Version 1.1
June 8, 2007

Cosmic Origins Spectrograph Instrument Handbook for Cycle 17

PRECEDENCE: This document describes the operational capabilities of the Cosmic Origins Spectrograph. If the information in any other document conflicts with this Instrument Handbook, this Handbook takes precedence. The sole exception is the Phase II Proposal Instructions, which takes precedence over this Handbook.

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COS Handbook History

Version	For Cycle	Date	Editor
1.1	17	June 2007	David Soderblom

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CHAPTER 1:
Introduction

In this chapter...

The Cosmic Origins Spectrograph (COS) is a fourth-generation instrument to be installed on the Hubble Space Telescope (HST) during Servicing Mission 4[1]. COS is designed to perform high sensitivity, medium- and low-resolution spectroscopy of astronomical objects in the 1150–3200 Å wavelength range. COS will significantly enhance the spectroscopic capabilities of HST at ultraviolet wavelengths and will provide observers with unparalleled opportunities for observing faint sources of ultraviolet light. COS is **not** meant to be a replacement for the Space Telescope Imaging Spectrograph (STIS), which will remain in HST after the servicing mission[2]. Both instruments have unique capabilities, which we describe and compare in this document.

This first chapter provides some basic information about this document and tells how to find additional information or help. The structure of the document is self-evident from the table of contents.

1. COS will be inserted into the HST bay currently housing COSTAR, the Corrective Optics Space Telescope Axial Replacement, which is no longer needed and has been out of use since SM3b.

2. As this is written plans are also being made to repair STIS during SM4, restoring its unique capabilities to HST's repertoire.

1.1 Purpose

This *COS Instrument Handbook* is meant to be the basic reference manual for the Cosmic Origins Spectrograph, and it describes COS' design, performance, operations, and calibration. 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;
- 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 *HST Data Handbook*.

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 as integers. 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 Spectrographs Branch and COS Team

Table 1.1 lists the COS contacts in the Instrument Division at STScI. Observers seeking more detailed information about the COS instrument performance or operations should contact one of the COS instrument scientists.

Table 1.1: COS Instrument Division Contacts at STScI

Instrument Scientist	E-mail	Phone
Alessandra Aloisi	aloisi@stsci.edu	410-338-4519
Linda Dressel	dressel@stsci.edu	410-338-4376
Scott Friedman	friedman@stsci.edu	410-338-4906
Charles (Tony) Keyes	keyes@stsci.edu	410-338-4975
David Soderblom	soderblom@stsci.edu	410-338-4543

1.2.2 The STScI Help Desk

Observers may also 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.

1.2.3 COS web pages and supporting information

Resources used in the preparation of this document include COS OP-01 (Morse et al. 2002, Rev. 17 and references therein) and the *STIS Instrument Handbook* (Kim Ouijano et al. 2003, v7.0). We thank the COS IDT members for their assistance with the preparation of this document, particularly Cynthia Froning, Jim Green, and Steven Penton. Additional COS information and planning tools, including a link to a preliminary spectral simulator, can be found on the COS webpage at http://www.stsci.edu/instruments/cos/.

1.2.4 Non-proprietary COS data

This Handbook is being written before COS is installed in HST and therefore no on-orbit data yet exist. However, there are many calibration datasets taken during testing on the ground. Readers wishing to examine those data should go to the MAST web page at http://archive.stsci.edu.

CHAPTER 2:

Special Considerations for Cycle 17

In this chapter…

The first use of COS is planned for Cycle 17. As this is written, we anticipate Cycle 17 starting near the end of 2008. The newness of COS and the operations of HST following a Servicing Mission result in several special considerations that observers should be aware of.

2.1 SM4 and the Installation of COS

COS will be installed into HST during Servicing Mission 4 (SM4), now scheduled for launch in September, 2008. NASA has indicated a firm commitment and desire to service HST, but many factors may change the launch date of SM4 or even preclude it. The availability of COS is obviously dependent on the success of SM4.

2.2 Knowledge of Instrument Performance

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.

2.3 SMOV

Once executed, SM4 will be followed by a period of Servicing Mission Orbital Verification (SMOV), during which HST's Science Instruments are activated, tested, and calibrated. The successful conclusion of critical SMOV tests leads to an instrument being available for science observations.

2.4 The Availability of COS During Cycle 17

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.

2.5 Limitations on Proposing to Use COS

2.5.1 The COS GTO program

The COS Instrument Definition Team (IDT) is responsible for the development, management, and scientific oversight of COS prior to launch. The COS IDT has approximately 550 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. Key personnel on the COS IDT include:

- ***Principal Investigator***: James Green (University of Colorado)

- ***Project Scientist***: Cynthia Froning (University of Colorado)
- ***Co-Investigators***: 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), and John T. Stocke (University of Colorado).
- ***Primary Contractor***: Ball Aerospace, Boulder CO.

As GTOs, the COS IDT is permitted to have exclusive access to the targets they will observe, and General Observers may not propose to observe those targets with COS. The COS GTO target list may be found on the MAST web page: http://archive.stsci.edu.

2.5.2 SNAPshots with COS

COS' detectors 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 the time needed to do this, in Cycle 17 our first priority will be GO observations, and COS SNAPshots will only be permitted if the objects to be observed lie within fields observed by GALEX.

2.5.3 Non-point sources uses of COS

COS was optimized for faint point sources (objects less that 0.1 arcsec in diameter) because such objects are the primary targets proposed by COS' Investigation Definition Team (IDT). The COS IDT specifically avoided compromising FUV throughput for the sake of making COS a more general purpose instrument since STIS is intended to fulfill that need.

Nevertheless, COS is very powerful and can be applied to many scientific investigations. There may be applications to extended or structured sources, but in general at a significant cost in the resolution or purity of the spectrum. With only a few exceptions, this document is written for point-source observing, with the intent of adding information on other uses once we can assess them after launch.

2.6 Should I Use STIS instead of COS?

Current plans for SM4 call for the astronauts to carry out a replacement of STIS' failed power supply so that STIS' capabilities can be restored.

Proposers for Cycle 17 should assume that both COS and STIS will be operational. In that environment both STIS and COS can be used for spectroscopic observations in the ultraviolet, so which is to be preferred? Here are some key differences to help you decide.

Point sources versus extended or structured objects

COS was designed and built to excel at obtaining ultraviolet spectra of point sources. COS is especially efficient at doing so in the far-UV, below about 2000 Å. Because of its design, COS is not at all suited to obtaining spectra of extended objects or when more than one point source is in the aperture. It is still possible to obtain data under such circumstances, of course, but the analysis of those data will be complex and not within the capabilities of the pipeline software.

In general, COS may be used effectively for single point sources, but other types of targets should use STIS.

Bright objects

Having photon-counting detectors, COS cannot observe objects that are too bright. 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.

The count rate limits for safety reasons are both local and global. In other words, the total (global) count rate over the entire detector cannot exceed a set limit without causing COS to shut down. At the same time, the count rate within any pixel may not exceed the local rate limit. These limits are discussed further below (see Section 8.2.1, “Limiting magnitudes and bright object limits,” on page 102) and are included in the COS Exposure Time Calculator (ETC). Note that the same count rate limits apply to all uses of COS, either for imaging and acquisitions, or for spectroscopy.

In general, we strongly recommend use of TIME-TAG mode with COS whenever possible because you will then obtain observations of consistently high quality for several reasons explained below. However, in some cases targets may be safe to observe with COS but will produce counts at a rate that exceeds TIME-TAG capabilities. In such cases you will need to use ACCUM mode, and again the relevant parameters are encoded in the COS ETC.

In some cases, COS can be used to observe bright targets if they are placed in the Bright Object Aperture. The BOA includes a neutral density filter that attenuates by a factor of approximately 200, but the BOA also degrades the image, thereby reducing spectroscopic resolution by a factor of 3 to 5. We anticipate that in almost all cases in which an object is too bright for COS that an observer will prefer to use STIS. Eschew the BOA.

Far-UV spectroscopy

In the far-ultraviolet (from about 1100 to 2000 Å), COS is more sensitive than STIS by factors of 10 to 30. However, COS offers only two spectroscopic resolving powers, 2,500 and 20,000, while STIS also offers a high resolution (R = 100,000) echelle mode and some other options as well.

Near-ultraviolet spectroscopy

In the near-UV, COS' gain over STIS is more modest (factors of 2 to 3) and there are compromises to deal with. In particular, COS' near-UV capability was added after the first design of the instrument. To accommodate the NUV channel and its optics, the NUV spectrum of COS is split into three non-contiguous sub-spectra. Obtaining a full spectrum of an object in the near-UV then requires several separate set-ups and exposures, and it is just coincidental if a single set-up contains all the spectroscopic features of astrophysical interest to the observer.

In other words, at any one near-UV wavelength, COS is more sensitive than STIS, but STIS is probably to be preferred for obtaining a broad-band near-UV spectrum. On the other hand, COS' background count rate is substantially lower than for STIS so that COS is superior for extremely faint sources.

As with the far-UV, in the near-UV STIS offers more capabilities than does COS, including a high resolution (R = 100,000) echelle mode.

CHAPTER 3:

A Tour through COS

In this chapter…

The Cosmic Origins Spectrograph (COS) was built to excel at obtaining low- and medium resolution spectra of faint point sources in the far ultraviolet (FUV). COS was optimized for faint point sources because such objects are the primary targets proposed by COS' Investigation Definition Team (IDT). The COS IDT specifically avoided compromising FUV throughput for the sake of making COS a more general purpose instrument since STIS is intended to fulfill that need.

This chapter provides a brief summary description of COS to help you understand how it operates and can be used. More detailed information is presented in the next several chapters.

3.1 COS' Location 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 place is shown in Figure 3.1 on page 13. 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 Primary Science Aperture (PSA) of COS is 325 arcsec from the V_1 axis, and that COS is located in the $+V_2, -V_3$ quadrant.

The apertures are very small, of course, so an enlargement of the region around them is also shown in Figure 3.2 on page 14. Note that the direction along the dispersion of a COS spectrum corresponds to motion equally in V_2 and V_3 in a direction radially away from the center 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.

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.

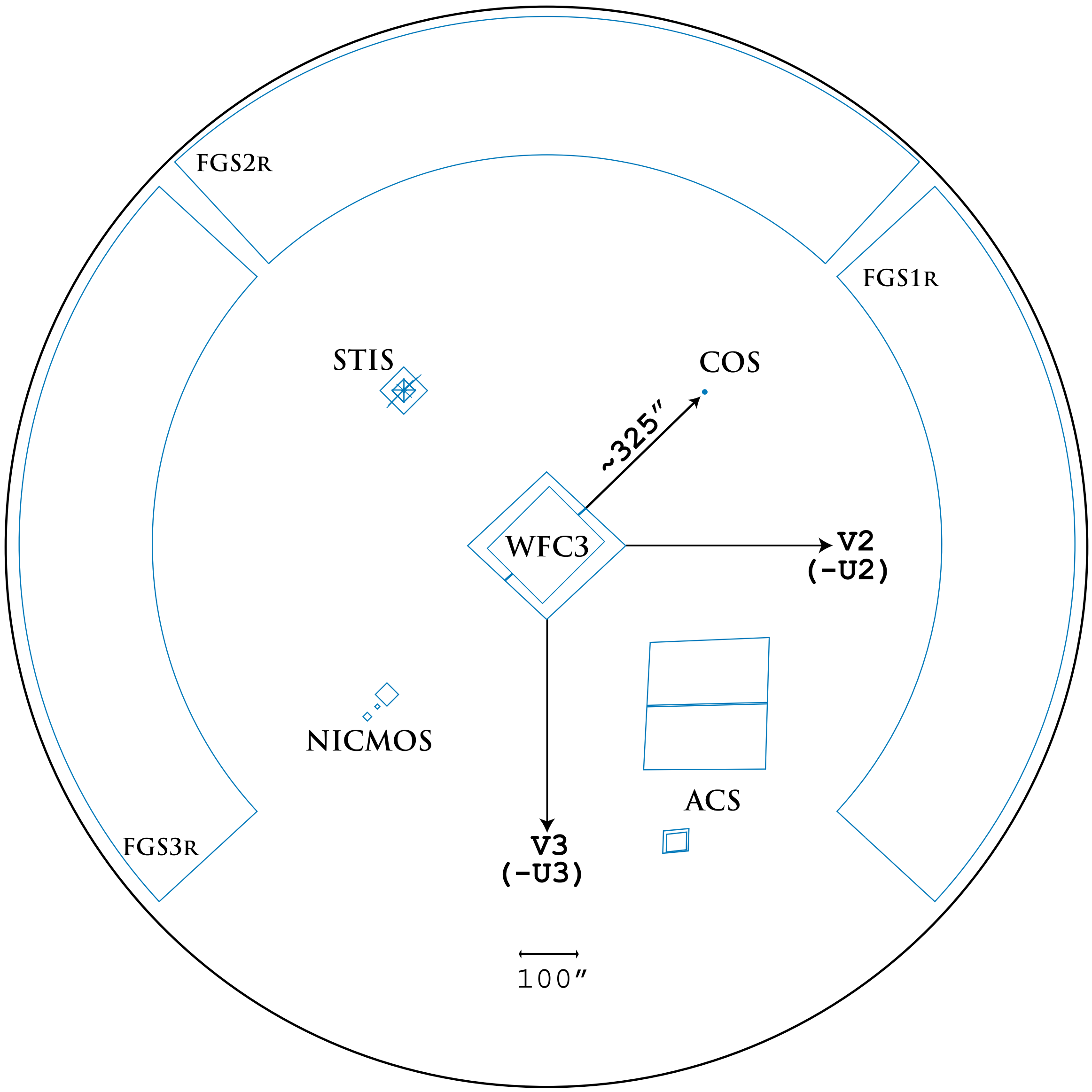


Figure 3.2: An enlargement of the HST focal plane in the region of the COS aperture.

Shown is the region from WFC3 to COS. Note that the direction of dispersion for COS is radially away from the HST optical axis and that the COS aperture is 325 arcsec from the optical axis (V_1).

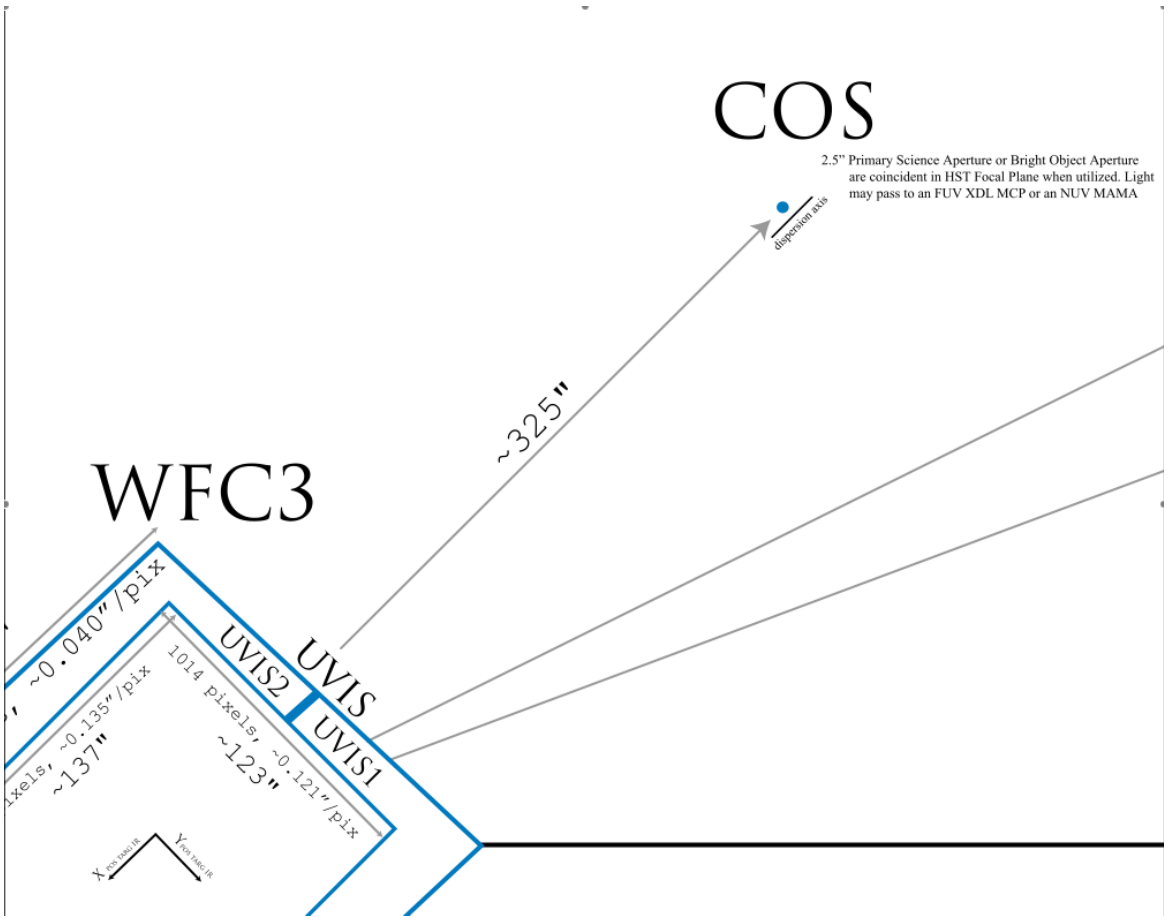
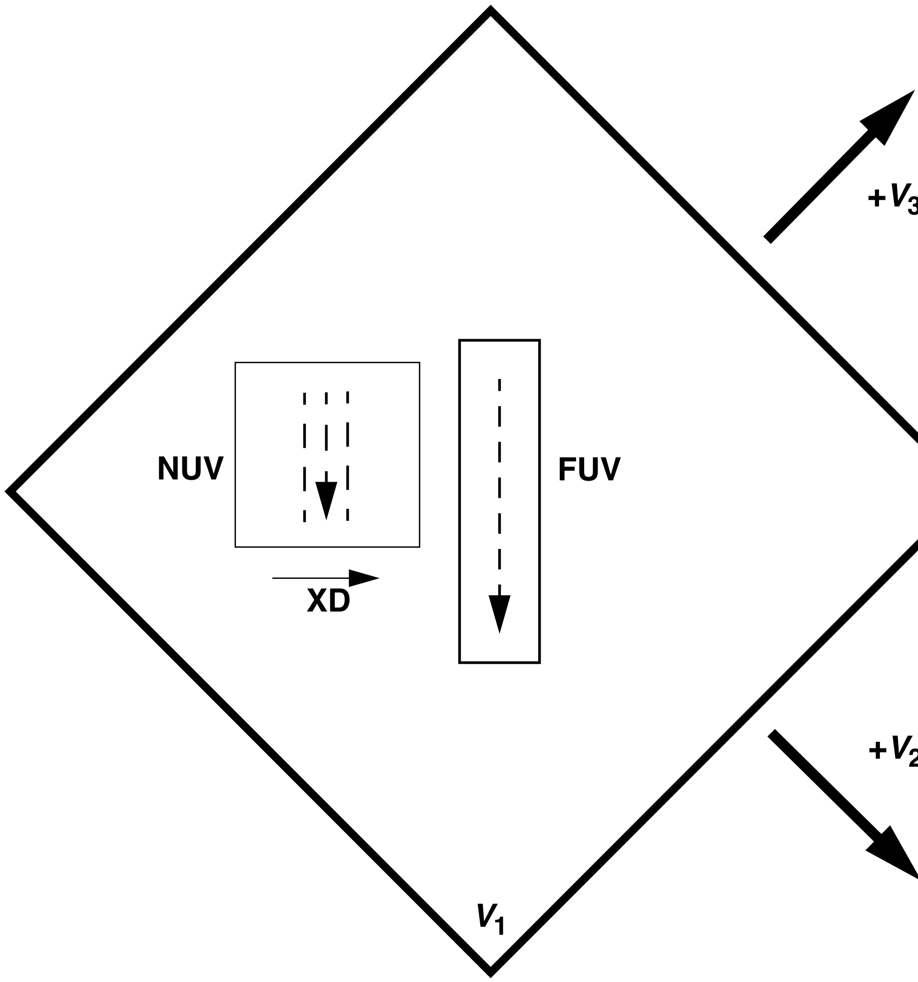


Figure 3.3: Schematic layout of the COS detectors.

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.



3.2 COS' Capabilities

COS was built for speed and was not intended as a general-purpose spectrograph. Nevertheless, COS is very powerful and can be applied to many scientific investigations. COS' single most critical criterion is that it is designed to observe point sources (objects less that 0.1 arcsec in diameter). There may be applications to extended or structured sources, but in general at a significant cost in the resolution or purity of the spectrum.

