which is not as good as `ACQ/IMAGE`. This can be improved significantly with `ACQ/PEAKXD` and `ACQ/PEAKD`.
- Airglow (or geocoronal) emission features fill the aperture, and at those wavelengths they can produce high count rates that make source detection difficult. This problem is most severe in the FUV and is averted by ignoring portions of the detector illuminated by airglow features. This is done by using sub-arrays on the detector, and this is carried out automatically by the flight software. Thus in practice airglow lines should not impede acquisitions.

7.6.1 FUV Dispersed-light Acquisition Summary

Airglow lines and sub-arrays

Nearly all the strong airglow lines are in the FUV (see a list of lines and strengths in Table 10.3). Of these, Lyman-α is by far the most important. To avoid the airglow lines, the dispersed-light acquisition process reads discrete sub-arrays on the XDL detector. In addition, segment B, which records the shortest wavelengths, gets very little light when grating G140L is used, and therefore only segment A is used for an acquisition with G140L.

Steps in a Dispersed-Light Acquisition

There are three steps needed to center a target with a dispersed-light acquisition:

1. A search (using `ACQ/SEARCH`) is carried out, in a spiral pattern, making a square with 2, 3, 4, or 5 points on a side. At each scan point the telescope stops and an integration is taken. After completion of the full $n \times n$ pattern, the data are analyzed and the telescope is moved to center the object.
2. A peak-up in the cross dispersion direction is performed to improve the centering (`PEAKXD`).
3. A peak-up in the along-dispersion direction is done as well (`PEAKD`).

The last two steps are optional and should be done in the order indicated (PEAKXD then PEAKD). Also, any one step may be done more than once (such as doing a 3 × 3 spiral search followed by a 2 × 2 one to improve the centering). As a result, there is a huge number of possible ways to acquire a target and improve its centering. Here we will concentrate on some specific scenarios that achieve good results in a reasonable time.

7.6.2 Mode=ACQ/SEARCH: The Spiral Target Search

The initial target search is done with the ACQ/SEARCH command for the COS/FUV configuration. In ACQ/SEARCH mode you can command the COS aperture to be moved in a spiral pattern to cover a square grid up to 5 × 5 steps in size. With a STEP-SIZE of 1.767 arcsec (the default and recommended value) and a 3 × 3 search pattern, your target will be found if it is within about 3 arcsec of the initial pointing.

You will need to specify:

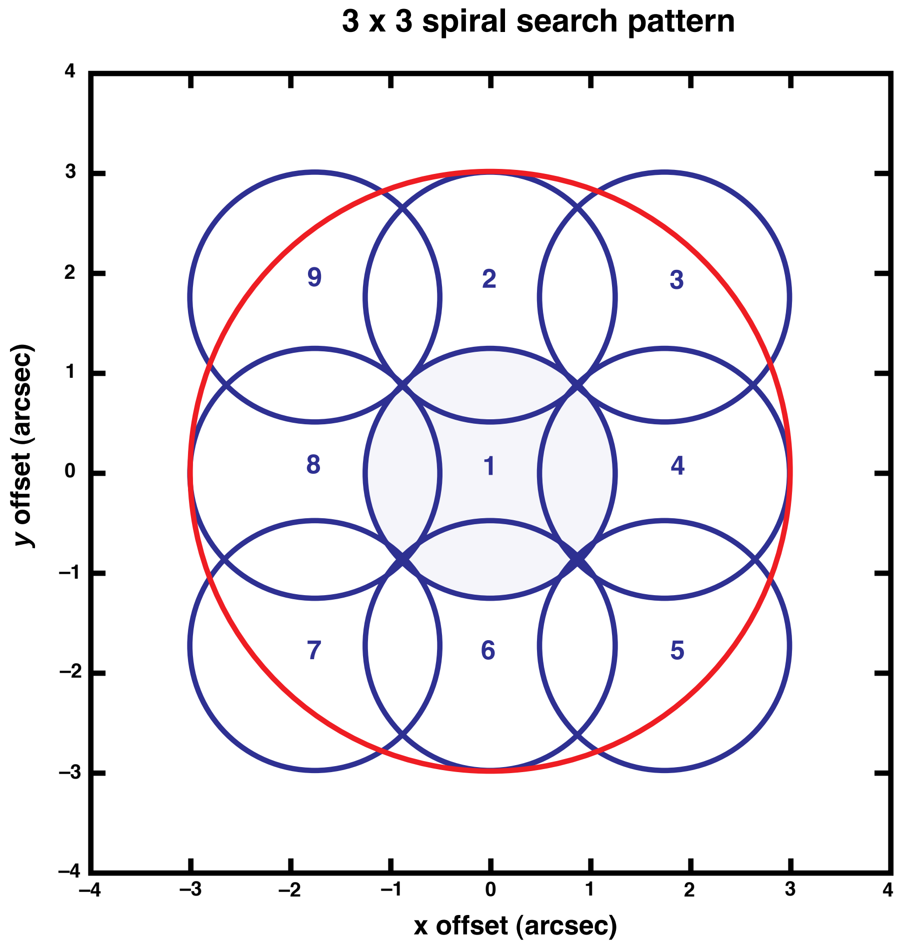
- The aperture to use, either PSA or BOA.
- The spectrum element (i.e., which grating) to be used and the wavelength setting. In general this will be the same as the grating and wavelength to be used for the science spectrum that follows. However, an observer may acquire with a different grating + wavelength combination than the one to be used for the science spectrum, and there may be advantages to doing so.
- The SCAN-SIZE, which is 2, 3, 4, or 5, corresponding to spiral patterns of 2 × 2, 3 × 3, etc.
- The exposure time per dwell point.

To calculate the total time needed for an FUV ACQ/SEARCH:

1. Add 20 sec to the exposure time to be used at each dwell point.
2. Multiply this value by the number of dwell points.
3. Add any overheads from Table 9.2 that apply to putting in place the spectral element you will use. Note that the "home" position for OSM1 leaves grating G130M in position. This means that G130M is in position by default at the start of a new visit.

Large SCAN-SIZE values should only be used in cases where the target coordinates are mediocre, which should occur only rarely. A 3 × 3 pattern should be adequate in virtually all cases. Note that the even SCAN-SIZE values (2 or 4) entail some additional overhead time because there is an additional movement of the telescope needed to displace the aperture by half of STEP-SIZE in both x and y (the coordinate system at the aperture). This is so the overall pattern remains centered on the initial pointing.

Figure 7.8: Example of a 3 × 3 Spiral Search Pattern.



This example was executed with the default STEP-SIZE of 1.767 arcsec. The blue circles represent the nine positions of the aperture, each 2.5 arcsec in diameter, and the numbers show the sequence of steps. The large outer circle in red has a radius of 3 arcsec. Thus an initial pointing that was good to 1 arcsec (1σ) would result in a successful acquisition with a 3 × 3 pattern 99.5% of the time.

The `STEP-SIZE` parameter determines the spacing, in arcsec, between dwell points in the pattern. It may be set at any value from 0.2 to 2.0 arcsec, but we strongly recommend using the default value of 1.767 arcsec. This default value has been chosen so that no part of the sky is missed, given the 2.5 arcsec diameter aperture ($2.5/\sqrt{2} = 1.767$).

Finding the Source

Once the integrations are all done, the flight software determines what point in the array to return to, and there are three options. The default, and recommended, option is `CENTER=FLUX-WT`. This algorithm uses a flux-weighted centroiding procedure to determine the center of the light and has been shown in simulations to be effective in locating a source. The algorithm contains a check that removes dwell points from the calculation if the number of counts at that point is below a certain percentage of the maximum counts seen in the brightest dwell point. That threshold (“LOCAL-THRESHOLD”) is set at 10% and is not selectable by the observer. The optimum threshold value will be checked during characterization of COS after launch.

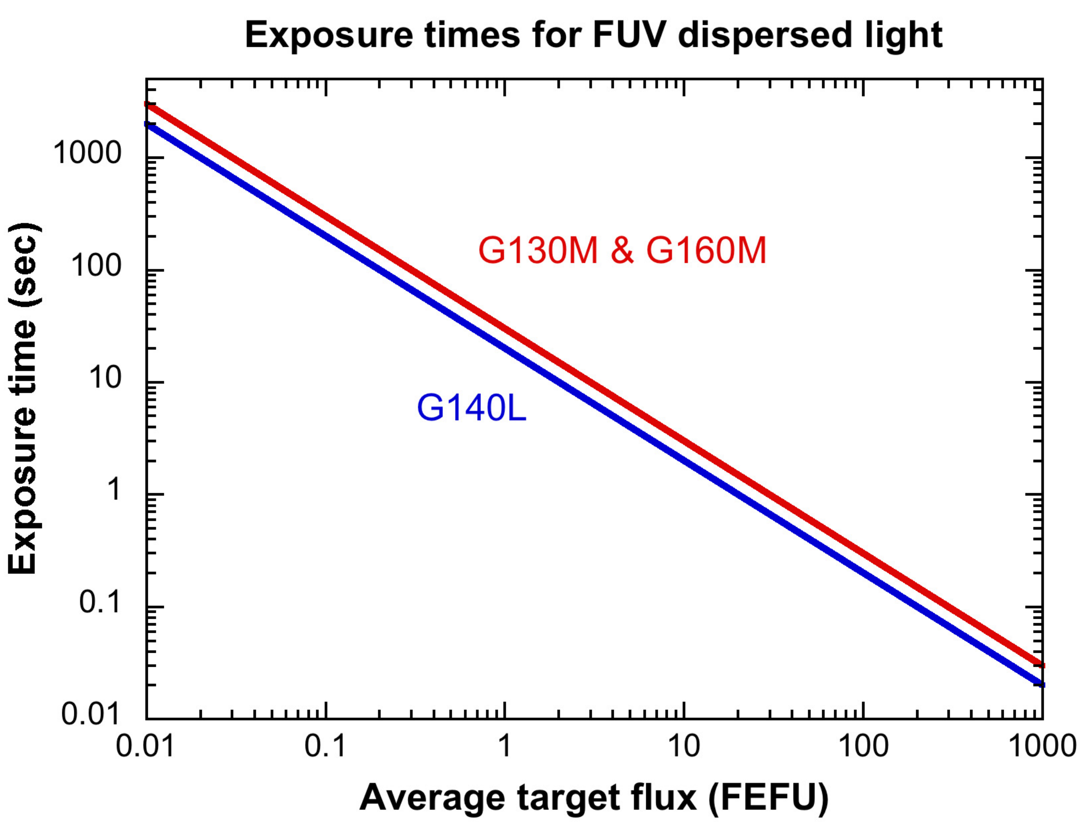
A variation on FLUX-WT is to use CENTER=FLUX-WT-FLR. In this case a floor is subtracted from all the array’s data points before the centroid is computed, and that floor is taken as the minimum number of counts seen in any one dwell point. FLUX-WT-FLR has the advantage of getting rid of background counts, but leaves one point in the array with zero. This can cause computational problems, and, as a result, FLUX-WT-FLR may not be used with SCAN-SIZE=2.

The last option for centering is to use CENTER=BRIGHTEST which simply centers the dwell point with the most counts. This is straightforward but not as accurate as the centroiding methods, although it may be appropriate for some situations that involve structured objects in which one wishes to center, say, a bright knot.

Exposure Times

Figure 7.9 allows you to estimate the exposure time needed for an FUV acquisition in dispersed light. The COS acquisition ETC should be used to get actual values, of course. Note that these exposure times apply to each separate dwell point of a pattern, which is the quantity entered into APT in Phase II.

Figure 7.9: Exposure Times Needed for FUV Dispersed-light Acquisitions.



The calculations have been made for a flat source spectrum and are based on achieving S/N = 40.

Quality of Centering After ACQ/SEARCH

The ability of COS to center objects accurately will be calibrated once it is installed in HST, and so this discussion relies on computational simulations. Those simulations, using realistic estimates of source brightness, coordinate accuracy, and noise levels, predict that the ACQ/SEARCH stage, by itself, together with CENTER=FLUX-WT should lead to a source being centered to within 0.2 arcsec in the along-dispersion direction and 0.1 arcsec in the cross-dispersion direction. However, statistical effects play a role, and the worst-case errors were 1.3 arcsec. If CENTER=BRIGHTEST is used instead, simulations show that the centering can often be off by 0.4 arcsec or more. FLUX-WT-FLR also produced good results, but not as good as FLUX-WT.

7.6.3 PEAKXD: Peaking up in the Cross-dispersion Direction

As noted, in most cases an ACQ/SEARCH by itself will center a source well in the cross-dispersion direction, generally well enough for most purposes. However, an additional command, ACQ/PEAKXD, exists to enable that centering to be improved.

ACQ/PEAKXD works very much like ACQ/SEARCH mode except that no movement of the telescope occurs. As with an ACQ/SEARCH, with PEAKXD you specify the aperture to use (PSA or BOA, the same as for your science exposure, in general); the grating and central wavelength, and the exposure time. You can optionally choose to just use one of the segments, A or B, but use of the default is recommended. The default uses both segments except that only segment A is used with G140L set at 1105 Å. The specific steps executed in ACQ/PEAKXD are:

- A spectrum is recorded in TIME-TAG mode for a time and using a sub-array tailored to each grating setting.
- The mean location of the spectrum in the cross-dispersion direction is computed.
- This mean is compared to a similar calculation for a short exposure of the wavelength calibration lamp, and a shift is then computed to apply to the target spectrum to center it in the default location.
- The telescope is then slewed by this offset to center the target.

Simulations show that use of PEAKXD should end up centering a source to within 0.03 to 0.04 arcsec in almost all cases.

The total duration of an FUV ACQ/PEAKXD is 80 sec plus the exposure time plus any overhead time for an OSM movement from Table 9.2.

7.6.4 PEAKD: Peaking up in the Along-dispersion Direction

A COS point-source spectrum as imaged onto the FUV detector has some aberrations, but is still basically a single line along the direction of dispersion. This makes the determination of the spectrum's center in the cross-dispersion direction straightforward, but centering the source in the aperture in the along-dispersion direction using the dispersed spectrum is not as easy. At the same time, as noted above, the centering in the along-dispersion direction is more important for the quality of the spectrum because it helps assure the wavelength zero point.

The ACQ/PEAKD command works very much like ACQ/SEARCH except that instead of a spiral, a linear motion of HST is made to integrate the spectrum. As with ACQ/SEARCH, the centroid is then computed. The number of steps may be chosen as 3, 5, 7, or 9, with 3 being the default. The STEP-SIZE can be 0.01 to 2.0 arcsec, and there is no default value, although 1.2 arcsec is recommended.

As with ACQ/SEARCH, there are three options for the centering algorithm, CENTER=FLUX-WT, =FLUX-WT-FLR, and =BRIGHTEST, and they work in the same way as described above. We recommend that you specify CENTER=DEFAULT, which uses FLUX-WT if NUM-POS=3, but uses FLUX-WT-FLR if NUMPOS=5, 7 or 9.

The duration of an FUV ACQ/PEAKD is the number of dwell points times the sum of the exposure at each dwell point plus 20 sec. OSM1 movements overheads (Table 9.3) must be added as well.

7.7 NUV Dispersed-Light Acquisitions

The same methodology used with the FUV detector for dispersed-light acquisitions is available with the NUV channel of COS. The various parameters have the same range of available values and recommended defaults as for the FUV, and will not be repeated here. There are, however, several key differences to be aware of:

- With the NUV, you can use mode=ACQ/SEARCH with one of the mirrors (MIRRORA or MIRRORB) as well as a grating. As noted above, this enables you to execute a spiral search in integrated light, which is generally faster and more accurate than with dispersed light.
- On the NUV side, the optics produce three separate spectrum stripes on the MAMA detector, as compared to the single linear spectrum formed on the FUV detector. In order to reliably locate and center these spectra, it is necessary to extract a fairly large region of the MAMA detector. This fact, combined with a background count rate that is significantly higher than for the FUV detector, means that a dispersed-light acquisition with the NUV MAMA is more vulnerable to noise and is less accurate as a result.

As with the FUV, you can use ACQ/PEAKXD and ACQ/PEAKD procedures to refine the centering in the cross-dispersion and along-dispersion directions, respectively. One difference exists: with the NUV and PEAKXD, you can choose to extract just one of the three spectrum stripes. This is described in the *Phase II Proposal Instructions*.

The durations of NUV dispersed-light acquisitions are as follows:

- For NUV ACQ/SEARCH and ACQ/PEAKD, add 20 sec to the exposure time for each point, then multiply by the number of dwell points.
- For NUV ACQ/PEAKXD, add 70 sec to the exposure time.

For all three NUV cases, be sure to add any overheads associated with movements of OSM1 or OSM2 (see Table 9.2 and Table 9.3).

7.8 Acquisition Techniques for Crowded Regions

Acquiring targets that lie in crowded regions can be difficult. During its early use we will test the ability of COS to work in this situation. For the present it is necessary to first acquire a nearby point source that is isolated enough to not cause problems (at least 5 arscec from another UV source), and to then offset to the desired object. This method would also work for acquiring objects that are not quite point sources themselves.

When doing this, you should refine the centering of the initial target before offsetting. Also be aware of potential bright object concerns that will now apply over a broader region.

7.9 Early Acquisitions and Preliminary Images

In some situations an observer may need to get an independent ultraviolet image of a region in order to be sure that no objects violate safety limits and that the target to be observed can be acquired by COS successfully. Such an early acquisition should be included in the Phase I proposal, and the observation should not use a photon-counting detector. The UVIS channel on WFC3 is recommended, but observers are encouraged to consult with an STScI instrument scientist.

CHAPTER 8:

Observing Strategy and Phase I

In this chapter…

8.1 Designing a COS Observing Proposal

Here are the steps to follow when designing a COS Phase I observing proposal. The process is likely to be iterative.

- Identify your science requirements and select the basic COS configuration to satisfy those requirements.
- Estimate exposure time to achieve required signal-to-noise ratio and check the feasibility, including count-rate, data volume, counter rollover, and bright-object limits.
- Identify any additional non-science (target acquisition, peakup, and calibration) exposures required.
- Determine the total number of orbits required, taking into account all overheads.

This *Handbook* provides the information needed to estimate exposures and timing, but proposers are urged to use APT to achieve the most accurate results.

8.1.1 Identify the Science Requirements and COS Configuration

Identify the science you wish to perform with COS. Some basic choices you will need to make are:

- FUV or NUV channel;
- TIME-TAG or ACCUM, considering time resolution and background minimization;
- Spectral resolution and spectral coverage;
- The need for multiple grating settings (especially for NUV);
- The need for imaging;
- Signal-to-noise requirements;
- Wavelength and photometric accuracy required; and
- Safety of the object to be observed (i.e., that it does not produce excessive count rates).

Spectroscopy

For spectroscopic observations, the base configuration needed is detector (configuration = FUV or NUV), operating mode (TIME-TAG or ACCUM), aperture, grating (spectral element), central wavelength, and wavelength dither offset (FP-POS). See Chapter 5 for detailed information about these quantities.

Imaging

For imaging observations, the base configuration is NUV detector (configuration = COS/NUV), operating mode (TIME-TAG or ACCUM), aperture (PSA or BOA), and mirror choice (spectral element = MIRRORA or MIRRORB).

8.1.2 Use of Available-but-Unsupported Capabilities

There are no Available-but-Unsupported modes for COS.

8.1.3 Calculate Exposure Time and Assess Feasibility

You can determine the expected count rate and the recommended BUFFER-TIME value (for TIME-TAG mode) for your targets with the COS ETC. Determine acquisition exposure times with the COS Target Acquisition ETC. Count rates and exposure times from the ETC will help you to determine the feasibility of using TIME-TAG and NUV ACQ/IMAGE. Determine the number of exposures needed to cover your desired spectral range.

Once you've selected your basic COS configuration, the next steps are:

- Estimate the exposure time needed to achieve your required signal-to-noise ratio, given your source brightness. (You can use the COS ETC for this.)

- Ensure that your observations do not exceed brightness (count rate) limits.
- For observations using ACCUM mode, ensure that for pixels of interest, your observations do not exceed the limit of 65,535 accumulated counts per pixel per exposure imposed by the COS 16 bit buffer.

