COS Instrument Science Report 99-01.0

COS Design Reference Mission and Ground System Volume Requirements

Charles D. (Tony) Keyes[1], Ray Kutina[1], and Jon A. Morse[2]

[1] Space Telescope Science Institute, Baltimore, MD
[2] Center for Astrophysics and Space Astronomy, Boulder, CO

15 April 1999

ABSTRACT

We describe a scenario for the expected usage of COS that incorporates predicted instrumental capabilities, the COS IDT DRM as currently envisioned, community input, a study of planned and actual usage of the previous HST spectrographs (FOS, GHRS, and STIS), and estimates of the time to be allocated to COS by future TACs. From this input we derive, for times of normal and stressed usage, estimates of the expected frequency of COS science- and calibration-related exposures (~12/day), average downlink volume (~600 Mbits/day), archive volume (TBD), and calibration reference file OPUS on-line storage volume (~1 Gbyte). We also provide summaries of COS instrumental capabilities and predicted sensitivities in comparison with those of the other HST spectrographs.

This report covers a variety of topics. To help you find information, we list the major sections of this document:

- Introduction and Summary Overview (page 2)
- COS Instrument Characteristics (page 5)
- COS Data-Taking Characteristics (page 10)
- COS Usage Scenarios (page 16)
- OPUS Pipeline Calibration: Archive Volume and CPU Time Estimates (page 28)
- On-line OPUS Calibration File Requirements (page 28)
- Appendix A: Science-related Uses of COS as Prime Instrument (page 29)
- References (page 38)
- Instrument Performance Figures (pages 39-40)
- Appendix B: IDT DRM Spreadsheets (page 41)

1. Introduction and Overview

This Instrument Science Report considers how we expect the Cosmic Origins Spectrograph (COS) to be utilized. Based upon projected instrument characteristics, and upon analysis of input from the COS IDT, a GO community survey, and usage of the previous HST spectrographs, we present a description of anticipated science and science-related calibration usage of COS. We evaluate the impact of typical and high usage levels on data volume and estimate the frequency of calibration programs.

As described in the following paragraphs, the details of our analysis are mostly found in section 4 (COS Usage Scenarios) and Appendix A. Important usage summaries are found in Tables 1-3, 10, and 11 (see pages 4, 26, and 27). We present an overview here:

We assume that a typical COS orbit will contain 50 minutes of target visibility. Most COS visits will last six orbits with an onboard target acquisition in the first orbit.

We find that approximately 80% of COS science orbits will consist of a single TIME-TAG science exposure followed by an internal wavecal taken in ACCUM mode. In these cases TIME-TAG mode is used solely to reduce data volume and not for any required scientific purpose.

We assume previous spectrograph usage rates as a guide in estimating that an additional component of approximately 10% of science time will be spent on observations that *require* a time-resolved capability. Time-resolved TIME-TAG observations at the highest loss-free count rates (estimated frequency of 10 orbits per cycle) are just at the threshhold of requiring special downlink management. Also, repeatobs ACCUM time-resolved observations (≤1% of all observations) at instrumental maximum readout rates for lengthy visits might require management of downlink data volume. High data rate time-resolved observations use less than 10% of COS orbits but could produce more than 80% of downlink data volume.

Based upon historical spectrograph usage, we estimate that approximately 10% of COS science usage will be bright target or high S/N ACCUM mode observations. XDL FUV high S/N observations are limited to a relatively small flux range due to bright object and time constraints. The backup MAMA G130MB modes would have to be enabled for prime science to provide a continuous target brightness range more typical of previous instruments for FUV high S/N observations. We assume that, unless implemented for routine science, the G130MB settings will be calibrated only occasionally, but they will be monitored periodically for contamination,

Additional details of our estimates and assumptions:

- STIS will continue to function nominally
- 1000 orbits (approximately 20% of HST observations) will be allocated by the TAC per cycle for COS prime science.

- COS will execute an average of 1 science exposure per orbit and 3 per day. These estimates are exclusive of internal wavecal exposures that occasionally will be associated with science exposures and are exclusive of target acquisition exposures.
- An average of ~4 internal calibration exposures (3 darks and 1 flat) will be executed by COS per day All of these will be in occultation periods. The flats will probably be in closely grouped series.
- At least 30 occultations per week (out of approximately 100 available) are required to accomplish the needs of the anticipated internal calibration program.
- Typically, one unique instrumental configuration will be used per orbit.
- We define "stressed" orbits as those orbits in which downlink data volume exceeds 20% of SSR capacity (that is, volume >2000 Mbits). Stressed visits have downlink volume at or near this SSR guideline for 2 or more orbits.
- The volume of data transmitted from the telescope per orbit, day, week, and year, which we refer to as the downlink volume, are given in Tables 1-3 and Table 10.
- The projected frequency and data volume of each type of science exposure (e.g., faint object, time-resolved, high S/N, and target acquisition observations) are given in Tables 11 and 12.
- The number of executions and the expected data volume for each type of exposure per year and for the projected 8-year mission are given in Table 10.
- Preliminary estimates of the volume of science data sent to the archive per orbit and per day are discussed in section 5 (archive volume).
- ~1 Gbyte of calibration reference files must be maintained by OPUS in the operational environment at any one time.

We have based our estimates of TIME-TAG data volume upon the frequency of readout implied by anticipated target fluxes. In practice, observers may be more conservative and dump the buffer more frequently to avoid possible data loss caused by underestimation of uncertain target fluxes. A correction factor that can be used to scale our estimates can be determined from STIS TIME-TAG usage after more observations are completed. This will affect only our faint and relatively low-volume TIME-TAG estimates.

For the purposes of these estimates we assume that COS will be operating as the prime instrument for an average of 3 orbits per day (1000 orbits per year, typical visit of 6 orbits executed every other day). Although COS has the potential to operate in parallel for the remaining 12-13 orbits per day, no compelling case has been made at present to justify the effort required to implement pure COS parallels. In this study, we assume that COS will not be operated purely in parallel with any other HST instrument and that any coordinated parallel program resource requirements are implicitly included in the routine usage assumptions we make. A summary of our results is provided in Table 1.

Table 1: Conclusions of Estimate Study

Item	Number
COS science orbits per day (averaged over cycle)	3
COS calibration occultations per week (typical)	24 dark; 8 flat
COS science exposures per day (average)	3
COS science-wavecal exposures per day (average)	3[a]
COS other exposures per day (average)	4
Overall average downlink volume per day	600 Mbits
Archive volume per day	TBD
Typical 3-Month On-Line OPUS Reference file Volume	0.9 Gbtyes

[a] internal wavecals are associated with each science exposure.

Table 2: An Average COS Week

Item	Per Week
COS science orbits	20
COS science visits	3
COS science datasets	26[a]
COS wavecal exposures	29[b]
COS dark exposures	24
COS flat exposures	8[c]
COS external calibration orbits	0.5 [d]
Pointed calibration exposures	2 [d]
downlink volume	~4200 Mbits [e]
archive volume	TBD

[a] a repeatobs multiple exposure series considered as a single dataset

[a] internal wavecals are associated with target acquisition sequence and each science exposure.

[c] performed in occultation, typical exposure length is 20 min, hence divide by 3 for lamp usage in hours

[d] presently in this ISR we have identified requirements for ~20 external (pointed) calibration orbits

[e] Overall yearly total from Table 10 divided by 52

Table 3: A COS Orbit and Visit

Item		Data Volume	Comment
Normal orbit	1 TIME-TAG exposure	XDL: 16 Mbits	.04 cts/sec/res-el (M mode F_λ=5. e-15)
		MAMA: 3.2 Mbits	.02 cts/sec/res-el (M mode F_λ=5. e-15)
Light orbit	1 TIME-TAG exposure	1.3 Mbits (XDL)	.003 cts/sec/res-el (XDL)
Stressed orbit			5.2 cts/sec/res-el (XDL);
TIME-TAG:	4.7 e6 photons per 192 sec	2240 Mbits	15.9 cts/sec/res-el (MAMA);
ACCUM:	XDL: 50 x 1 min exposures	XDL: 1440 Mbits	Assumed 50 min duration;
	MAMA: 100 x 30-sec exposures	MAMA: 1600 Mbits	x1.8 for CVZ
Typical visit	6 orbits	340-360 Mbits	XDL TIME-TAG; (M mode F_λ=5. e-15) Target Acq, 6 science, and 6 ACCUM wavecal exposures
Stressed visit	10 orbits	25 Gbits	x1.8 for CVZ
SSR capacity		10 Gbits	Nominal guideline: 2 Gbit per orbit

The remainder of this ISR is organized as follows. Section 2 ("COS Instrument Characteristics") presents an overview of COS design characteristics and capabilities. We also present a comparison of predicted COS sensitivities and capabilities with those of relevant STIS modes. Section 3 ("COS Data-Taking Characteristics") discusses the operational characteristics of each COS data-taking mode and possible exposure type including the data volume expected from each of them. In Section 4 ("COS Usage Scenarios", page 16), we provide a scenario for COS science and calibration usage. From this we derive the type and number of exposures and the downlink data volume expected from COS per orbit, visit, day, week, and year (see Tables 1-3 in section 1 and Tables 10-11 in section 4). In Section 5 ("Calibration in the OPUS Pipeline: Archive Volume", page 28). we give a very crude estimate of the pipeline data volume generated per science dataset for COS. In Section 6 "On-line OPUS Calibration File Requirements", page 28, we provide estimated on-line calibration file volume needs for OPUS. Section 7 (" Appendix A: Science Uses of COS as Prime Instrument", page 29), contains a detailed explanation of how we arrived at the scientific scenario (as presented in section 4) upon which the majority of the results in this document are based.