With only a few exceptions, this document is written for point-source observing, with the intent of adding information on other uses once we can assess them after launch.

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.

Table 3.1: COS Spectroscopic Modes

Grating	Useful wavelength range (Å)[1]	Bandpass per exposure (Å)	Resolving Power $R = \lambda/\Delta\lambda$[2]	Dispersion (Å $resel^{-1}$)
FUV Channel				
G130M	1150 –1450	300	20,000 – 24,000	0.066
G160M	1405 – 1775	370	20,000 – 24,000	0.083
G140L	1230 – 2050	>820	2,500 – 3,000	0.606
NUV Channel				
G185M	1700 – 2100	3 × 35	16,000 – 20,000	0.102
G225M	2100 – 2500	3 × 35	20,000 – 24,000	0.102
G285M	2500 – 3000	3 × 41	20,000 – 24,000	0.120
G230L	1700 – 3200	(1 or 2) × 398	1,550 – 2,900	1.166

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.
2. The lesser value of *R* is realized for the low-wavelength end of the useful range, and *R* increases roughly linearly with wavelength.

COS also incorporates a very limited imaging capability in its NUV channel. This is primarily useful for acquisitions, and is described in that chapter (see Chapter 6 on page 73).

3.2.1 Signal-to-noise considerations

The COS FUV channel will be capable of routinely delivering fully reduced spectra with a signal-to-noise (S/N) ratio of ~30 per resolution element in single exposures at specific grating settings, given sufficient detected photons, of course. Higher S/N ratios may be attainable, depending on the quality of the flat-field images obtained as part of the instrument calibration program. In addition, COS FUV science exposures can be obtained at slightly different focal plane positions in the dispersion direction. Alignment and co-addition of these "`FP-POS`" sub-exposures should further reduce the effects of fixed-pattern noise in the final calibrated spectrum. A full quantitative assessment of the fixed-pattern noise present in COS spectra and the potential for removal in the calibration process must await on-orbit calibration of the instrument.

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

3.2.2 Photometric (flux) precision

The limits on the precision and accuracy of fluxes measured with COS are the same as for STIS. COS does have the advantage of a fairly large aperture so that there are no slit losses. The 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). Repeated exposures of the same target at the same setting should deliver the 2% accuracy as well.

3.2.3 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 the various gratings then breaks down as shown in the following table. 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 error is due to target mis-centering in the aperture.

Table 3.2: Wavelength calibration uncertainties

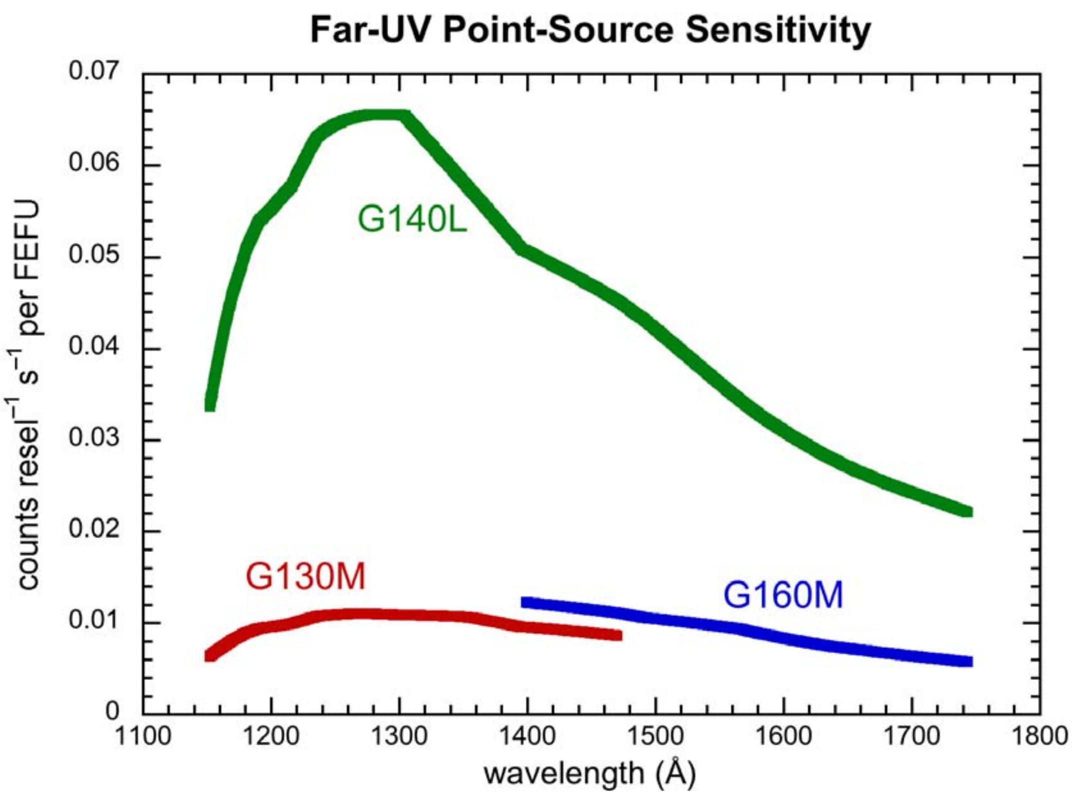
The quantities shown are 1σ.

Grating	Error goal		Internal error	External error
	km s^{-1}	pix	pix	arcsec
G130M	15	5.7 – 7.5	3.0 – 4.0	0.09 – 0.12
G160M	15	5.8 – 7.2	3.1 – 3.8	0.10 – 0.12
G140L	150	7.5 – 12.5	4.0 – 6.6	0.12 – 0.21
G185M	15	7.2 – 10.0	1.2 – 1.7	0.03 – 0.04
G225M	15	9.7 – 13.3	1.6 – 2.3	0.04 – 0.06
G285M	15	9.7 – 14.7	1.6 – 2.6	0.05 – 0.07
G230L	175	8.3 – 15.5	1.4 – 2.6	0.03 – 0.07

Observers need to be aware that tests of COS on the ground before flight showed some motion of the grating carrousel after it was stopped at its nominal position. 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 "`TAG-FLASH`" operating mode was designed. `TAG-FLASH` mode means using `TIME-TAG` observations with `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 photocathode well away from the science spectrum, one does not contaminate the other. `TAG-FLASH` is described further in Chapter 8 on page 99.

Figure 3.4: Far-ultraviolet sensitivity curves for COS.

The values shown are counts per resel per unit 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.

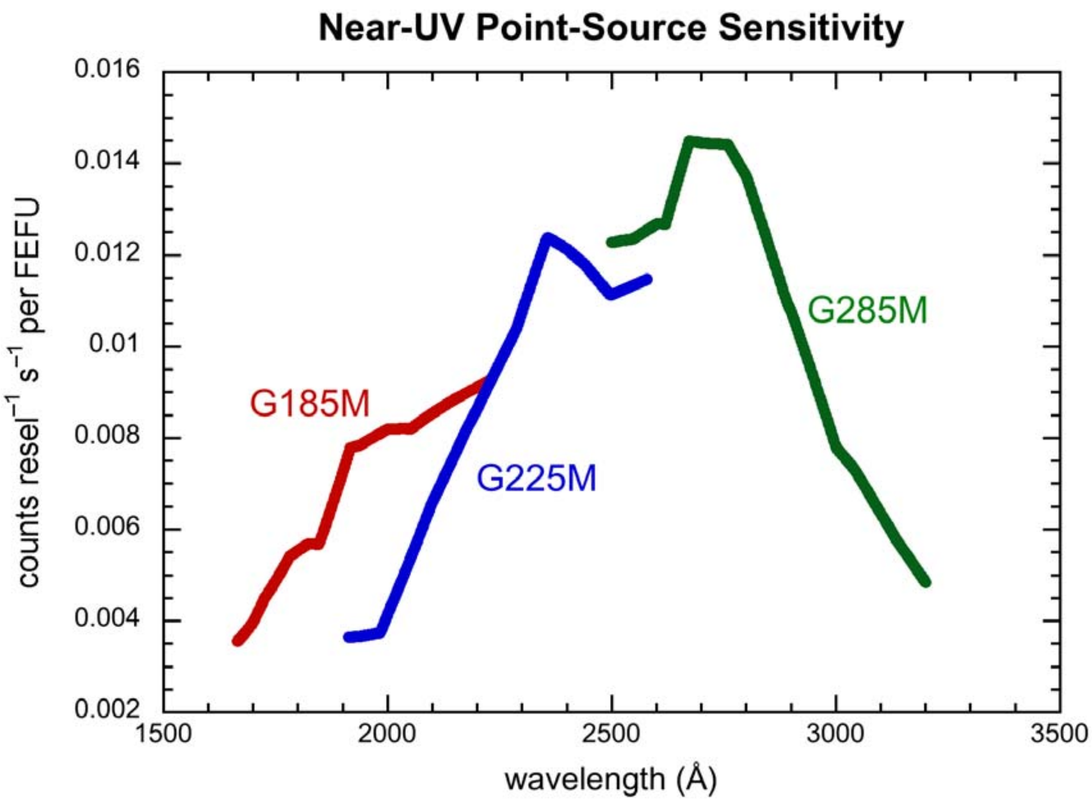


3.2.4 Sensitivity

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. Preliminary results for the end-to-end system throughputs of the COS FUV and NUV channels are shown in Chapter 4 on page 41. These estimates are appropriate for a point source centered in the COS primary science aperture (PSA). The throughput and effective area calculations include the throughput of the HST OTA and degradation of the light beam prior to entry into the COS instrumentation, as described by Burrows (1988, STScI internal memo).

Figure 3.5: Near-ultraviolet sensitivity curves for COS.

The values shown are in counts per resel per unit FEFU, and are for point sources.



The point source sensitivities (S_λ) for the COS spectroscopic modes are shown above. 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 9,200 seconds is required to reach S/N = 30 per 0.066 Å resolution element ($R \sim 20{,}000$) for an object with $F_{1300} \approx$ 10 FEFU. The same exposure with the STIS E140M mode and the 0.2 × 0.2 arcsec aperture (binned by a factor of 2.3 to a resolution $R \sim 20{,}000$) would take approximately 170,000 seconds after accounting for the STIS scattered-light backgrounds and slit losses. All COS sensitivity estimates shown are drawn from COS Thermal-Vacuum ground testing; updates based upon on-orbit measurements will be made during SMOV period and Cycle 17.

3.2.5 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.

The effect 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 the value of t given (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 = 13,500 counts sec^{-1}. Note that when the effect is near the 10% level that the FUV detector is near its global count rate limit (see Section 7.2, "Safety First: Bright Object Protection," on page 80) and so non-linear effects are small for the FUV detector.

There is an additional non-linear effect in the FUV channel that has not yet been quantified. A single "round robin" Detector Interface Board (DIB) 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 21,000 counts sec^{-1} in TIME-TAG mode.

For the NUV MAMA on COS, the dead-time has not been measured and will be calibrated on-orbit. Note, however, that for the STIS MAMAs the 10% level of non-linearity is reached for *C* = 300,000 counts sec–1, well above the safe global count rate limit and so not of concern. The MAMAs also show a local non-linear effect that is small and will be calibrated on orbit.

3.3 The Design of COS

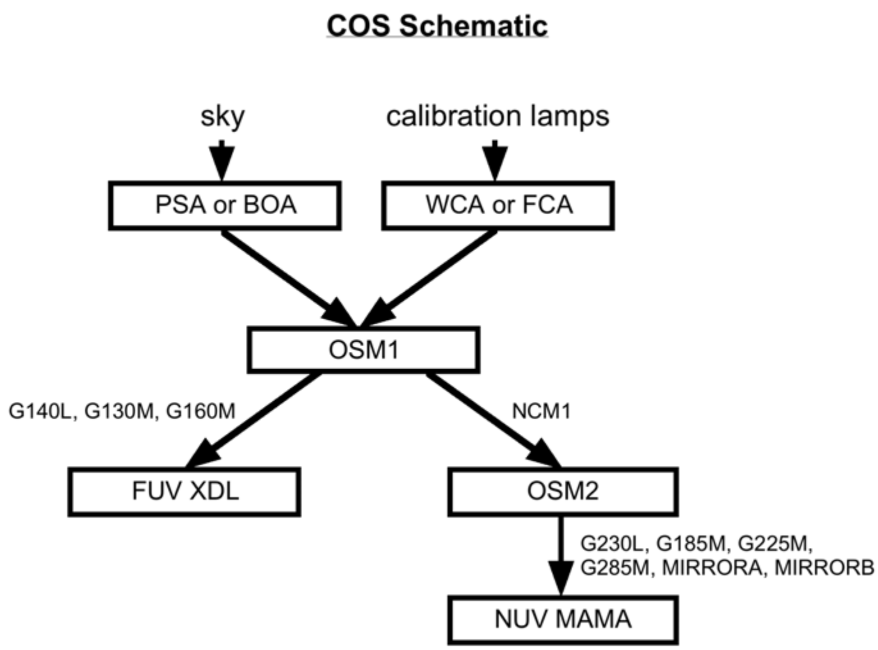
3.3.1 Optical Configuration

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. The entrance “aperture” is a field stop located near the point of maximum encircled energy. It is round, and 700 μm in diameter, corresponding to 2.5 arcsec on the sky. Because the apertures are not located at HST’s focus, they are slightly out of focus at the detector. It is the sky that is imaged onto the detector, not the entrance aperture. COS’ optics are designed for a point source that is centered in the aperture. Anything larger than 0.1 arcsec or off-center by more than about 0.1 arcsec will produce a degraded spectrum. For example, a source that is 0.5 arcsec in diameter will yield a spectrum with $R \approx 5{,}000$ instead of 20,000.

Figure 3.6: Schematic of the light flow through COS.

The elements in this diagram are explained in this chapter.



COS has a simple optical design that minimizes the number of reflections required to disperse and detect ultraviolet light in its two optical channels. COS has especially high throughput in the far ultraviolet, below about 2050 Å. The instrument is designed specifically for high-throughput spectroscopy of point sources. It may also be used to observe extended objects, but with limited spatial information and significantly degraded spectral resolution.

Light enters COS through one of two 2.5 arcsec diameter circular apertures and encounters an optical element that enables far-ultraviolet (FUV; 1150 to 2050 Å) or near-ultraviolet (NUV; 1700 to 3200 Å) observations. Figure 3.6 above shows the optical path of COS schematically. Here we explain the various elements of the optics. The next section describes COS' apertures. The gratings and mirrors are mounted on two mechanisms, OSM1 and OSM2, which are described next. The detectors are discussed in the next chapter. Some additional details of the design are provided in Chapter 13 on page 145.

3.3.2 Apertures

COS has two circular science apertures that are 2.5 arcsec (700 μm) in diameter. There are also two calibration apertures. A general description of COS' apertures is provided here, with some additional details in "Apertures" on page 146.

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 nature 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.

Because both science apertures always view the sky when the external shutter is open, the STScI target screening procedure must ensure that no bright targets are within a ~4 arcsec radius of either aperture for all observations. Since the spacecraft orientation may not be known and either of the science apertures could be specified, it may be prudent to screen the entire region within a ~17 arcsec radius of the nominal aperture position.

Primary Science Aperture

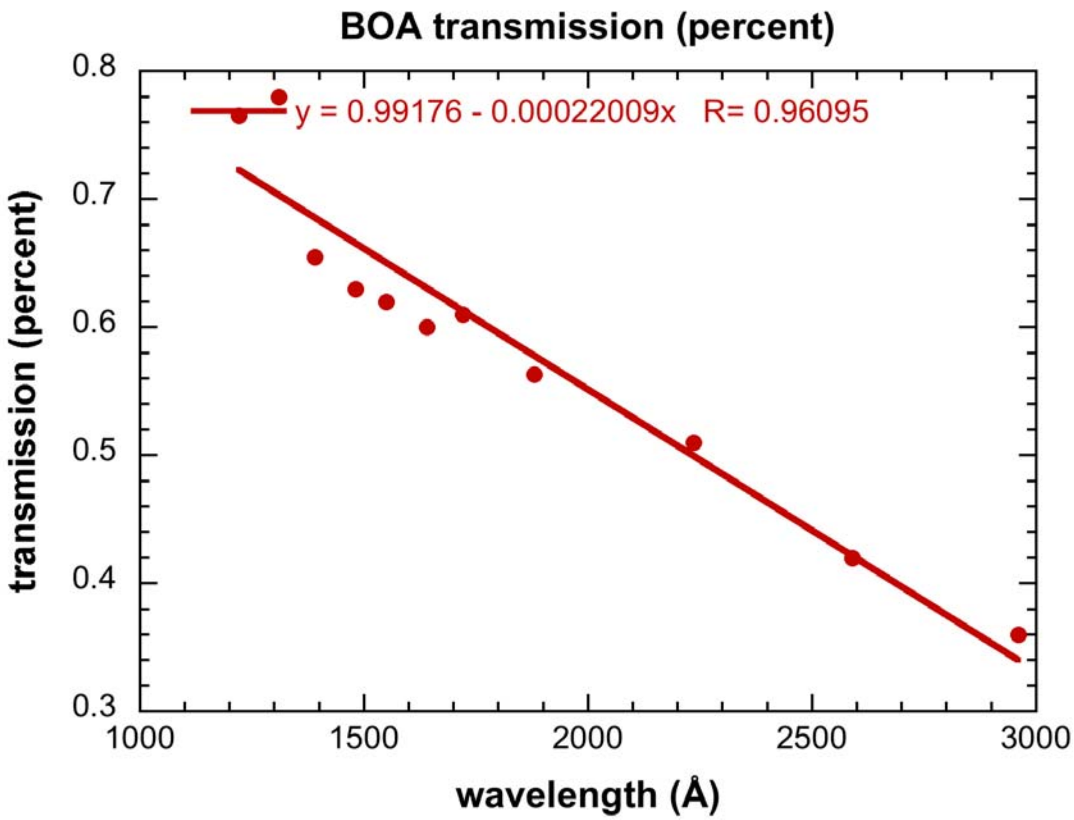
The Primary Science Aperture (PSA) is a 2.5 arcsec (700 μm) diameter field stop located on the HST focal surface near the point of maximum encircled energy. This aperture transmits about 95% of the light from a well-centered, aberrated stellar image delivered by the HST optics. The PSA is expected to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

Bright Object Aperture

The Bright Object Aperture (BOA) is also 2.5 arcsec (700 μm) in diameter with a neutral density (ND2) filter that permits COS to observe targets six magnitudes (factor of approximately 200) 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 nominal position of the PSA for science observations. Thus, science spectra obtained through either the PSA or BOA will utilize the same optical path and detector region (for a given channel), and so 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 and vice versa; therefore bright object screening for the field-of-view must include both apertures.

The transmission of the BOA is wavelength dependent, and is shown below. The straight line fit is given by transmission (in percent) = 0.99 – λ(Å)/4500.

Figure 3.7: 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 in the cross-dispersion direction, on the opposite side of the PSA from the BOA. Light from external sources cannot illuminate the detector through the WCA; instead the WCA is illuminated by the Pt-Ne lamp.

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 the 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 requirements, FLASH=YES (TAGFLASH) operation is not possible with the BOA.

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. The FCA must be moved to project from the on-board flat-field continuum lamp to create a spectrum along the desired detector rows (e.g., at the PSA position). When not in use, the FCA is stowed at a position that does not transmit any light from an internal (or external) light source. 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 is displaced in wavelength).