To determine your exposure-time requirements, consult Chapter 10, where an explanation of how to calculate a signal-to-noise ratio and a description of the sky backgrounds is provided. To assess whether you are close to the brightness, signal-to-noise, and dynamic-range limitations of the detectors, refer to Section 8.2 below.

8.1.4 Identify the Need for Additional Exposures

Having identified a sequence of science exposures, you next need to determine what additional exposures you may require to achieve your scientific goals. Specifically:

- If early acquisition images in support of bright object checking are necessary, they must be included in the Phase 1 orbit request.
- If the success of your science program requires calibration to a higher level of precision than is provided by routine STScI calibration data, and if you are able to justify your ability to reach this level of calibration accuracy yourself, you will need to include the necessary calibration exposures in your program, including the orbits required for calibration in your total orbit request.

8.1.5 Estimating Data Volume

For TIME-TAG observations: each photon recorded requires 4 bytes. Each buffer dump nominally contains 2.35×10^6 photons (~9 Mbytes). Data volume may be approximately estimated as: (exposure time / buffer-time) × 9 Mbytes. Observers are strongly urged to use TIME-TAG mode whenever possible.

For ACCUM observations: NUV ACCUM exposures require 2 Mbytes of on-board storage. FUV ACCUM exposures require 4 Mbytes per segment.

For acquisitions: NUV ACQ/IMAGE exposures require 4 Mbytes of on-board memory. All other acquisition types require insignificantly small amounts of storage.

If COS data are taken at the highest possible data rate for more than a few orbits or in the Continuous Viewing Zone (CVZ), it is possible to accumulate data faster than it can be transmitted to the ground. High data volume proposals will be reviewed and, on some occasions, users may be requested to break the proposal into multiple visits.

8.1.6 Determine Total Orbit Request

In this step, you place all of your exposures (science and non-science, alike) into orbits, including tabulated overheads, and determine the total number of orbits required. Refer to Chapter 9 when performing this step.

At this point, if you are satisfied with the total number of orbits required, you're done! If you are not satisfied with the total number of orbits required, you can adjust your instrument configuration, lessen your acquisition requirements, or change your target signal-to-noise or wavelength requirements, until you find a combination which allows you to achieve your science goals.

8.2 Bright Object Protection

The COS detectors are vulnerable to damage or performance degradation if exposed to too much light. Imaging acquisitions are a special risk because they concentrate the light of an object on a small area of the detector.

Users of COS must demonstrate that their targets are safe for the detectors of COS. Information on bright-object protection and screening is in Section 11.5.

8.3 Patterns and Dithering

There are as yet no patterns established for COS. This is because COS is intended to be used on point sources that are centered in its aperture. However, observers wishing to add coordinated parallel observations to COS primary observations should be able to displace a source in the cross-dispersion direction by small amounts without degrading performance; see Section 8.5.

8.4 A "Road Map" for Optimizing Observations

An outline summarizing how to prepare and submit a Phase I proposal for HST time is provided at:

http://apst.stsci.edu/apt/external/help/roadmap1.html

If you have APT running, this Web page will appear if you click "Roadmap" under "Help." Although the roadmap is detailed, it can be paraphrased and reduced to eight steps:

1. Learn about the tools to use and the rules governing HST proposals.
2. Prepare your proposal's first draft.
3. Choose the instruments and configurations you will use.
4. Check for potential problems.
5. Estimate your orbit needs.
6. Finish the proposal.

7. Edit all the needed information into APT and submit the proposal.
8. Talk to us so we can improve the process.

Most of these steps apply to any HST proposal and so are adequately described on the Web page noted. Here we emphasize any items specific to COS.

8.4.1 Get the Tools and Rules

As we described in Chapter 1, there are two essential software tools you will need:

- APT, the Astronomer's Proposal Tool (go to http://apt.stsci.edu), and
- The COS Exposure Time Calculator (ETC), available at:

`http://etc.stsci.edu/webetc/index.jsp`

For this first cycle of COS usage, there are no previously executed programs whose data you can examine, but the ETC includes a number of examples of many different kinds of celestial objects as reference points, or you can use an existing spectrum of your own or from the HST archive as a starting point.

The rules and policies that pertain to applying for HST time are described on the Web and in the *Call for Proposals* and the *HST Primer*. In particular, the *HST Primer* contains a brief description of all HST's scientific instruments, which should provide what you need to decide which instruments to use. A template is needed for the text portions of the proposal and it may be found on the HST Web pages.

We urge proposers to use APT in planning their observations, even for Phase I, for these reasons:

- APT includes detailed and accurate knowledge of an instrument's operation that can be difficult to describe. In particular, using APT will ensure that your estimates of the available exposure time in an orbit are accurate.
- Entering accurate and complete target information right at the start saves you from doing it later. Having photon-counting detectors, COS has Bright Object Protection requirements that must be satisfied by all observers, and observers may find that some targets are not safe to acquire because of nearby objects.
- A proposal with detailed descriptions of the potential observations is a more credible one.

We also urge you to use the ETC to determine accurate exposure times for both acquisitions and science exposures.

8.4.2 Choose Instrument Configurations

Determine your Science Requirements

- List your targets. You will probably want to start with more candidate targets than end up in the final proposal so that you can balance factors once you know how long the exposures will be.

- Note your spectroscopic data requirements. What features at what wavelengths are needed for your program? What resolving power is needed? What COS gratings and settings are necessary to get those wavelengths? What level of signal-to-noise is needed for the science?
- Are there other observing requirements? Does a particular target need an unusual acquisition, perhaps because of nearby objects? Is the object variable and needs to be observed at a particular time or phase?
- Determine instrument configurations: The above information should suffice to create a list of your targets and the COS instrument configurations for each.

Gather Essential Target Information

- Get target coordinates and fluxes. Depending on the type of source, you should be able to obtain target coordinates, magnitudes, and fluxes from on-line databases. For COS, target coordinates need to be accurate to one arcsec or better if the `ACQ/IMAGE` option is to be used. If that is not possible, you may need to use `ACQ/SEARCH`. Ideally, you want to base your exposure estimates on measured UV fluxes at or near the wavelengths of interest. Much of the time, however, you will need to make an estimate based on much less complete information. For much of the sky, observations from the Galex mission provide accurate UV fluxes for almost any object bright enough to observe with COS. In other areas, rougher estimates must be made by comparing the source to an analogous object for which better data exist. You will also need at least rough estimates of line fluxes and the breadth of lines if there are emission lines in your object's spectrum. This is so you can check to ensure local rate counts will not be excessive.
- Are there other objects near your targets? First, you want to avoid having more than one source within the COS 2.5 arcsec aperture, otherwise the recorded spectrum will be a blend (this can be mitigated by orienting objects along the cross-dispersion direction). Second, other objects that lie within the COS acquisition radius will have to be checked to ensure they are not too bright. Galex data work for much of the sky, but in other areas the available information is much rougher. Within APT, the Aladin tool allows you to display the Digital Sky Survey in the vicinity of a target and to overplot Galex sources if they are available.

Assess Target Acquisition Strategies

Acquisition strategy is not ordinarily a concern in Phase I, but you may wish to check that an ordinary acquisition will work for your targets because sophisticated acquisition strategies will use some time in the first orbit that would otherwise be available to use for the spectrum. Some considerations include:

- Check for nearby objects. As noted above, other UV-bright objects near your source could cause confusion during the acquisition, so extra care needs to be taken in crowded fields.
- Check target brightness. Some targets may be permissible to observe with COS to obtain a spectrum because the light is dispersed, but may be too bright for a safe imaging acquisition. The ETC provides a means of checking this. It is unlikely that a source could be too faint to acquire if a spectrum can be obtained of it. Again, the ETC will provide guidance.
- Estimate acquisition times. Use the COS acquisitions ETC to determine the exposure time needed, and then APT to get the full time required, including overheads. Special acquisitions will take longer, and you may wish to consult with a COS Instrument Scientist.

Determine the Science Exposure Needs

- Is the target flux safe? The COS ETC should warn you if a source will produce a count rate too high for COS. If you expect emission lines be sure to check that at their peaks there is no violation of the COS local count rate maximum.
- Should I use `TIME-TAG` or `ACCUM`? We strongly recommend use of `TIME-TAG` mode with the default parameters as a means of ensuring a well-calibrated, high-quality spectrum. However, some sources produce counts at too high a rate for `TIME-TAG` mode, in which case `ACCUM` should be used.
    - Are there special needs? Parallels? Variable objects? Observing at airglow wavelengths?
    - How many grating settings are required? With G140L a single exposure should suffice to record all the useful spectrum that can be obtained, but with the other gratings multiple settings are needed to record a continuous spectrum over the entire useful range of a grating.
    - Are the predicted count rates safe? See Section 11.5.

8.5 Parallel Observations While Using COS

Because the COS aperture is small, it makes sense to use COS as the prime instrument even if a camera, say, is used in parallel. Also, COS is intended to be used on point sources that are centered in its aperture, and that may prevent dithering any camera exposures obtained in parallel. However, small displacements (up to 0.3 arcsec on either side of the center) in the cross-dispersion direction should allow some movement of the image at a camera without degrading the COS spectrum and with only slight loss in throughput.

Proposers with an interest in developing parallel observations with COS are urged to contact an Instrument Scientist and to check the STScI Web pages for new information before the proposal deadline. Also, the HST *Call for Proposals* should be consulted for policies on using COS in parallel with other instruments.

CHAPTER 9:

Overheads and Orbit Usage Determination

In this chapter…

9.1 Observing Overheads

Overheads are the times required to execute various instrumental functions that are over and above an actual exposure time. For instance, mechanisms take a finite time to move into place, and electronic components must be configured properly for use.

This chapter helps you determine the total number of orbits that you need to request in your Phase I observing proposal. This process involves compiling the overheads for individual exposures or sequences of exposures, packing the exposure plus overhead time into orbits, and adding up the total number of orbits required. This will most likely be an iterative process as you modify exposures or their order to efficiently use orbital visibilities.

The Phase I *Call for Proposals* includes information on the observatory policies and practices with respect to orbit time requests. The *HST Primer* provides specific advice on orbit determination. Below we provide a summary of the generic observatory overheads, the specific COS overheads, and several examples that illustrate how to calculate your orbit requirements for a Phase I proposal.

All overheads provided here are accurate as of the writing of this Handbook and reflect both the specifications of the COS instrument commanding and the results of actual Phase II runs of APT. These numbers may be used in conjunction with the values in the *HST Primer* to estimate the total number of orbits for your Phase I proposal. After your HST proposal is accepted you will be asked to submit a Phase II proposal to support scheduling of your approved observations. At that time you will use the APT scheduling software which will contain the most up-to-date COS overheads. Allowing sufficient time for overhead in your Phase I proposal is very important; additional time to cover unplanned or overlooked overhead will not be granted later.

Accounting properly for all the overheads involved in an observation can be complicated. The information provided here is accurate but is meant to be illustrative for planning purposes. Proposers are urged to use APT and its capabilities to derive complete accurate determinations of these times.

9.2 Generic Observatory Overheads

The first time that you acquire an object you must include overhead for the HST guide-star acquisition (6 minutes)

In all subsequent orbits of the same visit you must include the overhead for the guide-star reacquisition (5 minutes); if you are observing an object in the Continuous Viewing Zone (CVZ), then no guide-star re-aquisitions are required.

You must allocate additional time for each deliberate movement of the telescope; e.g., if you are performing a target acquisition exposure on a nearby object and then offsetting to your target, or if you are taking a series of exposures in which you move the target on the detector (`POS-TARG`), you must allow time for the telescope moves (time varies depending on size of the slew - see Table 9.1).

Table 9.1: Generic Observatory Overhead Times

Action	Overhead type	Time needed
Guide star acquisition	Initial acquisition	6 min
	Re-acquisition	5 min per orbit
Spacecraft movements	Offset motion > 10 arcsec (1.5 arcmin max)	60 sec
	Offset > 10 arcsec	30 sec
	Offset < 10 arcsec	20 sec

9.3 Spectral Element Movement Overheads

For any COS exposure, including target acquisition exposures, an overhead must be included to allow for the time required for any change of spectral elements. Note that a transition from FUV to NUV may require both OSM1 and OSM2 to be moved as this transition requires movement of OSM1 to the NCM1 position, followed by a possible OSM2 movement. On the other hand, a transition from NUV to FUV requires only the movement of OSM1 from NCM1 to the desired FUV grating. Table 9.2 gives the times required for movement between all OSM1 spectral elements and Table 9.3 gives the times for movement between OSM2 spectral elements.

Note that all COS visits start with OSM1 at the G130M position and OSM2 at the G185M position. Also, OSM1 and OSM2 move sequentially, so that the net overhead is the sum of the two separate overheads.

Table 9.2: Overhead Times (seconds) for Motions Between OSM1 Spectral Elements.

Movement times (seconds)	**to G140L**	**to G130M**	**to G160M**	**to NCM1**
from G140L	—	158	200	115
from G130M	164	—	112	116
from G160M	206	116	—	159
from NCM1	121	109	154	—

Table 9.3: Overhead Times (seconds) for Motions Between OSM2 Spectral Elements.

Movement times (seconds)	**to G230L**	**to G185M**	**to G225M**	**to G285M**	**to MIRRORA**	**to MIRRORB**
from G230L	—	209	140	176	105	99
from G185M	204	—	136	102	169	175
from G225M	135	141	—	108	100	106
from G285M	170	107	103	—	136	142
from MIRRORA	100	174	105	141	—	71
from MIRRORB	94	181	112	147	77	—

9.4 Acquisition Overheads

An on-board target acquisition is required only once for a series of observations in contiguous orbits (i.e., once per visit). The drift rate in pointing induced by the observatory is less than 10 milliarcseconds per hour. Thermal drifts internal to COS are expected to be even less. The various types of on-board target acquisitions exposures are described in detail in Chapter 7. The exposure overheads associated with each are given below:

NUV ACQ/IMAGE: If this type of acquisition exposure is performed as the first exposure of a visit, the associated overhead is 7 minutes plus twice the specified exposure time; this includes OSM1 and OSM2 movements. If this exposure is performed subsequent to the first exposure of a visit (it may often follow an `ACQ/SEARCH`) with no OSM2 movement necessary, the associated overhead is 2 minutes plus twice the exposure time. The reason for doubling the exposure time in calculating overheads is that after the computed centering slew of HST is performed by the acquisition procedure, a final confirmation image is automatically taken by the on-board flight software.

NUV ACQ/SEARCH: Multiply the number of dwell points by (20 seconds + exposure time at each dwell) to account for slewing and exposure time overheads. Add the grating change overheads from Table 9.2 and Table 9.3.

NUV ACQ/PEAKXD: The overhead is 70 seconds plus exposure time. Add the grating change overhead from Table 9.2 and Table 9.3.

NUV ACQ/PEAKD: Multiply the number of dwell points by (20 seconds + exposure time at each dwell) to account for slewing and exposure time overheads. Add the grating change overhead from Table 9.2 and Table 9.3.

FUV ACQ/SEARCH: Multiply the number of dwell points by (20 seconds + exposure time at each dwell) to account for slewing and exposure time overheads. Add grating change overhead from Table 9.2 and Table 9.3.

FUV ACQ/PEAKXD: Overhead is 80 seconds plus exposure time. Add the grating change overhead from Table 9.2 and Table 9.3.

FUV ACQ/PEAKD: Multiply the number of dwell points by (20 seconds + exposure time at each dwell) to account for slewing and exposure time overheads. Add grating change overhead from Table 9.2 and Table 9.3.

BOA: Moving the BOA into position to replace the PSA requires 8 sec.

9.5 Science Exposure Overheads

Science exposure overheads are dominated by the time required to move OSM1 and OSM2, as well as the time needed to read out the on-board memory buffer at the end of each exposure. Please note that in Phase II the computed overheads may be less than the values presented below as all the interactions inherent in instrument commanding will be accurately accounted for by APT. It is important to plan Phase I with the conservative overheads, especially for detector readout, given below to ensure adequate time for proposal exposures.

The full overhead calculation for science exposures depends upon a number of factors including generic exposure setups (which are detector and observing mode dependent), whether an aperture change is required, whether a grating change is required, whether the grating is not changed but central wavelength setting for the grating is changed, and the directional sense of any required motion to implement an FP-POS change. Table 9.4 lists these additional overheads.

Table 9.4: Science Exposure Overhead Times

Add the values for grating change, wavelength change, aperture change, or segment reconfiguration only if those actions are being undertaken.

Overhead times (sec)	FUV		NUV	
	TIME-TAG	ACCUM	TIME-TAG	ACCUM
Exposure set-up	71	79	36	38
Grating change	see Table 9.2		see Table 9.3	
Central wavelength change	72		75	
FP-POS forward[1]	3		3	
FP-POS backward[1]	70		70	
Aperture change	10		10	
SEGMENT reconfiguration	330		N/A	
Memory readout[2]	110	108[2]	110	48[2]

1. "Forward" refers to the preferred direction of motion of OSM1 or OSM2 and "backward" to the opposite direction. The preferred direction is toward greater wavelength and toward larger FP-POS value.
2. ACCUM mode readout overheads can be hidden within subsequent exposures under certain circumstances, but those are complex to describe. Use these values as safe upper limits for proposing purposes.

To calculate a complete science (or FLASH=NO wavecal) exposure overhead, start with the desired exposure time rounded up to the next whole second, add the generic exposure setup overhead from Table 9.4; if a grating change has occurred from the previous exposure add the appropriate values from Table 9.2 and/or Table 9.3, if a central wavelength change is made add the appropriate value from Table 9.4, if an FP-POS movement is made add the appropriate value for a preferred direction (toward larger FP-POS) or non-preferred direction move, and for FUV only, if a detector SEGMENT reconfiguration is employed (a change involving any two of BOTH, A, or B in combination) add 330 sec for the associated overhead. Lastly, add the appropriate detector memory readout overhead.

9.6 Examples of Orbit Estimates

9.6.1 FUV Acquisition plus FUV TIME-TAG

In this example we start with an FUV ACQ/SEARCH followed by an ACQ/PEAKXD, then ACQ/PEAKD target acquisition, then add an FUV TIME-TAG exposure with G140L and SEGMENT=A.

Table 9.5: Overhead Values for FUV Acquisition with FUV TIME-TAG.

Action	Time required	Comment
Initial guide star acquisition	6 min	Required at start of a new visit
FUV ACQ/SEARCH, G130M at 1309 Å, 3 × 3 pattern, 15 sec exp.	9×(20+15) = 315 sec = 5.3 min	COS starts from G130M home on OSM1 so no initial move; 9 ACQ/SEARCH sub-exposures, so overhead includes 9 slews (20 sec each) plus 9 exposures (15 sec each)
FUV ACQ/PEAKXD, G130M at 1309 Å, 20 sec exp.	80 + 20 sec = 100 sec = 1.7min	No OSM1 movement; generic PEAKXD overhead; exp time
FUV ACQ/PEAKD, G130M at 1309 Å, 5 steps, 25 sec exp.	5×(20+25) = 225 sec = 3.8 min	No OSM1 move; five slews (20 sec each) plus 5 exp (25 sec each)
FUV G140L at 1235 Å, TIME-TAG, FLASH=YES, FP-POS=3, SEGMENT=A, 1500 sec exp.	71 + 164 + 330 + 110 + 1500 = 2175 sec = 36.3 min	Generic FUV TIME-TAG setup; OSM1 grating change (164); no central wavelength change; no FP-POS change; SEGMENT reconfiguration change; TIME-TAG memory readout; exp time
Total science time	36.3 min	
Total time used in orbit	53.1 min	

9.6.2 NUV TIME-TAG

In this example we start with an NUV ACQ/IMAGE target acquisition, then add two NUV TIME-TAG exposures with the same grating, but different central wavelengths, both utilizing default FP-POS and FLASH=YES.

Table 9.6: Overhead Values for NUV TIME-TAG.