All of the estimates presented in this ISR are based on our relatively early understanding of COS (prior to most instrument component assembly and in advance of development of any XDL-related flight/ground software), and upon our experiences with the previous HST spectrographs. The estimates are as conservative and reliable as can be determined at this stage.

2. COS Instrument Characteristics

COS will be installed on HST in the axial instrument bay presently occupied by COSTAR during the fourth Servicing Mission (SM4), currently anticipated in summer 2003. After the inclusion of COS (and presumably WFC3) the HST focal plane instrument complement will consist of ACS, NICMOS, STIS, WFC3, and COS.

After SM4 STIS will continue to provide a powerful spectroscopic capability for ultraviolet and visible observations of point sources and extended objects. COS will provide redundancy for some ultraviolet spectroscopic modes, but is not intended to duplicate important STIS capabilities for observation of bright or extended sources. COS will provide scientific capability that currently may be compromised by the high background of the STIS NUV MAMA. Primarily, however, COS will be the instrument of choice for UV spectroscopic observation of faint sources at moderate (R~20000) spectral resolution.

COS will have two ~2 arcsec diameter circular apertures for external target observations. The Primary Science Aperture (PSA) is a two arcsec "field stop" located on the HST *focal surface* near the point of maximum encircled energy. Approximately 90% of the light from a well-centered aberrated stellar image from the OTA will be transmitted through the PSA. For very bright sources a separate two arcsec Bright Object Aperture (BOA) and integral ND2 (attenuation factor of 100) neutral density filter will be available.

COS will provide significant improvement in sensitivity for faint object observation in comparison with previous HST spectrographs (see section 2.3). This high sensitivity is achieved by minimizing the number of reflections in the optical path.

COS will employ two detection channels - a far-ultraviolet (FUV) channel that covers the 1150-1775 Å region and a near-ultraviolet (NUV) channel that covers primarily the 1750-3200 Å region and which also provides a backup of the FUV wavelength region albeit with reduced sensitivity. Each channel will have its own detector and set of spectral elements. The two channels will *not* be able to perform simultaneous observations.

The FUV detector is a windowless microchannel-plate (MCP) array with an opaque CsI photocathode. A crossed delay-line readout (XDL), similar to the double delay-line detector used in the FUSE mission, is to be used. The COS XDL micro-channel plate detector has two segments, each with an active area of approximately 85 mm (dispersion direction) x 10 mm (cross-dispersion). The entire area of each detector segment will be divided into 16,384x1024 digitial pixels, although a much smaller number will be read out in any exposure (see section 3).

The NUV detector is the STIS flight spare MAMA. Unlike the STIS NUV MAMA, it will meet dark spec and will not be susceptible to particle-induced resets. The detector is 25.6 mm x 25.6 mm in size with 1024x1024 pixels spaced by 25 microns on center. The COS NUV MAMA will have the same data-taking modes as the STIS NUV MAMA, except that it will not have the 2048x2048 “high-resolution” pixel operating capability.

2.1 The FUV Channel

The FUV channel employs three holographically-ruled aspheric concave diffraction gratings which compensate for the OTA spherical aberration with only one reflection between instrument aperture and detector. Two of these gratings, G130M and G160M, will cover the entire 1150-1775 Å spectral region with a spectral resolution, $\lambda/\Delta\lambda$ or R, of 20,000 to 24,000 (~ 0.06 - 0.075 Å per resolution element). Each of these medium-dispersion gratings covers approximately 300 Å per exposure. The third FUV grating, G140L, will cover the 1150-2050 Å wavelength region at somewhat lower resolution (R ~ 2500-3500 or 0.6 Å per resolution element). The spectrum will be dispersed over the two segments of the XDL detector. There is a small region of insensitivity between the two segments. For the G140L grating, geocoronal Lyman α will be placed in this “detector gap,” which means that most of the usable G140L spectrum will be on the long wavelength segment. Standard central wavelength settings will be established for the operation of the XDL with all of these gratings. Secondary settings will be available for those, probably rare, circumstances when a scientifically important feature falls in the detector gap.

With one exception no subarrays will be specifiable by observers. Subarray readout regions will be encoded in the FSW and controlled by STScI via commanding and the PDB. During the lifetime of the COS mission, the default positions of the individual subarrays will be changed to minimize loss of detector gain due to charge depletion. With the exception of certain target acquisition exposures, the user community will not employ selectable subarray readout capability as a portion of routine science operations. A completely filled PSA will illuminate approximately 50 pixels perpendicular to dispersion, whereas the 90% flux contour of a point source centered in the PSA will illuminate approximately 30 pixels perpendicular to dispersion. The centroid of the BOA aperture spectra will be displaced approximately 200 pixels (2 mm) from that of the PSA spectra and will require a separate subarray readout area of the same size as for the PSA. Similarly, the wavelength calibration lamp spectra will pass through a special pinhole and will be displaced approximately 250 pixels perpendicular to dispersion from the PSA spectra, in the opposite direction from the BOA spectra, and will likewise require a separate set of subarry readout positions. Again, all these subarrays will be commanded and modified only via the PDB and special commanding. Two “stim pulse” subarrays for calibration will be positioned well off the active area.

Table 4: COS FUV Spectroscopic Modes

Grating	Nominal Wavelength Range[a]	l Coverage per Exposure	Resolving Power (R = l/D l)[b]
G130M	1150 - 1450 Å	300 Å	20,000 - 24,000
G160M	1405 - 1775 Å	375 Å	20,000 - 24,000
G140L	1230 - 2050 Å	> 820 Å	2500 - 3500

[a] Nominal Wavelength Range is the expected usable spectral range delivered by each grating mode. As described in the text, the G140L disperses the 100 - 1100 Å region onto one segment and 1230 - 2400 Å onto the other. The sensitivity to wavelengths outside the 1230 - 2050 Å region will be very low.

[b] The lower values of the Resolving Power shown are delivered at the shortest wavelengths covered, and the higher values at longer wavelengths. The resolution increases roughly linearly between the short and long wavelengths covered by each grating mode.

2.2 The NUV Channel

In the NUV channel, the input beam from the OTA is corrected for spherical aberration and magnified by a mirror, which directs the beam to its second reflection at the collimator. After collimation, light is then directed to one of four flat, first-order gratings or, for alignment purposes, a mirror. Medium-dispersion gratings G190M and G260M offer R ≥ 20,000 (~0.1 Å per resolution element) in the 1750-3200 Å wavelength range. Low-dispersion grating G230L will provide R~850 (~2 Å per resolution element) in the same spectral range. Grating G130MB will provide backup coverage for the FUV 1150-1800 Å region with R ≥ 20,000 (~0.07 Å per resolution element), but at a somewhat lower sensitivity than that of the XDL (see Table 5). The dispersed light from these gratings is imaged simultaneously onto a CsTe MAMA by three separate camera optics. Three separate spectra will be recorded in non-contiguous "strips" that are displaced from one another in the cross-dispersion direction on the detector. For the medium-dispersion gratings the individual strip spectra will cover approximately 50 Å, so that a total wavelength coverage of ~150 Å will be available per exposure. The wavelength regions will not be contiguous and the separation between their central wavelengths is fixed by the optical system. Naturally, the efficiency of individual programs that use the NUV M gratings will depend on the fortuitous distribution of spectral features in the individual strips. For the L mode grating all three strips also will be illuminated; however, only the middle strip will be highly sensitive to dispersed light in the spectral region indicated. Since order blocking filters will be used and since the detector is solar blind only 2nd order light in the 1700-2200 Å region will be recorded by one of these outer strips, but as the spectral resolution will be twice as high as for the middle strip in this region, it is possible that some useful data occasionally will be obtained in the outer strip.

Table 5: COS NUV Spectroscopic Modes

Grating	**Nominal Wavelength Range**[a]	**l Coverage per Exposure**	**Resolving Power (R = l/D l)**[b]
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

[a] Nominal Wavelength Range is the expected usable spectral range delivered by each grating mode, in three non-contiguous strips for the medium-resolution modes. As described in the text, the G230L disperses the 1st-order spectrum between 1700 - 3200 Å along the middle strip on the detector. G230L also disperses the 400 - 1400 Å region onto one of the outer spectral strips and the 3400 - 4400 Å region onto the other. The shorter wavelengths will be blocked by an order separation filter and the longer will not register because the detector is solar blind. The G230L 2nd-order spectrum between 1700 and 2200 Å may be detectable along the long wavelength strip.

[b] The lower values of the Resolving Power shown are delivered at the shortest wavelengths covered, and the higher values at longer wavelengths. The resolution increases roughly linearly between the short and long wavelengths covered by each grating mode.

As COS is slitless, resolution depends on the nature of the target. Unresolved sources are defined as having an intrinsic size ≤ 0.1″ FWHM. M mode gratings will deliver R ≥ 20,000, however for an extended source of 0.5″ in diameter, for example, R will be degraded to ~5000. We also note that, unlike previous HST spectrographs, the science apertures are not re-imaged by the spectrograph such that the apertures are slightly out of focus and do not project sharp edges on the detectors.

2.3 COS and STIS essential characteristics and sensitivity:

Figure 1 (page 39) presents a comparison of predicted raw COS sensitivities with actual STIS sensitivities with the 52x0.5 aperture for several relevant modes. Detector backgrounds, which are quite similar in the FUV and which favor COS in the NUV, have not been included in this initial comparison. The individual modes of each instrument produce different spectral dispersions per pixel and resolution element. For the purposes of this illustration, all sensitivities have been re-binned to 1 Å elements, which is approximately the STIS G140L spectral resolution. Spectral sensitivity is defined as counts/sec/Ångstrom detected per standard F_λ unit (erg/cm^2/sec/Ångstrom) incident on the OTA. Of course other factors such as detector background, crowding of interesting spectral features, morphology of target, and instrumental resolution can impact the suitability and efficiency of a spectrograph for particular types of science.