3.3.3 The FUV and NUV Channels

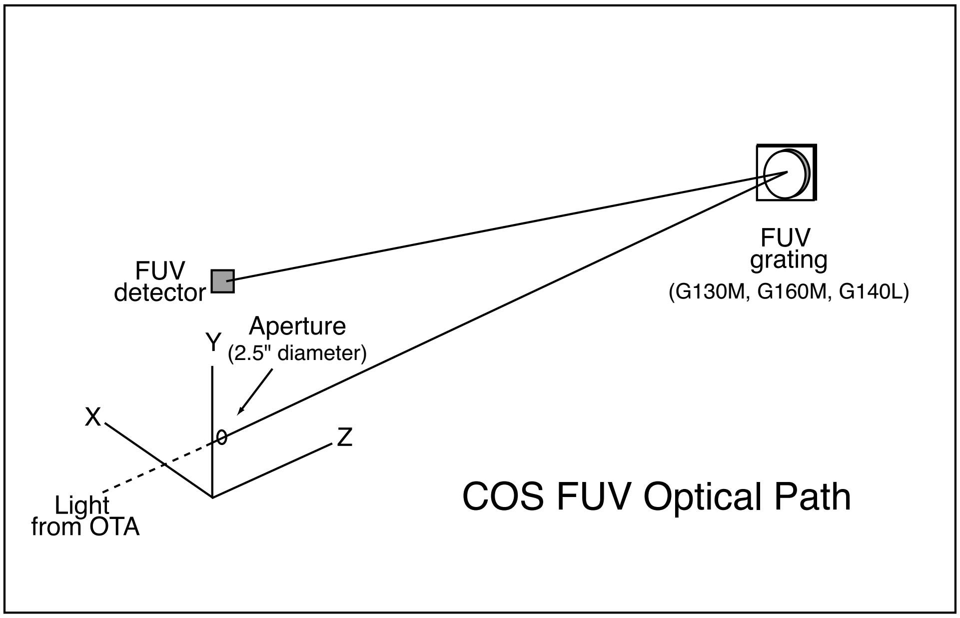
FUV channel optical design

The COS FUV channel covers the wavelength range 1150 to 1775 Å at low- and moderate spectral resolution. In the FUV channel, the light from HST's OTA illuminates a single optical element, one of three concave holographically-ruled diffraction gratings. An optic selection mechanism (OSM1) configures either the low-dispersion grating or one of two medium-dispersion gratings for the observation. The grating disperses the light, corrects for HST's spherical aberration, and focuses the light onto a crossed delay-line (XDL) micro-channel plate (MCP) detector. The XDL is described below ("FUV Detector (MCP+XDL)" on page 29), but it is important to note that it consists of two independent segments with a 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 line can cause.

The same OSM1 mechanism may also be used to place a mirror (NCM1) in the light path in place of the grating for NUV observations, as described in the next section. The COS FUV optical path is illustrated schematically in Figure 3.8.

The FUV channel is fundamentally a Rowland spectrograph, modified to meet the specific needs of HST. As noted, there is only one reflection between the aperture and the detector. The gratings have aspheric concave surfaces that compensate for spherical aberration. Holographically generated grooves provide dispersion and correct the astigmatism. Ion-etching creates a blaze that optimizes the grating efficiency over a narrow range of wavelengths. Details on the gratings are provided in "COS Optical Elements" on page 152.

Figure 3.8: The COS FUV optical path.



Two gratings, G130M and G160M, are used to cover the range 1150 to 1775Å wavelength range at medium resolution (*R* = 20,000 to 24,000). Each medium-dispersion grating covers roughly 300 Å in one exposure. A third grating, G140L, can be used to observe the 1230 to 2050 Å region at lower resolution (*R* = 2500 to 3500). The short wavelength cut-off of the low-dispersion grating is designed to avoid bright geocoronal Lyman-α emission at 1216 Å by placing it on the XDL detector gap.

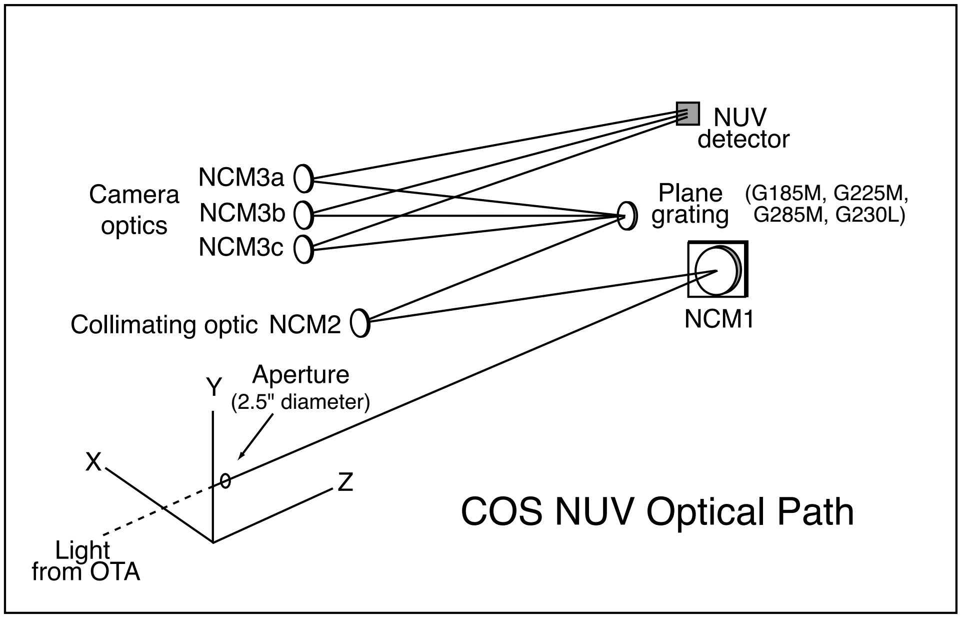
Although the nominal wavelength range of the G140L spectrum is 1230 to 2050 Å, this spectrum takes up only part of one detector segment. The grating actually directs light out to 2400 Å onto this detector segment, but the XDL sensitivity to these longer wavelengths is extremely low. On the other detector 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 the OTA mirrors and COS optics. Calculations predict that the effective area below 1150 Å plummets rapidly but is not zero.

NUV channel optical design

The COS NUV channel covers the wavelength range 1700 to 3200 Å at moderate spectral resolution. The NUV channel is fundamentally a Czerny-Turner design, fed by a mirror (NCM1) mounted on the OSM1. The NCM1 corrects the input beam for spherical aberration, magnifies it by a factor of ~4, and directs it to a collimating optic, NCM2. The collimated beam is then directed to one of several gratings mounted in the Optics Select Mechanism 2 (OSM2). The OSM2 contains several flat, first-order gratings and a mirror (TA1). Three medium-dispersion gratings, G185M, G225M, and G285M, deliver resolutions R = 20,000 to 24,000 over the wavelength range 1700 to 3200 Å. The dispersed light from the gratings is imaged onto a MAMA detector by three 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 the OSM2 to cover the entire NUV wavelength band. The NCM3a,b,c mirrors are spaced such that three 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 third exposure. In other words, two intermediate grating settings will cover the wavelength gap between the stripes in the first exposure.

A low-dispersion grating, G230L, delivers ~400 Å coverage per stripe with 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 three separate exposures using four spectral stripes on the detector. The optical design places 1700 Å at the beginning of the first stripe A and 3200 Å at the end of the second stripe B of a single exposure. Three exposures will be required for complete, contiguous coverage of the 1700-3200 Å region, with some overlap between each exposure.

Figure 3.9: The COS NUV optical path (schematic).



Over the FUV wavelengths the NUV MAMA detector actually has a QE of several percent, and second-order light from the FUV could appear on the detector with some gratings. To eliminate this second-order light, the coatings on the NUV optics are optimized for wavelengths above 1600 Å, but have some throughput at FUV wavelengths. The four optical bounces in the NUV channel will therefore effectively reduce unwanted 2nd-order light, such as from Lyman-α airglow. In addition, the G285M and G230L gratings have order blocking filters mounted directly to the gratings in order to block the 2nd-order blue spectra below ~1700 Å. Even so, second-order light will appear on the NUV detector in each of the G230L exposures, especially in the long wavelength stripe C. The 2nd-order spectra will have low sensitivity due to the detected wavelengths being so far off the 2nd-order blaze, but the spectral resolution will be twice as high and may yield useful data in some circumstances. The 2nd-order throughput should be measured during ground calibration and SMOV, and the extra photons should be included in count rate estimates during bright object screening. Wavelengths longer than 3200 Å that project onto the detector will have very low throughput due to the poor sensitivity of the Cs_2Te photocathode in the NUV MAMA detector.

3.3.4 Detectors

See also Chapter 4, "Detector Performance" on page 41.

FUV Detector (MCP+XDL)

The COS FUV detector is a windowless MCP (micro-channel plate) with a XDL (crossed delay line) anode that is similar to detectors used on the Far Ultraviolet Spectroscopic Explorer (FUSE). The detector is a photon counter with two segments, each of which has an active area of 10 × 85 mm, with a gap of 9 mm between them. The two detector segments are independently operable to provide redundancy. The active area of 10 × 85 mm is digitized to 1,024 × 16,384 pixels, with the long axis being in the direction of dispersion. The locations of detected events are recorded in pixel units. However, note that the XDL is an analog device and does not have physical pixels in the usual sense, and the location of an event is determined by the electronics as they occur. This lack of pixels creates some uncertainty in the exact location of an event and can limit the achieved signal-to-noise for this reason.

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 to match the curvature of the focal plane.

When photons strike the photocathode they produce photoelectrons which are then multiplied by micro-channel plates. There are two stacks, one for each detector segment, and each with three curved plates. An electron cascade typically produces a gain of 10 million, resulting in measurable charge clouds of 2 to 3 picocoulombs, each several mm in diameter.

The XDL's quantum efficiency is improved with a grid of wires placed in front of the detector (i.e., in the light path). However, these wires create shadows in the spectrum that must be removed during data reduction.

The location of charge events is determined by the crossed delay lines. There is one anode for each detector segment, and each anode has separate traces for the dispersion and cross-dispersion axes.

The electronics that create the digitized time signals also generate pulses which emulate counts located at the edges of the anode, beyond the illuminated regions of the detector. These "e-stims" or "stim pulses" have several purposes. They provide a first-order means of tracking and correcting distortions. They are also used for determining dead-time corrections.

NUV Detector (MAMA)

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 NUV optics focus light through the MgF_2 window onto the Cs_2Te photocathode. A photoelectron generated by the photocathode then falls onto a micro-channel plate (MCP) and the MCP then generates a cloud of about 700,000 electrons. 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. A photoelectron emitted by the photocathode has a 68% probability of being collected by the MCP.

3.3.5 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 identical Pt-Ne hollow cathode wavelength calibration lamps on its internal calibration platform whose 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 exposures, either as a separate wavecal for `ACCUM` exposures, or during a `TIME-TAG` exposure when `FLASH=YES` is specified. 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.

The Pt-Ne lamps will also be used during `ACQ/IMAGE` target acquisition sequences to provide a geometrical 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

Similarly, COS has two identical 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).

3.3.6 Mechanisms

COS uses four moving mechanisms to carry out its normal science observations: an external shutter, the Aperture Mechanism (ApM), the Optics Select Mechanism 1 (OSM1), and the Optics Select Mechanism 2 (OSM2).

External Shutter

The external shutter is a paddle shaped arm, with a shutter blade made up of a thin, circular disc approximately 1.5 inches 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 the COS instrument and prevents light from the COS internal lamps from exiting the instrument. The shutter travel-time is <500 msec. 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.

Aperture Mechanism (ApM)

The ApM is located near the HST OTA focal surface in the forward, lower portion of the COS enclosure. (Details are provided in "The Aperture Mechanism (ApM)" on page 147). The ApM positions the aperture block which contains the Primary Science Aperture (PSA), Bright Object Aperture (BOA), Wavelength Calibration Aperture (WCA), and Flat-field Calibration Aperture (FCA). The ApM is used to position the PSA at the optimum position along the optical beam to maximize throughput of a focused aberrated point source. The ApM is used to move the BOA to the position of the PSA for observations of bright targets (for both the FUV and NUV channels). Finally, the ApM is used to move the FCA to the desired position for obtaining flat-field exposures for PSA or BOA science spectra. The WCA need not be moved for wavelength calibration exposures associated with PSA science spectra. When the ApM is moved in the cross-dispersion direction for BOA science exposures, it must be commanded back to its nominal (PSA) position to project the WCA spectrum in the appropriate place for wavelength calibrations.

The ApM is not moved for FP-POS dithering, which is accomplished by small motions of the gratings. The three FUV gratings on the OSM1 will be at the same focus position and, hence, will require no movement of the ApM when switching between optics. However, we expect that the ApM will generally need to be moved when switching between the FUV and NUV channels (using the NCM1 optic on OSM1) so as to provide the best optical performance.

Additional information on the aperture mechanism is provided in "The Aperture Mechanism (ApM)" on page 147.

Optics Select Mechanism 1 (OSM1)

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).

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 one of ~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.

3.4 Basic Instrument Operations

3.4.1 Target acquisitions

The COS flight software (FSW) provides two very different methods for acquiring and centering a target in the aperture. The simplest and fastest method uses the `ACQ/IMAGE` command 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 strongly preferred method in almost all 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. The other acquisition method uses dispersed light from the object to be observed, and can be performed with either the NUV or FUV detector. The details of acquiring objects with COS are described in Chapter 7, "Target Acquisitions" on page 79.

As noted above, both COS detectors have both global and local count rate limits to ensure their safe operation. It is the local rate limit that matters during acquisitions that use ACQ/IMAGE, and the COS Exposure Time Calculator (ETC) provides tools for estimating acquisition count rates. The other safety concern for acquisitions is the presence of nearby objects that may be bright in the ultraviolet, and APT provides a means of checking that. For more information on count rate limits, see “Safety First: Bright Object Protection” on page 80.

3.4.2 TIME-TAG and ACCUM

In COS’ TIME-TAG mode, both the location and time 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 such data allows for more sophisticated data reduction if there is evidence after the fact for spectrum drift, say, or noise events. On the other hand, in TIME-TAG mode the maximum permissible count rate prevents the observation of some bright stars, and, in addition, the observer must provide a fairly accurate estimate of the BUFFER-TIME so that the memory buffer does not overflow with too many events and does not need to be read out too often either.

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.

3.4.3 Wavelength calibration

COS includes platinum-neon hollow-cathode lamps as a rich source of comparison lines for the ultraviolet. The lamp illuminates an aperture that is separate from that used for the astronomical source, and so the images of the Pt-Ne emission lines fall on a different part of the detector. It is the relative locations of the object and comparison spectra that are used to calibrate the wavelength scale. The pipeline software is written to do this automatically. In addition, when used in ACCUM mode the flight software will automatically correct the locations of detected events for the projected orbital motion of HST. In TIME-TAG mode this correction is not made on board but is removed later during the reduction in **calcos**.

One reason to prefer TIME-TAG mode over ACCUM is that TIME-TAG includes an option in which brief comparison spectra are obtained several times during the course of a long exposure. Doing this allows any drifts in the spectrum to be corrected for; small motions of the optics selection mechanism have been seen during ground tests of COS.

The quality of the acquisition of the object being observed also influences the quality of the wavelength calibration. In particular, an accurate wavelength zero point will only result if the object is well-centered in the aperture in the along-dispersion direction. More information on this is provided in the chapter on acquisitions (see “Centering accuracy and the wavelength scale” on page 86).

3.4.4 Typical observing sequences

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

- Acquisition of the object using ACQ/IMAGE. This should require no more than about ten minutes. This can be preceded by an ACQ/SEARCH if need be to scan a larger area of sky.
- Obtaining spectra in TIME-TAG mode with FLASH=YES so that the spectra can be corrected for any drifts. The COS ETC will provide a means of calculating essential parameters such as BUFFER-TIME.
- Obtaining more spectra during additional orbits as needed for fainter targets.

3.4.5 Data storage and transfer

In TIME-TAG Mode, COS produces an event stream with a time resolution of 32 milliseconds. The *x* and *y* pixel coordinates of each photon event are stored in a 32-bit word in the COS data buffer memory. At the start of an exposure and after every subsequent 32-msec period which contains photon events, a 32-bit time-of-day word is written to the data memory. 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 first such transfer in an exposure requires 110 seconds and all subsequent transfers require approximately 80 seconds. Users must specify a BUFFER-TIME corresponding to the predicted time to fill <u>half</u> the buffer capacity. 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 two 9-Mbyte buffers of memory. After the first BUFFER-TIME of an exposure is completed, data recording switches to the second of the two memory buffers, and the first buffer is read out and so on. If BUFFER-TIME is incorrectly overestimated, the on-board data buffer may fill before the scheduled memory dump, subsequently arriving photons in that buffer-time will not be counted, and a gap in recorded data will occur. The pipeline will correct actual exposure times for any such gaps, so flux calibrations will be correct. The COS ETC provides features to enable computation of BUFFER-TIME.

At the end of each ACCUM exposure, the science data are read out from the detector and transferred to the 18 Mbyte COS internal memory buffer. Subsequently, the data will be transferred to the HST data recorder, and eventually to the ground. Up to nine 1024 × 1024 NUV MAMA images or two sets of FUV XDL 16,384 × 128 pixel detector images for each of the two detector segments may be stored in the internal buffer at any one time. The full internal buffer can be transferred to the data recorder during subsequent exposures, as long as exposures are longer than approximately 3.5 minutes. The COS internal buffer uses 16 bits per pixel for ACCUM mode data, such that a maximum of 65,536 photons per pixel can be recorded prior to counter rollover.

3.5 COS Quick Reference Guide

Table 3.3: COS Instrument Characteristics

Property	FUV channel	NUV channel
Entrance aperture	2.5 arcsec round	2.5 arcsec round
Detector plate scale (cross dispersion)	22 mas per pixel 158 mas per resel	26 mas per pixel 77 mas per resel

Table 3.4: 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
Pixel size	6 × 24 μm	25 × 25 μm
Spectral resolution element size (= "resel")	7 × 10 pix	3 × 3 pix

		FUV XDL	NUV MAMA
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}	~34 cnt s^{-1} cm^{-2} ~2.1x10^{-4} cnt s^{-1} pix^{-1} ~1.9x10^{-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}
Dead-time constant		7.4 μsec	negligible

Table 3.5: COS 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	5 km s^{-1}	5 km s^{-1}
Absolute photometry	5%	5%
Relative photometry (same object at a different time)	2%	2%
Flat field random noise		
Flat field systematic effects	30:1	100:1

Table 3.6: Useful Figures and Tables

Topic	Sources
Usage planning	Table 3.1: "COS Spectroscopic Modes" on page 16
	Table 3.6: "Useful Figures and Tables" on page 38
	Table 5.3: "Wavelength ranges for FUV gratings" on page 69
	Table 6.1: "Wavelength ranges for NUV gratings" on page 82
	Table 10.2: "Background contributions from the Moon and Earth." on page 124
	Table 10.3: "Extinction in magnitude as a function of wavelength, using Seaton's 1979 Galactic model." on page 127
	Table 10.2: "Earthshine and zodiacal light in the COS PSA." on page 128
	Table 10.3: "Strengths of important ultraviolet airglow lines" on page 130
Aperture parameters and PSFs	Figure 3.2 on page 14: COS aperture location
	Figure 7.1 on page 84: COS PSF for 1450 Å
	Figure 7.2 on page 85: COS PSF for 2550 Å
	Figure 6.1 on page 77: COS two-dimensional PSF
Sensitivity and throughput	Figure 3.4 on page 19: far-UV sensitivity curves
	Figure 3.5 on page 20: near-UV sensitivity curves
	Figure 4.1 on page 44: COS throughputs in comparison to STIS
Acquisitions	Figure 7.1 on page 90: exposure times for ACQ/IMAGE
	Figure 7.1 on page 94: spiral search pattern
	Figure 7.2 on page 95: exposures times for FUV dispersed light
Detector characteristics	Figure 4.3 on page 47: schematic layout of XDL
	Figure 4.3 on page 47: schematic layout of MAMA
	Table 8.1: "COS Count Rate Limits" on page 103
	Table 8.2: "Local and global flux limits for COS" on page 103
	Table 10.1: "Detector background count rates for COS" on page 122

Topic	Sources
Overheads and observing parameters	Table 5.1: "TAGFLASH intervals" on page 63
	Table 5.2: "Times of TAGFLASH lamp exposures." on page 64
	Table 9.1: "Generic Observatory Overhead Times" on page 110
	Table 9.2: "Overhead Times for Motions Between OSM1 Spectral Elements" on page 111
	Table 9.3: "Overhead Times for Motions Between OSM2 Spectral Elements" on page 111
	Table 9.4: "Science Exposure Overhead Times" on page 113
Celestial backgrounds	Figure 10.1 on page 123: sky backgrounds vs. wavelength
	Figure 10.2 on page 124: background from the Sun and Moon
	Figure 10.3 on page 127: extinction

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 (crossed 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 which is digitized to 16384 × 1024 pixels. The long dimension 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 4.3 on page 47.

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. This lack of pixels creates some uncertainty in the exact location of an event and can limit the achieved signal-to-noise for this reason.

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. There are two stacks, each with three curved plates. An electron cascade typically produces a gain of 10^7, resulting in measurable charge clouds of 2 to 3 picocoulombs.

The XDL's quantum efficiency is improved with a grid of wires placed above the detector (i.e., in the light path). However, these wires create shadows in the spectrum that are removed during data reduction. The removal of these shadows is imperfect, leading to some systematic effects in the spectra.

The location of charge events is determined by delay lines. The charge cloud 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 electronics that create the digitized time signals also generate pulses which emulate counts located at the edges of the anode, beyond the illuminated regions of the detector. These "e-stims" have several purposes. First, they provide a first-order means of tracking and correcting distortions. They are also used for determining dead-time corrections.