Action	Time required	Comment
Initial guide star acquisition	6 min	Required at start of a new visit
NUV ACQ/IMAGE with 2 sec exposure time	7 min + 4 sec	ACQ/IMAGE is first exposure in visit, thus we include OSM1 change to NCM1 and OSM2 move to MIRRORA
NUV G185M at 1850 Å, TIME-TAG, FLASH=YES, FP-POS=3, 1200 sec exp.	36 + 174 + 110 + 1200 = 1520 sec = 25.3 min	Generic NUV TIME-TAG setup; change from MIRRORA to G185M [174]; no central wavelength change (default value); no FP-POS change (3=default); no aperture change from PSA; TIME-TAG memory readout; exp time
NUV G185M at 1812 Å, TIME-TAG, FLASH=YES, FP-POS=3, 600 sec exp.	36 + 75 + 110 + 600 = 785 sec = 13.1 min	Only change central wavelength, so generic NUV TIME-TAG exposure setup; no grating change; central wavelength change [75 sec]; no FP-POS change; TIME-TAG memory readout; exp time
Total science time[1]	38.4 min	
Total time used in orbit	51.4 min	

1. The indicated science time has been chosen to be less than the orbit visibility period less the various overheads.

9.6.3 NUV plus FUV TIME-TAG

In this example we start with an NUV ACQ/SEARCH followed by an ACQ/IMAGE target acquisition, then add an NUV TIME-TAG exposure followed by a switch to the FUV channel and an FUV TIME-TAG exposure.

Table 9.7: Overhead Values for NUV ACCUM with FUV TIME-TAG.

Action	Time required	Comment
Initial guide star acquisition	6 min	Required at start of a new visit
NUV ACQ/SEARCH, MIRRORA, 3 × 3 pattern, 10 sec exp.	116 + 169 + 9×(20+10) = 555 sec = 9.3 min	COS starts at G130M on OSM1, so move to NCM1 requires 116 sec; OSM2 home position is G185M, so move to MIRRORA takes 169 sec; 9 ACQ/SEARCH sub-exposures, so overhead includes 9 slews (20 sec each) plus 9 exposures (10 sec each)
NUV ACQ/IMAGE with 10 sec exposure time	2 min + 2×10 sec = 140 sec = 2.3 min	No OSM2 movement; so overhead includes only ACQ/IMAGE setup and twice exp. time
NUV G225M at 2250 Å, TIME-TAG, FLASH=YES, FP-POS=3, 1200 sec exp.	36 + 105 + 110 + 1200 = 1451 sec = 24.2 min	Generic NUV TIME-TAG setup; change from MIRRORA to G225 [105]; no central wavelength change (default value); no FP-POS change (3=default); no aperture change from PSA; TIME-TAG memory readout; exp time
FUV G130M at 1309 Å, TIME-TAG, FLASH=YES, FP-POS=3, 600 sec exp.	71 + 109 + 110 + 600 = 840 sec = 14.9 min	Switch from FUV to NUV adds no overhead (OSM2 not moved); generic FUV TIME-TAG setup; OSM1 move from NCM1 to G130M [109]; no central wavelength change; no FP-POS change; no SEGMENT change; TIME-TAG memory readout; exp time
Total science time	39.1 min	
Total time used in orbit	56.7 min	

9.6.4 FUV TIME-TAG with BOA and FLASH=NO

In this example we start with an NUV ACQ/IMAGE followed by a switch to the FUV channel and an FUV TIME-TAG science exposure with G160M, the BOA, and, as required with the BOA, FLASH=NO. The science exposure will be followed automatically by a 10-second wavecal (see Section 5.7.3). The next orbit starts with a longer science exposure using the same set-up as for the first orbit. Because more than 40 minutes will have elapsed since the first wavecal, another wavecal will be inserted automatically following this science exposure.

Table 9.8: Overhead Values for FUV TIME-TAG Using the BOA and FLASH=NO.

Action	Time required	Comment
Initial guide star acquisition	6 min	Required at start of a new visit
NUV ACQ/IMAGE, 2 sec exp.	7 min + 4 sec	ACQ/IMAGE is first exposure in visit, so overhead includes OSM1 change to NCM1; OSM2 move to MIRRORA
FUV G160M at 1600 Å, TIME-TAG, BOA, FLASH=NO, FP-POS=1, 1800 sec exp.	71 + 154 + 68 + 8 + 110 + 1800 sec = 2211 sec = 36.8 min	Generic FUV TIME-TAG setup; NUV to FUV adds no overhead; change from NCM1 to G160M [154]; no central wavelength change (default value); non-preferred direction FP-POS change [70 sec] (3=default to 1); aperture change from PSA to BOA; no SEGMENT change; TIME-TAG memory readout; exp time
FUV G160M at 1600 Å, TIME-TAG, AUTO WAVECAL, WCA, FP-POS=1, 10 sec exp.	71 + 10 + 110 = 191 sec = 3.2 min	AUTO WAVECAL to be inserted as FLASH=YES not allowed with BOA; generic FUV TIME-TAG setup; no OSM1 move, no central wavelength change; no FP-POS change; aperture change from BOA to WCA [10 sec]; no SEGMENT change; TIME-TAG memory readout; exp time
end of orbit 1; total science time = 40.0 min.; total time used = 53.1 min.		
Guide star re-acquisition	5 min	required at start of additional orbit
FUV G160M at 1600 Å, TIME-TAG, BOA, FLASH=NO, FP-POS=1, 2400 sec exp.	71 + 10 + 110 + 2400 = 2591 sec = 43.2 min	Generic FUV TIME-TAG setup; continue at same OSM1 position, same central wavelength and FP-POS; aperture change to BOA [10 sec]; no SEGMENT change; TIME-TAG memory readout; exp time
FUV G160M at 1600 Å, TIME-TAG, AUTO WAVECAL, WCA, FP-POS=1, 10 sec exp.	71 + 10 + 110 = 191 sec = 3.2 min	Another AUTO WAVECAL required as more than 40 min have elapsed since last one; again generic FUV TIME-TAG exposure setup; no grating change; no central wavelength change; no FP-POS change; aperture change from PSA to BOA [8 sec]; no SEGMENT change; TIME-TAG memory readout; exp time
Total science time (orbit 2)	45.4 min	
Total time used in orbit 2	50.4 min	

9.6.5 FP-POS=AUTO with FUV TIME-TAG and FLASH=YES

In this example we start with an NUV ACQ/IMAGE target acquisition followed by a switch to the FUV channel for an FP-POS=AUTO sequence (using a single exposure entry from which four individual exposures are automatically generated; that is, one exposure at each FP-POS wavelength dither position). In this example we will again use TIME-TAG, FLASH=YES, and G130M, but we will also use central wavelength 1327 rather than the default value of 1309. For FP-POS=AUTO sequences the observer specifies the total duration of the four individual exposures to be obtained in the sequence.

First an NUV ACQ/IMAGE will be performed. Next OSM1 is moved to put G130M in place at the standard default central wavelength position (λ_c = 1309 Å). Next, OSM1 is moved to select central wavelength 1327 at default FP-POS=3. Following this, the FP-POS=AUTO sequence will be executed. Since in an FP-POS=AUTO sequence the individual exposures will be executed in the order FP-POS=1, 2, 3, and 4, a non-preferred direction (backward) movement from position 3 to position 1 is performed first. After the position 1 exposure, a forward direction movement is made to position 2 and so on for positions 3 and 4. In the example provided, the total exposure time will not fit into a single orbit, so, as in the previous example, some exposures must be performed in a second orbit. As the second orbit is not completely filled, the observer would typically add additional exposures (not shown here) to fill that orbit.

Table 9.9: Overhead Values for FP-POS=AUTO with FUV TIME-TAG and FLASH=YES.

Action	Time required	Comment
Initial guide star acquisition	6 min	Required at start of a new visit
NUV ACQ/IMAGE, 10 sec exp., aperture = PSA	7 min + 20 sec = 7.3 min.	ACQ/IMAGE is first exposure in visit, so overhead includes OSM1 change to NCM1; OSM2 move to MIRRORA; add twice exposure time
FUV G130M at 1327 Å, TIME-TAG, BOA, FLASH=YES, FP-POS=AUTO, 3600 sec exp.	109 + 72 sec = 181 sec = 3 min	Move OSM1 from NCM1 to G130M (109 sec.); change G130M from default setting of 1309 to desired 1327 (72 sec.); default FP-POS=3
FP-POS=1 exposure	71 + 70 + 110 +900 = 1151 sec = 19.2 min	First exposure of FP-POS sequence: generic TIME-TAG set-up (71 sec.); move to position 1 (70 sec.); TIME-TAG memory read-out (110 sec.); exposure time = 3600/4 = 900 sec.
FP-POS=2 exposure	71 + 3 + 110 +900 = 1151 sec = 18.1 min	First exposure of FP-POS sequence: generic TIME-TAG set-up (71 sec.); move to position 1 (70 sec.); TIME-TAG memory read-out (110 sec.); exposure time = 3600/4 = 900 sec.
Total science time in orbit 1	40.3 min	
Total time used in orbit 1	53.6 min	
Guide star re-acquisition	5 min	required at start of additional orbit
FP-POS=3 exposure	71 + 3 + 110 +900 = 1151 sec = 18.1 min	As for FP-POS=2
FP-POS=4 exposure	71 + 3 + 110 +900 = 1151 sec = 18.1 min	As for FP-POS=2
Total science time in orbit 2	36.2 min	
Total time used in orbit 2	42.2 min	

CHAPTER 10:

Exposure-Time Calculator (ETC)

In this chapter…

10.1 The COS Exposure Time Calculators

Three COS Exposure-Time Calculators (ETCs) are available on the COS Web pages to help with proposal preparation; go to:

http://etc.stsci.edu/webetc/index.jsp

There are four ETCs for COS: the imaging ETC, the spectroscopic ETC, the target acquisition ETC, and the ETC for acquisition in dispersed light. These calculators provide count rates for given source and background parameters and calculate signal-to-noise ratios for a given exposure time, or the exposure time needed for a given signal-to-noise ratio. If you have a calibrated spectrum of your source, you can pass it as input via ftp to the Exposure Time Calculator. The ETC also determines peak count rates per pixel, to be compared to the local count rate limits. The spectroscopic ETC reports the total count rates, integrated over detector segments A and B (in the case of FUV observations) or integrated over the entire MAMA detector (in the case of NUV observations) to aid you in your feasibility assessment. The ETC also warns you if your observations exceed the local or global brightness limits (see Table 11.2). Lastly, in the case of the spectroscopic ETC, also displayed are the input spectrum, a simulated one-dimensional output spectrum, and S/N and number of counts per resolution element for the selected COS configuration and source. These outputs can also be downloaded by the user in ascii format. The ETCs have extensive online help which explains how to use them and provides the details of the performed calculations.

The imaging ETC is simple because COS has only a single imaging mode. However, this NUV mode does allow a variety of attenuations by selection of either the primary science aperture or bright object aperture, and selection of either MIRRORA or MIRRORB on OSM2. The ETC reports count rate in the brightest pixel, total counts in the detector, and S/N per resolution element.

The target acquisition ETC returns the acquisition exposure time to be entered in APT for both imaging and spectroscopic acquisitions. Target acquisition is described in Chapter 7.

10.2 Count Rate, Sensitivity, and S/N

10.2.1 Centering Accuracy and Photometric Precision

A complete theoretical discussion of the exposure time as a function of instrument sensitivity and signal-to-noise ratio is given in Chapter 6 of the STIS Instrument Handbook and will not be repeated here. However, COS has several characteristics which simplify the signal-to-noise calculations.

Both COS detectors are photon counters, which means that they have zero read noise. COS is optimized for point sources, and in this case the signal-to-noise ratio is given by:

$$S/N = (C \cdot t) \bullet (C \cdot t + N_{pix}[B_{sky} + B_{det}]t)^{-1/2}$$

where:

C = the signal from the astronomical source, in counts sec^{-1}

t = the integration time, in sec

N_{pix} = the total number of detector pixels integrated to achieve C

B_{sky} = the sky background, in counts sec^{-1} pixel^{-1}

B_{det} = the detector dark count rate, in counts sec^{-1} pixel^{-1}

With no detector read noise, the signal-to-noise ratio is proportional to the square root of the exposure time whether the target is bright or faint compared to the backgrounds and dark.

10.3 Detector and Sky Backgrounds

When calculating expected signal-to-noise ratios or exposure times, the background from the detector must be taken into account. For COS, the detector background is quite small, as discussed in the next section.

The sources of sky background which will affect COS observations include:

- Earthshine,
- Zodiacal light, and
- Geocoronal emission.

The ETC allows the user to select among several levels of intensity for each of these backgrounds, corresponding to different observing environments.

10.3.1 Detector dark background

The following table lists the dark count rate and read noise characteristics of the COS detectors as measured in ground tests. These values will be reevaluated during SMOV and as part of the COS calibration plan.

Table 10.1: Detector background count rates (per second) for COS.

Detector:	FUV XDL	NUV MAMA
Dark rate (counts sec^{-1})	0.5 per cm^2 7.2×10^{-7} per pixel 4.3×10^{-5} per resel	60 per cm^2 3.7×10^{-4} per pixel 3.3×10^{-3} per resel
Read noise	0	0

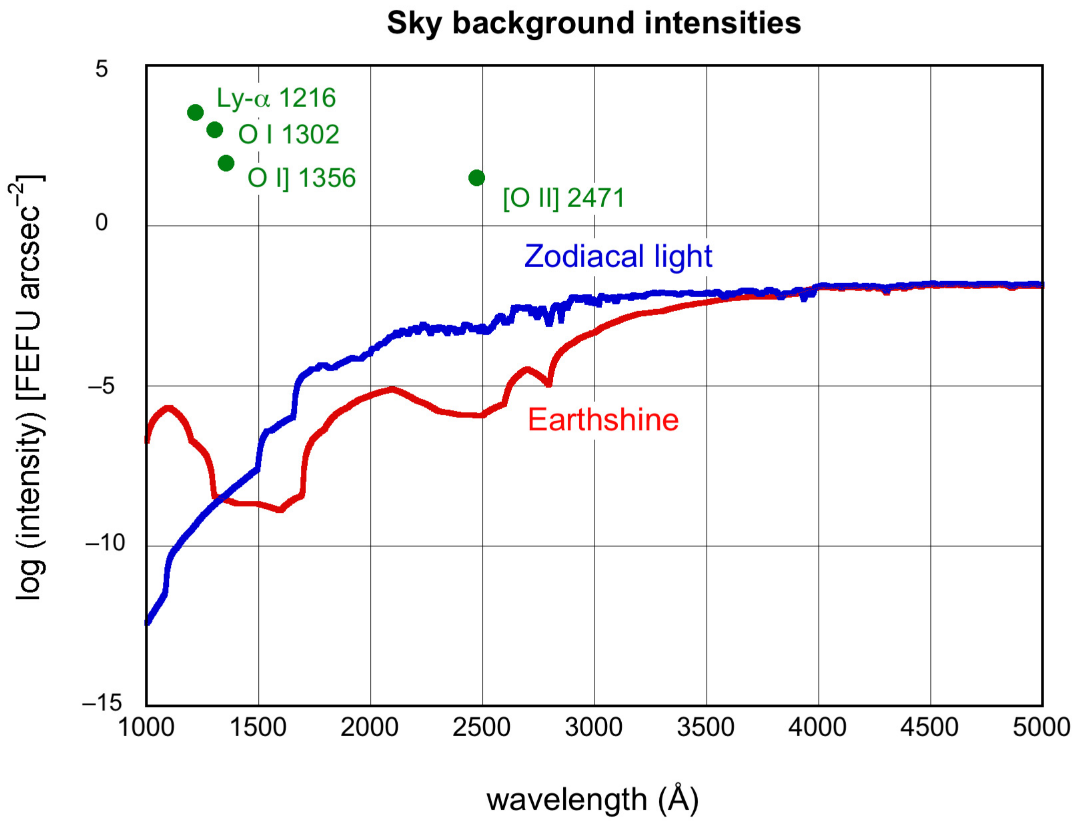
Note that, due in part to its windowless design, the dark current in the FUV detector is truly small, about 1 count resel^{-1} in six hours. It is the "resel," or resolution element, that matters most since that is the net "unit" for a spectrum.

10.3.2 Earthshine

The earthshine surface brightness corresponding to the "high" level is shown in Figure 10.1. There are four intensity levels to choose from in the ETC, with the following relative scaling factors:

(*shadow*, *average*, *high*, *extremely high*) = (0.0, 0.5, 1.0, 2.0).

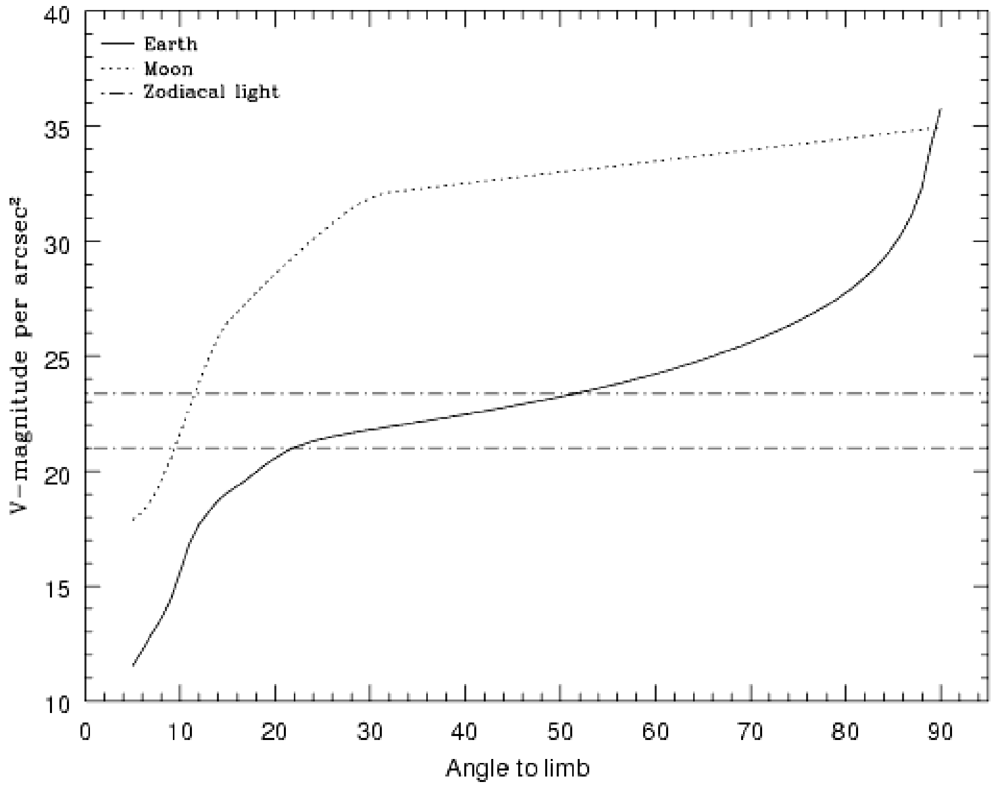
Figure 10.1: Sky Background Intensity as a Function of Wavelength.



The earthshine is for a target which is 24 degrees from the limb of the sunlit Earth. Use Figure 10.2 to estimate background contributions at other angles. The zodiacal contribution corresponds to a helio-ecliptic latitude and longitude of 30° and 180°, respectively, which corresponds to m_V = 22.7 per square arcsec. The upper limit to the [OII] 2471 intensity is shown. Note that the geocoronal day glow line intensities are integrated fluxes, in units of 10^{-15} erg cm^{-2} sec^{-1} arcsec^{-2}.

Earthshine varies strongly depending on the angle between the target and the bright Earth limb. The variation of the earthshine as a function of limb angle from the sunlit Earth is shown in Figure 10.2. The figure also shows the contribution of the Moon which is typically much smaller, and the full range of the zodiacal contribution. In Figure 10.2, limits on the zodiacal light contribution are also given. For reference, the limb angle is approximately 24° when the HST is aligned toward its orbit pole (i.e., the center of the CVZ). The earthshine contribution given in Table 10.2 and Figure 10.1 corresponds to this position.