For the FUV Figure 2 (page 39) presents the limiting flux required, at several samplings corresponding to important instrumental resolutions, for the COS M modes and the STIS M and medium E modes to obtain S/N=10 (Poisson only - 100 counts) in 3600 seconds. Figures 3 and 4 (page 40) present the same limiting fluxes as Figure 2 except at only 1 Å binning for both FUV and NUV regions. For each mode in the latter two figures a thicker line segment indicates the spectral range that can be obtained with a single exposure.

As a means of comparing the efficiencies of observation between modes with differing sensitivites and spectral ranges, we define a “spectral discovery efficiency” as the product of the spectral range and the mean sensitivity over that range. Several important characteristics are worth noting:

- COS FUV M mode gratings are more than 20 times as efficient as STIS M mode and approximately 8 times as efficient as STIS medium E mode if the full FUV spectral range is required.
- In the NUV, COS G190M COS M modes are about 4 times as efficient as STIS M modes (COS is about twice as sensitive and needs half as many settings to cover the region).
- Neglecting background characteristics, which should substantially favor COS for faint observation, COS G190M and STIS medium E mode are essentially equally efficient (COS is about 4 times as sensitive, but needs four exposures to cover the region to one for STIS).

- Again neglecting background, COS G260M is about 3 times as efficient (twice as sensitive) as STIS NUV M mode to cover the entire 2400-3200 Å region. Similarly, STIS E mode is about twice as efficient, though one-third as sensitive, as COS G260M to cover this entire region.
- Though not illustrated by these figures, the efficiency of the COS FUV M mode gratings is nearly equal to that of the COS FUV L mode grating. COS M mode sensitivity (as defined here) is greater than L mode sensitivity shortward of 1900 Å and is 1.8 times as high over most of the 1100-1800 Å region. Except for those cases requiring the greatest sensitivity and widest FUV spectral coverage, the COS M modes likely will be preferred to COS L modes.
- The advantage of COS M mode with respect to L mode continues to the long wavelength end of G190M at 2200 Å. At longer wavelengths COS M and L mode sensitivities are roughly comparable though M mode resolution is much higher, of course.

3. COS Data-Taking Characteristics

The COS Detector Interface Board (DIB) Flight Software (FSW) can *not* accept raw MAMA and raw XDL science data at the same time, so simultaneous operation of the two COS detectors is not possible. Additionally, there will be no data compression for COS.

<u>*NUV detector:*</u> A MAMA image consists of 1024x1024 pixels. A MAMA ACCUM image will record the signal with 16 bits (2 bytes) at each pixel, hence 2 Mbytes (16 Mbits) of buffer RAM are required to record the entire image. For MAMA TIME-TAG images, each photon is recorded with 32 bits (4 bytes), hence the 18 Mbytes (18x1024x1024) of RAM available allows recording of ~4.7 e6 photons. Additionally, every 32 msec an HST coarse time offset from the HST fine time (found in the header) will be written.

<u>*FUV detector:*</u> Each segment of the full XDL detector is digitized into 16384x1024 digital pixels, hence a total of 32 Mpixels on the two detector segments. If 16 bits were to be used to record each pixel in a XDL ACCUM image, a total of 64 Mbytes of RAM would be required to record signal from the entire XDL in ACCUM mode. As only 18 Mbytes are available, subarray readouts of some form must be used. At present it is envisioned, and we assume throughout this document, that the spatial (Y-coordinate) extent of COS XDL subarray readouts will cover only 50 pixels, hence 3.2 Mbytes (25.6 Mbits) per ACCUM image are required. As for the MAMA, XDL TIME-TAG exposures will also record each photon with 32 bits (4 bytes), hence the 18 Mbytes of RAM available allows recording of ~4.7 e6 photons. Again, specific subarrays will be used for XDL TIME-TAG readout. In addition to the two 16,384x50 pixel main subarrays, two additional "stim pulse" subarrays of size 50x50 pixels will be read out. Additionally, every

32 msec an HST coarse time offset from the HST fine time (found in the header) will be written.

Time to dump RAM (buffer) memory: The entire complement of 18 Mbytes of RAM can be dumped in 192 seconds including a one-time 28 second overhead. When more than one dump per exposure is required, RAM will be dumped in TIME-TAG mode in 9 Mbyte (72 Mbit) segments that require 110 seconds for the first buffer dump and 82 seconds for subsequent dumps during an exposure.

Maximum TIME-TAG count rate: With a zero-loss duty cycle, the maximum count rate per detector for TIME-TAG mode is 4.7×10^6 / 192 or approximately 24,400 counts/sec from the entire detector.

A summary of data-taking modes and anticipated exposure types follows:

3.1 Pulse-height distribution (PHD) "exposure"

Description:

XDL: The FUV detector has the engineering capability to return a table that characterizes the distribution of photoelectron production - the so-called “pulse-height” distribution. At the end of each XDL exposure a histogram characterization of the pulse height distribution of the previous observing interval will be added to the science data stream. This image will add approxiamtely 1 Kbyte (8 Kbits) to the science data stream.

MAMA: No PHD images are produced by the MAMA and none will be associated with MAMA data streams.

Exposure Data Volume: 8 Kbit per PHD image, 1 PHD image per XDL exposure. Negligible impact on data volume and will be essentially ignored in following analyses.

3.2 ACCUM

Description:

XDL: The counts recorded by each of the 16,384x50 pixel subarrays on each XDL detector segment and the two 50x50 pixel “stim pulse” subarrays will be accumulated in memory.

MAMA: The counts recorded by each of the 1024x1024 pixels on the MAMA detector will be accumulated in memory as is currently done for STIS MAMAs.

Exposure Data Volume:

XDL: 16,384x50x2+50x50x2 or ~3.2 Mbytes (25.6 Mbits) of memory per XDL ACCUM exposure; approximately 5 XDL ACCUM images will fit in buffer memory. FSW requirements that the entire buffer being used be emptied before it can be employed for the next exposure implies that the shortest exposure time for a repeated series of FUV ACCUM observations is ~50 seconds.

MAMA: 1 Mbyte of pixels; 16 bits (2 bytes) per pixel, hence 2 Mbytes (16 Mbits) of memory per image; approximately 9 MAMA ACCUM images will fit in buffer memory. As for the FUV case, FSW requirements imply that the shortest exposure time for a repeated series of NUV ACCUM observations is ~25 sec. As for STIS, we will employ 30 seconds as the minimum value.

3.3 TIME-TAG

Description:

XDL: The x- and y-positions (in detector pixels) and pulse height amplitude of each photon detected by the two16,384x50 pixel detector segments and the two 50x50 “stim pulse” subarrays will be recorded. HST coarse time offset from HST fine time is written every 32 msec, as well. The data volume occupied by the time stamps issued during a typical 50-minute visibililty corresponds to less than 1% of available RAM.

MAMA: The x- and y-positions (in detector pixels) and arrival fine time offset from last coarse time written in datastream (unlike STIS, this fine time offset is always set to zero in COS MAMA TIME-TAG observing) for each photon detected by the 1024x1024 pixel detector will be recorded. HST coarse time offset from HST fine time is written every 32 msec, as well. The data volume occupied by the time stamps issued during a typical 50-minute visibililty corresponds to less than 1% of available RAM.

Exposure Data Volume: Strongly depends upon count rate; 32 bits (4 bytes) per event; nominal maximum data volume rate is 18 Mbytes per 192 second minimum buffer dump time or ~24,400 counts/sec (~5.2 counts/sec/resolution-element for XDL and ~15.9 counts/sec/resolution-element for MAMA). A 50-minute visibility produces ~2248 Mbits (281 Mbytes) of data at this maximum rate.

3.4 TARGET ACQUISITION

Description:

COS target acquisition (TA) procedures are not yet fully defined. The following scenario for target acquisition is based upon the current multi-phase model for an autonomous methodology as outlined in SER COS-FSW-001 (Ebbets and Becker, 1998) and in Chapter 5 of the COS OP-01. This procedure is intended to be appropriate for point sources, resolved sources smaller than the PSA, extended sources with bright knots, or diffuse targets not requiring precise centering. This procedure is to be available for use with either the XDL or MAMA detector.

At present acquisition procedures for bright objects (BOA aperture) also could follow this standard autonomous procedure, but bright-object-protection (BOP) issues remain to be resolved. Acquisitions of targets in crowded fields of comparable objects may employ IMAGE mode exposures, ground analysis, and a form of the reuse_target_offset commanding on a subsequent visit. Alternatives for these two cases, such as the use of another SI, probably STIS, for a standard target acquisition followed by direct slew to the appropriate COS aperture (and BOA peakup as required) might be possible. The practicality of such dual-instrument offset procedures, which would routinely involve guide star handoffs, remains under discussion though is not considered likely at present. As the COS autonomous procedure provides an upper bound to target acquisition data volume, and since we anticipate no significant difference in science orbit structure with either method, our estimates assume the COS autonomous method for all COS target acquisitions.

Phase I - Determine position of dispersed spectrum on detector relative to nominal: Aperture is closed; includes wavecal lamp exposure; records values perpendicular to dispersion; calculates a positional offset; upper bound on data volume obtained is that for a single ACCUM mode exposure (3.2 Mbytes for XDL case; 2 Mbytes if full MAMA array is read out); TIME-TAG operation would significantly reduce data volume. Present planning is to discard the spectrum and return only the calculated offset in a standard header, probably less than 100 Kbytes (800 Kbits) in size.