The XDL includes an ion repeller grid. This reduces the background rate by preventing low-energy thermal ions from entering the open-faced detector. However, the grid wires also cast out-of-focus shadows onto the detector, and these shadows create structure in the recorded spectrum that is difficult to remove. At present, the achievable signal-to-noise with the FUV XDL detector appears to be about 30:1.

4.1.2 XDL spectrum response

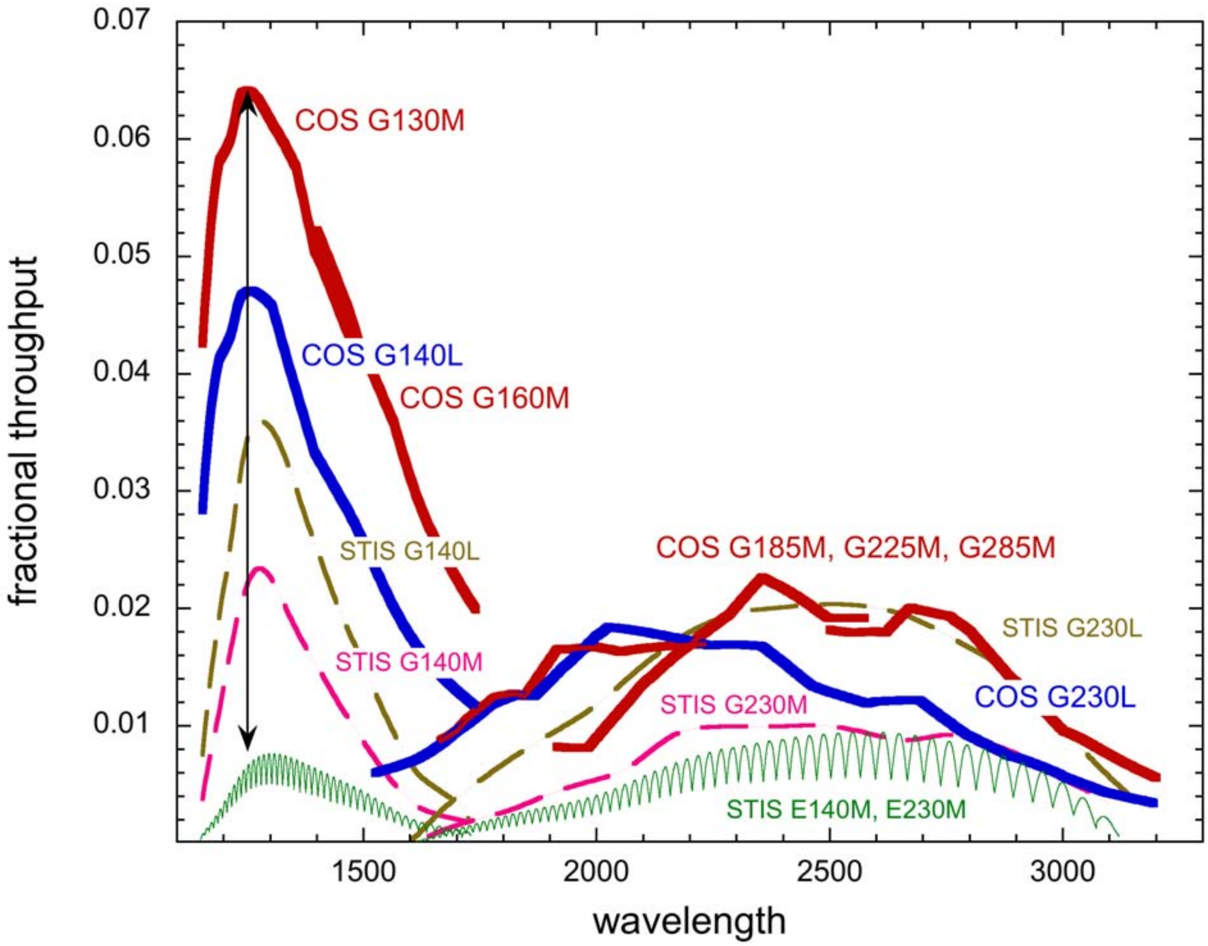
Initial measurements of the throughputs of the COS optical systems indicate that COS will be considerably more sensitive than STIS and earlier generation HST instruments at comparable spectral resolutions. Current estimates for the end-to-end system throughputs of COS are shown in Figure 4.1 on page 44. These estimates are appropriate for a point source centered in the COS primary science aperture (PSA). The throughput and effective area calculations include the throughput of the HST OTA and degradation of the light beam prior to entry into the COS instrumentation due to spherical aberration.

At FUV wavelengths, the peak throughput is 6.5% near 1300 Å with the G130M grating. At NUV wavelengths, the peak throughput is 2.2% near 2350 Å with the G225M grating. For comparison, similar calculations for several STIS MAMA spectroscopic modes covering the same ultraviolet wavelengths are also shown. At FUV wavelengths, the system throughput with the COS medium-resolution mode is at least a factor of 10 higher than for the STIS medium-resolution echelle mode (E140M), as shown by the vertical arrow, and is a factor of ~2 or more higher than for the STIS low-resolution mode (G140L), neglecting STIS slit transmission losses (which are typically 30% or more). At NUV wavelengths, the COS medium-resolution throughput is at least a factor of 2 higher than it is for the STIS medium-resolution echelle mode (E230M) and exceeds the throughput of the STIS low-resolution mode (G230L) below 2200 Å.

The point source sensitivities (S_{λ}) for the COS spectroscopic modes are shown in “Sensitivity” on page 19.

Figure 4.1: Throughputs for COS in the FUV and NUV. The effect of the HST OTA is included.

Also shown are data for STIS in comparable modes. The STIS throughputs do not include slit losses.



4.1.3 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 have been butted, but that leaves 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 – fall on the gap. Without this feature, Lyman-α emission would often trigger excessive count rates in the detector.

It is important to reiterate that the XDL devices do not have physical pixels in the way a CCD, say, does. Instead, a detected event gets assigned to a location in the (x, y) coordinates of the detector based on the delays in the signal that are detected. The XDL detectors are very fast and sensitive, but this method of recording an event carries with it an inherent uncertainty in the location. That uncertainty in location, in turn, limits the achieved signal-to-noise because it is not possible to obtain a flat-field exposure that precisely corresponds to the observed science spectrum.

Because of the orientation of the XDL detector within COS, the detector x axis is in the direction of dispersion, but the sense is opposite to that of the wavelength. In other words, *increasing* x in pixel space corresponds to *decreasing* wavelength. The detector y axis is in the cross-dispersion direction. The FUV XDL detector is shown schematically below.

Below is shown an example of an FUV comparison spectrum obtained during ground testing. Note the difference in x and y axis scales.

Figure 4.2: Example of a COS FUV spectrum.

Shown is a comparison spectrum obtained during ground testing. Because of the test set-up, the comparison lamp fills both the WCA and the PSA, hence the two spectra.

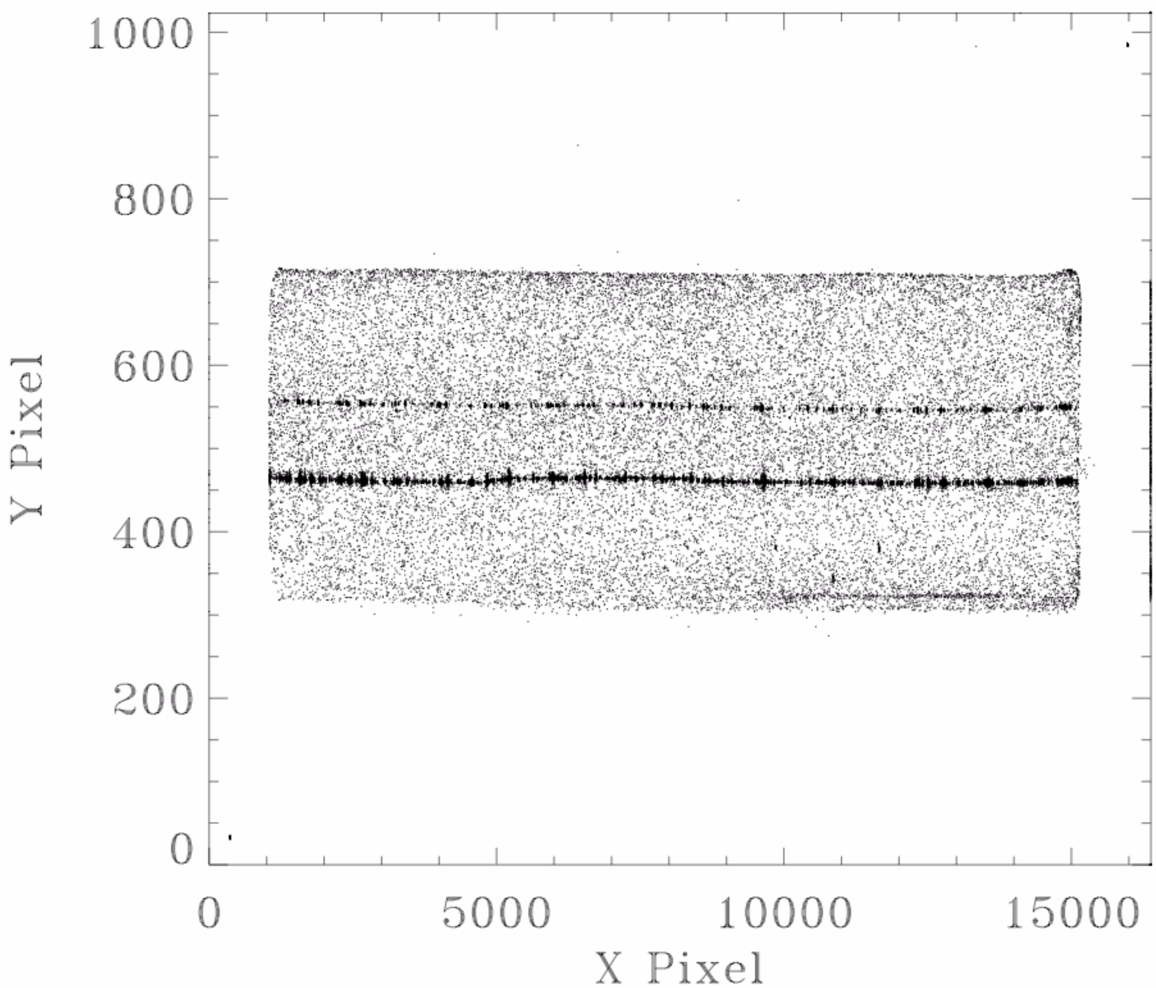
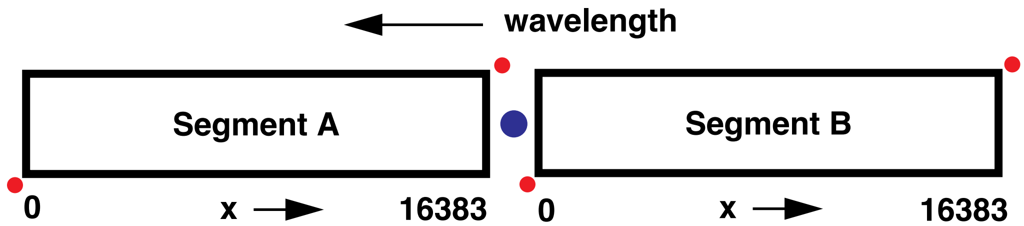


Figure 4.3: The FUV XDL detector, shown schematically.

Note that wavelngth increases in the direction opposite to the detector coordinate system. The red dots show the approximate locations of the e-stims. The blue dot between the segments shows the origin of the detector coordinate system in y, so that y = 0 at the center.



4.1.4 Analog-to-digital conversion

As noted, each detected photon is assigned to a pixel. In ACCUM mode, an area 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 array of the detected photons across the detector.

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. The time is binned into 32 msec increments, but more than one event can be recorded within a single 32 msec time interval.

The dead time associated with the detection electronics of the XDL detector is 7.4 μsec. For more on non-linear effects, see “Non-linear photon counting effects (dead-time correction)” on page 21.

4.1.5 Stim pulses (e-stims)

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, tailed pulses which are capacitively coupled to both ends of the delay line anode. When active, these e-stims emulate counts located at the edges of the anode, beyond the illuminated portions of the detector. These e-stims are useful in several ways. Some of those ways have to do with calibrations and monitoring the instrument, but for observers they provide a means to track changes in image shift and stretch during an exposure and provide a first-order check on the dead-time correction.

Four e-stim rates are available: 0, 2, 30, and 2000 Hz. 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.

4.1.6 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 plate. It measures the gain of the MCP electron amplification. 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.

4.1.7 FUV detector lifetime adjustments

The FUV XDL detector is subject to gradual charge depletion over its lifetime which reduces its sensitivity. The effect is small, but can be localized by, for example, geocoronal Lyman-α hitting the same spot in the detector repeatedly. The requirement for COS is for the effect to be no more than a 1% loss in quantum efficiency after 10^9 events mm^{-1} 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 by offsetting the aperture mechanism.

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 NUV optics focus light through the MgF_2 window onto the Cs_2Te photocathode. A photoelectron generated by the photocathode then falls onto a micro-channel plate (MCP) and the MCP then generates a cloud of about 700,000 electrons. 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. A photoelectron emitted by the photocathode has a 68% probability of being collected by the MCP. The MCP multiplies the detected photoelectron to generate a space charge saturated pulse containing ~7×10^5 electrons.

A single curved MCP manufactured by Litton Electro-Optical Systems is used to multiply photoelectrons generated by the photocathode into a charge pulse containing ~7×10^5 electrons. The channel curvature suppresses ion feedback to the proximity focused photocathode and greatly improves the detector efficiency over a chevron MCP configuration.

4.2.2 MAMA spectral 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 greater.

4.2.3 MAMA non-linearity

As noted in "Non-linear photon counting effects (dead-time correction)" on page 21, the MAMA detector is expected to be essentially linear over the count rate range permissible. For count rate limits, see "Safety First: Bright Object Protection" on page 80.

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 for the wavelength calibration data. This is shown schematically in the following figure. Note that each stripe is separated by 2.80 mm from its neighbor, and there is a gap of 3.70 mm between the reddest science stripe and the bluest calibration stripe.

Shown below is an example of an NUV spectrum obtained during ground testing.

Figure 4.4: Test data for an NUV spectrum.

Shown is a comparison spectrum, with both the WCA and the PSA illuminated by the lamp in this set-up. Note the “science” spectrum on the left and the comparison spectrum each have three stripes.

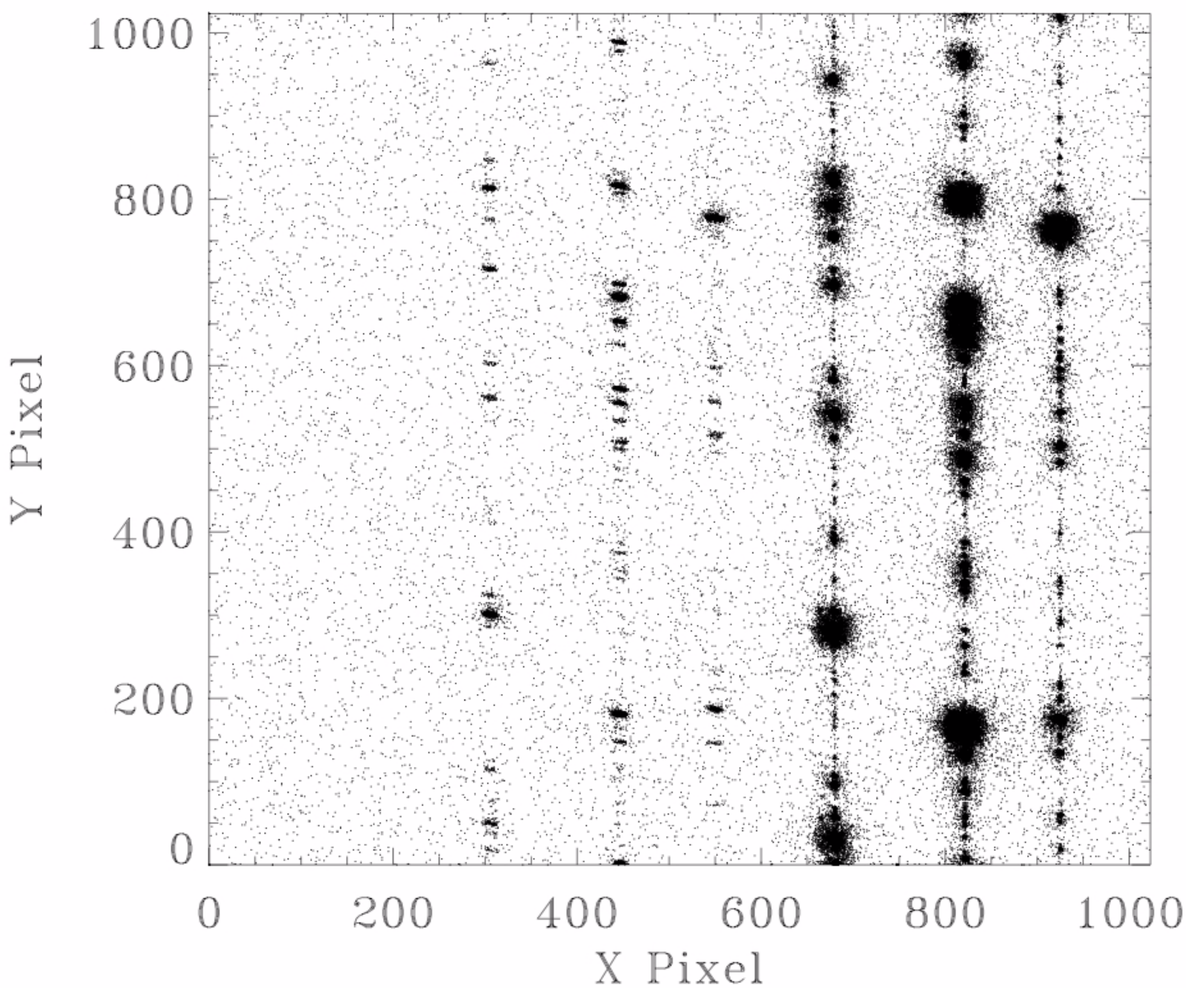
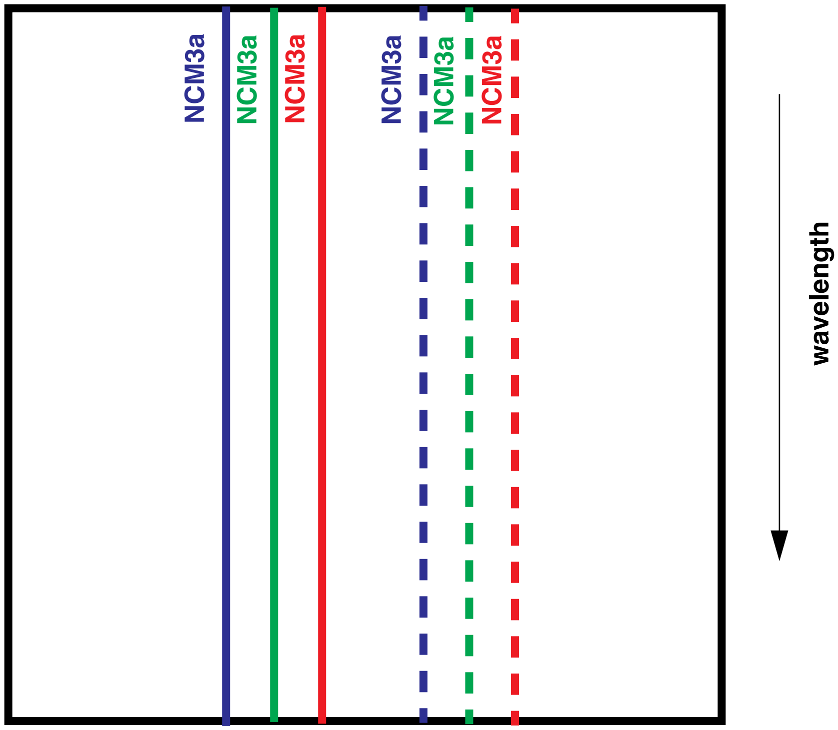


Figure 4.5: Spectrum layout for the COS MAMA.

The blue, and red stripes correspond to the shortest- and longest wavelengths, with green being intermediate. The stripes on the left are the science spectra and those on the right are wavelength calibration spectra.



4.2.5 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.