Figure 10.2: Background Contributions from the Moon and Earth.



The values are V magnitude per square arcsec due to the moon and the sunlit Earth as a function of angle between the target and the limb of the Earth or moon.

10.3.3 Zodiacal Light

Away from the airglow lines, at wavelengths between about 1300 and 3000 Å, the background is dominated by zodiacal light, and is generally lower than the intrinsic detector background, especially for the NUV detector. Figure 10.1 shows the zodiacal light for the "average" level in the ETC. The selectable levels and the factors by which they are scaled from this are:

(*low*, *average*, *high*) = (0.576, 1.0, 1.738).

The contribution of zodiacal light does not vary dramatically with time, and varies by only a factor of about three throughout most of the sky. For a target near ecliptic coordinates of (50,0) or (–50,0), the zodiacal light is relatively bright at $m_V = 20.9$, i.e. about 9 times the faintest values of $m_V = 23.3$.

Observations of the faintest objects may need the special requirement LOW-SKY in the Phase II observing program. LOW-SKY observations are scheduled during the part of the year when the zodiacal background light is no more than 30% greater than the minimum possible zodiacal light for the given sky position. LOW-SKY in the Phase II scheduling also invokes the restriction that exposures will be taken only at angles greater than 40 degrees from the bright Earth limb to minimize earthshine and the UV airglow lines. The LOW-SKY special requirement limits the times at which targets within 60 degrees of the ecliptic plane will schedule, and limits visibility to about 48 minutes per orbit.

The ETC provides the user with the flexibility to separately adjust both the zodiacal (*low*, *average*, *high*) and earthshine (*shadow*, *average*, *high*, *extremely high*) sky background components in order to determine if planning for use of LOW-SKY is advisable for a given program. However, the absolute sky levels that can be specified in the ETC may not be achievable for a given target; e.g., as shown in Table 10.2 the zodiacal background minimum for an ecliptic target is m_V = 22.4, which is still brighter than both the low and average options with the ETC. By contrast, a target near the ecliptic pole would always have a zodiacal = *low* background in the ETC. The user is cautioned to carefully consider sky levels as the backgrounds obtained in HST observations can cover significant ranges.

10.3.4 Geocoronal Airglow Emission

In the ultraviolet, the sky background contains important contributions from airglow lines. These vary from day to night and as a function of HST orbital position. The airglow lines may be an important consideration for spectroscopic observations at wavelengths near the lines, and may be quite important for NUV imaging observations.

Background due to geocoronal emission originates mainly from hydrogen and oxygen atoms in the exosphere of the Earth. The emission is concentrated in a very few lines. The brightest line by far is Lyman-α at 1216 Å. The strength of the Lyman-α line varies between about 2 and 20 kilo-Rayleighs (i.e., between 6.3×10^{-14} and 6.3×10^{-13} erg sec^{-1} cm^{-2} arcsec^{-2}, where 1 Rayleigh = 10^6 photons sec^{-1} cm^{-2} per 4π steradians, which equates to 3.15×10^{-17} erg sec^{-1} cm^{-2} arcsec^{-2} at Lyman-α) depending on the time of the observation and the position of the target relative to the Sun. The next strongest line is the O I line at 1304 Å, which rarely exceeds 10% of Lyman-α. The typical strength of the O I 1304 Å line is about 2 kilo-Rayleighs (which corresponds to about 7×10^{-14} erg sec^{-1} cm^{-2} arcsec^{-2}) on the daylight side, and about 150 times fainter on the night side of the HST orbit. The O I] 1356 Å and [O I] 2471 Å lines may appear in observations on the daylight side of the orbit, but these lines are at least 10 times weaker than the O I 1304 Å line. The widths of the lines also vary, but a representative value for a temperature of 2000 K is about 3 km s^{-1}. The geocoronal emission lines are essentially unresolved at the resolution of COS, but the emission fills the aperture in the spectrum and spatial directions. For the FUV modes, the aperture width is approximately 114 pixels, or 1.12, 1.36, and 9.46 Å for G130M, G160M, and G140L, respectively. For the NUV modes, the aperture width is approximately 105 pixels, or 3.87, 3.46, 4.18, and 41.21 Å for G185M, G225M, G285M, and G230L, respectively.

It is possible to request that exposures be taken when HST is in the umbral shadow of the earth to minimize geocoronal emission (e.g., if you are observing weak lines at 1216 Å or 1304 Å) using the special requirement SHADOW. Exposures using this special requirement are limited to roughly 25 minutes per orbit, exclusive of the guide-star acquisition (or reacquisition) and can be scheduled only during a small percentage of the year. SHADOW reduces the contribution from the geocoronal emission lines by roughly a factor of ten, while the continuum earthshine is set to 0. If you require SHADOW, you should request it in your Phase I proposal (see the Call for Proposals).

An alternate strategy for reducing the effects of geocoronal emissions is to use time-resolved observations, so that any data badly affected by geocoronal emission can simply be excluded from the final co-addition. This can be done either by doing the observations in TIME-TAG mode, the default for all COS observations if the target is not too bright, or by just taking a series of short (~ 5 min) ACCUM mode exposures over the course of each orbit.

As noted, geocoronal Lyman-α is by far the strongest airglow feature to contend with. Despite this, we estimate that on the day side of HST's orbit, when Lyman-α is at its strongest, it will produce a net count rate of 20 counts sec^{-1} $resel^{-1}$, well below rates at which bright lines are a concern.

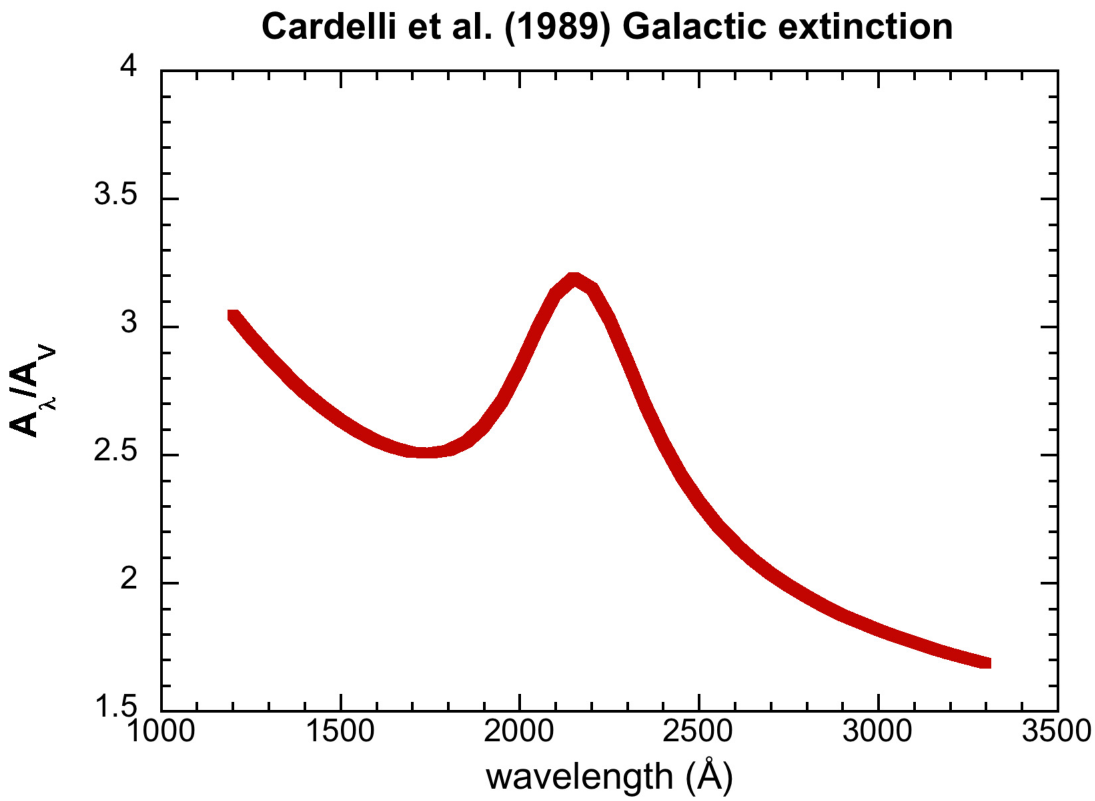
10.4 Extinction Correction

Extinction can dramatically alter the counts expected from your source, particularly in the ultraviolet. Figure 10.3 shows A_λ/A_V values applicable to our Galaxy, taken from Cardelli, Clayton, & Mathis (1989, ApJ, 345, 245). A value of $R = 3.1$ was used. This corresponds to the "Average Galactic" selection of the ETC.

Extinction curves, however, have a strong metallicity dependence, particularly at ultraviolet wavelengths. Sample extinction curves can be seen in Koornneef and Code [ApJ, 247, 860 1981 (LMC)], Bouchet et al. [A&A, 149, 330 1985 (SMC)], and Calzetti et al. [ApJ, 429, 582, 1994], and references therein. At lower metallicities, the 2200 Å bump which is so prominent in the Galactic extinction curve disappears, and $A_V/E(B-V)$ increases at shorter UV wavelengths.

The ETC allows the user to select among a variety of extinction curves and to apply the extinction correction either before or after the input spectrum is normalized.

Figure 10.3: Extinction in Magnitude as a Function of Wavelength.



The Galactic model of Cardelli et al. (1989) is shown, computed for *R* = 3.1.

10.5 Tabular Sky Backgrounds

Below is a table of the *high* sky background numbers as plotted in Figure 10.1, for reference. The *high* sky values are defined as the earthshine at 24° from the limb and by the typical zodiacal light of m_V = 22.7. Table 10.2 lists the average value of the zodiacal and earthshine backgrounds (excluding the contributions from geocoronal emission lines) in each wavelength interval.

The line widths and intensities of some important geocoronal emission lines in the COS bandpass are listed in Table 10.3.

Table 10.2: Earthshine and Zodiacal Light in the COS PSA.

Wavelength (Å)	Earthshine	Zodiacal Light	Total
1000	6.48 E–7	1.26 E –12	6.48 E –7
1100	1.66 E –6	6.72 E –11	1.66 E–6
1200	4.05 E–7	6.23 E–10	4.06 E –7
1300	2.66 E–8	3.38 E –9	2.99 E–8
1400	2.28 E –9	1.32 E–8	1.54 E–8
1500	1.95 E–9	2.26 E–7	2.28 E–7
1600	1.68 E–9	1.14 E–6	1.14 E–6
1700	6.09 E–8	3.19 E–5	3.19 E–5
1800	6.19 E–7	6.63 E–5	6.69 E–5
1900	2.30 E–6	1.05 E–4	1.07 E–4
2000	5.01 E–6	2.07 E–4	2.12 E–4
2100	6.97 E–6	5.95 E–4	6.02 E–4
2200	3.94 E–6	9.82 E–4	9.86 E–4
2300	1.83 E–6	9.67 E–4	9.69 E–4
2400	1.27 E–6	1.05 E–3	1.05 E–3
2500	1.37 E–6	1.01 E–3	1.01 E–3
2600	6.33 E–6	2.32 E–3	2.32 E–3
2700	2.66 E–5	4.05 E–3	4.08 E–3
2800	3.79 E–5	3.67 E–3	3.71 E–3
2900	2.17 E–4	7.46 E–3	7.68 E–3
3000	4.96 E–4	8.44 E–3	8.94 E–3
3100	1.04 E–3	9.42 E–3	1.05 E–2
3200	1.72 E–3	1.10 E–2	1.27 E–2
3300	2.18 E–3	1.34 E–2	1.56 E–2
3400	3.12 E–3	1.30 E–2	1.62 E–2
3500	4.06 E–3	1.31 E–2	1.72 E–2
3600	5.15 E–3	1.24 E–2	1.77 E–2
3700	5.89 E–3	1.49 E–2	2.18 E–2
3800	6.19 E–3	1.41 E–2	2.03 E–2
3900	7.80 E–3	1.39 E–2	2.17 E–2
4000	1.14 E–2	2.07 E–2	3.21 E–2
4250	1.13 E–2	2.17 E–2	3.40 E–2
4500	1.33 E–2	2.53 E–1	3.86 E–2
4750	1.35 E–2	2.57 E–2	3.92 E–2
5000	1.30 E–2	2.50 E–2	3.80 E–2

The rates assume the *high* level in the ETC and are listed in units of FEFUs for the total COS PSA, which is 4.91 arcsec^2 in area.

Table 10.3: Typical Strengths of Important Ultraviolet Airglow Lines

Airglow feature	Intensity					
	Day			Night		
	Rayleighs	FEFU-Å arcsec^{-2}	FEFU-Å per PSA	Rayleighs	FEFU-Å arcsec^{-2}	FEFU-Å per PSA
O I 911	17	0.7	3.5	8.3	0.35	1.7
O I 989	161	6.2	30	0.6	–	–
H I 1025	571	21	105	2.7	–	–
O I 1027	64	2.4	12	0	–	–
O I 1152	28	0.93	4.6	0	–	–
H I 1216	20,000	630	3100	2,000	63	310
O I 1304	2,000	59	290	13	0.38	1.9
O I] 1356	204	5.8	28	12.5	0.35	1.7
O I 2471	45	0.70	3.4	1	–	–

10.6 Examples

In this section we present a few examples of the way in which the COS ETCs may be used. They illustrate the information that is returned by the ETCs, and how they can be used to plan your observations.

10.6.1 A Flat-spectrum Source

One often does not know the exact spectrum shape of the object to be observed, so the answer to a simple question is desired: How long will it take to achieve a given signal-to-noise ratio at a given wavelength if the flux at that wavelength is specified? The easiest way to determine this is to use a flat spectrum as input. How long will it take to achieve *S*/*N*=10 per resolution element at 1320 Å with a source flux of 1 FEFU, using a medium resolution mode?

Only the G130M grating covers the desired wavelength at medium resolution, but several choices of central wavelength are available. We select a setting of 1309 Å. We enter these values into the spectroscopic ETC, select the Primary Science Aperture (PSA), select "Exposure time needed to obtain a S/N ratio of 10.0," and enter the specified wavelength of 1320 Å. For the spectrum distribution, choose a flat continuum in F_λ. Make sure the reddening, *E(B–V)*, is set to 0. Normalize the target to 1.0×10^{-15} (i.e., 1 FEFU). The zodiacal light and earthshine were not specified, so we choose average values.

When this case is computed with the ETC, we find the required time is 10,397 sec; the total count rates are 34 and 214 counts sec^{-1} in detector segments A and B, respectively, well below the safety limit; the count rate in the brightest pixel is 0.082 counts sec^{-1}, also well within the safe range; and the buffer time indicated by the ETC is 9,536 sec.

What if somewhat higher *S/N* were desired and one were willing to devote 5 HST orbits to the observation? Assuming each orbit allows 50 minutes of observing time (ignoring the acquisition time here), we find that in 15000 sec we will get $S/N = 12.0$ per resel. Note that $(15000/10397)^{1/2} = (12.0/10.0)$. That is, the *S/N* ratio scales as $t^{1/2}$, as stated in Section 10.2.

If a low-resolution observation is acceptable, then one could switch to the G140L grating. With a grating setting of 1105 Å and $S/N = 10$ per resel, we find the required exposure time is 1852 sec, considerably shorter than the medium resolution case required. Note that ordinarily only segment A is used for the G140L observations but that segment B could also be used if the object has measurable flux below Lyman-α.

However, also note that the sensitivity of G130M is higher than that of G140L once resolving power is taken into account. In other words, a G130M spectrum that is rebinned to the same resolution as a G140L spectrum can be obtained in less time for a given S/N, although, of course, with diminished wavelength coverage. If only a limited portion of the source's spectrum is of interest, using G130M is more efficient than using G140L.

These cases also illustrate that the earthshine and zodiacal light are completely negligible in the FUV unless the target flux is much lower than that considered here. This is also true of the airglow if the wavelength of interest is away from the airglow lines. Of course, the airglow cannot be ignored in terms of the total count rate of the detector, or the local count rate if the source contributes at the same wavelengths as the airglow lines.

10.6.2 An Early-type Star

We wish to observe an O5 star at medium spectral resolution at a wavelength of 1650 Å. We know that the star has a magnitude of $V = 16$. How long will it take to obtain $S/N = 15$?

We select the G160M grating set to 1623 Å. We select a Kurucz O5 stellar model, and set the normalization to be Johnson $V = 16$. All other settings remain the same as in the previous example. We find that the required exposure time is 607 sec.

Suppose this star is reddened, with $E(B–V) = 0.2$. We select the *Average Galactic* extinction law, which is shown in Figure 10.3. We must now decide if this extinction is to be applied before or after the normalization. Since the star has a measured magnitude, we want to apply the reddening before normalization. Otherwise, the extinction would change the *V* magnitude of the stellar model. Making this selection, we find that $S/N = 15$ can be obtained in 1,472 sec.

10.6.3 A Solar-type Star with an Emission Line

We want to observe a solar-type star with a narrow emission line. Consider the Si II 1810 Å line, with the following parameters: FWHM = 30 km sec^{-1} or 0.18 Å at 1810 Å, and integrated emission line flux = 1 × 10^{-14} erg cm^{-2} sec^{-1}. The measured magnitude of the star is $V = 12$. The desired exposure time is 1000 sec.

In the ETC we select a G2V star and an NUV grating, G185M, set to a central wavelength of 1817 Å. Select a 1000 sec exposure, with the *S/N* specified to be evaluated at 1810 Å. We add an emission line with the line center at 1810, FWHM=0.18, and integrated flux of 1 × 10^{-14}. We specify the normalization as Johnson $V = 12$. We set the zodiacal and earthshine to be *average*.

The ETC returns *S/N* = 19.1 per resel. The local and global count rates are within safe limits. The buffer time recommended is 27,170 seconds. As in the flat-spectrum case above, this `BUFFER-TIME` exceeds the exposure time of 1000 sec, and so the `BUFFER-TIME` should be set at 1000.

10.6.4 A Faint QSO

An important science goal for the design of COS was to obtain moderate S/N spectra of faint QSOs in the FUV. In the ETC, use the standard QSO spectrum provided, and choose G130M at 1309 Å, S/N = 20, and a continuum flux of 1 FEFU at 1320 Å. The indicated exposure time is 41,586 sec, or about 14 orbits. The source count rate is 0.0016 (counts per sec), with a background rate of 0.000035, 100 times lower than the source. The background is completely dominated by the dark current of the detector. The count rate over the entire detector is 261, well under any safety limits, and the maximum `BUFFER-TIME` is about 9041 sec. In this case, to be conservative, use 2/3 that value, or about 6,000 sec for `BUFFER-TIME`.

CHAPTER 11:

COS in Phase II

In this chapter…

The Phase II Proposal Instructions define the capabilities of HST. Therefore those Instructions take precedence over this Handbook if there is any conflict of information.

11.1 Essential Program Information

A fully specified COS exposure needs to include these data:

1. The target to be observed and its coordinates.
2. The COS aperture to use: PSA or BOA (or WCA for user-defined wavecals).
3. The COS channel being used: FUV or NUV.
4. The instrument mode, such as `ACQ/SEARCH`, or `TIME-TAG`.
5. For spectra, the grating, wavelength setting, and `FP-POS` usage.
6. The exposure time, and for `TIME-TAG` mode, the `BUFFER-TIME`.

11.2 A “Roadmap” for Phase II Program Preparation

1. Learn about the tools to use and the rules governing HST programs.
2. Prepare your program’s first draft.
3. Check for potential problems.
4. Estimate your orbit needs.
5. Iterate as needed to adjust to the orbits you were awarded.
6. Edit all the needed information into APT and submit the program.
7. Talk to your Program Coordinator to ensure your program is implemented the way you wish.
8. Talk to us so we can improve the process.

Most of these steps apply to any HST proposal; here we emphasize those aspects specific to COS.

11.3 Get the Tools and Rules

As with Phase I, there are two essential software tools you will need:

- APT, the Astronomer’s Proposal Tool, and
- The COS Exposure Time Calculator (ETC).