Phase II - Coarse target area search (for PSA observations only): 3x3 or possibly 5x5 spiral target search; record all counts; upper bound on data volume obtained per dwell-point is that for a single XDL ACCUM mode exposure (3.2 Mbytes per FUV dwell point), lower bound in data volume is to record ONLY the sum of detected counts in each dwell; an intermediate course would be to record the observed count spectrum after integration of the cross-dispersion direction (approximately 128 Kbytes of data volume per dwell point). Present planning is to discard all spectral information and to retain only the integrated counts at each dwell point for return in a standard header, probably less than 100 Kbytes (800 Kbits) in size.

Phase III - Cross-dispersion peakup: After translation to position determined by the spiral search, record an additional spectrum and determine its cross-dispersion centroid relative to Phase I expected position. An upper bound on data volume obtained is that for a single XDL ACCUM mode exposure (3.2 Mbytes). The present planning is to retain this ACCUM exposure for downlink (XDL: 25.6 Mbits; NUV: 16 Mbits).

Phase IV - Dispersion-direction peakup: Perform a linear, five dwell-point search and find target via algorithm similar to the spiral search. Present planning is to discard all spectra and retain only the integrated counts at each dwell point for return in a standard header, probably less than 100 Kbytes (800 Kbits) in size. Certain programs needing the most precise centering (≤0.1 arcsec) may require a repetition of the peakup steps (Phases III and IV).

The procedure is identical for XDL and MAMA

Exposure Data Volume: Most intermediate target acquisition data will not be downlinked under current planning. TIME-TAG mode could be used with reduced size subarrays for COS target acquisition exposures. For the purpose of determining an upper bound to COS target acquisition data volume we assume XDL ACCUM mode with default subarrays and the retention of intermediate quantities as described above. Under these assumptions, COS TA data volume is 0.1+0.1+3.2+0.1 ~ 3.5 Mbytes (28 Mbits) per acquisition. An additional pair of peakup stages (repeat Phases IV and V) adds approximately 3.3 Mbytes (26 Mbits).

3.5 IMAGE

Description:

XDL: no capability

MAMA: This is *not* presently considered a science mode. We expect NUV MAMA images will be used as part of engineering-level instrument alignments. The anticipated field of view is only slightly larger than the PSA size and subarrays are likely to be employed. Possible science uses could be as an option for crowded field acquisition via some form of reuse_target_offset or for verification of target acquisition accuracy,

Exposure Data Volume: Upper limit of 1024x1024 pixel (2 Mbyte, 16 Mbit) image size

3.6 WAVECAL

Description:

We assume that all wavecal exposures will be taken in ACCUM mode for both detectors. No simultaneous exposure of internal lamps and an external source will be allowed. The internal lamps will illuminate a different portion (subarray) of the detector than will an external source. A wavecal exposure will be executed after, and associated with, each science exposure that follows a change of aperture and/or grating. A wavecal will always be taken at least once per visibility. As an upper bound, we assume throughout this analysis that a wavecal is taken after *every* external COS exposure.

Exposure Data Volume: ACCUM mode upper bound ~3.2 Mbytes (25.6 Mbits). If TIME-TAG were to be employed routinely for wavecals, then data volumes could be dependent on the actual lamp used and would be somewhat smaller (we estimate representative TIME-TAG wavecal size ~120 Kbytes (approximately 1 Mbit).

3.7 DARK

Description:

We anticipate that all dark exposures will be taken in TIME-TAG mode for both XDL and MAMA. We assume the duration of dark exposures will be similar to STIS exposures (1380 sec), taken frequently (1-3 times per day per detector) in occultation.

Exposure Data Volume:

XDL: The current COS IDT estimate of 1 count/sec/cm^2 (Morse, private communication) yields 1.12 cts/sec/detector subarray or ~1500 counts per 1380 second exposure. To build statistics at approximately the same rate as current STIS practice requires 3 dark exposures per day, 21 per week, or approximately 1100 per year. One 1380 second TIME-TAG exposure at these counting rates requires only about 6 Kbytes (48 Kbits). If ACCUM mode is used, 3.2 Mbytes (25.6 Mbits) of downlink volume is required.

MAMA: We assume COS NUV MAMA will meet the original STIS NUV dark specification of 1.25e-4 cts/sec/pixel or ~130 cts/sec/detector. A 1380 second TIME-TAG exposure yields approximately 180,000 counts and produces a data volume of ~5.8 Mbits (~720 Kbytes). Anticipated frequency is 3 per week or ~150 per year. If ACCUM mode is used, 2 Mbytes (16 Mbits) of downlink volume is required.

3.8 FLAT

Description:

We expect that all flatfield exposures will be taken in ACCUM for both XDL and MAMA. Flats will be required for all science subarray regions for all gratings and both apertures. For the present, we assume that one flat will be sufficient for all “tilts” of each scannable NUV grating. As a working model we anticipate two flatfield exposures per year for each setup (cf., COS OP-01).

Exposure Data Volume:

XDL: 6 flats required (3 gratings and 2 apertures). Based upon the count rate limits specified in OP-01 Table 2-6, we find that XDL flats will require approximately 11 hours or 29 occultation periods of 1380 seconds per setup (174 total exposures per epoch). Each exposure will produce 25.6 Mbits (3.2 Mbytes) of data.

MAMA: 8 flats required (4 gratings and 2 apertures). Based upon OP-01 Table 2-6, we find that MAMA flats will require approximately 1 hour or 3 occultation periods per setup (24 total exposures per epoch). Each exposure will produce 16 Mbits of data.

<u>COS Data-Taking Summary</u>: We anticipate that a typical COS XDL observing sequence will be as follows: Target acquisition sequence (including additional ACQ/PEAK if required and PHD dump after each exposure); TIME-TAG or ACCUM science exposure; PHD dump; wavecal exposure (PHD dump). A typical MAMA sequence would be identical with the exception that no PHD dumps would occur. For the purposes of this analysis, we assume *every* science exposure, *regardless of duration*, will be followed by a wavecal. In current STIS practice, wavecals are taken with every spectral element change and/or new visibility, so our assumption is an upper limit for data-volume, lamp lifetime, and command volume purposes. Presently, we assume that all dark data volumes are determined by the actual number of events detected in TIME-TAG mode and that all wavecals will be taken in ACCUM mode.

4. COS Usage Scenarios

This section summarizes how we expect COS to be utilized for science and calibration. We combine the results of the COS IDT GTO DRM compilation (Morse, 1998), community responses to an IDT solicitation for possible programs (also found in Morse, 1998), examination of the PRESTO and DADS STScI databases to review both proposed and actual usage of FOS, GHRS, and STIS, and estimates of routine COS pointed calibrations based upon STScI experience. Additional details and background information that support the assumptions in this scenario are found in Appendix A.

Table 6 presents a number of instrumental characteristics that are useful for evaluating usage scenarios and trade-offs between COS data-taking modes. Based upon the assumptions and characteristics described in this ISR, Table 10 (page 26) gives predicted exposure rates and resultant calculated data volumes per cycle and per 8-year mission for each COS exposure type. Table 11 (page 27) presents the resultant data volumes for the various classes of COS science exposure per orbit, per visit, and per cycle under the usage scenarios described in this section. The summary estimates of average data volume presented in Tables 1-3 are derived from the results presented in Tables 10 and 11.

<u>The IDT DRM</u>: The GTO program consists of approximately 520 orbits – see Tables 15 and B1. More than 90% of the program (by exposure time) concentrates on faint object science. Approximately 3% is devoted to time-resolved observations – mostly occultations by moving targets. Less than 1% is devoted to bright object science (defined here as either observations that require the BOA or that acquire data faster than the maximum no-loss TIME-TAG data rate – see Table 6).

<u>The Community Solicitation</u>: The community contributions have been combined with the GTO program and normalized to produce an 8-year mission of approximately 8000 orbits – see Table B2. Again, the overwhelming majority of programs concentrate on faint objects that will be observed in TIME-TAG mode. A very large component of this sample

is the so-called “QSO Legacy Project,” essentially an expanded and improved FOS QSO Absorption Line Key Project which comprises 45% of the entire contributed program. Although future TACs may indeed designate very large projects for inclusion in the HST second decade era, the results of the community response are very heavily weighted by this single program. Additionally, no further moving target observations have been added to the pool, so that the moving target fraction is lowered to less than 1%. Time-resolved observations of CVs are included at the 4% level. No additional science that requires either BOA or ACCUM mode are currently included.

Table 6: COS Data-taking and Sensitivity Characteristics

Item	Value
MAMA ACCUM image data volume	2 Mbytes (16 Mbits)
XDL ACCUM image data volume	3.2 Mbytes (25.6 Mbits)
Target acquisition sequence data volume (upper bound in brackets, [ ])	3.5 Mbytes (28 Mbits) [6.8 Mbytes] (54 Mbits)
Data volume in 3000 sec at maximum TIME-TAG data rate	~280 Mbytes (2.2 Gbits)
Max. TIME-TAG readout rate (for no data loss):	24,479 counts/sec/detector
Max. no. photons in TIME-TAG buffer list	4.7 e6
Buffer RAM capacity	18 Mbytes (144 Mbits)
SSR capacity	1.25 Gbytes (10 Gbits)
SSR one-orbit maximum-input guideline	250 Mbytes (2 Gbits)
F_λ (M mode) for max TIME-TAG no-loss readout rate	F_λ=5.2 e-13 (XDL)[a] F_λ=2.0 e-12 (MAMA)[a]
F_λ = 1.0e-14[a] (at peak M mode sens) in 3000 sec of T-T yields	5.6 Mbyte (45 Mbit) XDL 0.37 Mbyte (3 Mbit) MAMA
F_λ to produce T-T data volume = ACCUM data volume in 3000 sec (e.g., XDL: 800,000 counts; MAMA: 500,000 counts)	F_λ=5.7 e-15 (XDL)[a] F_λ=1.3 e-14 (MAMA)[a]

[a] BOA fluxes are 100 times brighter; all F_λ units are ergs-cm^{-2}-sec^{-1}-Å^{-1}

The STScI archive review: Review of the STScI DADS and PRESTO databases provides a variety of statistical information including the frequency of science and calibration observation by observing mode, spectral region, target brightness and type, and exposure duration. Much of this information that is relevant to COS usage is summarized in Table 15 and in the discussion in section 7. For example, we find that

- depending upon the instrument, previous time-resolved observations have consumed 4-10% of exposure time and
- moving target observations have used 3-10% of exposure time.
- Both FOS and STIS usage indicate that time-resolved sample times longer than 30 seconds were very rare.
- The mean FOS RAPID readout time was 7 seconds with nearly 20% of readouts shorter than 1 second.