CHAPTER 5:

Spectroscopy with COS

In this chapter…

This chapter describes COS spectroscopic observations. Both the FUV and NUV channels are used in essentially identical ways, but we point out the differences as appropriate. The discussion includes:

- Characteristics of `TIME-TAG` and `ACCUM` observing modes.
- Details and effects of `BUFFER-TIME` for `TIME-TAG` observing.
- General exposure time considerations.
- Characteristics of the FUV spectrum gap and how to fill it in.
- A description of the Optional Parameters that are a routine part of COS observing and their use in specific situations.
- A practical description of the TAGFLASH (`FLASH=YES`) wavelength calibration feature.
- Using a single segment with the FUV channel.
- Obtaining the highest possible signal-to-noise with `FP-POS`.

- A description of the various calibrations and what, if any, calibration observations the GO may perform.
- The use of the EXTENDED optional parameter.

5.1 Configurations and Optical Elements

To obtain a spectrum, an exposure must use either the FUV or NUV detector configuration. A spectral element, central wavelength, and FP-POS must be chosen for each exposure as well.

Both detectors may be used efficiently within the same visit and the same orbital visibility period as there is very little overhead involved in switching between detectors for consecutive exposures. To do this it is necessary to move the Optical Selection Mechanism to a different grating, but the time needed to do that is the same for any grating, meaning that there is no penalty for switching from the NUV to the FUV or vice versa. For the times needed for these motions, see Chapter 9 on page 109.

Detector memory and buffer-time considerations are the same for both the NUV and FUV when using TIME-TAG mode (see below). However, only two FUV ACCUM images can fit in the on-board memory, whereas up to nine NUV ACCUM images can be accommodated. This means that more time may be needed for detector readout with the FUV than with the NUV in ACCUM mode observing.

5.2 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 3,000 seconds are normally appropriate only for visits with the CVZ special requirement. 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 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 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.

5.3 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.

See “Apertures” on page 23 for more information.

5.4 TIME-TAG or ACCUM?

COS exposures may be obtained in either a time-tagged photon address (TIME-TAG) mode, in which the position and time 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.

3. 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.

Recommendations:

Simply put, TIME-TAG should be used for COS observations whenever possible as it provides distinct post-pipeline advantages for temporal sampling, exclusion of poor quality data, and – for the FUV – better background removal. 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 obtained properly flux-calibrated data, but loss of some continuous time-periods within the exposure 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.

5.4.1 TIME-TAG mode

The preferred mode of data acquisition for both the COS FUV and NUV channels is TIME-TAG mode. The flight software does not make any adjustments for the doppler shift of the spectrum when observing in TIME-TAG mode. However, the doppler correction will be applied during ground processing of the data in the **calcos** pipeline.

An important distinguishing characteristic of COS/FUV TIME-TAG observations is the inclusion of pulse-height information for each individual photon event (the pulse-height distribution, or PHD). Note that no pulse-height information is available for COS/NUV TIME-TAG observations.

Important considerations for BUFFER-TIME

All TIME-TAG observations 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 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 time just estimated and multiply 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. 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. 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.

A conservative value of BUFFER-TIME is recommended (err on the low side) to avoid data loss. You should not merely specify the minimum allowed BUFFER-TIME for all exposures, as this may lead to operational inefficiencies.

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 $\sim 6 \times 10^7$ counts, or about 2 GBits (close to 20% of the solid-state recorder capacity).

Doppler correction for TIME-TAG mode

No 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 distribution 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 to create a PHD later during data processing. See also "Pulse-height distributions" on page 48.

5.4.2 ACCUM mode

ACCUM mode should be used primarily for brighter targets, where the high count rate would fill the on-board buffer memory if the data were taken in TIME-TAG mode.

Doppler- or other corrections for ACCUM mode observations cannot be performed in the post-observation pipeline as the identity of individual photons was 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.

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 (about 1/4 of the full detector area). 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 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

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.

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.

5.5 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 an 18-20 Å gap in the wavelength coverage for the G130M and G160M gratings, for example. 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 others.

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 that half of the detector. If `B` is selected, only segment B of the detector will be activated and used to generate data.

If grating G140L is specified with the 1105 Å wavelength setting, then the value must be 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.

5.6 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 <u>all</u> 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 usage of the default `FLASH=YES` mode of wavelength calibration.

5.6.1 What "TAGFLASH" does during TIME-TAG observations

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 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.

FLASH=YES TIME-TAG sequences provide the highest amount of 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.

The details of how TAGFLASH works

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 and are given in Table TBD.

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 length of time, t_{since}, that has elapsed since the last major OSM move and the start of the science exposure.

The first step is to determine t_{since} for the start of the exposure. Determine the interval (1,2,3,…,n) from Table 5.1 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 5.1 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 5.1 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 x.1, 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 5.2 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*.

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; $0 \le f_j \le 1$

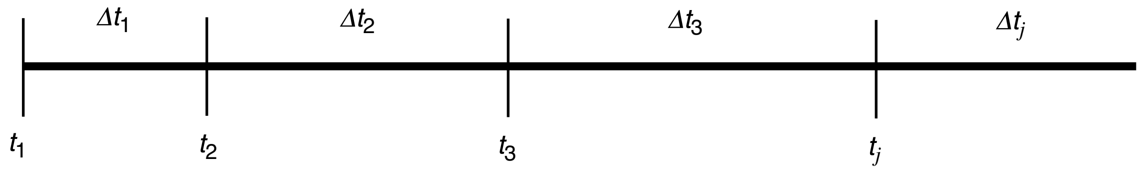
Δt_j = time between scheduled flashes j and $j + 1$.

Rules:

1. At the start of the first science exposure after a major OSM move, intercept the timeline shown in Figure 5.1 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 5.1: 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 5.1 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 5.1: TAGFLASH intervals

Interval times and relative interval times are in seconds.

interval no.	t_{int}	Δt_{int}	f
1	0	600	0.33
2	600	1800	0.20

interval no.	t_{int}	Δt_{int}	f
3	2400	2400	0.33
4	4800	2400	0.33
j	$t_4 + 2400(j-4)$	2400	0.33

Table 5.2: Times of TAGFLASH lamp exposures.

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

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 <120	not allowed	0 to <120	not allowed	0 to <120	not allowed
120 to 200	0	120 to 360	0	120 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	—	—	—	—

5.6.2 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 TIME-TAG Mode 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 OSM offset (FP-POS), 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. 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 FLASH=NO` observations will be less efficient than `FLASH=YES TIME-TAG` observations in terms of on-target utilization of orbital visibility and in terms of resultant wavelength calibration due to possible OSM motions.

5.6.3 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). 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. Note: the default is `FLASH=YES`, which will result in the calibration lamp being flashed rather than commanded continuously on for the exposure. Initially, lamp flash durations are identical to the required default wavelength calibration exposure times, however this identity may be changed.

5.7 Achieving Higher Signal-to-noise

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 default is to use 4 `FP-POS` positions: a nominal position, 1 position toward shorter wavelengths, and 2 positions toward longer wavelengths.

The nominal position is executed first, then the longest-wavelength position, the remaining longer-wavelength position, and finally the shortest-wavelength position.

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 in pipeline processing. Wavelength calibration spectra will automatically be obtained for each FP-POS position.

FP-POS (=AUTO, 1, 2, 3(default), or 4) indicates at which position or positions to take separate exposures. 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 3, 1, 2, 4. FP-POS=4, for example, takes a single spectrum at position number 4. Obtaining exposures at small wavelength offsets from the specified central wavelength aids in the correction of the fixed-pattern defects of the detector. 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.

The values FP-POS=1, 2, 3, 4 or not specified on the proposal will result in the exposure being taken at an offset from the specified central wavelength determined by the value. 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.

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.

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.

5.8 EXTENDED

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. No aspect of on-board data-taking is affected by this parameter.

As noted several times in this document, COS is designed as a point-source spectrograph. Observing extended objects with COS will, at best, produce a spectrum with significant degradation in spectral resolution. 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.

5.9 Calibrations

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

5.9.1 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 will be obtained during the ground-based calibration of COS. These data should be applicable to either single exposures or multiple exposures made with the FP-SPLIT procedure. We expect them to remain valid until charge depletion causes the pixel-to-pixel variations in the detector response to change significantly.

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 may be determined on-orbit with the use of external targets.

Sensitivity

The sensitivity calibration is the relationship between observed count rates and astrophysical flux. It has been predicted measured during pre-launch Thermal-Vacuum testing, and will be calibrated using HST flux-standard stars on-orbit. There are provisions for time-variability in COS sensitivity built into the **calcos** procedures, if necessary. The sensitivity will be monitored regularly in routine science cycle calibration programs.

Background rates

Background dark counts will be subtracted from every observation during the reduction process. The dark count rate can either 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 FUV Wavelength Settings And Ranges

The following tables show the actual 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 the shortest wavelength that is adjacent to the gap so that the indicated wavelength is an actually recorded one.

Table 5.3: Wavelength ranges for FUV gratings

Grating	Nominal wavelength setting	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 – 1789
G140L	1105	<300 – 970	1105 – 2253
	1230	<300 – 1095	1230 – 2378

Table 5.4: Wavelength ranges for NUV gratings

Grating	Nominal wavelength setting	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	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	2435 – 2834	2750 – 3150	
	2950	1650 – 2050	2750 – 3150	
	3000	1700 – 2100	2800 – 3200	
	3360	2059 – 2458		

CHAPTER 6:

NUV Imaging

In this chapter…

6.1 Summary

This chapter describes COS NUV imaging. This includes:

- A description of the optical elements used in imaging mode.
- Some exposure time considerations.
- A description of ways to attenuate the signal from bright objects.
- A description of the complications associated with extended or multiple objects in the imaging field.
- Some numerical characteristics of the imaging PSF.

6.2 Configurations and Optical Elements

COS has a simple NUV imaging mode with a minimal number of options available for the observer. No FUV imaging is possible.

To obtain an image, OSM1 and OSM2 are set to their mirror positions. These are referred to as NCM1 and TA1, respectively. TA stands for target acquisition, and it is anticipated that the greatest use of imaging mode will be for target acquisition (see Chapter 7 on page 79), but science exposures may be obtained as well. When OSM1 and OSM2 are in the mirror positions, a circular image of the sky, 2.5 arcsec in diameter is formed on the NUV MAMA detector.

The NUV imaging mode requires the observed to make only two optical element selections. First, either the PSA or BOA is selected. The BOA provides an attenuation factor of approximately 170 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 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.

6.3 Exposure Time Considerations

All COS exposure times must be an integer multiple of 0.1 seconds (see below for FP-POS=AUTO). 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.

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 for FP-POS=AUTO, the TIME_PER_EXPOSURE is divided equally among the four FP-POS offset exposures, each of which must range from 0.1 to 6,500 seconds.

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.

6.4 TIME-TAG or ACCUM?

Most of the considerations regarding TIME-TAG and ACCUM exposures for NUV imaging are the same as for NUV spectroscopy; the reader is referred to Chapter 6 on page 71 for a discussion. One difference is that, in contrast to spectroscopy in ACCUM mode, no doppler correction is performed on the events in imaging mode.

We caution that particular attention should be given to the expected count rate, since imaging mode is efficient and can lead to high count rates compared to spectroscopic observations.

6.5 Attenuation Considerations

As mentioned at the beginning of this chapter, there are two instrument parameters which must be specified for imaging: PSA or BOA, and MIRRORA or MIRRORB. With attenuation factors of 100 and 25 respectively, BOA and MIRRORB allow one to observe a large dynamic range of target fluxes. For example, the imaging exposure time calculator indicates that a target with a flat spectrum of 1 FEFU will give a total source count rate of 263 counts sec^{-1}, and a rate of about 26 counts sec^{-1} in the brightest pixel, using the PSA and MIRRORA. These are both well within acceptable NUV detector safety limits. With the BOA, one could image a target with a flux of 100,000 FEFU at the same count rate. With both the BOA and MIRRORB, the flux becomes 2.5×10^6 FEFU.

6.6 Extended Objects

As noted in Chapter 7 on page 79, for a centered point source approximately 95% of the light passes through the aperture. An extended source will have a changing level of transmission as a function of radius from the center of the aperture, out to a radius of about 2 arcsec. Standard pipeline processing will not be able to reconstruct the image with high accuracy for the case of spatially variable extended objects, or for multiple point sources within a radius of 2 arcsec.

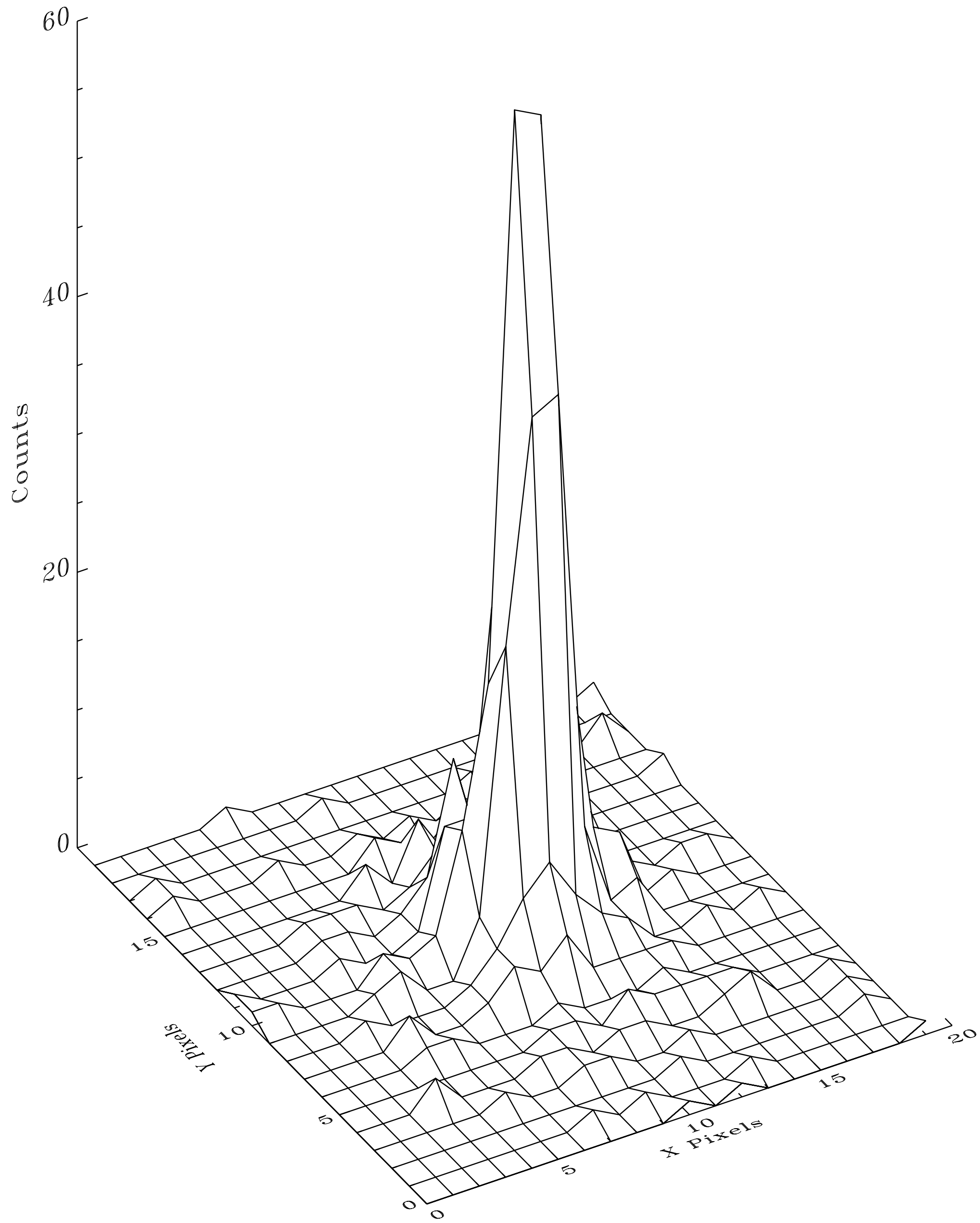
The use of MIRRORB presents another complication with respect to imaging multiple sources. MIRRORB actually produces two images: a primary image from the first surface of the order-sorter filter, and a secondary image from the second surface of the filter. Thus, the image will contain “double sources.” Ground testing shows that the secondary image will contain ~1/2 the flux of the primary image. Due to the slight wedge-shape of the order-sorter filter, the secondary image projects ~20 pixels in the $-y$ (dispersion) 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.

6.7 Image Characteristics

Figure 7.1 shows an image of a point source obtained in ground testing. A 2-dimensional Gaussian fit to this PSF has the following characteristics:

FWHM (x-direction): 2.47 pixels = 58.1 mas
FWHM (y direction): 2.29 pixels = 53.8 mas
Fraction of light in brightest pixel: 10.1%.

Figure 6.1: Two-dimensional PSF for COS.



CHAPTER 7:

Target Acquisitions

In this chapter…

7.1 Planning a COS Acquisition

This chapter describes how to plan COS acquisitions. COS offers several very different methods for locating your source on the sky and centering it in the aperture you'll use. The information here assumes that the object to be acquired is a point source. The COS acquisition software was written to work on point sources (objects less than about 0.1 arcsec in diameter). COS is not well-suited to observing extended objects, but if you need to acquire something other than a point source, then we recommend that you start by acquiring a point source that is near to your target and then offsetting, using a POSTARG.

The acquisition of your target has three goals:

- Isolation of the specific object of interest if there are other sources nearby.
- Accurate centering of the target to get the best overall throughput and adequate photometric accuracy.
- Precise centering of the target in the along-dispersion direction to ensure an accurate wavelength scale.

You will also need to ensure that your target is safe to acquire; i.e., that it itself does not produce too high a count rate for the COS detectors nor do any nearby objects.

As we show below, the quickest and simplest acquisitions use `ACQ/IMAGE` mode and the NUV detector, no matter which detector one wishes to obtain the science spectrum with. The COS acquisition ETC allows you to estimate accurately the acquisition count rates achieved for different kinds of sources. Acquisitions of faint sources are likely to use the `PSA` and `MIRRORA` to get the best throughput, but if the count rate is estimated to be above limits then one can choose to use `MIRRORB`, or the `BOA`, or both, to attenuate to various degrees.

An observer also has the choice of acquiring an object using its dispersed light. A dispersed-light acquisition is relatively slow and less precise than an acquisition done with `ACQ/IMAGE`, but can be done for any object that is itself safe to observe.

7.2 Safety First: Bright Object Protection

Photon-counting detectors are vulnerable to physical damage if hit 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 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.

7.2.1 FUV bright object protection

There are five levels of protection for COS FUV:

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 are set at 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.
2. At the next level, within COS the "Take Data Flag" is monitored during an exposure. If an event occurs that causes the TDF to drop (such as loss of lock), then the COS external shutter is commanded closed.

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 takes the FUV spectrum, collapses it in the cross-dispersion direction to create a one-dimensional array, and then bins the data by 4096 pixels at a time. These bins are then examined to see if they exceed a threshold value. The limit set is 75 events sec^{-1} per resel.
4. Global rate monitoring is next. The COS flight software monitors the total event rate for both FUV detector segments. If that rate exceeds a threshold, the high voltage to that segment is shut off and the external shutter is closed.
5. At the highest level, the instrument is protected by the software sensing an overcurrent condition in the high voltage; this shuts down the detector entirely.

7.2.2 NUV bright object protection

The same five protections also apply to the NUV MAMA with two exceptions. With the MAMA, the local count rate check is performed by taking a short exposure, with the flight software then examining that exposure for groups of pixels with excessive counts. For the global rate monitoring, the software checks to see if the total count rate exceeds 77,000 in 0.1 sec and if so the high voltage to the MAMA is turned off. The highest level of protection is done by the detector electronics, which performs a Bright Scene Detection. If the total counts within 0.138 msec exceeds 17,000, then the MAMA high voltage is turned off and the external shutter is closed.

Note that all of the higher level safings that shut off high voltage and close the external shutter also turn off any calibration lamps that may be on.

7.2.3 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 of two kinds – global and local – and both limits must be adhered to. These limits were provided in “COS Quick Reference Guide” on page 36, in the discussion of the detectors. They are:

Table 7.1: 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
	irregular	global	6,000 per segment
		local	40 per resel
NUV	predictable	global	30,000 per stripe
		local	75 per pixel
	irregular	global	12,000 per stripe
		local	75 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.

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.

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; this is described below.

7.2.4 Risks from nearby objects

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

- Given errors in the initial pointings of objects with HST, even with good coordinates, an unintended source may end up in the 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 a particular risk if the BOA is the aperture in use because a fainter-but-still-bright object could end up in the PSA. An very bright source could possibly fall in the BOA when it is the PSA that is in use, of course.
- 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 6.5 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.