For this first cycle of COS usage, there are no previously executed programs whose data you can examine, but the ETC includes a number of examples of many different kinds of celestial objects as reference points, or you can use an existing spectrum of your own or from the HST archive as a starting point.

In addition, you will need the *Phase II Proposal Instructions*, to ensure your syntax and usage are correct.

11.4 Specify Instrument Usage Particulars

11.4.1 Gather Essential Target Information

Get Target Coordinates and Fluxes

Depending on the type of source, you should be able to obtain target coordinates, magnitudes, and fluxes from on-line databases. For COS, target coordinates should be accurate to one arcsec or better, and that should be the case if they are specified in the

GSC2 reference frame. If that is not possible, you may wish to consider acquiring a nearby object with well-determined coordinates and then offsetting to your target.

Ideally, you want to base your exposure estimates on measured UV fluxes at or near the wavelengths of interest. Much of the time, however, you will need to make an estimate based on much less complete information. For much of the sky, observations from the Galex mission provide accurate UV fluxes for almost any object bright enough to observe with COS. In other areas, rougher estimates must be made by comparing the source to an analogous object for which better data exist.

You will also need at least rough estimates of line fluxes and the breadth of lines if there are emission lines in your object's spectrum. This is so you can check to ensure local rate counts will not be excessive.

The HST *Phase II Proposal Instructions* provide information on how the names, coordinates, and fluxes of targets should be specified.

Are There Neighboring Objects?

Are there other objects near your targets? First, you want to avoid having more than one source within the COS 2.5 arcsec aperture, otherwise the recorded spectrum will be a blend. Second, other objects that lie within the COS acquisition radius will have to be checked to ensure they are not too bright. Galex data work for much of the sky, but in other areas the available information is much sparser.

Within APT, the Aladin tool allows you to display the Digital Sky Survey in the vicinity of a target and to overplot Galex sources if they are available. In some situations it is possible for a bright object to fall within the BOA when the PSA is in use and that may cause a violation of count rate limits. The Bright Object Tool in APT allows the observer to deal with these situations.

11.4.2 Assess Target Acquisition Strategies

Check for Nearby Objects

As noted above, other UV-bright objects near your source could cause confusion during the acquisition, so extra care needs to be taken in crowded fields.

Check Target Brightness

Some targets may be permissible to observe with COS to obtain a spectrum because the light is dispersed, but may be too bright for a safe acquisition. The ETC provides a means of checking this.

It is very unlikely that a source could be too faint to acquire if a spectrum can be obtained of it. Again, the ETC will provide guidance. It may sometimes be necessary to use the BOA, MIRRORB, or both.

Estimate Acquisition Times

Ordinarily, a COS acquisition uses several minutes at the beginning of the first orbit of a visit; see Chapter 7 and Chapter 9. Special acquisitions will take longer, and you may wish to consult with a COS Instrument Scientist.

11.4.3 Determine the Science Exposure Needs

Is the target flux safe?

The COS ETC should warn you if a source will produce a count rate too high for COS. If you expect emission lines be sure to check that at their peaks there is no violation of the COS local count rate maximum.

TIME-TAG or ACCUM?

We strongly recommend use of `TIME-TAG` mode with the default parameters as a means of ensuring a well-calibrated, high-quality spectrum. However, some sources produce counts at too high a rate for `TIME-TAG` mode, in which case `ACCUM` should be used.

Are There Special Needs?

Parallels? Variable objects? Observing at airglow wavelengths?

How Many Grating Settings?

In low-resolution mode, a single exposure should suffice to record all the useful spectrum that can be obtained, but in medium-resolution mode the bandpass recorded can be limited, especially in the near-UV.

Are Predicted Count Rates Safe?

See the next section, Section 11.5.

11.5 Safety First: Bright Object Protection

COS users are required to check their targets when preparing their Phase II programs to determine that they are safe to observe. The specific procedures to be followed will be provided at the time Cycle 17 proposals are selected. Here we provide the technical information about bright object protection for COS.

Photon-counting detectors are vulnerable to physical damage or degradation if illuminated with too much light at one time. Well before that flux level is reached, excess light leads to poor results because the electronics cannot handle the high event rates (the dead-time correction). In the case of the COS FUV detector, the very high gains mean that over-illumination of an area on the detector leads to charge depletion that can permanently impair the sensitivity of the detector at that point. This is also true to a lesser degree for the NUV MAMA detector.

For all these reasons COS has stringent count-rate limits that all observations must conform to. Similar procedures are used for the STIS and ACS/SBC MAMA detectors.

11.5.1 Limiting Magnitudes and Bright Object Limits

Like STIS, COS has a set of bright limit restrictions that will preclude some objects from being observed. Since the throughput of COS is considerably higher than that of STIS, particularly in the FUV, it may be necessary to observe some bright sources with STIS rather than COS, or to use the bright object aperture with COS. COS has two general types of bright limits: global and local. For the FUV detector, the global bright limit is ~60,000 ct s^{-1} $segment^{-1}$, and the local count rate limit is ~1.67 ct s^{-1} pix^{-1} (100 ct s^{-1} $resel^{-1}$). For the NUV detector, the global bright limit is ~170,000 ct s^{-1}, and the local count rate limit is 500 ct s^{-1}, measured over 4 pixels. The NUV global count rate limit can be increased slightly at the expense of doppler compensation during the course of the exposure.

Table 11.1 contains approximate estimates of the bright limit fluxes for the medium- and low-resolution COS modes at several wavelengths. Below each flux limit we also list the approximate corresponding visual magnitude of an unreddened O9 V star. The final operational screening limits set by STScI may be more restrictive than those listed in Table 11.1.

Table 11.1: COS Count Rate Limits.

Detector	Mode	Type of limit	Limiting count rate (sec^{-1})
FUV	TIME-TAG	global	21,000 per segment
		local	100 per resel
	ACCUM	global	60,000 per segment
		local	100 per resel
NUV	TIME-TAG	global	21,000
		local	200 per pixel
	ACCUM	global	170,000
		local	200 per pixel

Table 11.2: Local and Global Flux Limits for COS

Detector	Wavelength	Local limit (FEFU)[1]		Global limit (FEFU)	
		M gratings	L grating	M gratings	L grating
FUV	1300	6600 9.8	4100 12.3	530 14.5	300 14.7
	1600	20,000 7.9	8600 10.8	570 14.0	
NUV	1800	82,000 8.1	10,000 10.3	14,000 10.0	1200 11.4
	2300	73,000 7.4	6300 9.9	11,000 9.4	
	2800	80,000 6.6	8300 9.1	11,000 8.9	

1. Second value listed is the equivalent *V* magnitude of an O9V star.

Limiting Magnitudes for NUV Imaging

The following are the *V* magnitudes of an O5 star that is safe to observe with COS using NUV imaging. Therefore anything brighter for which measured UV flux data are not available is judged to be unsafe to observe.

- PSA with MIRRORA: $V = 19.14$
- PSA with MIRRORB: $V = 16.13$
- BOA with MIRRORA: $V = 14.14$
- BOA with MIRRORB: $V = 11.13$

Limiting Fluxes for NUV Imaging

The following fluxes are the highest permissible for a flat-spectrum source being acquired in ACQ/IMAGE mode:

- PSA with MIRRORA: 2 FEFU.
- PSA with MIRRORB: 30 FEFU.
- BOA with MIRRORA: 400 FEFU.
- BOA with MIRRORB: 6,000 FEFU.

11.5.2 Bright Object Protection Procedures

Any of the instrument protection levels shown below being activated is regarded as a serious breach of our instrument health and safety screening procedures and is cause for an investigation. Several of these conditions lead to a situation in which COS shuts itself down and subsequent observations do not take place until the instrument goes through a safe-mode recovery procedure that is run from the ground. Observers are responsible for ensuring that their observations do not cause an on-orbit problem with the instrument.

FUV Bright Object Protection

There are five levels of protection for the COS FUV XDL detector:

1. At the lowest level are the screening limits imposed on observers in order to provide a margin of safety for the instrument. The screening limits (see Section 11.5.2) are set at about a factor of two below actual risk levels, and we expect observers to work with us to ensure these limits are adhered to. They are determined by estimating the expected count rate from an object, both globally over the detector, and locally in an emission line if appropriate. The COS ETC is the estimating tool used for this check.
2. At the next level, within COS the "Take Data Flag" (TDF) is monitored during an exposure. If an event occurs that causes the TDF to drop (such as loss of lock on a guide star), then the COS external shutter is commanded closed. If this occurs, only that one exposure is lost.
3. Next comes local rate monitoring. It is possible to permanently damage a localized region of the micro-channel plates without necessarily exceeding the global rate limits. This could occur if an object with bright emission lines were observed, for example. The flight software in COS analyzes the FUV spectrum to ensure that local count rates do not exceed a threshold value. The limit is set at 100 events sec^{-1} per resel. If the local rate limit is exceeded, the COS flight software closes the external shutter and turns off the calibration lamps.
4. Global rate monitoring is next. The COS flight software monitors the total event rate for both FUV detector segments. If the rate for either segment exceeds a threshold, the high voltage to the detector is set to its lowest value, internal lamps are turned off, and the external shutter is closed. The detector high voltage cannot be turned up again until special commanding is executed, and so if the global rate check is violated subsequent COS observations are likely to be lost.
5. At the highest level, the instrument is protected by the software sensing an overcurrent condition in the high voltage; this shuts down the high voltage entirely.

NUV Bright Object Protection

Similar protections also apply to the NUV MAMA:

1. At the lowest level are the screening limits imposed on observers in order to provide a margin of safety for the instrument. The screening limits (see Table 11.3) are set at about a factor of two below actual risk levels, and we expect observers to work with us to ensure these limits are adhered to. They are determined by estimating the expected count rate from an object, both globally over the detector, and locally in an emission line if appropriate. The COS ETC is the estimating tool used for this check.
2. At the next level, within COS the "Take Data Flag" (TDF) is monitored during an exposure. If an event occurs that causes the TDF to drop (such as loss of

lock on a guide star), then the COS external shutter is commanded closed. If this occurs, only that one exposure is lost.

3. Next comes local rate monitoring. It is possible to permanently damage a localized region of the micro-channel plates without necessarily exceeding the global rate limits. This could occur if an object with bright emission lines were observed, for example. The flight software in COS analyzes the NUV spectrum and takes a short exposure to check for groups of pixels exceeding a threshold value. This short exposure is not recorded. If the local rate limit is exceeded, the COS flight software closes the external shutter and turns off the calibration lamps. Again, if this occurs only the one exposure is lost.
4. Global rate monitoring is next. The COS flight software monitors the total event rate for the NUV MAMA. If the total count rate exceeds 77,000 in 0.1 sec the high voltage to the MAMA is turned off, the external shutter is closed, and the calibration lamps are turned off. COS can resume operations only after a safemode recovery procedure.
5. At the highest level, the NUV MAMA is protected by the detector electronics. If the detected count rate exceeds 77,000 in 138 msec, then the high voltage to the MAMA is turned off, the external shutter is closed, and the calibration lamps are turned off. COS can resume operations only after a safemode recovery procedure. This “Bright Scene Detection” procedure differs from the global rate monitoring in two ways: BSD is done in hardware, not software, and what is measured is not a digitized count rate but instead current from a grid of wires over the MAMA detector.

Screening Limits

Screening limits are the count rate limits that we at STScI expect observers to adhere to, in order to provide a margin of safety in instrument operations. Screening limits are of two kinds – global and local – and both limits must be adhered to. The COS screening limits are shown in Table 11.3.

Bear in mind that these are “screening limits,” which means that if a target is predicted to cause counts in excess of these rates, then a more thorough check must be made. There are two higher limits that are important. First, a factor of two above the screening limits is the practical operation limit, the level we will not knowingly allow an observation to exceed, so as to provide a margin of safety for COS. In addition, if the FUV detector is used in `TIME-TAG` mode, significant data drop-outs occur when the count rate exceeds 21,000 per segment. The highest of these rate limits are those specified in the HST Constraints and Restrictions Document (CARD). If the CARD limits are exceeded on-orbit, the software and hardware within COS turn off the high voltage to the detector and COS goes into safe mode. This requires a safe-mode recovery procedure that must be executed from the ground, and no COS observations can be executed until that recovery is carried out.

Table 11.3: COS Count Rate Screening Limits.

Detector	Source type[1]	Type of limit	Limiting count rate[2]
FUV	predictable	global	15,000 per segment;
		local	40 per resel[3]
	irregular	global	6,000 per segment
		local	40 per resel[3]
NUV	predictable	global	30,000 per stripe
		local	80 per pixel
	irregular	global	12,000 per stripe
		local	80 per pixel

1. "Predictable" means the brightness of the source can be reliably predicted for the time of observation to within 0.5 magnitude.
2. Entries are counts per second.
3. An FUV resel is 6 pixels wide by 10 high.

If a target is too bright to observe in the Primary Science Aperture (PSA), it may be possible to observe it with the Bright Object Aperture (BOA), which attenuates flux by a factor of approximately 200. However, the neutral density filter in the BOA also degrades the optical quality of the source image, reducing the effective resolving power for a point source by a factor of 2 to 3.

If a target is safe to observe in the PSA but is too bright for a straightforward acquisition with ACQ/IMAGE mode in the NUV channel, it is possible to acquire with an attenuating mirror, with the BOA, or with both. The target may also be acquired in dispersed light, which is explained in Section 7.6 and Section 7.7.

Risks from Nearby Objects

It is not sufficient for just a potential target to be safe to observe, because nearby bright objects can pose a risk as well. There are three scenarios:

- Given the errors in the initial pointings of objects with HST, even with good coordinates, an unintended source may end up in either aperture, BOA or PSA. With good coordinates, objects beyond 5 arcsec should not pose a risk.
- Even without errors, a bright object could unintentionally end up in the other COS science aperture. This is true no matter which COS aperture is designated for use because light from both apertures reaches the detector for both the FUV and NUV. The most significant risk occurs when the BOA is in use because an over-bright source could unintentionally end up in the PSA.
- Finally, a nearby source that is very bright could throw enough light into the PSA to cause problems. Here we adopt the same criterion as used for STIS. The region of concern is an annulus that extends from 5 to 15 arcsec from the center of the PSA. Any object falling in this annulus may not produce a global count rate per second in excess of 1×10^5 per segment for the FUV or 2×10^5 per stripe for the NUV, nor a local count rate over 200 per resel (FUV) or 400 per pixel (NUV). These limiting count rates are those estimated with the ETC as though the source were in the center of the aperture.

To guard against the risks imposed by these scenarios, observers are required to use the tools in APT to certify that no potentially UV-bright objects lie within a zone that could cause problems. In some cases it may be necessary to choose a specific `ORIENT` for the observation to ensure that nearby bright objects cannot fall in a COS aperture.

11.6 Recap of COS Optional Parameters

Most of the parameters to be specified in Phase II are self-evident, such as COS/FUV, or TIME-TAG, the Config and Mode, respectively. Here we provide cross-references to discussions of the various Optional Parameters than can be specified.

BUFFER-TIME

Required with `TIME-TAG` mode. See Section 5.5.1.

CENTER

Used in `ACQ/SEARCH` and `ACQ/PEAKD`. See Section 7.6.2 and Section 7.6.4.

EXTENDED

Indicates an extended source for the data reduction pipeline. Used in `TIME-TAG` and `ACCUM` modes. See Section 5.9.

FLASH

Used in `TIME-TAG` mode only. See Section 5.7.1.

FP-POS

Used in `TIME-TAG` and `ACCUM` modes. See Section 5.8.

NUM-POS

Used in `ACQ/PEAKD`. See Section 7.6.4.

SCAN-SIZE

Used in `ACQ/SEARCH`. See Section 7.6.2.

SEGMENT

Selects segment A, segment B, or both in the FUV channel. Used in `ACQ/SEARCH`, `ACQ/PEAKXD`, and `ACQ/PEAKD`, as well as `TIME-TAG` and `ACCUM`. See Section 5.6.

STEP-SIZE

Used in `ACQ/SEARCH` and `ACQ/PEAKD`. See Section 7.6.2 and Section 7.6.4.

STRIPE

Used in `ACQ/PEAKXD` in the NUV channel. Selects one of the three stripes for the process. See Section 7.6.3.

CHAPTER 12:

Data Products and Data Reduction

In this chapter...

The data products that arise from an instrument are ordinarily described in the *Data Handbook*, but as this is written that is not yet available for COS. Here we provide some information on COS data reduction to the extent it may be helpful to observers.

12.1 FUV TIME-TAG Data

12.1.1 Raw FUV TIME-TAG Data

COS FUV TIME-TAG raw data consists of detected events for a particular segment in sequential order, based on the time the event was detected. Each event in the FITS table includes:

- Time of the event (to the nearest 32 msec, floating point) after the start of the exposure,
- Dispersion location (raw *x* value, 16 bit integer),
- Cross-dispersion location (raw *y* value, 16 bit integer),
- Pulse-height amplitude (8 bit integer).

The raw data include source counts, sky background, detector background, and stim pulses. The data from the two detector segments are interleaved in the flight electronics, but they are later separated in the ground software.

12.1.2 Corrected FUV TIME-TAG Data

The corrected `TIME-TAG` data consist of 9 quantities. Note that `XFULL` and `YFULL` are present only for `TIME-TAG` data taken with `FLASH=YES`.

Table 12.1: Data in corrected FUV TIME-TAG files.

Column name	Description
TIME	time of event in seconds after start of exposure
XCORR	*x* (column) pixel number, corrected for distortion
XDOPP	*x* pixel number, corrected for doppler shift and distortion
YCORR	*y* (row) pixel number, corrected for distortion
XFULL	*x* pixel number, corrected for offset, distortion, and doppler shift in the dispersion direction, based on the TAGFLASH wavecal spectrum
YFULL	*y* pixel number, corrected for offset, distortion, and doppler shift in the dispersion direction, based on the TAGFLASH wavecal spectrum
EPSILON	weight for the event, based on the flat field and dead time
DQ	data quality flag
PHA	pulse height amplitude

- `TIME` is the time for each event. As noted earlier, the time is recorded to the nearest 32 msec. However, the sequence of photon events in the `TIME-TAG` array is the true order in which they occurred for any one segment (FUV) or for the MAMA (NUV). At the same time, for the FUV it is possible for the ordering between segments to not be maintained because of the interleaving of events; i.e., the electronics that combines the events from the two segments has a finite response time and the timing of events that are closely spaced can get confused under conditions of high count rates. The ordering of events for each segment will be correct, but it not possible to determine if a specific event on segment A occurred before or after a segment B event that has the same time stamp.
- Note that `XCORR` and `YCORR`, the location of the event in detector coordinates, are corrected for thermal distortion (characterized by the stim pulses) and geometric distortion (determined during ground testing). These new *x* and *y* values are now floating point numbers instead of integers.

- XDOPP is the *x*-position of the event in non-integral pixels corrected for orbital and heliocentric doppler effects. This allows for the spectrum to be in either detector coordinates or wavelength space. The examination of both images allows for detector features, such as a hot spot, to be evident, or for a wavelength-dependent feature to be sharp.
- XFULL and YFULL are present only for TIME-TAG data with FLASH=YES. XFULL is copied from XDOPP and YFULL from YCORR. XFULL and YFULL are then corrected for any drift of the spectrum as determined from the wavecal flashes. The offsets in both the dispersion and cross-dispersion directions are determined from each exposure of the wavecal lamp and a linear interpolation in time is made between lamp exposures.
- EPSILON is the sensitivity or weighting term for a photon event. It combines pixel-to-pixel response variations and the dead-time correction.
- DQ represents the quality factor for a given event, based on its location. The value of DQ is determined from a list of detector blemishes and the like. For example, an event within a bounding box around a hot spot will be assigned a value of DQ to indicate that it is probably from that hot spot. The DQ values are assigned during ground processing from a reference file.
- PHA is the pulse height for an event. The value of PHA represents the amount of charge extracted from the micro-channel plate for that photon, or, alternatively, the electron gain for that event. The pulse height can be used later as a filter to select the most significant events as a way of reducing noise. The PHA values range from 0 to 31.