- Apart from a slightly brighter median and truncated extrema, the distributions of time-resolved target brightnesses for FOS and STIS are not greatly different from the distributions for all types of observations with those instruments.

Although COS bright object protection limits are much more stringent than those of the first generation spectrographs, it would seem prudent to make some allowance for historical levels of both bright object observations and time-resolved observations in our usage study. The “COS Adopt” column of Table 15 reflects our attempt to modify the projected IDT and community program characteristics to partially reflect previous bright object and time-resolved observing patterns.

In the subsequent subsections of section 4, we estimate the rate at which we expect exposures, datasets, and volumes of data to be generated by COS. To estimate the COS volume from GO/GTO prime science we need to understand the ways in which COS is likely to be utilized scientifically. We will consider various types of science observations (e.g., “faint” and “bright” object science, necessarily time-resolved or high S/N observations, and target acquisitions, as well as calibration programs.

In the following sections we divide COS science observations into several broad classes:

1. Observations that *require* time-resolution
2. Observations that require high S/N and FP-SPLIT in particular
3. Observations that require ACCUM mode
4. Everything else, which we call “faint object” science

A convenient reference point is the target brightness that, when observed in TIME-TAG mode for 3000 sec or one standard orbit visibility, produces an ACCUM image data volume (26 Mbits for XDL; 16 Mbits for MAMA). This brightness will produce 175 counts/res-el with the XDL and 330 counts/res-el with the MAMA (see Table 6). We presume that all observations of targets fainter than a “few,” say 10, times this level will comprise class 4 above and be performed in TIME-TAG mode. All brighter targets that do not require either time-resolution or special high S/N consideration will be observed in standard ACCUM mode (class 3 above). The actual flux-level that separates class 3 from class 4 does not need to be precisely defined given the modest data volume sizes associated with ACCUM mode observations.

Table 11 presents the anticipated distribution of COS science observations among these four classes. We estimate that class 1, necessarily time-resolved observations, will comprise approximately 10% of all COS science observations, class 2, high S/N and/or FP-SPLIT, 5% of science observations, class 3, objects too bright for convenient TIME-

TAG data-taking, about 5%, and class 4, “faint” and typically TIME-TAG, the remaining 80% of COS science observations.

Tables 10-12 summarize the content of the COS usage scenario presented in section 4.

4.1 Faint Object Science (Class 4)

We estimate that ~80% of exposure time will be devoted to faint object science (in an approximate 40:60 FUV:NUV ratio). All observations of sources with average fluxes less than 5.7e-15 (count rate <0.06 counts/sec/res-el at XDL M mode peak sensitivity) can be expected to use TIME-TAG mode. Sources that are brighter than a few, approximately 10, times this level will use ACCUM mode. The first orbit of these visits will consist of a target acquisition sequence, one visibility-long science exposure, and a single wavecal – all at the same aperture/grating position. Subsequent orbits will consist of a single visibility-long science exposure and associated wavecal. This will generate one target acquisition dataset, as described in section 3.4, and several science datasets that each contain 1 science and 1 wavecal image.

- ~30% of all COS prime orbits will be devoted to long integration observations of “faint” sources with the FUV XDL detector. All observations of sources with average fluxes less than 5.7e-15 (count rate <0.06 counts/sec/res-el at M mode peak sensitivity) can be expected to use TIME-TAG mode.

  Data volume: Typical first orbit downlink for faint object FUV science is 80 Mbits composed of one 26 Mbit science, one 26 Mbit wavecal, and one 28 Mbit target acquisition dataset. Subsequent orbits would produce 52 Mbits of downlink volume (one science and one wavecal dataset).

- ~50% of all COS prime orbits will be devoted to long integration observations of ‘faint’ sources with the NUV MAMA detector. All of these observations of sources with average fluxes less than 1.3e-14 (count rate <0.11 counts/sec/res-el at M mode peak sensitivity) can be expected to use TIME-TAG mod.

  Data volume: Typical first orbit downlink for faint object NUV science is 52 Mbits composed of one 16 Mbit science, one 16 Mbit wavecal, and 20 Mbit target acquisition dataset. Subsequent orbits would produce 32 Mbits of downlink volume (one science and one wavecal dataset).

4.2 High S/N and Bright Object Science (classes 2 and 3)

Approximately 10% of exposure time will be used for various types of bright object science that do not *require* precise timing. High S/N observations of ISM absorption features superposed on bright continua and UV-bright standard stars for interstellar reddening programs are examples.

- ~5% of all COS prime orbits will utilize the FPSPLIT mode to obtain high S/N spectra (class 2 above). These visits typically will consist of a target acquisition, a series of 4 split exposures (normally in ACCUM mode) and a single wavecal with a single aperture-grating combination followed by additional split series with other gratings or grating rotations. This will generate one target acquisition dataset as described previously, and, for each FSPLIT series, one science dataset with four split exposures, and one wavecal. On the assumption that ACCUM mode is used for the splits, a 4 exposure XDL science dataset will have ~100 Mbits downlink volume. The corresponding MAMA FPSPLIT series science data volume would be ~64 Mbits. Note that each of the 4 FPSPLIT exposures is at a slightly different grating rotation, but only one wavecal is taken with each series. Depending upon target brightness, subsequent orbits may contain one or two FPSPLIT exposure series, each including a wavecal at 125 Mbits volume (or 80 Mbits for MAMA) per series. Commanding volumes will be highest in multiple-exposure FPSPLIT orbits. Although TIME-TAG would produce larger volumes of data for bright targets, the data volume upper limit will be set by ACCUM mode limits as TIME-TAG is unlikely to be a requirement for FPSPLIT observations.

Data volume: Typical acquisition data volume is 28-54 Mbits, depending upon requirement for precise peakup, as described in section 3.4. Each FPSPLIT series and associated wavecal produces ~125 Mbits (or ~80 Mbits for MAMA) of data volume. In rare cases for relatively faint targets, orbits may not contain entire FPSPLIT exposure series. In these cases data volume will be the standard ACCUM mode volume per exposure. Our estimates in Tables 10 and 11 assume an upper bound case of two 4-exposure FPSPLIT XDL series per orbit (250 Mbits per orbit composed of 200 Mbits of science data and 50 Mbits from wavecals).

- ~5% of COS prime observations (class 3) will observe objects that are too bright for TIME-TAG mode, but for which time-resolution and the highest (FPSPLIT) S/N are not necessary.

  Data volume: XDL output data volumes from these ACCUM science exposures will be 26 Mbits plus an additional 26 Mbits for the associated wavecal. Depending upon mechanism motion overheads, several (we assume an upper limit of 8 in Tables 10 and 11) of this type of exposures could be executed per orbit.

4.3 Necessarily Time-resolved Science (class 1)

Based on FOS, GHRS, and STIS experience as derived from our inspection of the HST Archive, we assume spectrosocopy that *requires* time-resolution (class 1) will constitute about 10% of the GO observing programs, overall (see Table 15 in section 7).

- 10% of all COS prime orbits will be devoted to 1024x1024 NUV MAMA or 16,384x2x50 XDL time-resolved readouts, for example planetary occultations or binary star tomography. Nine-tenths of these orbits will be obtained in TIME-TAG mode and one-tenth in repeatobs ACCUM mode.
- TIME-TAG time-resolved observations of targets for which the observed countrate is less than the maximum no-loss TIME-TAG rate (~24,400 counts/sec/detector) are assumed feasible. At the maximum rate, one 50-minute visibility produces ~2240

Mbits of data with either detector, which is slightly over the current one-orbit SSR guideline. This high data rate through the PSA is produced with peak M mode sensitivity by targets whose flux is ~5.2e-13 for the XDL and ~2.0e-12 for the MAMA (factor of 100 brighter for the BOA). Recourse to repeatobs ACCUM is possible to lower the data volume for fluxes within a factor of several of this limit, but only if time resolutions of 30-60 seconds are acceptable. Based upon previous HST usage we estimate that ~10% of time-resolved observations (or 1% of all COS observations) would be within a factor of two of this brightness limit and thereby be candidates for high rate repeatobs data-taking.

  Data volume: In our data volume estimates in Tables 10 and 11 we have assumed that these TIME-TAG observations will be comprised of nine 10-orbit visits each corresponding to 9% of COS observations. We assume a distribution of target brightnesses that produce one visit at the maximum data volume rate (2240 Mbits per orbit), six at one-half this rate, and two visits at one-fourth this rate.

