Performance of the Cosmic Origins Spectrograph for the Hubble Space Telescope

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Abstract. We present an overview of the expected performance and science goals of the Cosmic Origins Spectrograph (COS) for the *Hubble Space Telescope* (*HST*). COS is an ultraviolet spectrograph optimized for observing faint point sources with moderate spectral resolution (R $\geq 20,000$). The instrument has a far-UV channel covers the wavelength 1150 – 1775 Å and a near-UV channel that covers the range 1750 – 3200 Å.

1. Introduction

The Cosmic Origins Spectrograph (COS) will be installed abord the *Hubble Space Telescope* (*HST*) during the fourth Servicing Mission, currently scheduled for early 2003. COS will go into the bay currently occupied by COSTAR, which, after the third Servicing Mission, will no longer be in use. COS will complement and extend the suite of scientific instruments aboard *HST*, joining ACS, STIS, NICMOS, and WFC3 at the focal plane for the period 2003 until 2010 (the projected end of the *HST* mission).

COS is a high-throughput ultraviolet (UV) spectrograph that is optimized to observe faint point sources. COS will be, by a large factor, the most sensitive UV spectrograph ever flown aboard *HST*. It will bring the diagnostic power of UV spectroscopy to bear on such fundamental issues as the ionization and baryon content of the intergalactic medium and the origin of large-scale structure in the Universe; the ages, dynamics, and chemical enrichment of galaxies; and stellar and planetary origins. These science programs require having the capability to obtain moderate resolution (R > 20,000) spectroscopic observations of faint UV sources, such as distant quasars.

2. COS Science Modes

COS achieves high sensitivity, particularly in the far-ultraviolet, by minimizing the number of reflections, which leads to an inherently simple spectrograph design. Because the unique capabilities of COS derive from a fundamentally different design approach, and not from new technology, we are able to provide an instrument with flight heritage in all of its critical areas, such as optics, detectors, and electronics.

In designing COS, we have assumed that STIS will continue to work well. COS is not intended to duplicate the powerful capabilities of STIS for observing bright or extended sources. COS does not have many "bells and whistles," but the capabilities of COS are unique, opening a huge volume of discovery space. Researchers will be able to obtain moderate resolution spectra of objects down to unprecedented flux levels, drawing on the new target lists compiled by UV imaging telescopes, such as *UIT* and *GALEX*.

2.1. Science Operations Summary

COS has two channels: a far-ultraviolet (FUV) channel that covers the 1150 – 1775 Å wavelength region, and a near-ultraviolet (NUV) channel that covers the 1750 – 3200 Å wavelength region (with a reduced sensitivity back-up of the FUV wavelength domain). Each channel has its own detector and selection of gratings. The two channels cannot make parallel observations, as the FUV optics select mechanism either rotates a grating into position for FUV spectroscopy or else an optic that feeds the NUV channel. An observer will specify a target, its coordinates, an exposure time, and then select which channel (COS/FUV or COS/NUV), which aperture, and which grating to use. Finally, the observer will specify the central wavelength of the exposure. The central wavelength will be chosen from a table of pre-set values designated for each grating. These values will allow any region of interest in the entire 1150 - 3200 Å wavelength region to be covered. The NUV gratings, in particular, are flat gratings mounted in a collimated beam that are meant to be scanned in order to achieve wide wavelength coverage (due to the relatively small format of the NUV detector). The FUV gratings, on the other hand, each cover approximately 300 Å per exposure and will normally operate at a "standard" central wavelength setting.

2.2. COS FUV Channel

The COS FUV channel covers the wavelength range 1150 - 1775 Å. The FUV channel employs concave diffraction gratings and a curved detector. It is fundamentally a Rowland spectrograph, modified to meet the specific needs of *HST*. There is *one* reflection between the aperture and the detector (see Fig. 1). The gratings have aspheric concave surface figures specified to 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. Two gratings, G130M and G160M, are used to cover the range 1150 – 1775 Å wavelength range at high resolution (R = 20,000 – 24,000). Each high-dispersion grating covers roughly 300 Å in one exposure. A third grating, G140L, covers the entire 1230 – 2050 Å region at lower resolution (R = 2500 – 3500). (The short wavelength cut-off of the low-dispersion grating is designed to avoid bright geocoronal Lyman α emission at 1216 Å.) The three gratings are mounted on a rotating mechanism used to select each grating mode. The detector is a windowless microchannel-plate (MCP) array, with an opaque CsI photocathode, and a double delay-line readout that has been adapted from the *FUSE* mission. Table 1 summarizes the COS FUV spectroscopic modes.

Table 1. COS FUV spectroscopic modes.