12.1.3 Corrected FUV TIME-TAG Image

The corrected image is, like the raw data, 16384 × 1024 in size, and consists of effective counts per second, which is the sum of all the EPSILON factors associated with the photon events in a given pixel, divided by the exposure duration. This corrected image is formed from the corrected TIME-TAG data using XDOPP values and standard threshold values for the pulse heights. This image is not corrected for background counts.

12.1.4 FUV TIME-TAG Error Array

The error array is also 16384 × 1024 in size and includes the errors in the corrected image for each pixel. These errors are calculated using Poisson statistics from the gross counts, and are corrected for flat field and dead-time. The units are the same as for the corrected image, namely effective counts sec^{-1}.

12.1.5 FUV TIME-TAG Science Spectrum

The extracted one-dimensional science spectrum consists of 11 quantities.

Table 12.2: Data in extracted FUV TIME-TAG science spectrum files.

Column name	Description
SEGMENT	FUVA or FUVB
EXPTIME	exposure time, in seconds, corrected for any gaps [double precision]
NELEM	the length of the arrays that follow [integer]
WAVELENGTH	array of wavelengths (Å) [double precision]
FLUX	array of fluxes [floating point]
ERROR	array of error estimates for fluxes [floating point]
GROSS	array of count rate [floating point]
NET	array of count rates corrected for background, flat field, and dead time
BACKGROUND	array of background count rates
MAXDQ	maximum data quality flag in extraction region
AVGDQ	average data quality flag in extraction region

These quantities will be explained in detail in the *Data Handbook*. The count rates are computed for bins of equal physical width. The background rate is determined from regions of the detector immediately above and below the science spectrum and is averaged over a larger region than just one pixel to improve the statistics since the rate is very low. This background is measured away from any sky signal and so does not include that.

The net count rate is converted to flux using calibration reference files. The final error σ is in flux units and includes all the known sources of error. The MAXDQ is the maximum of all the quality flags for the individual events, while the AVGDQ is the average of those.

If multiple spectra have been obtained using `FP-POS`, the individual spectra are weighted by their relative exposure duration and then merged into a single file. If there are multiple exposures taken at the same `FP-POS` value, those are first merged together. These combined files are then merged to form the final spectrum.

12.2 NUV TIME-TAG Data

12.2.1 Raw NUV TIME-TAG Data

For the NUV, no pulse heights are recorded, and so the raw data consist of t, x, and y.

12.2.2 Corrected NUV TIME-TAG Data

For the NUV, the corrected array of `TIME-TAG` events consists of the same as for the FUV except that PHA is not present and the wavelength is in the y direction. Also, NUV `TIME-TAG` data include `YDOPP` values, which is the column of y pixel coordinates corrected for orbital doppler shift.

12.2.3 Corrected NUV TIME-TAG Image

A corrected 1024 × 1024 image is formed from the corrected array of `TIME-TAG` events. The value in each pixel is effective counts sec^{-1}, which is the sum of all counts in a pixel multiplied by its ε factor and divided by the exposure duration.

12.2.4 NUV TIME-TAG Error Array

The error array is also 1024 × 1024 and is based on Poisson statistics from the gross counts, correcting for flat field effects and the dead time. The units are effective counts sec^{-1}.

12.2.5 NUV TIME-TAG Science Spectrum

The one-dimensional science spectrum is a table with the same quantities as for FUV TIME-TAG data.

12.3 FUV ACCUM Data

12.3.1 Raw FUV ACCUM Data

The raw data is an array of dimensions 16384 × 1024 pixels. Each pixel is 16 bits deep and so can handle up to 65,535 counts. Note that the actual image size sent from the instrument is only 128 pixels high to minimize data quantities, but the full image size is maintained in the ground processing to allow for future movements of the spectrum on the detector. The unused pixels are filled with zeroes. There are separate sub-arrays for the stim pulses. Because it is done on-board in the flight software, the raw data are already corrected for the doppler motion of the spacecraft.

12.3.2 Corrected FUV ACCUM Data

The corrected image is also 16384 × 1024 pixels and is corrected for doppler motion of the spacecraft (done on-board in the flight software), flat-field response, and detector dead time. The value in each pixel is effective counts sec^{-1}, which is the total counts in a pixel multiplied by that pixel's ε factor and divided by the exposure duration. The images are corrected for geometric distortion, but not for background or thermal drift.

12.3.3 FUV ACCUM Error Array

The error array is another 16384 × 1024 image that has per-pixel errors computed from Poisson statistics using the gross counts and correcting for flat-field effects and the dead time.

12.3.4 FUV ACCUM Science Spectrum

This includes the same quantities described for FUV TIME-TAG data; see Section 12.1.5.

12.4 NUV ACCUM Data

The data products for NUV ACCUM mode are all as for the FUV except that the images are 1024 × 1024.

12.5 NUV ACQ/IMAGE Data

12.5.1 Raw NUV ACQ/IMAGE Data

The raw data for `ACQ/IMAGE` is 1024 × 1024.

12.5.2 Corrected NUV ACQ/IMAGE Image

The corrected image is 1024 × 1024 × 16 bits and includes effective counts sec^{-1}, the gross counts multiplied by a pixel's `EPSILON` factor and divided by the exposure duration. Note that acquisition images are not calibrated by the pipeline, but exposures obtained in imaging mode are.

12.6 COS Output files and Naming Conventions

12.6.1 General Rules

For all output files (except final corrected image, "_flt", or calibrated spectrum, "_x1d") stemming from a single exposure at a particular spectral element and central wavelength combination: use exposure "rootname" as the first portion of the filename identifier. For the final corrected image and calibrated spectrum stemming from a single exposure, use "productname" as the first portion of filename identifier.

For any output file that is a product of the combination of more than one exposure, use "productname" as first portion of filename identifier.

12.6.2 Spectroscopy

For each individual spectroscopic exposure (rootname), i.e., for each individual FP-POS exposure, the pipeline produces the following output files:

For all exposures regardless of detector and mode:

Rootname_asn.fits (association file to control calibration processing)

Rootname_spt.fits (support file containing primary engineering information)

For NUV data:

Rootname_rawtag.fits (for TIME-TAG) or rootname_rawimage.fits (for ACCUM)

Rootname_corrtag.fits (only for TIME-TAG)

Rootname_flt.fits (corrected detector image)

Rootname_counts.fits (temporary file that may be saved)

Rootname_lampflash.fits (only for TIME-TAG with FLASH=YES)

Rootname_x1d.fits (calibrated one-dimensional spectrum file)

For FUV segment A:

Rootname_rawtag_a.fits (for TIME-TAG) or rootname_rawimage_a.fits (for ACCUM)

Rootname_pha_a.fits (pulse-height distribution for segment A)

Rootname_corrtag_a.fits (only for TIME-TAG)

Rootname_flt_a.fits (corrected detector segment A image)

Rootname_counts_a.fits (temporary file that may be saved)

For FUV segment B:

Rootname_rawtag_b.fits (for TIME-TAG) or rootname_rawimage_b.fits (for ACCUM)

Rootname_pha_b.fits (pulse-height distribution for segment B)

Rootname_corrtag_b.fits (only for TIME-TAG)

Rootname_flt_b.fits (corrected detector segment B image)
Rootname_counts_b.fits (temporary file that may be saved)

For FUV combined data (segment A + segment B):

Rootname_lampflash.fits (only for TIME-TAG with TAGFLASH)
Rootname_x1d.fits (calibrated one-dimensional spectrum file)

If only one exposure is taken for a grating and central wavelength combination, then the rootname portion of the output file identifier is renamed to a productname for the "flt" and "x1d" files.

If more than one FP-POS exposure is taken in any order without changing the grating and central wavelength combination, the "rootname" files listed above are produced for each individual exposure and one or more "productname" files containing summations of individual exposures are also produced. Grand total calibrated "x1dsum" spectra are produced by combining data from all exposures from all FP-POS. Additionally, all FP-POS=1 exposures are weighted by their exposure times and combined into an "x1dsum1" calibrated extracted spectrum file and so on for the other FP-POS positions utilized in the exposure sequence.

For FUV and NUV calibrated spectrum files:

Productname_x1dsum1.fits (sum of all FP-POS=1 exposures)
Productname_x1dsum2.fits (sum of all FP-POS=2 exposures)
Productname_x1dsum3.fits (sum of all FP-POS=3 exposures)
Productname_x1dsum4.fits (sum of all FP-POS=4 exposures)
Productname_x1dsum.fits (sum of all FP-POS positions) (ultimate calibrated product)

12.6.3 Imaging:

For NUV imaging observations, all of the same types of files as for NUV spectroscopy are produced except no _x1d files are produced. A productname_flt.fits file is normally the final product. However, if multiple image exposures are taken consecutively, then the repeated imaging exposures are combined to produce a summed productname_fltsum.fits file as the final product of the sequence.

12.6.4 Target acquisition:

Target acquisition observations produce the following much more limited set of output:

Rootname_raw.fits

CHAPTER 13:

Reference Material

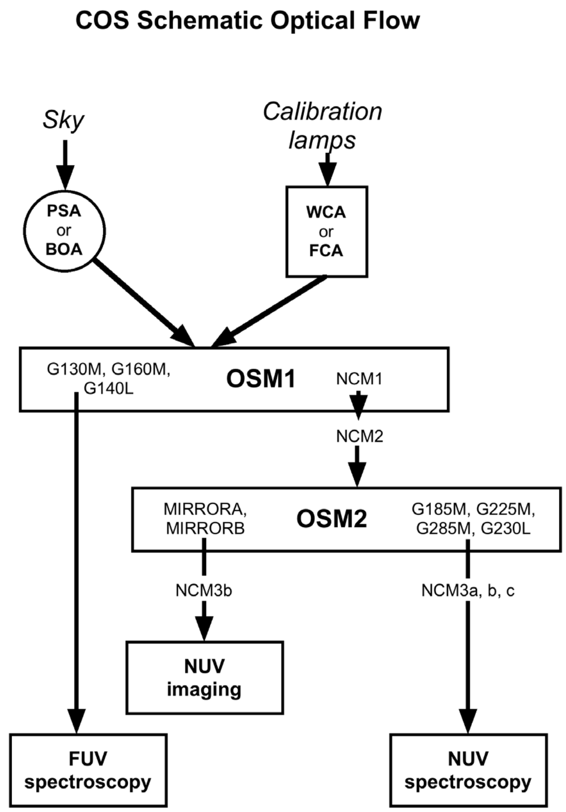
In this chapter…

Here we provide some additional information on the design of COS. These details are not needed for most uses of the instrument and so distract from the description in Chapter 3, but this information may be helpful in some cases and is needed for a complete documentation of the instrument.

The logical flow through COS (Figure 13.1) starts with the Aperture Mechanism (ApM) and its four apertures. From there the light goes to Optics Select Mechanism 1 (OSM1), which holds the three FUV gratings (G130M, G160M, G140L) and a mirror (NCM1). If an FUV grating has been selected, the light then goes to the FUV detector.

If NCM1 has been placed into position, it corrects the beam for spherical aberration and magnifies it by a factor of about four. The light then goes to a collimating mirror, NCM2, and then to OSM2. OSM2 holds the four NUV gratings (G185M, G225M, G285M, G230L) and a flat mirror (TA1 = MIRRORA/MIRRORB). The NUV gratings are plane gratings (see below), and the dispersed light from them goes to three camera mirrors (NCM3a, b, c) and then to the detector, forming three separate stripes.

Figure 13.1: Schematic of the Light Flow Through COS.



Some elements in this diagram are explained in this chapter.

13.1 Apertures

COS has four apertures. Two (PSA and BOA) are used for science exposures (i.e, they see the sky via HST's optics). Two (WCA and FCA) are used for obtaining wavelength calibration lamp exposures and flat-field exposures. We include the FCA here for completeness, but note that observers may not obtain flat-field exposures on their own; that is a calibration activity of STScI.

The COS science apertures are field stops in the aberrated beam and are not traditional focal-plane entrance slits like those used on STIS and earlier HST spectrographs. Thus, they do not project sharp edges on the detectors. Because COS is a slitless spectrograph, the spectral resolution depends on the angular size of the astronomical object being observed. Although COS is not optimized for observations of extended objects, it can be used to detect faint diffuse sources with lower spectral resolution than would be achieved for point (< 0.1 arcsec) sources.

The four apertures are cut into a single plate and so have fixed relationships to one another. There is an isolation wall on the plate so that light entering either calibration aperture cannot reach the portion of the detector used for science. The dimensions of the apertures are given in the table below, and their sizes and positions are shown in Figure 13.2.

Table 13.1: COS Aperture Dimensions.

Aperture	Full name	Purpose	Size (mm)
PSA	Primary Science Aperture	clear aperture	0.700 circular
BOA	Bright Object Aperture	science aperture with ND2 filter	0.700 circular
WCA	Wavelength Calibration Aperture	wavecals with Pt-Ne lamp	0.020 × 0.100
FCA	Flat-Field Calibration Aperture	flat field with deuterium lamp	0.750 × 1.750

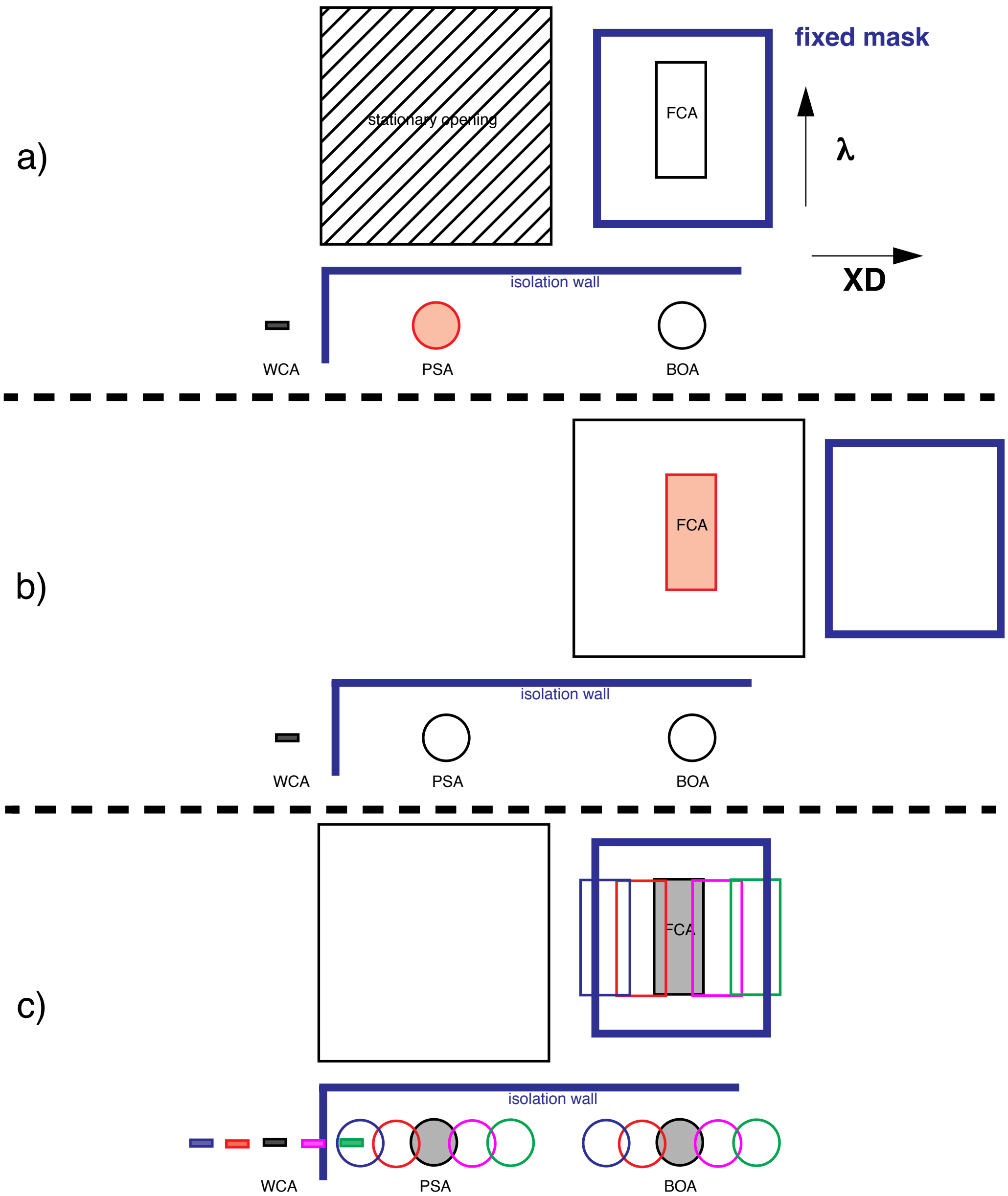
13.1.1 The Aperture Mechanism (ApM)

The aperture plate is mounted on a mechanism that has two degrees of freedom. The Aperture Mechanism (ApM) is used routinely to select between the two science apertures, the PSA and the BOA. The aperture chosen by the observer is moved into place so that either aperture occupies exactly the same physical location when a science spectrum is exposed. This is necessary, of course, because COS' optics work properly only for point sources centered in the aperture, and, in particular, the off-axis aberrations are particularly severe in the NUV channel.

The relative locations of the COS apertures are shown in Figure 13.2. Note that when the BOA is in use it is not possible to get light from the wavelength calibration lamp via the WCA. For this reason it is not possible to use `TIME-TAG` mode with `FLASH=YES` when the BOA is used. Also note that the ApM must be moved to place the FCA over the stationary opening to let deuterium lamp light into the spectrograph. Flat field exposures are not taken by observers but are instead done as part of the COS calibration program by STScI.

Finally, the ApM will be used occasionally to relocate the area of the FUV XDL detector that records the science spectrum. This will be done because each use of the XDL depletes charge in the area exposed. Over time this reduces the sensitivity of that portion of the detector, and so there is an advantage in moving to a fresh area. Plans for COS call for such a movement to be done up to four times after launch, thus using five different XDL locations.

Figure 13.2: The Arrangement of COS Apertures.



The large cross-hatched square in the upper left is a stationary opening. In the nominal position (a), the PSA, in red, is available for science observing and the WCA for wavecals. The FCA will not admit light into the spectrograph because it is not over the stationary opening. The BOA will admit light, but it will be optically degraded by being off-axis. Note the isolation wall (blue "L") that prevents calibration light from either the wavecal or flat-field lamp from entering a science aperture. The direction of increasing wavelength is shown, as is the cross-dispersion ("XD") direction.

In (b), the aperture plate has been moved so that the FCA is over the stationary opening, to enable a flat-field exposure.

In (c), alternate positions for the PSA are shown. These will be used periodically to allow access to fresh areas of the XDL detector. Note the BOA, WCA, and FCA are all on the same plate and so move in lock-step with the PSA.

13.1.2 Primary Science Aperture

The Primary Science Aperture (PSA) is a 2.5 arcsec (700 μm) diameter field stop located on the HST focal surface near the point of circle of least confusion. This aperture transmits ≥ 95% of the light from a well-centered aberrated point-source image delivered by the HST optics. The PSA is expected to be used for observing in almost all instances.

13.1.3 Bright Object Aperture

The Bright Object Aperture (BOA) is also 2.5 arcsec (700 μm) in diameter. It is a neutral density (ND2) filter made of MgF_2 that permits COS to observe targets five magnitudes (factor of approximately 200; see Figure 3.4) brighter than the Bright Object Protection limits allow through the PSA. The BOA is offset 3.70 mm in the cross-dispersion direction from the PSA on the aperture plate. The BOA must be moved with the Aperture Mechanism to the (currently used) position of the PSA for science observations. Thus, science spectra obtained through either the PSA or BOA will utilize the same detector region (for a given channel) and may employ the same flat-field calibration. Nonetheless, the BOA is open to light from the sky when the PSA is being used for science, therefore bright object screening for the field-of-view must include both apertures.