- Repeatobs ACCUM observations can be executed at rates limited by buffer memory dumping restrictions and SSR data volume management. For the STIS NUV MAMA, exposures were limited to ≥30 seconds and, as noted in section 3.2, we assume the same for COS NUV. Each readout produces 16 Mbits of data. A 50-minute visibility would produce 100 science exposures and a single wavecal, all at a single aperture/grating position hence one science dataset of ~1600 Mbits containing 101 exposures (100 science and 1 wavecal). This data volume is close to the nominal 20% of SSR capacity guideline maximum for one orbit. *CVZ orbits or normal visits with multiple orbits at these NUV rates would require special downlink managment.*
- Due to the larger XDL ACCUM image size, the FSW restrictions preclude operation of the XDL at the NUV MAMA reapeatobs exposure rate. As indicated in section 3.2, the maximum XDL repeatobs dumping maximum rate is approximately every 50 seconds. This rate produces a similar amount of data as the NUV case described above. A 50-minute visibility would produce 60 science exposures and a single wavecal, all at a single aperture/grating position hence one science dataset of ~1600 Mbits containing 61 exposures (60 science and 1 wavecal). Again, we assume here that this "stress" can be accommodated occasionally).
- We define "stressed" orbits as those orbits in which downlink data volume exceeds 20% of SSR capacity (that is, volume >2000 Mbits). Stressed visits have downlink volume at or near this SSR guideline for 2 or more orbits. Observations of bright targets in time-resolved modes will produce the most stressful orbits and visits. Based upon previous HST usage we estimate that ~20% of time-resolved observations (or 2% of all COS observations) would be within a factor of two of the fluxes that produce stressful data volumes
- Data volume: In our repeatobs data volume estimates in Tables 10 and 11 we have assumed that these observations will be comprised of a single 10-orbit visit corresponding to 1% of COS observations. We assume an upper limit of the maximum repeatobs exposure rate described above per “stressed” visibility to provide maximum per orbit data volume estimates (~1600 Mbits) for both detectors.

4.4 Moving Target Science

Moving target observations could be executed with either ACCUM mode or TIME-TAG as discussed above. Moving target science observations can be placed in one of the above categories, so no special consideration is necessary here. We do note that certain moving target observations, such as very high data rate occultations of bright stars, may require TIME-TAG readouts with gaps in the time series.

4.5 Target Acquisition Considerations

The current working model for COS target acquisition (TA) uses a series of exposure stages to center the target. Some uncertainty currently exists about the details of subarray size, data-taking mode, the amount, and, to a lesser degree, the type of data that would be stored and downlinked. In section 3 we estimated that a reasonable upper bound for downlink volume is 28 Mbits (3.5 Mbytes) in the event ACCUM mode and normal science subarrays are used. Utilization of an additional ACQ/PEAKUP sequence for the most precise centering requirements adds two exposure stages and an additional upper bound of 26 Mbits (3.3 Mbytes). If TIME-TAG mode is used, target acquisition datasets could be ≤1 Mbyte in size.

Entries in Table 10 assume an equal distribution of FUV and NUV target acquisitions. We assume 200 target acquisition sequences will be executed per cycle. Each target acquisition sequence contains a single wavecal exposure.

For the purposes of estimating *command* volume (though not for any of the conclusions presented in this document) it is also important to consider the nature of the target acquisitions which will be performed. Tables 7 and 8 summarize the types of acquisitions we expect to be performed. Roughly 25% of target acquisitions (those for science requiring the most precise pointing – highest photometric or wavelength accuracy) are expected to be followed by the additional peakup stages described above.

Our assumption is that IMAGE mode could handle crowded field and some diffuse source acquisitions in the same manner as the FOS image and reuse_target_offset combination did. Objects that are unsafe for PSA, and/or presumably IMAGE, might be handled via acquisition with another SI, such as STIS.

Table 7: COS Target Acquisitions

Acquisition Type	Percent of Acquisitions which are of this Type
isolated “PSA-safe” point source	75
crowded field	5
diffuse source	5
Planetary/moving target	10
Very Bright Object (BOA – BOP issues)	5

Table 8: Acquisitions

Acquisition Type	%
standard	85 (~1/4 are peakups)
IMAGE mode	10?
other SI handoff	5?

4.6 Parallel COS Observing

We currently assume that there will be ***no*** COS pure parallel observing allowed. The effect of COS usage in coordinated parallel with another SI is included above as if it were COS prime science.

4.7 COS Calibration

The following presents our discussion of COS calibrations deemed likely at present. We expect that most internal calibrations, with the exception of wavecals and flats, will be taken in TIME-TAG mode, but most external calibration observations will be obtained in ACCUM mode.

Flat and wavecal observations will dominate the calibration data volume as they will be taken in ACCUM mode. On the assumption that a fill-removal algorithm will be available, dark internals would be taken in TIME-TAG mode and, unlike STIS, would not produce large amounts of amounts of data. If darks must be taken in ACCUM mode, they will produce a large, but manageable, weekly volume. We estimate that, on the average, approximately 30 orbital occultations per week will be devoted to internal COS calibration. Most will produce data volumes <2.4 Mbits (300 Kbytes), and 4-10 will produce 25 Mbits (3.2 Mbytes) per occultation orbit.

Pointed (external) calibration: Sensitivity, external wavelength calibration, scattered light, and vignetting calibrations are examples. Targets are typically bright, mostly suitable for FPSPLITs if desired. A few might be feasible in TIME-TAG mode (<24000 counts/sec), but, most of these targets, if observed in TIME-TAG mode, would generate larger data volumes than ACCUM mode. For the purposes of data volume estimation we assume that all pointed calibrations will be taken as ACCUM exposures without FPSPLITs.

At present we have identified requirements for ~20 orbits per cycle of recurring (non-SMOV) external pointed calibration observations, however based on HST spectrograph experience we budget for up to 100 orbits (10% of science allocation). If executed in ACCUM mode, data volumes for external calibration targets would be relatively modest, as well (<240 Mbits, 30 Mbytes, per orbit).

Sensitivity calibration: We assume there will be 15 primary wavelength positions, 6 secondary positions, and 8 tertiary (MAMA FUV backup) positions. This program requires S/N 30-100 per resolution element. The primary settings would be observed 3 times per cycle (twice for PSA, once for BOA), the secondary settings once per cycle. No routine sampling of the tertiary settings would be performed, although we expect there will be an SMOV calibration of all these settings and that a periodic (annual?) contamination check of at least one tertiary setting will be executed. A total of 51 ACCUM (15 FUV and 36 NUV) exposures are required annually for this primary and secondary position calibration. Table 9 presents a summary of the various grating configurations to be calibrated.

Table 9: COS Sensitivity configurations

Grating	primary	secondary	tertiary
G130M	1	2	
G160M	1	2	
G140L	1	2	
G190M	5		
G260M	5		
G230L	2		
G130MB			8
Totals	15	6	8

Absolute external wavelength calibrations: We assume a bright target, three gratings per visibility; a minimum of two, probably three, orbits per visit. This calibration would be performed annually.

Total external target orbit requirement (current estimate): 60 exposures in 15-20 orbits per cycle; 5-6 orbits per visit.

Additionally, special external calibrations to provide flatfields, to check for any vignetting, and to assess the presence of scattered light are likely to be performed. These programs probably would not be executed on a recurring basis, but should utilize targets whose brightness is similar to those in the sensitivity calibration. For the present we assume 100 external ACCUM mode calibration exposures are required per year and we assume the FUV:NUV ratio will be approximately 40:60.

Non-pointed (internal) calibration:

All internal calibrations (flats, darks, and wavecals will be performed in occultation periods. We assume typical durations of 20-25 minutes. For each exposure type Table 10 presents a summary of the assumed typical data volume, the number of exposures anticipated per year and for the mission, and the resultant predicted data volume per year and mission.

Flats: If we assume a sampling rate of twice per year, one flat per XDL grating and aperture, then, per the COS OP-01, 500-1000 hours of XDL flat exposure are required to achieve appropriate flat S/N exposure (there is a factor of two uncertainty concerning whether both apertures require separate flat exposures or can be read out simultaneously; for the present we use the larger exposure). This implies 60-120 hours per year (8-year mission), hence 180-360 20-minute internal exposures during a year or about 4-8 per week. For the MAMA, OP-01 suggests 120 hours over 8 years or 15 hours per year, so 45 exposures per year or 1 per week on average. In practice, all exposures for a particular grating/aperture combination would be obtained within a few days.

Darks: As indicated in section 3, many internal 23-minute exposures are required to achieve the counting statistics utilized for STIS. We will need 21 XDL darks per week (approximately 1100 per year) and 3 MAMA darks per week (approximately 150 per year). All darks will be executed in TIME-TAG mode. Downlink exposure volume will be only 50 Kbits (6 Kbytes) for XDL darks and ~6 Mbits (720 Kbytes) for MAMA darks. If ACCUM mode must be used for darks, then weekly volumes become 550 Mbits (67 Mbytes) for XDL and 48 Mbits (6 Mbytes) for MAMA.

Wavecals: Wavecals will be taken with each science exposure, but to insure a consistent set of contemporaneous checks on dispersion (and possibly spectral distortion), complete samplings of all central wavelength settings for all 7 spectral elements with each aperture should be taken on a regular basis, perhaps quarterly. Four exposures per occultation would require 12 occultation periods per quarter or 48 per year. All these exposures would be in ACCUM mode and produce an upper limit of 64 Mbits (8 Mbytes) per occultation with MAMA and ~100 Mbits (12.8 Mbytes) per occultation for XDL.