7.3 How Accurate an Acquisition Do I Need?

7.3.1 Centering accuracy and photometric precision

Figure 7.1 on page 84 and Figure 7.2 on page 85 show the HST point-spread function (PSF) at the nominal position of the COS aperture. Note that this is an aberrated PSF that includes spherical aberration. The COS Primary Science Aperture (PSA) is 2.5 arcsec in diameter, and it passes 95.4% of the total flux from a point source when that source is perfectly centered.

Figure 7.1: 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. These images were calculated with TinyTim and are for 1450 Å (left) and 2550 Å (right). Note that these images are stretched to show the light in the outer regions. The energy contained within the 2.5 arcsec PSA (red circle) is 95.4%.

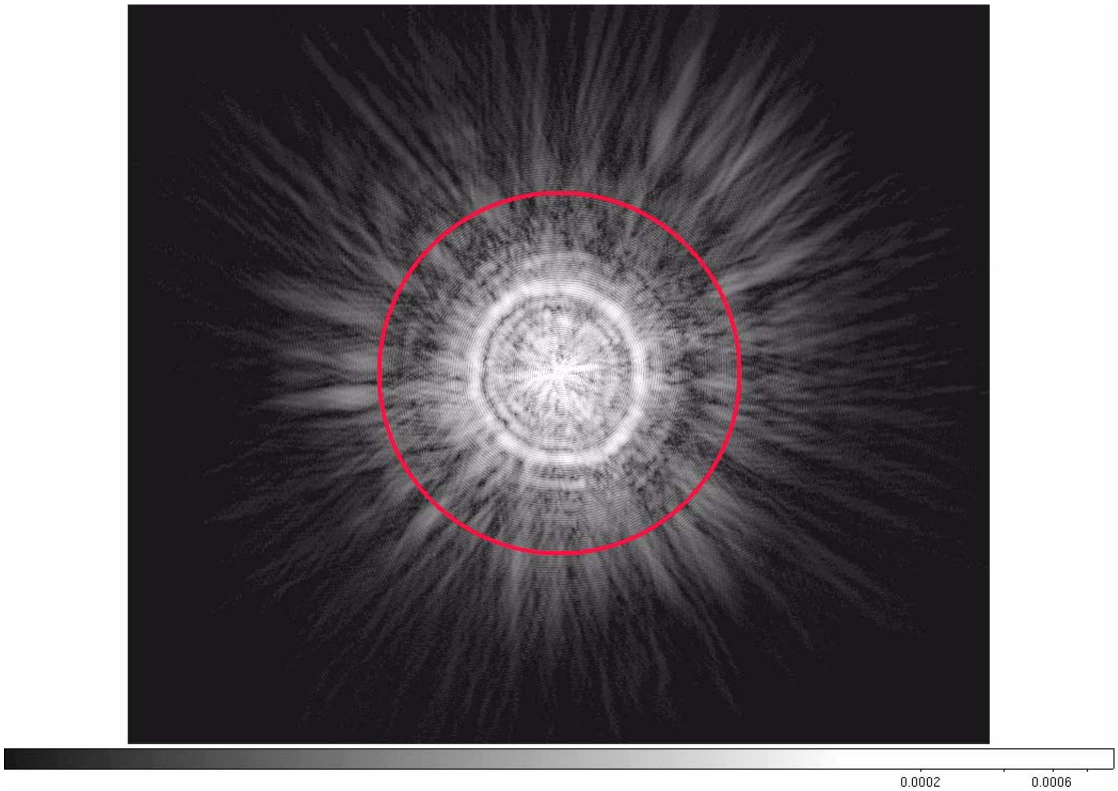


Figure 7.2: The HST Point Spread Function at the COS PSA for 2550 Å.

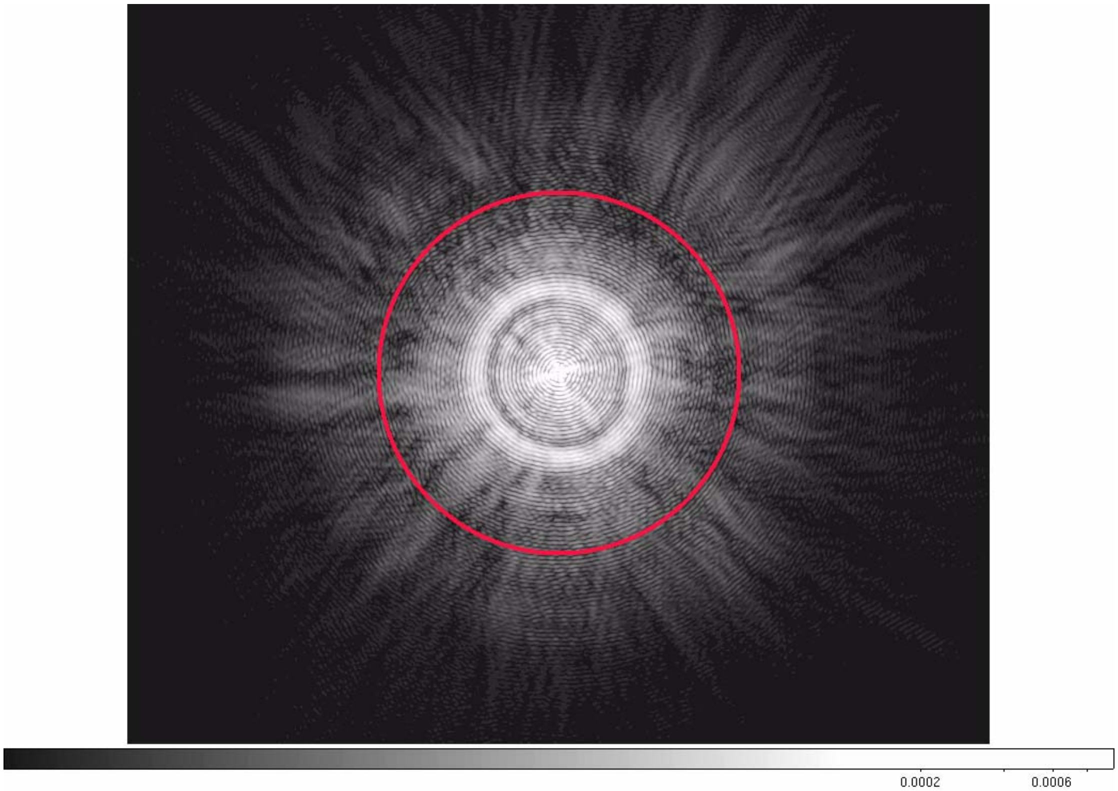


Figure 7.3: Relative transmission of the COS PSA at 1450 and 2550Å.

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 and 2550 Å. Note that the absolute transmission with a point source centered is approximately 95.4%.

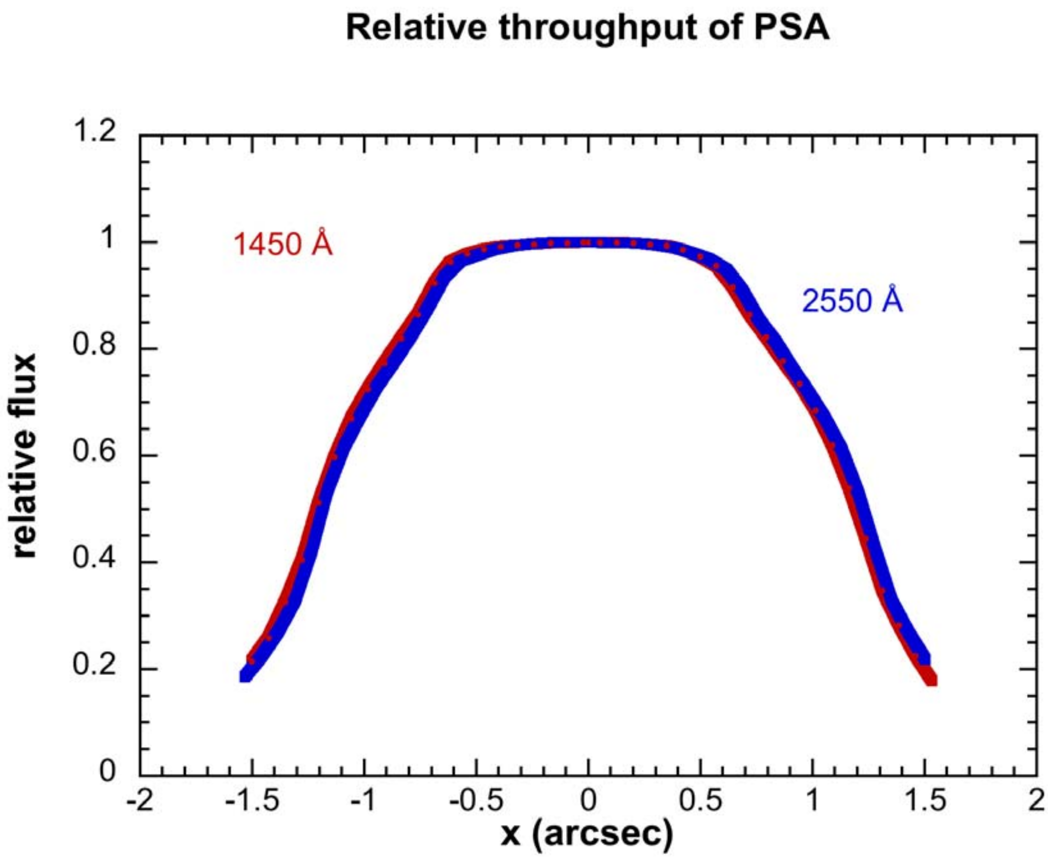


Figure 7.3 and shows the *relative* transmission of the PSA as a function of displacement of a point source from the aperture center, computed using the PSFs in Figure 7.1 on page 84 and Figure 7.2 on page 85. Obviously any mis-centering of a source leads to some loss of throughput, but that loss is 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 centering errors.

7.3.2 Centering accuracy and the wavelength scale

If an accurately 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. If we then wish to center to within 1 pixel, that corresponds to about 1/40 arcsec (the actual plate scale is 42.3 NUV pixels per arcsec). Simulations of COS acquisitions have been calculated that show that a centering precision of about 0.02 arcsec is, in fact, feasible.

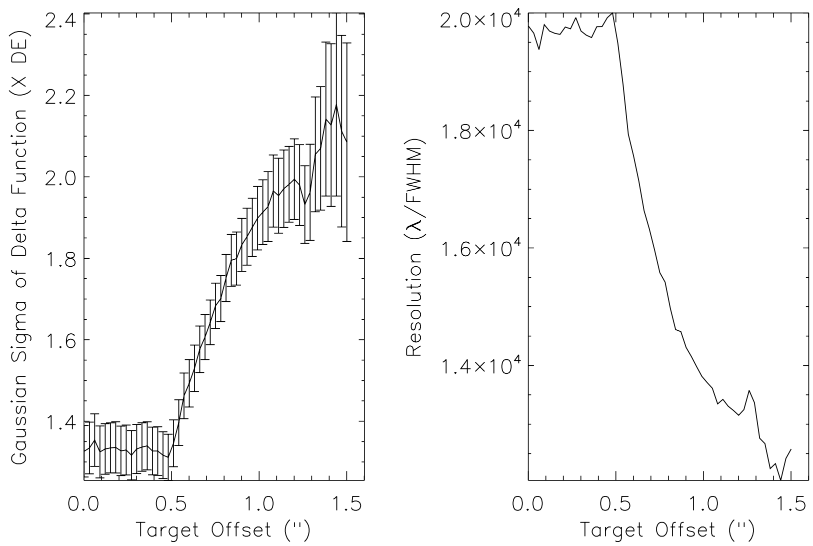
Dispersed-light acquisitions, whether with the FUV or NUV detector, are unlikely to achieve such a high pointing precision without requiring a substantial amount of time. This is because dispersed-light acquisitions require movements of HST, and those need finite times. Simulations of dispersed-light acquisitions have used 0.1 arcsec as a centering tolerance and can achieve that in reasonable times, as 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 absorption lines that can serve to establish relative velocities.

7.3.3 Centering accuracy and spectroscopic resolution

The plot below shows the effect on spectroscopic resolving power of displacing a point source in the PSA. The measurements were made during ground tests on grating G130M, and the results agree with calculations done from ray tracing. The net effect is that there is no loss of spectroscopic resolution with a displacement as large as 0.5 arcsec.

Figure 7.4: Spectroscopic resolving power versus source displacement in the aperture for grating G130M.



7.4 COS Acquisitions and Coordinate Accuracy

The strategy you choose for your COS acquisition will depend on the accuracy of your target coordinates. Unlike STIS, COS has only its small aperture to work with. Given uncertainties in the initial pointing of HST, errors in your coordinates should be 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, your acquisition should start with an acquisition in ACQ mode. In ACQ 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), your target will be found if it is within about 5 arcsec of the initial pointing. There is more on this below.

7.5 Imaging Acquisitions

We anticipate that most observers most of the time will 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 no time penalty in switching from an NUV acquisition to an FUV spectrum.

In ACQ/IMAGE mode the following steps occur:

1. The Pt-Ne calibration lamp is turned on and the location of its image is measured. This then determines the location of the science aperture (either the PSA or the BOA), given the known offset between the two. This operation is done with the external shutter closed.
2. The shutter is then 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.
3. A 9 × 9 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.
4. 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.

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 7.1: Exposure time needed for ACQ/IMAGE mode.

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

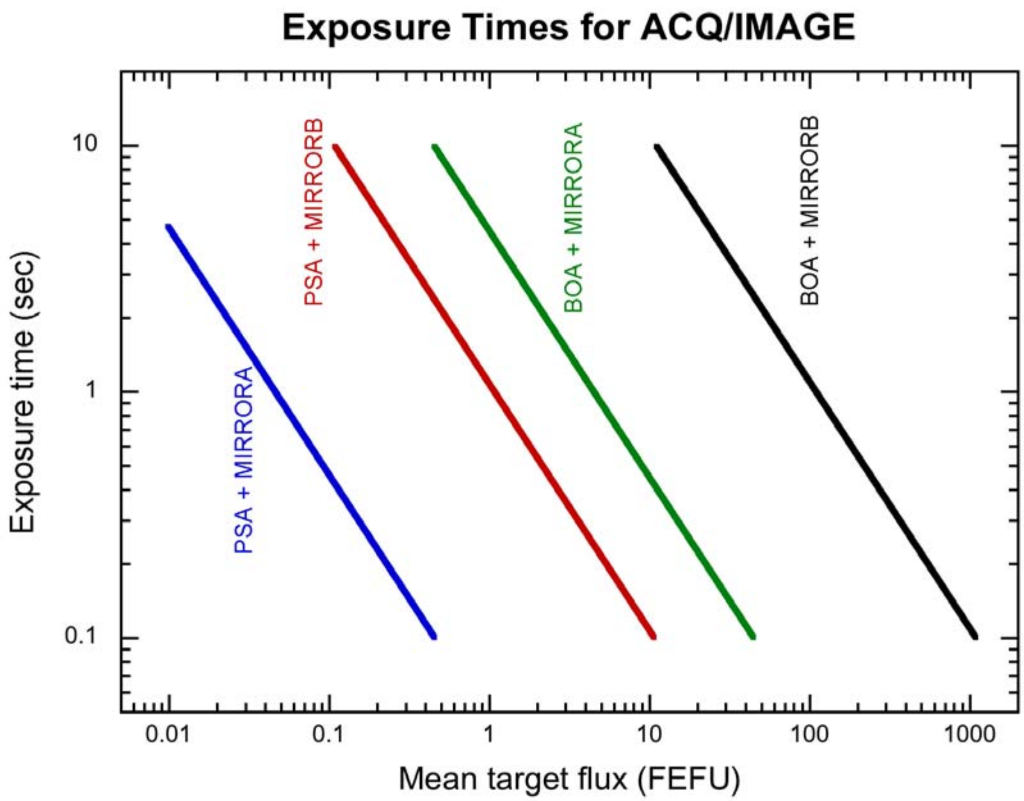


Figure 7.1 on page 90 shows acquisition exposure times needed to reach S/N = 40 for various combinations of mirrors and apertures. A flat source spectrum is assumed.

7.5.2 Imaging acquisitions with mediocre coordinates

If you are not confident that your source will fall within the aperture after the initial pointing by HST, 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 "NUV Dispersed-Light Acquisitions" on page 96 below), except that the spectral element is chosen to be `MIRRORA` or `MIRRORB`. Use of `SCAN-SIZE=3`, for example, is adequate to find the object if it falls within 3 arcsec of the aperture center.

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, dispersed-light acquisitions achieve pointing precision of about 0.1 arcsec, which is not as good as `ACQ/IMAGE`.
- In dispersed light, airglow (or geocoronal) emission features fill the aperture and 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.

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 Chap5xx). 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 an acquisition

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

1. The Pt-Ne comparison lamp is turned on so that the position of its image can be found. The known offset between the calibration and science spectra then indicates the location of the aperture on the detector.

2. A spiral search is then 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. The resultant $n \times n$ image is then analyzed and the telescope is moved to center the object.
3. A peak-up in the cross dispersion direction is performed to improve the centering (PEAKXD).
4. 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: The spiral target search

The initial target search is done with the ACQ command for the COS/FUV configuration. 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. This should be the same as the grating and wavelength to be used for the science spectrum that follows.
- 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.

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.

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 have all been 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 any one dwell point. That threshold is set at 10% and is not selectable by the observer.

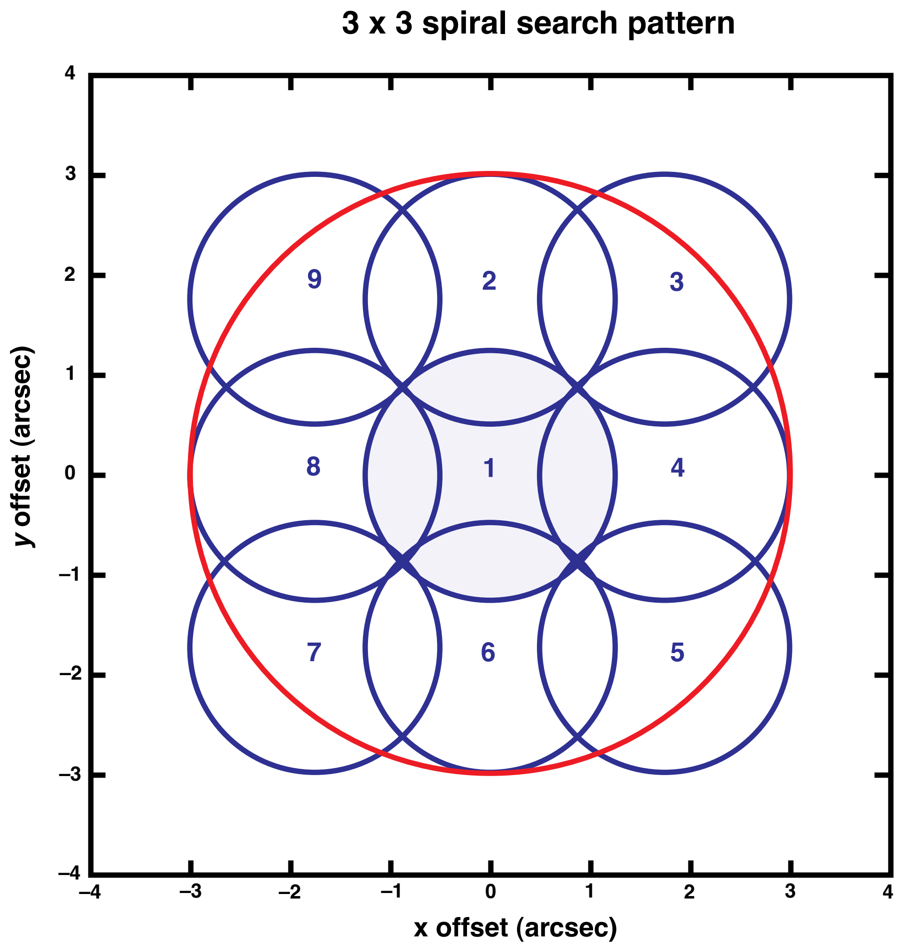
A variation on `FLUX-WT` is to use `CENTER=FLUX-WT-FLR`. In this case a floor is subtracted from all the array's data points before the centroid is computed, and that floor is taken as the minimum number of counts seen in any one dwell point. `FLUX-WT-FLR` has the advantage of getting rid of background 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.

The methodology used to locate the spectrum is to collapse it in the x direction, to make use of the relatively few counts that have been detected. It is for this reason that `ACQ/SEARCH` centers the spectrum well in the cross-dispersion direction, but not as well along the dispersion.

Figure 7.1: 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.