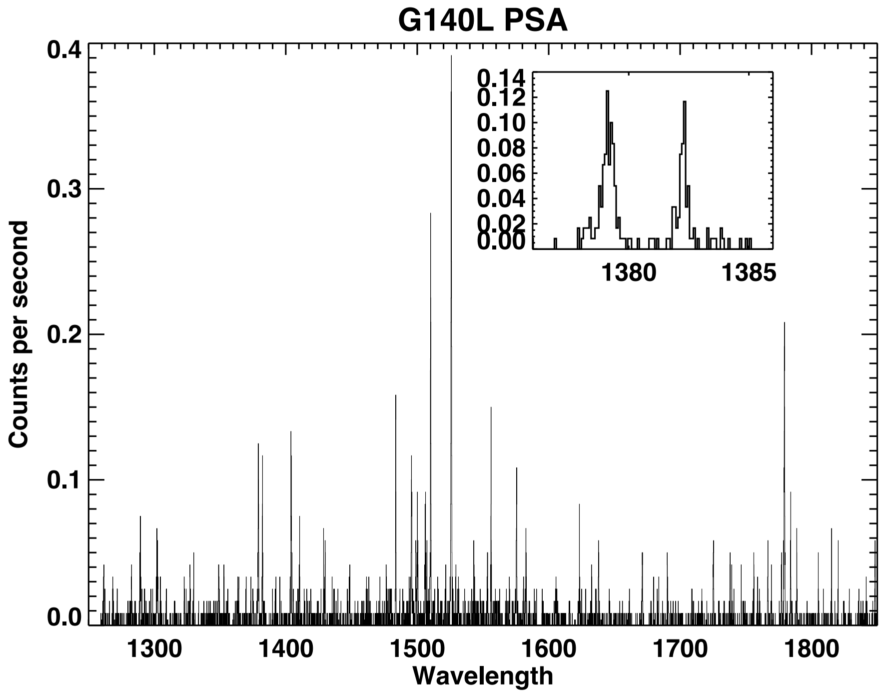
The throughput versus wavelength for the BOA is shown in Figure 3.4. The BOA material has a slight wedge shape so that the front and back surfaces are angled relative to one another by about 15 arcmin. This wedge is sufficient to degrade the spectroscopic resolution realized when the BOA is used, decreasing G140L to R = 1500, G230L to 500, G185M to 3500, G225M to 4600, and G285M to 5000. Measured values are not available for the other FUV gratings, but R = 5000 is anticipated.

The effect of the BOA on R can be seen in the accompanying illustrations. Figure 13.3 shows an example of a test exposure of an external wavelength calibration lamp as seen through the PSA. The inset enlarges a pair of the lines in the spectrum. Figure 13.4 shows the same thing, only using the BOA.

13.1.4 PSA/BOA "Cross-talk"

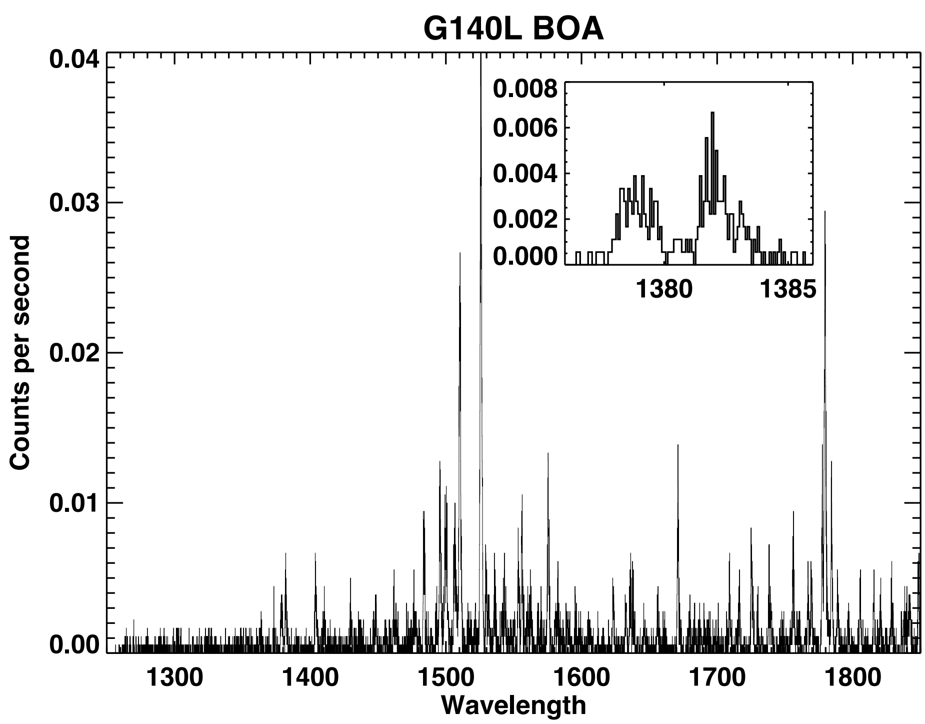
Either aperture may be selected for use during an exposure. No matter which aperture is chosen, light from the other aperture can reach the detector. This fact is especially important in considering bright-object protection (see Section 11.5), but observers should be aware that an extraneous object could bring light into the spectrograph during an exposure, even if that object does not necessarily impose a safety risk.

Figure 13.3: Wavelength calibration spectrum obtained with the PSA.



The exposure is of an external source, and the inset shows an enlargement of two lines.

Figure 13.4: Same as Figure 13.3, but using the BOA.



13.1.5 Wavelength Calibration Aperture

The Wavelength Calibration Aperture (WCA) is offset from the PSA by 2.5 mm in the cross-dispersion direction, on the opposite side of the PSA from the BOA. Light from external sources can not illuminate the detector through the WCA.

The wavelength calibration spectrum can be used to assign wavelengths to pixel coordinates for science spectra obtained through either the PSA or BOA. The size of the WCA is 20 microns in the dispersion direction by 100 microns in the cross-dispersion direction. The wavelength calibration spectra will be obtained at WCA's nominal offset position from the PSA on both the NUV and FUV detectors. If the BOA is moved to the PSA position and used for science observations, the WCA aperture will be moved 3 mm away from its nominal position. Hence, in order to obtain wavecal spectra for BOA observations, the WCA must be moved back into its nominal position before the wavecal exposure is taken. Not only does this place the wavecal spectrum in the correct location on the detector, but it ensures that the Flat-field Calibration Aperture is masked from transmitting any photons from the wavecal lamps during the wavecal exposure. As a result of this requirement, TIME-TAG observations with FLASH=YES are not possible with the BOA.

13.1.6 Flat-field Calibration Aperture

A Flat-field Calibration Aperture (FCA) is offset by ~2 mm in the dispersion direction and by 3.7 mm in the cross-dispersion direction from the PSA. The size of the FCA is 0.75 mm by 1.75 mm. External light can only go through the PSA and BOA science apertures; light from the internal calibration lamps can only go through the WCA and FCA apertures. The FCA must be moved to project the flat-field continuum spectrum along the desired detector rows (e.g., at the PSA position). While not in use, the FCA is stowed at a position that does not transmit any light from an internal (or external) light source such as the wavelength calibration lamp. After moving the FCA to the desired position, the flat-field spectrum falls along the same detector rows as the PSA or BOA science spectra (though it is displaced in wavelength).

13.2 COS Mechanisms

The Aperture Mechanism was discussed above. The other three mechanisms are the Optics Select Mechanisms, OSM1 and OSM2, and the external shutter.

13.2.1 Optics Select Mechanism 1 (OSM1)

The function of the OSM1 is to position an optic into the optical beam of the COS instrument. The optics mounted on OSM1 receive the input light beam from the HST OTA through the ApM and direct it to the FUV detector or the NUV channel, depending on which optic is rotated into place. The optic positioned by this mechanism will be the first reflecting surface that the light encounters once it enters the instrument. The mechanism will position any one of four different optics into the beam. The OSM1 contains the G130M, G160M, and G140L gratings, and the NCM1 mirror. The gratings direct light to the FUV detector while the mirror directs light to the NUV channel. The four optics mounted on OSM1 are arranged at 90-degree intervals.

Once an optic is positioned by OSM1, the mechanism must allow for small adjustments in 2 degrees of freedom. Rotational adjustments are required to move the spectra on the FUV detector in the dispersion direction for `FP-POS` positioning in the FUV channel and for recovering wavelengths that fall on the FUV detector gap. Translational adjustments are required to refocus the instrument on orbit in order to optimize the focus of each of the FUV gratings and the NCM1 mirror, and to accommodate any instrument installation misalignments or any modifications to the location of the HST secondary mirror. The translational motions are in the *z*-direction (towards or away from the HST secondary).

OSM1 holds four optical elements. The home position (default) is G130M, and, in cyclical order from there are located G160M, G140L, and NCM1. The home position is that to which the mechanism returns at the end of a visit. In other words, OSM1 is positioned so that G130M is in position at the start of every new visit. Since it is anticipated that G130M will be the most frequently used grating in COS, this should save most observers time.

13.2.2 Optics Select Mechanism 2 (OSM2)

The NUV optics mounted on OSM2 receive light from the NCM2 collimating mirror and direct the spectrum or image to the three camera mirrors (NCM3a,b,c). The OSM2 contains the G185M, G225M, G285M, and G230L gratings, and the TA1 mirror. OSM2 rotates but does not translate. Rotations move the spectrum or image in the dispersion direction on the NUV detector. The gratings are flat and each medium resolution grating must be positioned at ~6 discrete positions in order to achieve full wavelength coverage. Small rotational adjustments will also be used for `FP-POS` positioning.

The five optics on OSM2 are distributed at 72-degree intervals. The home position (default) is G185M, and, in cyclical order from there are located G285M, G225M, G230L, and TA1 (MIRRORA/MIRRORB).

13.2.3 External Shutter

The external shutter of COS is a small paddle-shaped device with a shutter blade that is a disk about 38 mm in diameter. It is located at the front of the COS enclosure, in the optical path before the Aperture Mechanism. When closed, the shutter blocks all external light from entering COS and it also prevents any light from within COS (such as the calibration lamps) from leaking out. The external shutter is for protection and is not used to determine exposure durations. To protect COS from exposure to bright objects, the shutter is ordinarily closed and is commanded to open at the start of an exposure. It is then closed at the end of the exposure, with the exception of acquisition sub-exposures.

13.3 COS Optical Elements

13.3.1 FUV Gratings

Table 13.2 provides the dimensions of the gratings used in the FUV channel. The FUV gratings are concave and have holographically-generated grooves to provide dispersion and correct for astigmatism. The gratings have aspherical surfaces to correct for HST's spherical aberration. The FUV "M" gratings have been ion etched to produce triangular groove profiles for better efficiency and they are coated with MgF_2. G140L has grooves with a laminar profile and is also MgF_2 coated.

Note that the surface of the optic is a sphere of the quoted radius, but with a deviation of $\Delta z = a_4 r^4 + a_6 r^6$, where z is measured along the vertex normal. The quantities γ, δ, r_c, and r_d are the standard positions of the recording sources as defined in Noda, Namioka, and Seya (1974, J. Opt. Soc. Amer., 64, 1031).

Table 13.2: FUV Optical Design Parameters.

Dimension	G130M	G160M	G140L
secondary mirror vertex to aperture (z, mm)	6414.4		
V_1 axis to aperture (mm)	90.49		
aperture to grating (mm)	1626.57		
α (degrees)	20.1	20.1	7.40745
β (degrees)	8.6466	8.6466	–4.04595
α – β (degrees)	11.4534		
grating to detector (mm)	1541.25		
detector normal vs. central ray (degrees)	9.04664		
groove density (lines mm^{-1})	3800	3093.3	480
radius (mm)	1652	1652	1613.87
a_4	1.45789×10^{-9}	1.45789×10^{-9}	1.33939×10^{-9}
a_6	-4.85338×10^{-15}	-4.85338×10^{-15}	1.4885×10^{-13}
γ (degrees)	–71.0	–62.5	10.0
d (degrees)	65.3512	38.5004	24.0722
r_c (mm)	–4813.92	–4363.6	3674.09
r_d (mm)	5238.29	4180.27	3305.19
recording wavelength (Å)	4880		

13.3.2 NUV Gratings

Several of the NUV optics and gratings are coated with MgF_2 on Al (see Table 13.3), both to maintain high reflectivity and to suppress FUV light. The NUV MAMA detector has low but measurable sensitivity at FUV wavelengths, and with some gratings second-order light could contaminate the spectrum. To minimize this effect, the coated optics are optimized for wavelengths above 1600 Å. Given the four reflections used in the NUV channel, wavelengths below 1600 Å, including geocoronal Lyman-α, are very effectively eliminated. In addition, gratings G230L and G285M have order-blocking filters mounted directly on them to block the second-order spectra below 1700 Å. Even with these filters, it is possible for second-order light with G230L to appear on the NUV MAMA, especially in the long-wavelength stripe.

Table 13.3: NUV Grating Parameters.

Dimension	G185M	G225M	G285M	G230L
groove density (mm^{-1})	4800	4800	4000	500
useful range (Å)	1670 – 2100	2000 – 2500	2500 – 3200	1700 – 3200
α (degrees)	27.24	33.621	35.707	5.565
β (degrees)	25.85	32.23	34.32	1.088
peak efficiency wavelength (Å)	1850 ± 100	2250 ± 100	2850 ± 100	2300 ± 100
coating	Al + MgF_2	Al only	Al only	Al + MgF_2

13.3.3 Mirrors

NCM1 is a flat, fused silica mirror 40 mm in diameter, coated with aluminum and MgF_2.

“MIRRORA” and MIRRORB” refer to the same optical element used in different ways; see Section 6.2.

13.4 Modeling of the HST PSF at the COS Aperture

13.4.1 Optical Modeling Procedure

The HST Point Spread Function (PSF) has been modeled at the nominal position of the COS PSA. These calculated PSFs are based on the known aberrations present in the HST optical design and the surface errors present on the HST primary and secondary mirrors. The method used involved three steps:

- First, the commercial optical design program Zemax was employed to calculate the low-order optical aberrations present in the HST PSF at the PSA location, due only to the HST optical design itself.
- Next, the amount of defocus, astigmatism, coma, and spherical aberration present in the PSF were calculated for the PSA location. This was done with value for the HST primary mirror conic constant determined by Krist and Burrows (1995).
- The HST PSF modeling program Tiny Tim was used to simulate the extent of the HST PSF at the COS aperture location. Tiny Tim incorporates actual surface maps based on measurements for the HST primary and secondary mirrors and the corresponding path differences (Krist & Burrows 1995). While the HST primary and secondary mirrors are among the most precise optics ever produced, they still exhibit a number of zonal surface errors that limit the quality of the PSF, especially at ultraviolet wavelengths.
- The Tiny Tim model was adjusted to account for the position of the COS aperture relative to the nominal HST focal plane, taking into account the defocus, astigmatism, coma, and spherical aberration determined from the Zemax model. Figure 13.5 and Figure 13.6 show the Tiny Tim models of HST (PSF) at the nominal position of the COS aperture for 1450 and 2550 Å.

Summary

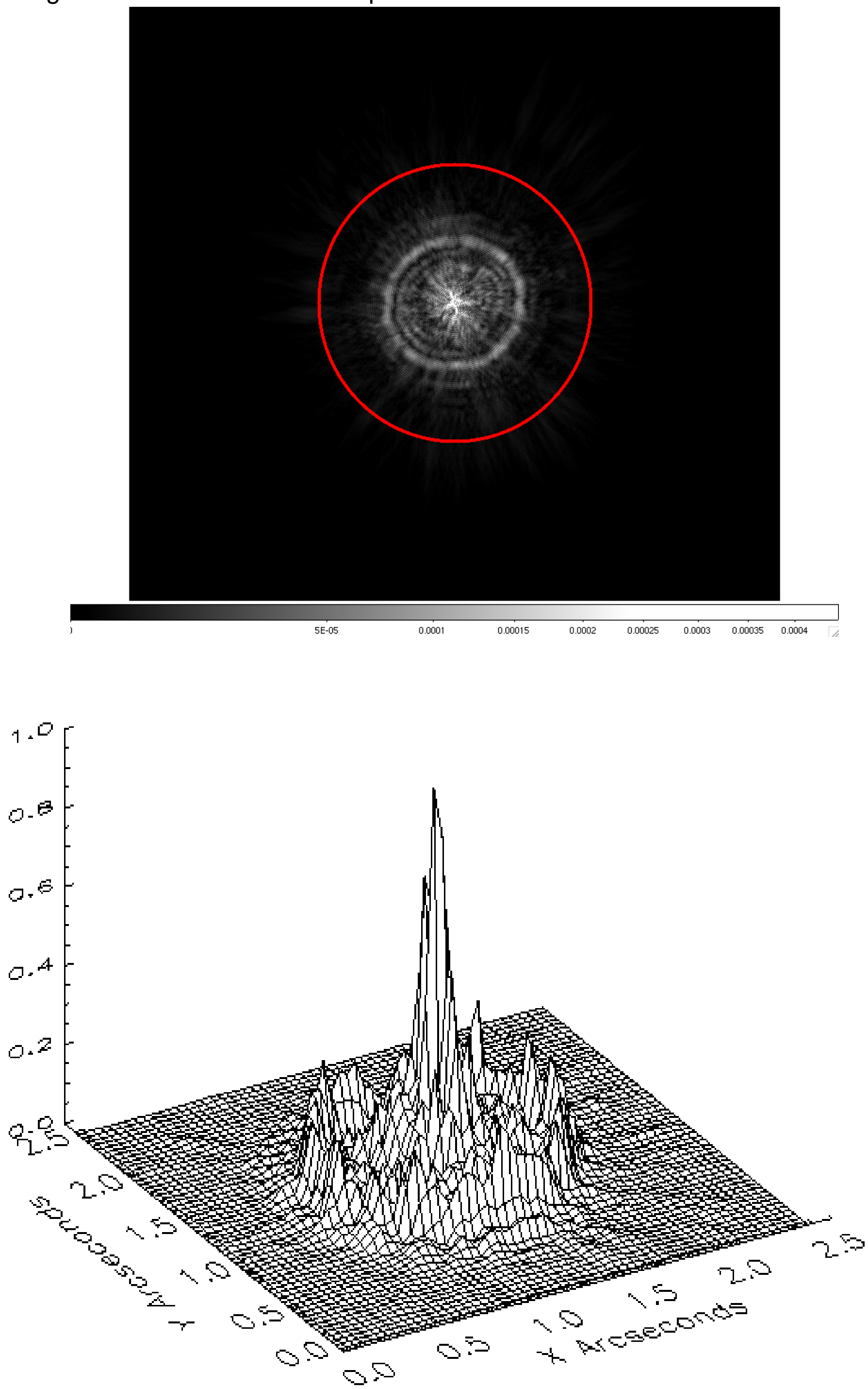
At least 95% of the energy in the HST PSF is contained within the 2.5 arcsec-diameter COS PSA at both 1450 and 2550 Å. Those portions of the PSF that fall outside the PSA are primarily due to the surface errors in the HST optics themselves, not to the low-order aberrations present in the HST optical design.

13.4.2 PSF Model Results

Figure 13.5 and Figure 13.6 show the aberrated HST PSF at the nominal position of the COS aperture. The COS PSA is 2.5 arcsec in diameter and these models indicate that the PSA will pass at least 95% of the total flux from a perfectly-centered point source. The surface brightness of that portion of the PSF that is outside the PSA is extremely low. Note that most of the energy in the PSF is contained within a radius of 0.5 arcsec and that essentially all of that 95% is within about 0.7 arcsec radius.