Table 10: Predicted COS Exposure Rates and Data Volumes for All Observations

Exposure Type	Exposures per visit (or occ)	Visits per year	Mode/data vol per exp (Mbits)	Exposures per year	Data vol per year (Mbits)	Exposures in mission	Total data volume in mission
Wavecals:							
Int cal with XDL	3*2=6	4	ACC/25	24	600	192	~5000
Int cal with MAMA	(12+8)*2=40	4	ACC/16	160	2560	1280	21,000
TA (both detectors)	1	200	ACC/20*	200	0	1600	0
With sci datasets (both)	6-7	200	ACC/20*	1300	26000	10,400	208,000
Ext cal datasets (both)	10	5-10	ACC/20*	100$^\nabla$	2000	800	16,000
Σ (XDL,				680	15700	5440	125,000
MAMA,				1100	15600	8800	125,000
Both)				1780	30600	14,280	250,000
Flats:							
XDL	1		ACC/25	358	28650	2864	71600
MAMA	1		ACC/16	48	6160	384	6200
Σ (Both)				406	34810	3248	77800
Dark:							
XDL	1		T-T/.048	1092	52	8800	416
MAMA	1		T-T/5.8	156	896	1250	7200
Σ (Both)				1248	948	10,050	7616
Target Acquisition	1	150 std	ACC/28	200	6300	1600	50400
(non-wavecal stages)	4-6 stages	50 dbl pkup	ACC/54				
Science exposures (from Table 11)	6-7	200	various	1300	155,800	10,400	1,246,400
Pointed Calibration exp	10	5-10	ACC/25^f	100$^\nabla$	2000	800	16000
PHD exposures			PHD/.008	2800	26	22,400	184
Totals:							
XDL							
internal				2130	TBD	~17000	TBD
TA				100		800	
external				560		~4500	
Total				3090	TBD	24,700	TBD
MAMA							
internal				1300	TBD	10,400	TBD
TA				100		800	
external				840		~6700	
Total				2040	TBD	21,100	TBD
Total							
internal				3430	TBD	27,400	TBD
TA				200		1600	
external				1400		11,200	
Total				5730	206,050	45,800	1,648,400

[*] wavecal average dataset size assuming 60% NUV and 40% FUV; all assume ACCUM

[f] upper limit; a combination of FUV (26 Mbit) and NUV (16 Mbit) ACCUM exposures will be used

[∇] ~60 exposures currently accounted for in this ISR; no calibration FPSPLITs assumed;

assume 40:60 FUV:NUV split for external obs and associated wavecals; 50:50 split for TA exposures and wavecals

Table 11: Volume Requirements for Estimated COS Science Observing Scenarios

Class of Science	Percent of COS Prime Time	No, of Orbits per cycle	Exposures/Orbit	Assumed Upper Limt Data Volume per orbit	Data Volume in 6 orbit "day" (Mbits)	Data Volume in 10 orbit "day" (Mbits)	Downlink Volume in 1 year (Mbits)
Faint Target TIME-TAG FUV	30%	300	TIME-TAG photon list	26	156	260	7800
Faint Target TIME-TAG NUV	50%	500	TIME-TAG photon list	16	96	160	8000
Required Time-resolved, TIME-TAG FUV/NUV	9%	10	MAMA or XDL TIME-TAG photon lists (assume 10 orbits at max rate, 60 at half-max, 20 at one-fourth)	2240	13,440[a]	22,400[a]	67,200
		60		1120	67200	11,200	22,400
		20		560	3360	5600	11,200
		Σ=90					
Bright Time-resolved, repeatobs ACCUM FUV/NUV	1%	10	60 XDL (2x16384x50) or 100 MAMA (1024x1024)	16,000[a]	9600[a]	16,000[a]	16,000
Bright Science ACCUM FUV/NUV	5%	50	8 XDL (2x16384x50)	8*26	1248	2080	10,400
			or	or	or	or	
			10 MAMA (1024x1024)	10*16	960	1600	
Bright High S/N (FPSPLIT) FUV/NUV	5%	50	1-8 XDL (2x16384x50)	8*26	1248	2800	
			or	or			
			1-16 MAMA (1024x1024)	16*16	1540	2560	12,800
TOTAL OVERALL	N/A	1000	N/A	N/A	N/A	N/A	165,800

[a] "stressed" visit

Table 12: Summary of Science Observations (% by exposure time)

Item	GTO	GTO/GO	COS Adopted	external cal
Faint	97	96	80	0
Bright non-TIME-TAG	<1	<1	10 (5 high S/N; 5 other)	>80
Bright TIME-TAG or repeatobs ACCUM	2	3	10 (9 TIME-TAG; 1 ACCUM)	<20

5. OPUS Pipeline Calibration: Archive Volume and CPU Time Estimates

Estimates of the increase of COS data volume as a result of passage through the OPUS pipeline are premature at this point. The `calcos` calibration routines and requirements have not been drafted as yet. Nonetheless, COS NUV MAMA characteristics should be quite similar to those for STIS and we note that STIS data volume expansion from transmitted to archived data were of the order of factors of 10-15. After processing, a STIS NUV MAMA raw exposure produced approximately 25 Mbytes of data for archiving in addition to the raw input data. Processed COS NUV datasets should be about the same size as the STIS case. By simple analogy with STIS products, we estimate that a single COS FUV exposure will produce about 70 Mbytes of processed data in addition to the raw input data. However, current plans for “on-the-fly” calibration of data retrieved from the archive suppose that only raw data plus equivalently-sized data quality arrays will actually be archived.

Similarly, meaningful estimates of CPU time and processing requirements for `calcos` are not possible at the present, particularly for XDL observations.

6. On-line OPUS Calibration File Requirements

Based upon a very preliminary estimate of the types, sizes, and selection dependencies of calibration reference files (details below), we estimate that OPUS will need (at a minimum) room to store on-line roughly 5 1024x1024 images and 30 files of dimension 16,384x2x50, for a total of ~0.9 Gigabytes of disk space, over any 3-month period. This is a rough estimate.

6.1 Justification

In Table 13 below we list an estimate of the calibration images needed by `calcos`, their sizes, and an estimate of the rate at which they may be expected to change. The number listed is the total number of calibration science data images. Each data file will also have an accompanying data quality and error file of similar dimension. The data quality file will contain 16-bit format values rather than 32-bit; the science and error file will be in 32-bit format. Thus, a 1024 x 1024 calibration file has a size of 10 Megabytes and a 16,384x2x50 file has a size of ~32 Mbytes.

For some modes and some calibration types, the rate at which the calibration files will change with time is uncertain, as it will depend sensitively on the way in which the detectors and components respond to the radiation environment in space, however these estimates should be helpful for an initial estimate of disk space resource requirements. They seem consistent with the resources we routinely have had available to analyze calibration data and prepare and install new reference files. The change frequencies specified are for normal steady-state operational periods. Natually, during and following SMOV4 a rapid rate of change of calibration images should be expected.

Table 13: COS Calibration File Requirements

Name	Selection Criteria	Number	File Size	On-line Storage Requirement	Change rate
sensitivity	λ, grating, aperture, MAMA	4*3*2=24	1024	0.24 Mbytes	semi-annually?
	grating, aperture, XDL	3*2=6	16384*2	1.9 Mb	
wavecals	grating, aperture, MAMA	4*3*2=24	1024	0.24 Mb	annually?
	grating, aperture, XDL	3*2=6	16384*2	1.9 Mb	
dark	detector, MAMA	1	1024x1024	10 Mb	monthly
	grating, aperture, XDL	3*2=6	16384*2x50	190 Mb	
flat field	observation mode, MAMA	4	1024x1024	40 Mb	semi-annually?
	grating, aperture, XDL	3*2=6	16384*2x50	190 Mb	
spatial distortion?	detector, MAMA	1	1024x1024	10 Mb	annually?
	detector, XDL	3*2=6	16384*2x50	390 Mb	
Total				870 Mbytes	

The volume estimates are dominated by the flat field images and XDL spatial distortion file estimates, which are at best very crude. The operating assumption for both of these file types is that each XDL subarray will need a separate flatfield reference file for each grating. Should this not be the case, calibration reference file resource requirements will be diminished substantially.

There will also be a currently unknown number of additional calibration tables such as the wavelength and sensitivity files included in Table 14. These should be small in size and will not materially affect the volume estimates.

7. APPENDIX A: Science Uses of COS as Prime Instrument

In this Appendix, we describe the background and details of our analysis of how we expect COS to be utilized for Prime Science. We combine results from 1.) the COS IDT DRM compilation (Morse, 1998) – the GTO observations, 2.) community responses to a WWW-based solicitation for possible observation programs (also found in Morse, 1998), and 3.) examination of both PRESTO and DADS databases for proposed and/or actual usage of FOS, GHRS, and STIS – the STScI archive study. Together these provide the justfication for the assumptions and analysis presented in section 4 which were used to calculate the ground system and other operational requirements (as presented in Tables 1-3, 10, and 11).

7.1 FUV Versus NUV Science with COS

The IDT DRM plan, summarized in Table 14 and Appendix B Table B1, indicates that only approximately 42% of COS science time would be spent on FUV observations, which, at first glance, is rather surprising for an instrument originally proposed with only an FUV channel. Factoring in the limited community responses (see Table B2) yields an even more extreme 34%:66% FUV:NUV split. In contrast, as shown in Table 15, STIS cycle 7 proposed usage produced a 59:41 split in favor of FUV observation, whereas both FOS and GHRS were used in approximate 33:67 FUV:NUV ratios. Once we understand the seemingly unusual COS ratio, these differences are actually illustrative of the differing capabilities of the various HST spectrographs and the types of science performed.

Despite only ~40% of COS IDT observing time allocated to FUV spectra, 65% of the detected photons would be obtained in the FUV range due to the unique COS FUV optimization. Inclusion of the community response does not alter this ratio of detected photons, although the very large "QSO Legacy Project" - essentially an enhanced version of the FOS QSO Absorption Line Key Project at higher S/N and R=20,000 - comprises 45% of the "community" sample and 75% of its observing time is spent in the NUV.