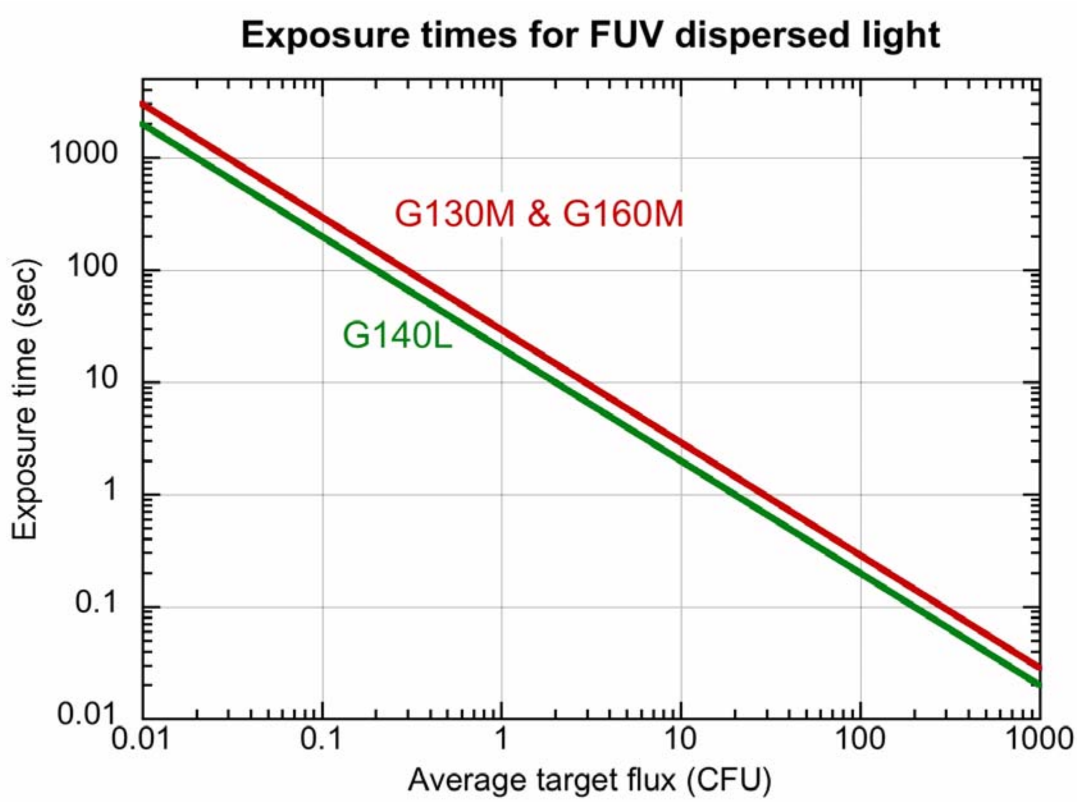


Exposure times

Figure 7.2 on page 95 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.

Figure 7.2: 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

This is being written before we have on-orbit experience with COS and so we rely 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 mode except that no movement of the telescope occurs. As with an ACQ, 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.

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

7.6.4 PEAKD: Peaking up in the along-dispersion direction

A COS spectrum as imaged onto the FUV detector has some aberrations, but is still basically a line. 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 we 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 except that instead of a spiral, a linear motion of HST is made to integrate the spectrum. As with ACQ, 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. The value of STEP-SIZE chosen clearly depends on the precision of centering desired. If the initial ACQ is good to 0.3 arcsec (see above), then a 9-point PEAKD with STEP-SIZE=0.07 should find the object reliably and center it to a fraction of that STEP-SIZE.

As with ACQ, 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 use FLUX-WT if NUM-POS=3, but uses FLUX-WT-FLR if NUMPOS=5, 7 or 9.

Each execution of ACQ/PEAKD needs about 2 minutes total, even for fairy faint sources (1 CFU) with G130M.

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` 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*.

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 use `POSTARG` to 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.

CHAPTER 8:

Observing Strategy and Phase I

In this chapter…

8.1 Designing a COS Observing Proposal

Here we describe the sequence of steps you will need to follow when designing your STIS Phase I observing proposal. The process is likely to be iterative. The basic sequence of steps in designing COS observations are:

- 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 roll-over, and bright-object limits.
- Identify an additional non-science (target acquisition, peakup, and calibration) exposures required.
- Determine the total number of orbits required, taking into account all overheads.

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
- 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 needed
- Signal-to-noise requirements
- Wavelength and photometric accuracy required.

Spectroscopy

For spectroscopic observations, the base configuration needed is detector (configuration), operating mode (TIME-TAG or ACCUM), aperture, grating (spectral element), central wavelength, and wavelength dither offset (FP-POS). See chapter 8 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 TIME-TAG BUFFER-TIME 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 Exposure Time Calculator 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, "Exposure-Time Calculator (ETC)" on page 119, where an explanation of how to calculate a signal-to-noise ratio and a description of the sky backgrounds are provided. To assess whether you are close to the brightness, signal-to-noise, and dynamic-range limitations of the detectors, refer to "Bright-Object Protection" 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

For `ACCUM` observations: NUV `ACCUM` exposures require 2 Mbytes of on-board storage. FUV `ACCUM` exposures require 8 Mbytes.

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, "Overheads and Orbit Usage Determination" on page 109 when performing this step.

At this point, if you are happy with the total number of orbits required, you're done! If you are unhappy 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

8.2.1 Limiting magnitudes and bright object limits

Micro-channel plates are susceptible to degradation if exposed to bright sources of ultraviolet light. 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, 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 ~200 ct s^{-1} pix^{-1} (~1800 ct s^{-1} $resel^{-1}$). The NUV global count rate limit can be increased slightly at the expense of Doppler compensation during the course of the exposure.

Table 2-2 contains approximate estimates of the bright limit fluxes for the medium- and low-resolution COS modes at several wavelengths using the count rate limits listed in Table 2-1. 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 2-2.

Table 8.1: COS Count Rate Limits

Detector	Mode	Type of limit	Limiting count rate[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	2 per pixel
	ACCUM	global	170,000
		local	200 per pixel

1. Entries are counts per second.

Table 8.2: 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	9600 11.3	1300 13.5	1900 13.0	780 13.7
	1600	16,000 10.1	3100 11.9	1900 12.3	
NUV	1800	420,000 6.3	34,000 9.0	26,000 9.0	6800 11.4
	2300	170,000 9.0	19,000 11.4	24,000 10.3	
	2800	120,000 6.2	28,000 7.7	20,000 6.8	

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

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.

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/roadmap.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, 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.

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.
- A proposal with detailed determinations 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 need 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 need 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 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.

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 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 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.

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.

Step 4: 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 R2k mode a single exposure should suffice to record all the useful spectrum that can be obtained, but in R20k mode the bandpass recorded can be limited, especially in the near-UV.

Are predicted count rates safe?

See Section 7.2, "Safety First: Bright Object Protection," on page 80.

8.5 Parallel Observations While Using COS

As this is written plans for using COS in parallel with other instruments on HST are being developed. Because the COS aperture is so 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.

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.

CHAPTER 9:

Overheads and Orbit Usage Determination

In this chapter…

9.1 Summary

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.

Please note that the information provided here on overheads is illustrative and meant as an aid to approximation. Proposers are urged to use APT and its capabilities to derive accurate determinations of these times rather than the rougher numbers presented here.

9.2 Generic Observatory Overhead

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 (also 6 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	6 min per orbit
Spacecraft movements	Offset motion > 10 arcsec (1.5 arcmin max)	60 sec
	Offset > 1 arcsec up to 10	30 sec
	Offset < 1 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.

As there are setup overheads associated with moving and seating the COS OSM assemblies, you must add 60 seconds to the values in Table 9.2 and Table 9.3 to obtain the complete overhead required for the movement.

Note that all COS visits start with OSM1 at the G130M position and OSM2 at the G185M position.

Table 9.2: Overhead Times for Motions Between OSM1 Spectral Elements

Movement times (sec)[1]	to G140L	to G130M	to G160M	to NCM1
from G140L	—	96	138	53
from G130M	102	—	50	54
from G160M	144	54	—	97
from NCM1	59	47	92	—

1. Add 60 sec to each indicated time to get the total time needed.

Table 9.3: Overhead Times for Motions Between OSM2 Spectral Elements

Movement times (sec)[1]	to G230L	to G185M	to G225M	to G285M	to MIRRORA	to MIRRORB
from G230L	—	147	78	114	43	37
from G185M	142	—	74	40	107	113
from G225M	73	79	—	46	38	44
from G285M	108	45	41	—	74	80
from MIRRORA	38	112	43	79	—	9
from MIRRORB	32	119	50	85	15	—

1. Add 60 sec to each indicated time to get the total time needed.

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, "Target Acquisitions" on page 79. 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 exposure time, which 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 on page 111 and table 9.3 on page 111.

NUV ACQ/PEAKXD: The overhead is 70 seconds plus exposure time. Add the grating change overhead from table 9.2 on page 111 and table 9.3 on page 111.

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 on page 111 and table 9.3 on page 111.

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 Tables 10.2 and 10.3.

FUV ACQ/PEAKXD: Overhead is 80 seconds plus exposure time. Add the grating change overhead from table 9.2 on page 111 and table 9.3 on page 111.

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 on page 111 and table 9.3 on page 111.

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 10.4 lists these additional overheads.

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 10.4; if a grating change has occurred from the previous exposure add 60 plus the appropriate values from Tables 10.2 and/or 10.3, if a central wavelength change is made add the appropriate value from Table 10.4, 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.

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[1]	see table 9.2 on page 111		see table 9.3 on page 111	
Central wavelength change	70		73	
FP-POS forward[2]	1		1	
FP-POS backward[2]	68		68	

Overhead times (sec)	FUV		NUV	
	TIME-TAG	ACCUM	TIME-TAG	ACCUM
Aperture change	8		8	
SEGMENT reconfiguration	330		N/A	
Memory readout[3]	110	108[3]	110	48[3]

1. As noted above, add 60 sec to each value in Table 9.2 and Table 9.3.
2. "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.
3. 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.

9.6 Examples of Orbit Estimates

9.6.1 Example 1: 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 9.5: 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 + 60 + 112 + 110 + 1200 = 1518 sec = 25.3 min	Generic NUV `TIME-TAG` setup; change from `MIRRORA` to `G185M` [60+112]; no central wavelength change (default value); no `FP-POS` change (3=default); no aperture change from PSA; no `SEGMENT` change; TIME-TAG memory readout; exp time

Action	Time required	Comment
NUV G185M at 1812 Å, TIME-TAG, FLASH=YES, FP-POS=3, 600 sec exp.	36 + 73 + 110 + 600 = 783 sec = 13.1 min	Only change central wavelength, so generic NUV TIME-TAG exposure setup; no grating change; central wavelength change [73 sec]; no FP-POS change; no SEGMENT change; TIME-TAG memory readout; exp time
Total science time	38.4 min	
Total time used in orbit	51.4 min	

9.6.2 Example 2: 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 9.6: 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.	60 + 54 + 107 + 9×(20+10) = 270 sec = 2.5 min	COS starts at G130M on OSM1, so move to NCM1 requires 60+54 sec; OSM2 home position is G185M, so move to MIRRORA takes 107 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 + 60 + 43 + 110 + 1200 = 1449 sec = 24.2 min	Generic NUV TIME-TAG setup; change from MIRRORA to G225 [60+43]; no central wavelength change (default value); no FP-POS change (3=default); no aperture change from PSA; no SEGMENT change; TIME-TAG memory readout; exp time

Action	Time required	Comment
FUV G130M at 1309 Å, TIME-TAG, FLASH=YES, FP-POS=3, 600 sec exp.	71 + 47 + 110 + 600 = 838 sec = 14.0 min	Switch from FUV to NUV adds no overhead (OSM2 not moved); generic FUV TIME-TAG setup; OSM1 move from NCM1 to G130M; no central wavelength change; no FP-POS change; no SEGMENT change; TIME-TAG memory readout; exp time
Total science time	38.2 min	
Total time used in orbit	51.0 min	

9.6.3 Example 3: 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 9.7: 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) = 220 sec = 3.7 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, 600 sec exp.	71 + 60 + 102 + 330 + 110 + 600 = 1273 sec = 21.2 min	Generic FUV TIME-TAG setup; OSM1 grating change (60+102); no central wavelength change; no FP-POS change; SEGMENT reconfiguration change; TIME-TAG memory readout; exp time
Total science time	21.2 min	
Total time used in orbit	31.9 min	

9.6.4 FUV TIME-TAG with BOA and FLASH=NO

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 9.8: 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, 3000 sec exp.	71 + 60 + 112 + 68 + 8 + 110 + 1800 sec = 2229 sec = 37.1 min	Generic FUV TIME-TAG setup; NUV to FUV adds no overhead; change from NCM1 to G160M [60+92]; no central wavelength change (default value); non-preferred direction FP-POS change [68 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 + 8 + 110 = 199 sec = 3.3 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; no SEGMENT change; TIME-TAG memory readout; exp time
end of orbit 1		
Guide star re-acquisition	6 min	required at start of additional orbit
FUV G160M at 1600 Å, TIME-TAG, BOA, FLASH=NO, FP-POS=1, 2400 sec exp.	71 + 8 + 110 + 2400 = 2589 sec = 43.2 min	Generic FUV TIME-TAG setup; continue at same OSM1 position, same central wavelength and FP-POS; aperture change to BOA [8 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.		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 to BOA [8 sec]; no SEGMENT change; TIME-TAG memory readout; exp time

Action	Time required	Comment
Total science time	38.4 min	
Total time used in orbit	51.4 min	

CHAPTER 10:

Exposure-Time Calculator (ETC)

In this chapter…

In this chapter we discuss the COS exposure time calculators, which are essential tools for planning your observations. We show the backgrounds which contribute to the spectrum or image, and discuss the various choices of levels available in the ETCs. We also discuss extinction, which can have a large effect on the observed flux from a target.

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. These are the imaging ETC, the spectroscopic ETC, and the target acquisition ETC. 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 compare against 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 Chapter 2xx). 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 time for both imaging and spectroscopic acquisitions. Target acquisition is described in Chapter 7xx.

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 the 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. 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 lists the dark current and read noise characteristics of the COS detectors:

Table 10.1: Detector background count rates for COS

Detector:	FUV XDL	NUV MAMA
Dark rate (counts sec^{-1})	0.5 per cm^2 7.5×10^{-7} per pixel 4.5×10^{-5} per resel	34 per cm^2 2.1×10^{-4} per pixel 1.9×10^{-3} per resel
Read noise	0	0

Note that, due 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.

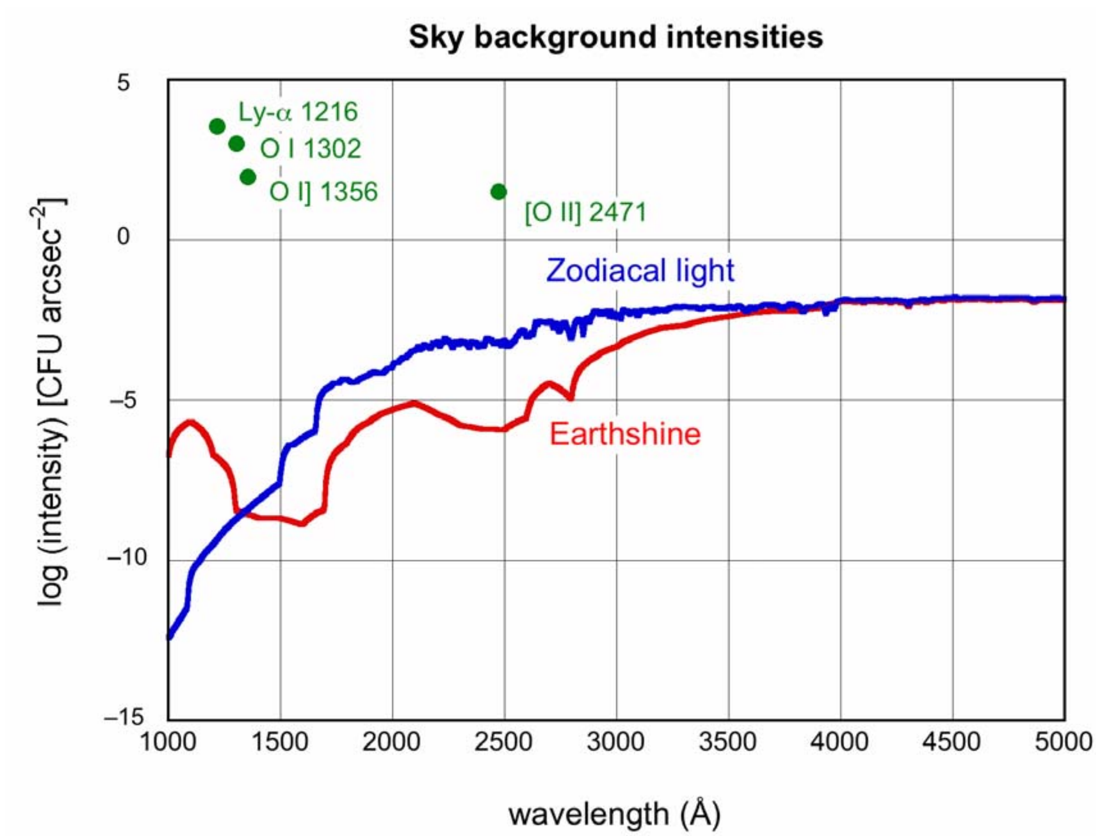
10.3.2 Earthshine

The Earthshine surface brightness corresponding to the "high" level is shown in Figure 5.1xxx. 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.

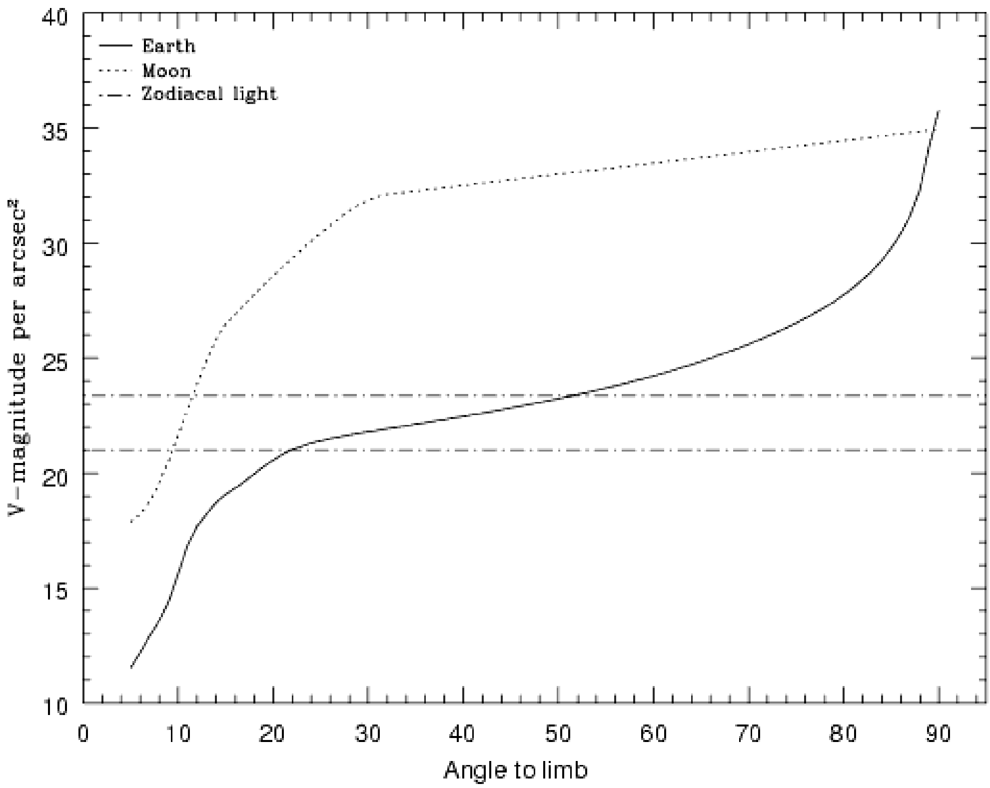
The Earthshine is for a target which is 24 degrees from the limb of the sunlit Earth. Use Figure 5.2xx to estimate background contributions at other angles. The Zodiacal contribution corresponds to a helio-ecliptic latitude and longitude of 30° and 180°, respectively, which corresponds to $m_V = 22.7$ 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 on page 128 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 air glow 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 on page 128 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 6.1×10^{-14} and 9.2×10^{-13} erg sec^{-1} cm^{-2} arcsec^{-2}, where 1 Rayleigh = 10^6 photons sec^{-1} cm^{-2} per 4π steradians) 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 5.7×10^{-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 slit in the spectrum and spatial directions. For the FUV modes, the slit width is approximately 115 pixels, or about 1.1, 1.4, and 9.9 Å for G130M, G160M, and G140L, respectively. For the NUV modes, the slit width is approximately 106 pixels, or about 3.6, 3.6, 4.2, and 41 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.