Grating	λ Range	Total λ per Exp.	Resolution ($\lambda/\Delta\lambda$)
G130M	1150 – 1449 Å	300 Å	20,000 – 24,000
G160M	1406 – 1775 Å	375 Å	20,000 – 24,000
G140L	1230 – 2050 Å	820 Å	2500 – 3500

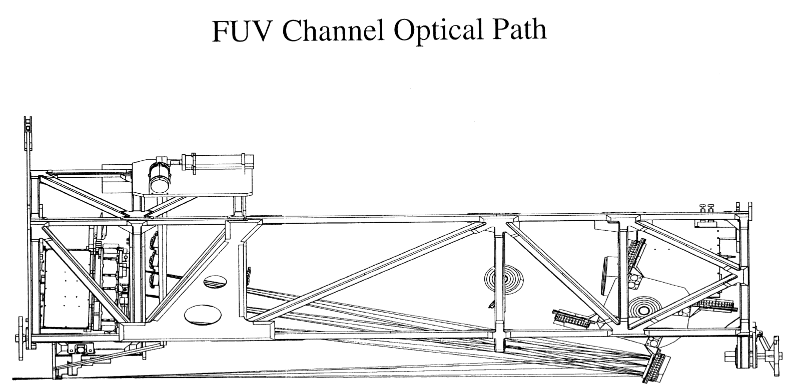

Figure 1. *Schematic of the COS primary FUV channel. Light is received from the HST OTA through an aperture (lower left), is dispersed by a concave diffraction grating, and finally is recorded on a curved double delay-line MCP detector adapted from the FUSE mission.*

2.3. COS NUV Channel

The COS NUV channel employs a Czerny-Turner design (see Fig. 2). This channel provides excellent sensitivity for moderate resolution spectroscopy of faint UV targets in the 1750 – 3200 Å region. It serves partially to back up the STIS NUV spectroscopic modes and also will restore capability to observe faint targets that may have been compromised by the high background of the STIS NUV MAMA detector. The COS NUV channel is fed by a mirror on the primary optics select mechanism that corrects the spherical aberration. The beam is collimated by a second optic and sent to the secondary optics select mechanism which contains several flat, first-order gratings and a mirror used for imaging during instrument testing and alignment. Two high-dispersion gratings, G190M and G260M, deliver resolutions R $\geq$ 20,000 over the wavelength range 1750 – 3200 Å. The dispersed light from the gratings is imaged onto a CsTe MAMA detector by three camera optics. The spectra appear as three non-contiguous $\sim$ 50Å strips on the MAMA detector, allowing $\sim$ 150Å wavelength coverage per exposure. The gratings can be scanned to cover the entire NUV wavelength band. A low-dispersion grating, G230L, delivers 1000Å coverage per exposure with a resolution of $\sim$ 2Å. Because the CsTe NUV MAMA is also sensitive to FUV wavelengths, we include a reserve grating, G130MB, that covers the FUV wavelength region with resolution R $\geq$ 20,000. This grating serves as a reduced-sensitivity back-up to the FUV channel in case of a failure in the primary FUV channel. The COS NUV spectroscopic modes are summarized in Table 2.

Table 2. COS NUV spectroscopic modes.

Grating	λ Range	Total λ per Exp.	Resolution ($\lambda/\Delta\lambda$)
G190M	1750 – 2400 Å	3 × 45 Å	20,000 – 27,000
G260M	2400 – 3200 Å	3 × 55 Å	20,000 – 27,000
G230L	1700 – 3200 Å	1000 Å	850 – 1600
G130MB	1150 – 1800 Å	3 × 30 Å	20,000 – 30,000

2.4. COS Science Apertures

COS is optimized for observing faint UV point sources. The Primary Science Aperture (PSA) is a $\sim 2''$ field stop located on the *HST* focal surface near the point of maximum encircled energy. This aperture transmits close to 90% of the light from a well-centered aberrated stellar image delivered by the *HST* OTA. The PSA is expected to be used for most COS observations. We also provide a Bright-Object Aperture (BOA) with diameter $\sim 2''$ and using an attenuating neutral density (ND2) filter that permits COS to observe targets several magnitudes brighter than the Bright Object Protection limits allow through the PSA.

2.5. COS Sensitivity Summary

The predicted sensitivities for observations of point sources with the COS FUV and NUV spectroscopic modes using the PSA are shown in Fig. 3. As a figure of merit, we expect to obtain S/N $\approx$ 10 per resolution element in the R $\geq$ 20,000 channels for sources with fluxes of $1 - 2 \times 10^{-15}$ ergs cm^{-2} s^{-1} Å^{-1} in 10,000 sec per exposure across most of the 1150 – 3200 Å wavelength range covered by COS. More details about the COS instrument can be found at the COS Web site at http://cos.colorado.edu. This Web page will be updated periodically as the COS instrument capabilities and performance are developed.

Because COS is a slitless spectrograph, the spectral resolution depends on the nature of the target. The high-dispersion gratings deliver resolutions

NUV Channel Optical Path

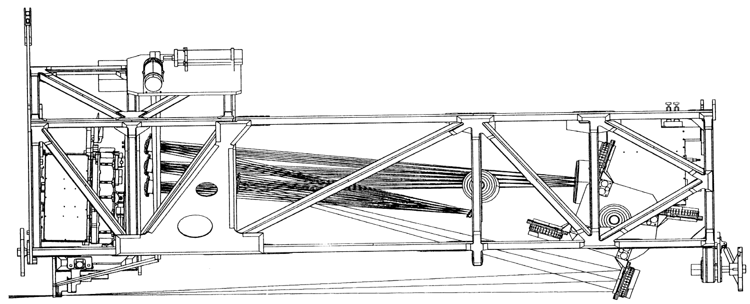

Figure 2. *Schematic of the COS secondary NUV channel. The optical beam is received from the HST OTA through the aperture (lower left), and is magnified by a mirror on the primary optics select mechanism. The light is directed to a second optic which collimates the beam and sends it to the secondary optics select mechanism (small optic near center) containing several flat gratings and a mirror. The dispersed spectrum is imaged by three camera optics onto a CsTe MAMA detector adapted from STIS.*