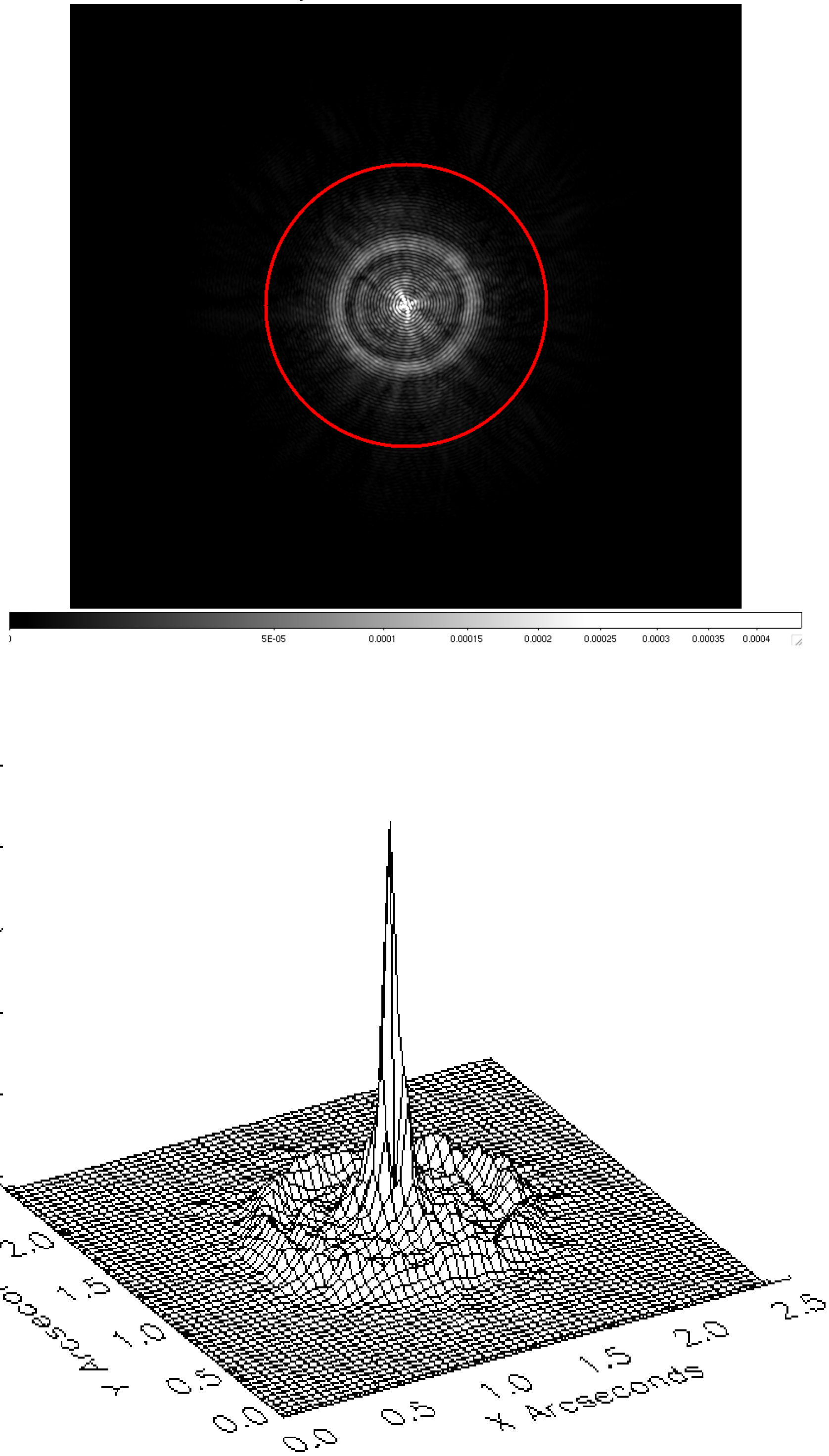
Figure 13.7 shows a one-dimensional profile of the PSF for 2550 Å, scaled to unity at aperture center.

Figure 13.5: The HST Point Spread Function at the COS PSA for 1450 Å.



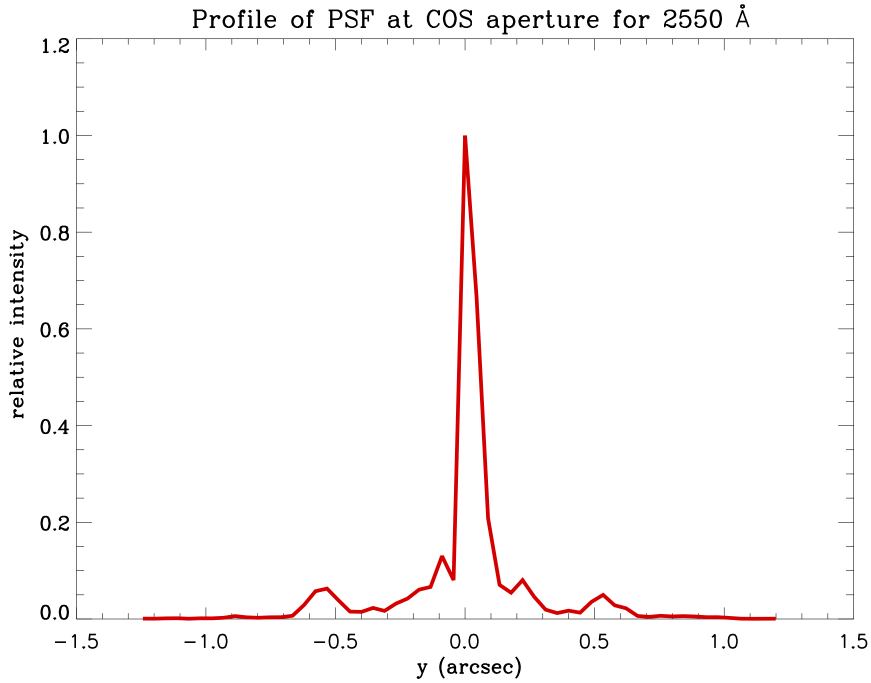
Note that the COS apertures lie near, but not in the HST focal plane, and their location was chosen to maximize throughput. This image was calculated with Tiny Tim. The top portion is displayed with a square root scale. The energy contained within the 2.5 arcsec PSA (red circle) is at least 95% of the energy in the total HST PSF. The bottom panel shows the PSF that falls within the PSA in a two-dimensional plot on a linear scale.

Figure 13.6: The HST Point Spread Function at the COS PSA for 2550 Å.



The top panel is displayed with a square root scale, and the red circle represents the PSA diameter of 2.5 arcsec. The bottom two-dimensional plot is on a linear scale and shows the portion of the PSF that falls within the PSA. As for 1450 Å, the energy contained within the 2.5 arcsec PSA (red circle) is at least 95% of that in the total PSF.

Figure 13.7: Profile of the aberrated HST PSF at the COS entrance aperture for 2550 Å.



13.5 Details of TAGFLASH Execution

When an object is observed through the PSA, light from the Pt-Ne lamps can pass through the WCA and illuminate a portion of the detector separate from the science spectrum. When an external source is observed through the BOA, the Pt-Ne wavecal beam is blocked from reaching the active area of the detector, hence TAGFLASH is available only for PSA observations.

The lamp flash durations required to obtain a sufficient signal level to determine a usable wavelength calibration offset are grating dependent. They are listed at the end of the COS chapter in the *Phase II Proposal Instructions*. Almost all are either 5 or 10 seconds, with a few as long as 30 seconds.

Every COS TAGFLASH exposure begins with a lamp flash. Depending upon the length of the exposure and the time since the last major OSM movement, one or more lamp flashes may be inserted at intermediate times during an exposure. Also, depending upon the proximity of the most recent flash, a lamp flash may be inserted at the very end of an exposure.

The first step in the process of specifying the placement of lamp flashes within any particular science exposure involves the determination of the length of time, t_{since}, that has elapsed since the last major OSM move and the start of the first science exposure at that grating setting.

The next step is to determine t_{since} for the start of the exposure. Determine the interval (1, 2, 3, …, n) from Table 13.4 in which the start of the exposure occurs. For the first exposure after a major OSM move only, reset the value of t_{since} to be the time t_{int} in Table 13.4 at the start of this interval, and also align the relative times so that t_{int} corresponds to the beginning of the science exposure. For all subsequent exposures with the same optical element, again determine the time interval from Table 13.4 in which the start of the exposure occurs and reset the timeline to align the exposure start with the t_{int} of that interval, but do not reset t_{since}. (In nearly all cases for COS, the initial t_{since} of the first exposure will fall in the first interval of Table 13.5, such that the value of t_{since} will be reset to the start of interval 1 or to a value of 0.)

A complete list of times of TAGFLASH lamp flashes, in exposure elapsed time, is given in Table 13.5 below as a function of exposure duration for exposures starting in each t_{since} interval.

The following section provides important definitions and describes the detailed rules employed for placement of lamp flashes within a TAGFLASH exposure. The exposure times for the lamp flashes are provided in the COS chapter of the *Phase II Proposal Instructions*.

13.5.1 Detailed Definitions and Rules for Lamp Flash Sequences

Definitions:

t_{exp} = duration of science exposure.

t_{since} = wall-clock time since last major (grating-grating) OSM move (t_{since} is not reset after central wavelength changes or FP-POS moves.)

t_j = time at beginning of time interval j; also time at beginning of scheduled flash j.

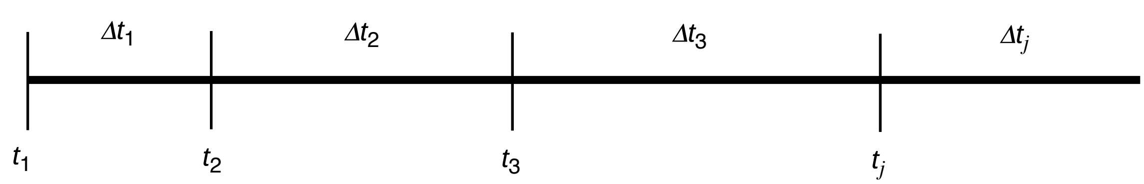
f_j = fraction of interval j to be used to check if flash at exposure end is needed; $0 \le f_j \le 1$.

Δt_j = time between scheduled flashes j and $j + 1$.

Rules:

1. At the start of the first science exposure after a major OSM move, intercept the timeline shown in Figure 13.8 below such that $t_i \le t_{since} < t_{i+1}$.(that is, determine which interval in the timeline contains the exposure start). Shift the timeline such that t_i marks the beginning of the science exposure and, importantly, adjust t_{since} such that $t_{since} = t_i$. For all subsequent exposures with the same grating, intercept the timeline in the same way, but do not reset t_{since}.

Figure 13.8: Schematic of a TAGFLASH Timeline.



Each of the t values represents a flash of the calibration lamp.

2. Flash the lamp at the beginning of each science exposure. The beginning of the lamp flash should coincide as closely as possible with the beginning of the science exposure. Due to latency in lamp discharges, some flashes may be delayed approximately one second.

3. Insert intermediate lamp flashes as scheduled in the TAGFLASH Interval Table (Table 13.4 below) for flashes scheduled to occur before the end of the science exposure. A caveat to this rule concerns the case where an intermediate lamp flash might extend past the end of an exposure. In that case, the start of the lamp flash is moved earlier such that its end coincides as closely as possible to the end of the science exposure.

4. Insert flash at the end of the science exposure only if $(t_{exp} - t_i) \geq f_i \, \Delta t_i$. Note that the interval fraction, f, is not the same for all intervals. The end of the lamp flash should coincide as closely as possible with the end of the science exposure.

5. The minimum allowable TAGFLASH exposure duration is 120 seconds.

6. If the rules above produce two lamp flashes that overlap in time, only the later flash should be executed at its nominal time of execution.

t_{since} is reset only for the first exposure after a major OSM move (rule 1). Therefore, the internal flash patterns of identical exposures obtained in sequence may be different; more flashes potentially occurring in the earlier exposures in the sequence. This allows efficient tracking of the approximately exponential decay of the OSM drift while using a minimum number of flashes so as to preserve lamp lifetime.

Table 13.4: TAGFLASH Intervals

interval no.	t_{int}	Δt_{int}	f
1	0	600	0.33
2	600	1800	0.20
3	2400	2400	0.33
4	4800	2400	0.33
j	$t_4 + 2400(j-4)$	2400	0.33

Interval times and relative interval times are in seconds.

Table 13.5: Times of TAGFLASH Lamp Exposures

Exposure starts in interval 1		Exposure starts in interval 2		Exposure starts in interval 3	
Exposure time	**Lamp flashes at *t* =**	**Exposure time**	**Lamp flashes at *t* =**	**Exposure time**	**Lamp flashes at *t* =**
0 to 200	0	0 to 360	0	0 to 800	0
>200 to 600	0, end	>360 to 1800	0, end	>800 to 2400	0, end
>600 to 960	0, 600	>1800 to 2600	0, 1800	>2400 to 3200	0, 2400
>960 to 2400	0, 600, end	>2600 to 4200	0, 1800, end	>3200 to 4800	0, 2400, end
>2400 to 3200	0, 600, 2400	>4200 to 5000	0, 1800, 4200	>4800 to 5600	0, 2400, 4800
>3200 to 4800	0, 600, 2400, end	>5000 to 6500	0, 1800, 4200, end	>5600 to 6500	0, 2400, 4800, end
>4800 to 5600	0, 600, 2400, 4800	>6500	not allowed	>6500	not allowed
>5600 to 6500	0, 600, 2400, 4800, end	—	—	—	—
>6500	not allowed	—	—	—	—

Given are elapsed times (in seconds) as a function of exposure duration for exposures that begin in the specified t_{since} interval.

13.5.2 TAGFLASH Exposure Parameters

Table 13.6 below is taken from the *Phase II Proposal Instructions* and shows the duration of a “flash” in TAGFLASH mode.

Table 13.6: TAGFLASH Exposure Durations

Grating	Wavelength (Å)	Flash duration (sec)	Grating	Wavelength (Å)	Flash duration (sec)
G130M	1300	10	G225M (cont.)	2325	10
	all others	5		2339	5
G160M	1600	10		2357	10
	all others	5		2373	5
G140L	all	5		2390	5
G185M	1786	10		2410	5
	1817	5	G285M	2617	5
	1835	10		2637	5
	1850	20		2657	5
	1864	30		2676	10
	1882	15		2695	5
	1890	10		2709	5
	1900	20		2719	5
	1913	10		2739	5
	1921	10		2850	5
	1941	10		2952	5
	1953	15		2979	15
	1971	15		2996	5
	1986	10		3018	10
	2010	10		3035	5
G225M	2186	5		3057	5
	2217	10		3074	5
	2233	5		3094	10
	2250	10	G230L	2635	5
	2268	10		2950	5
	2283	5		3000	5
	2306	10		3360	5

Glossary

A Glossary of Terms and Abbreviations

ACCUM

Operating mode for COS in which only the locations of detected photons are recorded. No time information is recorded, and this makes it possible to deal with higher count rates and hence brighter objects. See also TIME-TAG.

ApM

Aperture Mechanism, used to place either the BOA or PSA into position as the science aperture. The ApM is also moved to place the FCA into position if a flat-field exposure is to be taken.

APT

The Astronomer's Proposal Tool, software provided by STScI for writing Phase I proposals and Phase II programs. The use of APT is encouraged in all cases, even for Phase I proposals, because it provides an accurate estimation of the actual time needed to get an observation. For more information, go to:

http://www.stsci.edu/hst/proposing/apt

BOA

Bright Object Aperture. Like the PSA, the BOA is 2.5 arcsec in diameter, but it also includes a neutral density filter that attenuates by a factor of about 200. Because of a 15 arcmin wedge in this optical element, the BOA also degrades the spectral resolution when it is used. See Figure 3.4.

ETC

Exposure Time Calculator, software provided by STScI to estimate exposure times needed to achieve, say, a given signal-to-noise level on a source. Although information is provided in this Handbook on exposure estimation, the ETC provides the most accurate way to determine the exposure times involved in acquiring or observing an object. In addition to what is in the ETC, APT includes factors such as instrumental overheads. For more information, go to:

http://etc.stsci.edu/webetc/index.jsp

FCA

Flat-field Calibration Aperture, the aperture through which the on-board deuterium lamps illuminate the COS optical system.

FEFU

"femto-erg flux unit." 1 FEFU = 10^{-15} erg cm^{-2} sec^{-1} $Å^{-1}$

FP-POS

A command used to move the spectrum on the detector so as to use different portions, thereby reducing the effects of fixed-pattern noise.

FUV

Far ultraviolet, the channel of COS that is used from about 1150 to 1800 Å.

Galex

Galaxy Evolution Explorer, a NASA mission observing the sky in two ultraviolet bandpasses. Galex data is useful for determining the likely UV fluxes of COS targets. For more information, go to:

http://www.galex.caltech.edu/

GTO

Guaranteed Time Observer, a member of the COS science team who has been granted a share of telescope time as part of their involvement in designing and building COS.

home position

The default position for a mechanism. COS is reconfigured at the start of each new visit and so the mechanisms will be found in their home positions at that time. For the ApM the home is the PSA. For OSM1, home is G130M, and for OSM2 home is G185M.

IDT

Instrument Development Team, NASA's term for the group that proposed and built COS.

LSF

Line Spread Function, the shape of a point source along the direction of dispersion.

MAMA

Multi-Anode Micro-channel Array, a photon-counting UV detector, used in the NUV channel.

MAST

The Multi-mission Archive at Space Telescope, which makes available data from a number of NASA missions (including HST) and other sources. Go to:

http://archive.stsci.edu

MCP

Micro-Channel Plate, a resistive glass plate with 10-15 micron-sized holes used within both the XDL and MAMA detectors to amplify photo-electrons into charge pulses large enough for downstream electronic processing.

MIRRORA, MIRRORB

MIRRORA and MIRRORB are used for NUV imaging in COS. MIRRORA provides the highest throughput. MIRRORB uses a reflection off of the order-sorting filter of MIRRORA to get lower throughput, which can be helpful when observing brighter targets.

NUV

The near ultraviolet channel of COS.

OSM1, OSM2

The Optics Select Mechanisms on COS that place gratings or mirrors in the optical path.

OTA

Optical Telescope Assembly, HST's optical system of primary and secondary mirrors, plus the structure that holds them and maintains alignment.

pixel

The basic stored unit of data. In the NUV channel, MAMA pixels correspond to physical portions of the detector. In the FUV channel, the position of a detected event is assigned a pixel based on calculations, but there are no physical pixels as such.

PHD

Pulse-Height Distribution, a histogram of the charge cloud sizes collected in a particular exposure or portion thereof. The PHD is a useful diagnostic tool of data quality and is recorded as a data product for FUV exposures. No PHD data are available for NUV exposures. See Section 4.1.7.

PSA

Primary Science Aperture, which is 2.5 arcsec in diameter and is completely open.

PSF

Point Spread Function, the two-dimensional distribution of light produced by HST's optics.

resel

Resolution element, the basic unit of resolution in a spectrum. In the FUV channel, resels are 6 pixels wide (dispersion direction) by 10 tall. In the NUV channel, resels are 3 × 3 pixels. Note that spectra are recorded in pixel units and that any rebinning into resels is done later during data reduction. Also note that a resel corresponds approximately to the FWHM of narrow wavelength calibration lines, although the actual resolution is somewhat different from one grating to the next.

SMOV

Servicing Mission Observatory Verification, the period immediately following a servicing mission in which HST's instruments are activated, tested, and made ready for science observing. Only a minimal set of calibrations are done in SMOV to confirm instrument performance; more detailed calibrations are done in the ensuing cycle.

stim pulse

A virtual point source that is located in pixels at opposite corners of each segment of the FUV XDL detector system. These point sources allow for thermal distortion to be calibrated and aid in determining the dead-time correction. For more information, see Section 4.1.6.

TAGFLASH

Use of TIME-TAG mode with FLASH=YES selected. This adds wavelength calibration spectra at periodic intervals during a TIME-TAG observation so that any drifts of the spectrum due to residual motion of the optics can be removed.

TIME-TAG

A COS observing mode in which the locations (pixels) and times (to the nearest 32 msec) are recorded for each detected photon. Doing this can consume buffer capacity but allows great flexibility in reducing and analyzing the data later.

wavecal

A wavelength calibration exposure; i.e., an exposure of the Pt-Ne wavelength calibration lamp through the WCA.

WCA

Wavelength Calibration Aperture, which is illuminated by a Pt-Ne wavelength calibration lamp.

XDL

Cross Delay Line, the type of detector used in the FUV channel of COS.

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