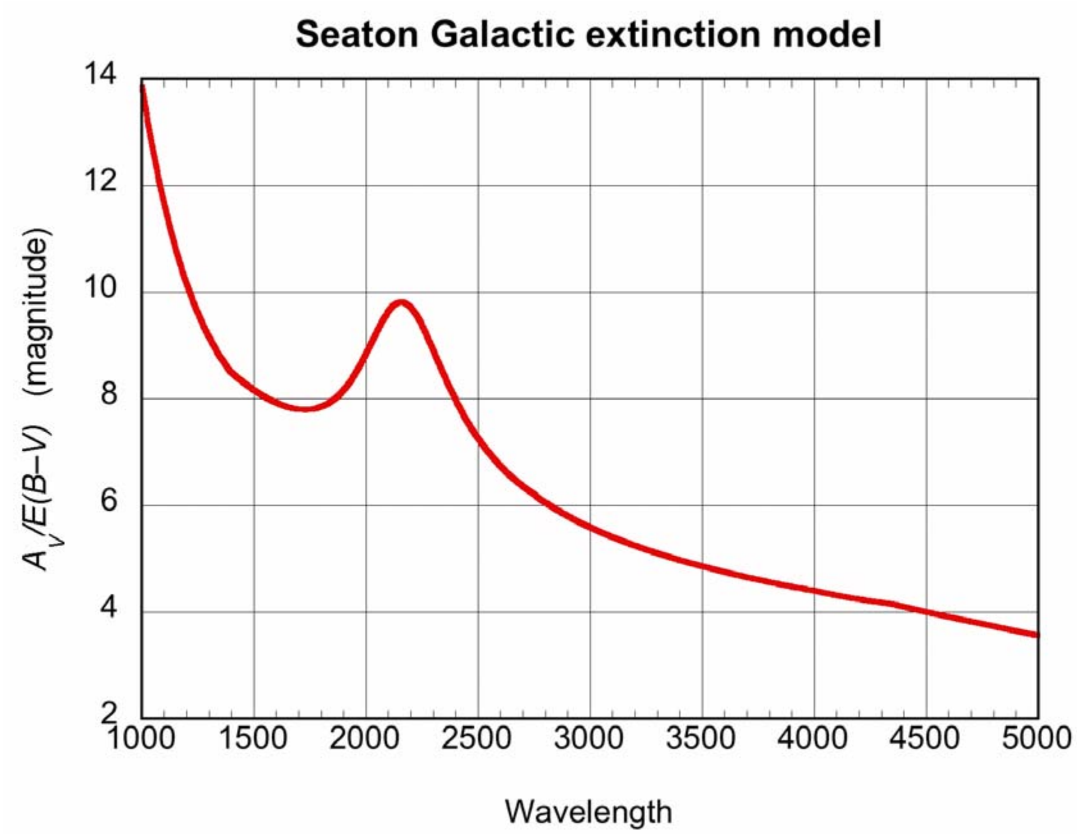
10.4 Extinction Correction

Extinction can dramatically alter the counts expected from your source, particularly in the ultraviolet. Figure 10.3 on page 127 shows $A_V/E(B\text{–}V)$ values applicable to our Galaxy, taken from Seaton (1979, MNRAS, 187, 73P). 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 $A_V/E(B\text{–}V)$ 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, using Seaton's 1979 Galactic model.



10.5 Tabular Sky Backgrounds

Below is a table of the *high* sky background numbers as plotted in Figure 10.1 on page 123, 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 5.2xx 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 on page 130.

Table 10.2: Earthshine and zodiacal light in the COS PSA.

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.

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

Wavelength (Å)	Earthshine	Zodiacal Light	Total
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

Table 10.3: 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	0.006	0.011	8.3	0.003	0.006
O I 989	161	0.053	0.104	0.6	–	–
H I 1025	571	0.187	0.367	2.7	–	–
O I 1027	64	0.021	0.041	0	–	–
O I 1152	28	0.009	0.018	0	–	–
H I 1216	20,000	610	12,000	2,000	61	1,200
O I 1304	2,000	57	1,120	13	0.38	0.75
O I 1356	204	5	100	12.5	0.004	0.008
O I 2471	45	0.015	0.029	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 that 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 input a flat spectrum.

The question then is: how long will it take to achieve S/N=10 per resolution element at 1320 Å with a source flux of 1 CFU, 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}. The Zodiacal light and Earthshine were not specified, so we choose average values.

When this case is submitted, we find the required time is 9917 sec; the total count rates are 39 and 104 counts sec^{-1} in detector segments A and B, respectively, well below the safety limit; the count rate in the brightest pixel is 15 counts sec^{-1}, also well within the safe range; and the buffer time is 16,500 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* = 12.3 per resel. Note that $(15000/9917)^{1/2}$ = (12.3/10.0). That is, the *S/N* ratio scales as $t^{1/2}$, as stated in section 5.2xx.

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 1678 sec, considerably shorter than the medium resolution case required. Note that only segment A is used for the G140L observations.

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 of wavelength of 1650 Å. We know that the star has a magnitude of *V* = 16. How long will it take to obtain *S/N* = 30?

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 1510 sec.

Suppose this star is reddened, with *E(B–V)* = 0.2. We select the *Average Galactic* extinction law, which is shown in Figure 5.3xx. 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* = 30 can be obtained in 3544 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 exposure time is 1000 sec.

In the ETC we select an NUV grating, G185M, set to 1817 Å. Select a 1000 sec exposure, with the *S/N* specified 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* = 16.9 per resel. The local and global count rates are within safe limits. The buffer time is 1752 seconds.

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.

This chapter describes how to write a Phase II program to observe with COS and how to specify the Optional Parameters that are available. In Phase I, you submit a *proposal* to use HST. If approved, that then becomes a Phase II *program*, and you need to provide complete details to ensure your observations produce the results you want.

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 and wavelength setting.
6. The exposure 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 refer to 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. 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.

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 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.

11.4.2 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 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.

Estimate acquisition times

Ordinarily, a COS acquisition uses several minutes at the beginning of the first orbit of a visit; see Chapter 7, "Target Acquisitions" on page 79 and Chapter 9, "Overheads and Orbit Usage Determination" on page 109. 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 count rate limits in “Safety First: Bright Object Protection” on page 80.

11.5 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

Used with `TIME-TAG` mode. See “TIME-TAG mode” on page 56.

CENTER

Used in ACQ/SEARCH and ACQ/PEAKD. See "Finding the source" on page 92 and "PEAKD: Peaking up in the along-dispersion direction" on page 96.

EXTENDED

Indicates an extended source for the data reduction pipeline. Used in TIME-TAG and ACCUM modes. See "EXTENDED" on page 67.

FLASH

Used in TIME-TAG mode only. See "What "TAGFLASH" does during TIME-TAG observations" on page 61.

FP-POS

Used in TIME-TAG and ACCUM modes. See "Achieving Higher Signal-to-noise" on page 65.

NUM-POS

Used in ACQ/PEAKD. See "PEAKD: Peaking up in the along-dispersion direction" on page 96.

SCAN-SIZE

Used in ACQ/SEARCH. See "Mode=ACQ: The spiral target search" on page 92.

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 "Single segment usage" on page 59.

STEP-SIZE

Used in ACQ/SEARCH and ACQ/PEAKD. See "Mode=ACQ: The spiral target search" on page 92 and "PEAKD: Peaking up in the along-dispersion direction" on page 96.

STRIPE

Used in ACQ/PEAKXD in the NUV channel. Selects one of the three stripes for the process. See "PEAKXD: Peaking up in the cross-dispersion direction" on page 95.

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 COS Data Products

12.1.1 FUV TIME-TAG data

Raw data

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

- Dispersion location (x value),
- Cross-dispersion location (y value),
- Time of the event, and
- Pulse-height value.

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.

Corrected TIME-TAG data

The corrected TIME-TAG data consist of seven quantities:

- x and y, the location of the event in detector coordinates, 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 instead of integer.
- x_d, 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 (x, y) or wavelength space (x_d, y). 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.
- t, 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 list is the true order in which they occurred, although it is possible for the ordering between segments to not be maintained because of the interleaving of events.
- h_p is the pulse height for an event. The value of h_p is the 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.
- ε is the sensitivity or weighting term for a photon event. It combines pixel-to-pixel response variations and the dead-time correction.
- q represents the quality factor for a given event, based on its location. The value of q 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 q to indicate that it is probably from that hot spot. The q values are assigned during ground processing from a reference file.

Corrected image

The corrected image is, like the raw data, 16384 × 1024 in size, and consists of an effective counts per second which is the sum of all the ε factors associated with a given pixel, divided by the exposure duration. This corrected image is formed from the corrected TIME-TAG data using x_d and y values and standard threshold values for the pulse heights. Thus this corrected image is in wavelength space and corrected for doppler smearing. The width of each pixel is uniform in physical space, i.e., in microns. This image is not corrected for background counts.

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}.

Science spectrum

The extracted science spectrum consists of:

- λ, the central wavelength for a pixel,
- C_G, the gross count rate,
- C_B, the background count rate,
- C_N, the net count rate,
- F, the flux,
- σ, the error in F,
- MDQ, the maximum data quality in a resolution element, and
- ADQ, the average data quality.

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 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 MDQ is the maximum of all the quality flags for the individual events, while the ADQ 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.

12.1.2 NUV TIME-TAG data

Raw NUV TIMED-TAG data

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

Corrected TIME-TAG list

For the NUV, the corrected list of TIME-TAG events consists of x, y, x_d, t, ε, and q.

Corrected NUV TIME-TAG image

A corrected 1024 × 1024 image is formed from the corrected list 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.

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}.

Science spectrum

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

12.1.3 FUV ACCUM data

Raw FUV ACCUM data

The raw data is an array of dimensions 16384 × 1024 pixels. Each pixel is 16 bits and so can handle up to 65,535 counts. Note that the actual image size sent from the instrument is much smaller than 1024 in height 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.

Corrected FUV ACCUM data

The corrected image is also 16384 × 1024 pixels and is corrected for doppler motion of the spacecraft (done on-board), 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 thermal drift and geometric distortion, but not for background.

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.

Science spectrum

This includes the same quantities described for FUV TIME-TAG data.

12.1.4 NUV ACCUM data

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

12.1.5 NUV ACQ/IMAGE data

Raw data

The raw data for ACQ/IMAGE is 1024 × 1024 × 16 bits.

Corrected image

The corrected image is 1024 × 1024 × 16 bits and includes effective counts sec^{-1}, the gross counts multiplied by a pixel's ε factor and divided by the exposure duration.

CHAPTER 13:

Reference Material

In this chapter…

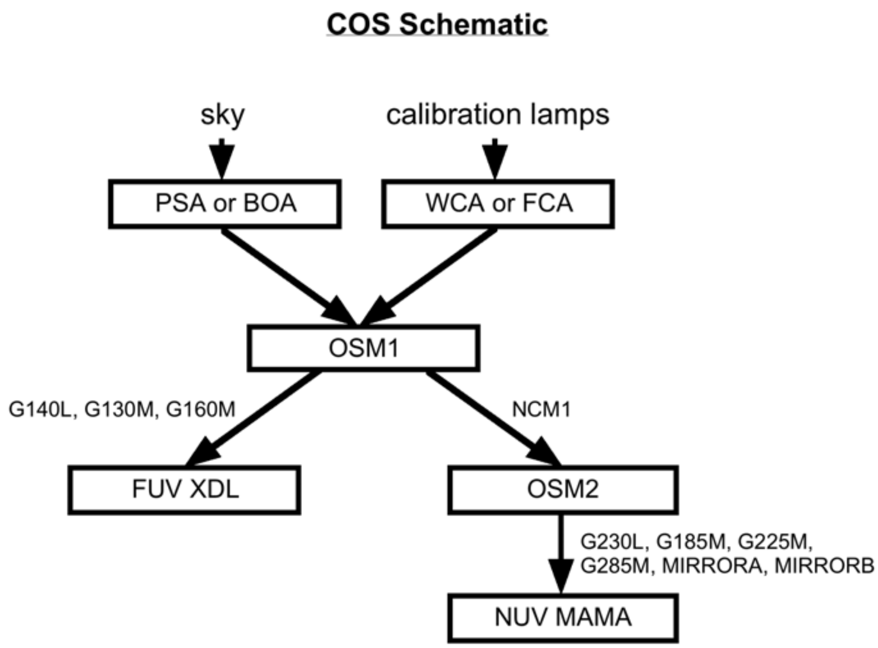
Here we provide some additional information on the design of COS. These details are not needed for most uses of the instrument and so distract from the description in Chapter 3, *A Tour through COS*, on page 11, but this information may be helpful in some cases and is needed for a complete documentation of the instrument.

The logical flow through COS (Figure 13.1 on page 146) 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 collimator, NCM2, and then to OSM2. OSM2 holds the four NUV gratings (G185M, G225M, G285M, G230L) and a flat mirror (TA1 = MIRRORA). 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 nature 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 on page 148.

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	0.020 × 0.100
FCA	Flat-Field Calibration Aperture	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 on page 148. Note that when the BOA is in use that 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.

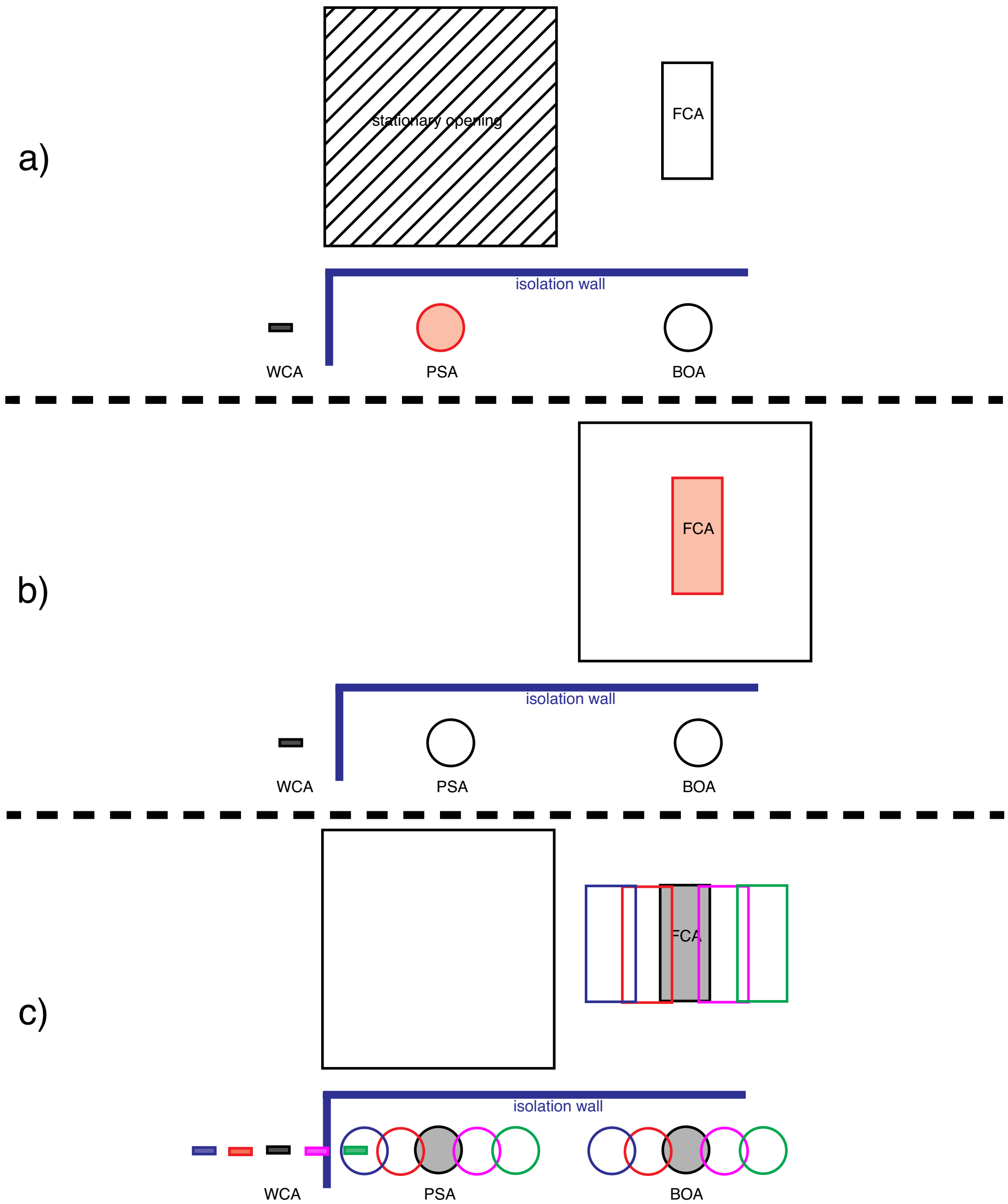
Figure 13.2: The arrangement of COS apertures.

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) that prevents calibration light from either the wavecal or flat-field lamp from entering a science aperture.

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 maximum encircled energy. This aperture transmits essentially all of the light from a well-centered aberrated stellar 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 with a neutral density (ND2) filter that permits COS to observe targets five magnitudes (factor of approximately 200) 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 and vice versa, therefore bright object screening for the field-of-view must include both apertures.

The throughput versus wavelength for the BOA is shown in Figure 3.7 on page 25.

13.1.4 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 WAC'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.

13.1.5 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 - e.g., 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 is displaced in wavelength).

Table 13.1 on page 147 shows the sizes of the COS science and calibration apertures, and Figure 13.2 on page 148 shows their placement on the aperture plate. Because both science apertures always view the sky when the external shutter is open, the STScI target screening procedure must ensure that no bright targets are within a ~4 arcsec radius of either aperture for all observations. Since the spacecraft orientation may not be known and either of the science apertures could be specified, it may be prudent to screen the entire region within a ~17 arcsec radius of the nominal aperture position.

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).

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, thus each rotational transition is at least ~72 degrees.

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

The following table 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 surfaces of the gratings have aspherical surfaces to correct for HST's spherical aberration. The FUV gratings have been ion etched to produce triangular groove profiles for better efficiency.

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
$\alpha - \beta$ (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		

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).

13.3.2 NUV Gratings

Several of the NUV optics and gratings are coated (however, G225M and G285M have bare aluminum surfaces), 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 eliminate 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})	5870	4800	4000	500
useful range (Å)	1700 – 2000	2000 – 2500	2500 – 3200	1700 – 3200
α (degrees)	34.658	33.621	35.707	5.565
β (degrees)	33.27	32.23	34.32	1.088
blaze angle (degrees)	33.96 ± 2.0	32.93 ± 1.6	35.01 ± 1.4	3.327
blaze wavelength (Å)	1850 ± 100	2250 ± 100	2850 ± 100	2300 ± 100

13.3.3 Mirrors

NCM1, also known as TA1, is a flat, fused silica mirror 40 mm in diameter, coated with aluminum and MgF_2. Its surface quality is better than $\lambda/100$, with a surface roughness of less than 10 Å rms.

CHAPTER 14:

Glossary

In this chapter…

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.

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 this optical element, the BOA also degrades the spectral resolution when it is used.

e-stim

A virtual photon source that is located in pixels at opposite corners of each segment of the FUV XDL detector system. These pixels allow for thermal distortion to be calibrated and aid in determining the dead-time correction. For more information, see “Stim pulses (e-stims)” on page 47.

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 times needed to acquire or observe an object because it includes factors such as instrumental overheads.

FCA

Flat-field Calibration Aperture, the aperture through which the deuterium continuum lamp illuminates 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.

IDT

Investigation Definition 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.

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, an amplifying portion of both the MAMA and XDL detectors.

MIRRORA, MIRRORB

MIRRORA and MIRRORB are used for NUV imaging in COS. MIRRORA provides the highest throughput. MIRRORB uses a secondary reflection off of the coating 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 Selection 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, the distribution of the pulse heights seen 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 "Pulse-height distributions" on page 48.

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 such that the spectrum is Nyquist sampled. In the FUV channel, resels are 7 pixels wide (dispersion direction) by 10 tall. In the NUV channel, resels are 3 × 3 pixels.

SMOV

Servicing Mission Orbital 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; most of the calibrations are done in the following cycle.

TAG-FLASH

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 can be removed.

TIME-TAG

A COS observing mode in which the locations (pixels) and times (to the nearest 32 msec) are recorded. 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 comparison lamp through the WCA.

WCA

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

XDL

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