R $\geq$ 20,000 for unresolved sources (intrinsic diameter $\leq 0''.1$). However, for an extended source, for example, $\sim 0''.5$ in diameter, the spectral resolution is degraded to R $\approx$ 5000. Though not optimized for extended objects, COS can be used to detect faint, diffuse sources with degraded spectral resolution.

COS is designed to take full advantage of *HST* capabilities (large aperture, UV coatings, excellent pointing, and image quality). COS is optimized to observe faint UV sources (Fig. 4) with spectral resolution high enough to determine the physical conditions in a broad range of astrophysical environments. Its design meets programmatic requirements for reliability and redundancy, and its simplicity and efficient operation ensure a high science return. With these capabilities, we anticipate a high degree of interest in using COS throughout the world-wide astronomical community.

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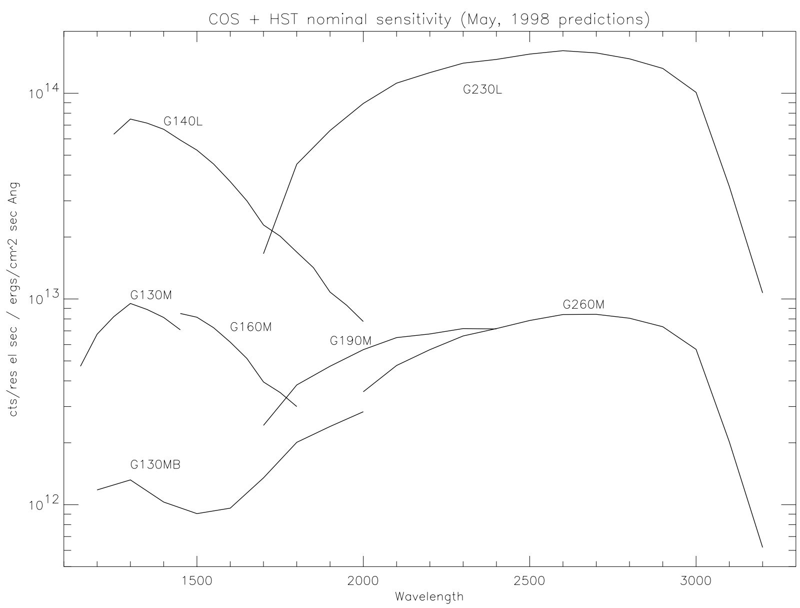

Figure 3. *Sensitivity predictions for the COS FUV and NUV grating modes. The curves shown are for point sources and include a 'slit' transmission of* $\sim 90\%$ *through the Primary Science Aperture.*

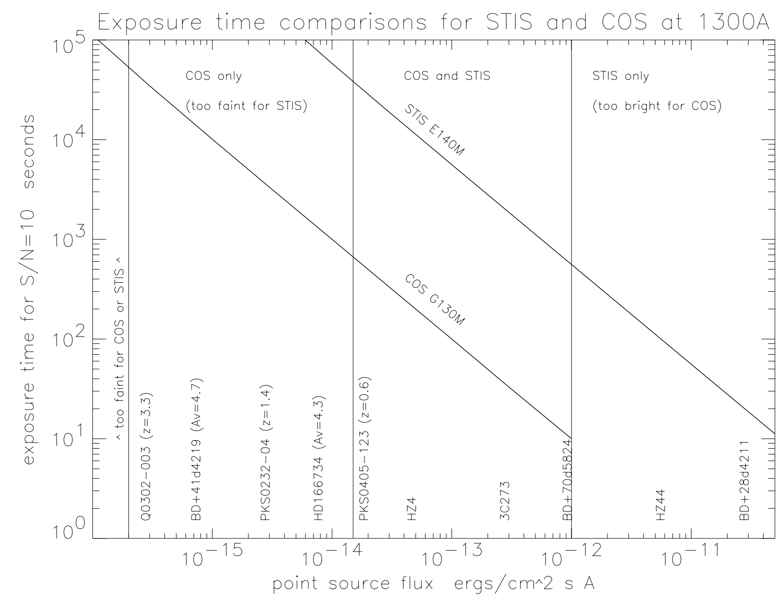

Figure 4. *Summary of predicted exposure times to achieve S/N=10 per resolution element as a function of flux for the $R \geq 20{,}000$ resolution COS G130M FUV grating, assuming the Primary Science Aperture is used. Example targets are noted along the horizontal axis above their corresponding UV fluxes. Exposure times for the STIS E140M echelle mode are shown for comparison. The region of bright fluxes to the right* can *be accessed by COS using the Bright-Object Aperture.*