As discussed in section 2, COS will be the first HST spectrograph to have approximately equal sensitivity between FUV and NUV at comparable resolutions. FOS and GHRS FUV sensitivities were more than an order of magnitude poorer than comparable-resolution NUV sensitivities. Observers with those legacy instruments obtained many more NUV exposures and far more NUV counts, but FOS and GHRS total FUV and NUV observing time was nearly evenly balanced. The FUV sensitivity improved with STIS and the scientific emphasis shifted to FUV as both the number of exposures and total exposure time were dominated by FUV observations. For COS the greatly increased FUV sensitivity allows the exposure time ratio to substantially favor the NUV for those programs requiring comparable S/N between the two regions while also allowing a concentration on FUV science in relatively short exposures. Given the approximate parity between STIS and COS NUV sensitivities, there may be a tendency for observers who need both FUV and NUV observations with all but the echelle resolutions to propose entirely for COS due to its FUV advantage. Similarly, the COS NUV advantage at low countrates due to the better COS MAMA background may promote COS NUV usage. On the other hand, STIS echelle “discovery efficiency” is comparable or better than COS if full NUV wavelength coverage is required. The interplay of spectral region required for the science and length and number of exposures required to observe it will be complex and could be quite different for different proposals.

If we assume that the COS proposal mix will reflect an historical mix of programs with most needing both FUV and NUV observations to achieve science goals, and if we assume that efforts will be made to obtain comparable S/N in both regions, then an FUV:NUV ratio similar to that found in the GTO and community missions is suggested on the basis of the ratio of FUV/NUV instrumental sensitivities.

On the other hand, a substantial body of FUV-only programs not seen before would alter the FUV:NUV ratio. This type of program might be promoted by the unique COS FUV optimization (e.g., Gunn-Peterson studies). Of course, one can also argue that there are faint targets feasible with COS, for which both FUV and NUV observation are needed, that were possible with STIS/NUV but too faint for STIS/FUV (e.g., some IS extinction studies in nearby galaxies).

We have chosen to use the COS GTO and community mission, exclusive of the very large “QAL Key Project,” as the starting point for projected usage characteristics. We have incorporated the results of our archive study to reflect HST historical spectroscopic usage for observation in time-resolved and certain high S/N modes that would be logical candidates for COS observation. Data volumes estimates would not be severely altered if our assumed FUV:NUV ratio were reversed.

7.2 Typical COS Science: “Faint” Source Observing

The COS IDT has identified a number of major science goals and provided a rough view of the typical exposure lengths for these projects (Morse, 1998). This information is summarized in Table 14 which is drawn from spreadsheet Table B1 in Appendix B. Note that each spectroscopic observation of a new target typically will be preceded by a target acquisition once per roughly six orbits and that a wavecal will be taken with each change of grating element or following each orbit.

From the information presented in Table 14, a “typical” non-acquisition COS GTO orbit will consist of a single 45-50 minute science exposure followed by a wavecal. Such long exposure times are not unexpected. As the observational capability to reach fainter sources evolves and the scientific interest in those fainter sources grows, we would expect the typical HST exposure to lengthen. The median STIS exposure is slightly longer than that for FOS and, with the optimization of COS for faint sources, we would expect the median exposure to be longer than for any previous HST spectrograph. Additionally, since COS has photon-counting detectors, we expect them to be utilized predominantly to take relatively long exposures, as only with long integration times can high signal-to-noise be achieved while maintaining count rates in the linear regime.

Table 14: Potential COS IDT Observations (condensed from Morse, 1998).

Science Topic	Detector	Typical Fluxes (F_{λ}x10^{-15})	S/N	Minutes per Exposure	Number of Exposures	Number of Targets	Orbits (exposures) per Target
He II Gun Peterson	FUV	.1 - .5	10	45-50	50	3	17
D/H	FUV	5 - 30	20	45-50	60	4	15
	NUV			45-50	60		15
Lyman-alpha forest / hot gas	FUV	1 - 40	20-30	45-50	30	4	7
	NUV			45-50	90		22
Local Starbursts	FUV	1 - 5	20	45-50	30	4	7
	NUV			45-50	45		11
Young SNRs	FUV	.1 - 5	20	45-50	11	2	5
	NUV			45-50	11		6
Cold ISM	FUV	.7 - 20	20	45-50	22	3	7
	NUV			45-50	33		11
UV extinction	FUV	.1 - 5	20	45-50	12	4	3
	NUV			45-50	12		3
UV extinction: standards	FUV	10,000	30	2	5	5	1
	NUV			2	5		
Planet Occultations	FUV	100-1000	15	45-50	5	5	1
	NUV			45-50	6		1
Pluto and Triton	NUV	.5 - 5	10	45-50	44	2	22

Conservatively, we conclude that a typical COS faint orbit will contain, 1 science exposure and 1 accompanying wavecal. Including the target acquisition, we predict 1 target acquisition dataset (a multi-stage series of observations with an upper limit data volume of ~28-54 Mbits), and 1 science dataset (with a science exposure and a wavecal) in the first orbit of each visit. There will be one similar science dataset in each subsequent orbit in the visit. We assume that a typical visit would last 6 orbits (a typical SAA-free period without special effort to hide SAA in occultation). Unless COS observations are made interruptible in order to facilitate very long visits with observing in SAA-impacted orbits, most GTO programs will require multiple visits per target to achieve the desired signal. We anticipate that nearly all will be obtained in TIME-TAG mode, so that they will generate relatively little data volume (see the data volume columns in Tables B1 and B2).

Exceptions: Instances where a large exposure/data volume is generated

Some programs will observe brighter targets with shorter exposures. Previous HST spectrographs with faint object capability were also used for high count rate and high data volume science.

As described above, it is anticipated that the vast majority of COS science will utilize fairly long exposures (> 40 minutes) and thereby generate small numbers of exposures or datasets per orbit and fairly modest data volumes. However, several scenarios can be envisioned where large numbers of exposures, and in some instances large data volumes, are created in short amounts of time.

We note that (1) the overall use of time-resolved spectroscopy (sample times < 2 minutes) has always been relatively small for the HST spectrographs - we expect it to continue at the rate seen in previous cycles, roughly 10% of the time, and (2) in nearly all cases the large number of exposures generated will be combined into a single dataset by OPUS for passage to the archive.

The scenarios described below in which we expect large numbers of exposures and/or data volume to be generated quickly include:

- necessarily time-resolved spectroscopy
- very bright object observing
- FPSPLIT observations.

Table 15: Summary of STScI PRESTO and DADS Study and COS projections

Item	FOS	GHRS	STIS	COS GTO	COS Community	COS Adopt
Science: fraction by number [e]	73%	95%	75%			75%
Pointed calibration: fraction by number [e]	27%	5%	25% [a]			25% [a]
Science: fraction by exposure time [e]	89%	98%	87%			90%
Pointed calibration: fraction by exposure time [e]	11%	2%	13% [a]			10% [a]
AVERAGE science spectrum exposure time	1821 sec	1889 sec	1050 sec			
MEDIAN science spectrum exposure time	1380 sec	1088 sec	1434 sec	~2500 sec		~2500 sec
Moving Target: MEDIAN sci. sp. exposure	960 sec	1011 sec	790 sec	2700 sec[b]		2700 sec [b]
Moving Target: science fraction by number	13%	12%	3%	11%	1%	<10%
FP-SPLIT fraction by number	n/a	~25%	~3%			5%
FUV:NUV % by number	37:63	34:66	57:43			
FUV:NUV % by exposure time	49:51		59:41	42:58	34:66	40:60
RAPID: fraction by number	10%	4%	8% (TIME-TAG)	3%	4%	8-10%
RAPID: median readout time	7 sec	---	n/a			
RAPID: median V magnitude	13		10.1			14.?
RAPID: moving target : fixed target ratio				100:0	15:85	20:80
Median V magnitude	13.9	5.8	13.4			15. [c]
$\nu^{-1} F_{\lambda}$(1400 A) for median V magnitude	3.9e-14	6.7e-11	6.2e-14			1.e-14 [cd]

[a] does not include wavecal exposures associated with science exposures

[b] COS moving target times are estimates of "typical" exposure duration and not median values

[c] estimated typical COS faint target

[d] produces S/N~10-15 in 2000 sec with COS M modes; all F_{λ} units are ergs-cm^{-2}-sec^{-1}-Å^{-1}.

[e] considers only external observations exclusive of target acquisition

7.3 Necessarily Time-Resolved Spectroscopy

COS time-resolved spectroscopy can be obtained with repeatobs ACCUM mode or with TIME-TAG mode. Earlier instruments have used time-resolved spectroscopy about 10% of the time.

Repeatobs ACCUM mode: As with STIS, time-resolved ACCUM mode observers can use the "REPEATOBS" (or nexp=many) option which will cause a series of identical exposures to be taken. We assume this capability will be available for both MAMA and XDL ACCUM mode observations. With STIS there is a roughly 5-second interval between exposures. This mode would be used to monitor variability on minute timescales, typically generating a single exposure per minute. Monitoring of variability over the course of an orbit would generate roughly 50 exposures. OPUS will package these many associated exposures into a single large datatset.

Data volume for this mode is limited by the rate at which data can be transferred from internal memory to the recorder (1 NUV MAMA exposure every 16 seconds and 1 FUV XDL exposure every 25 seconds). As an upper limit, we assume that we can read out the 1024 x 1024 array every 30 seconds in this mode. Thus a single orbit NUV MAMA time-resolved spectroscopic observation could accumulate roughly 100 exposures or 1600 Mbits (200 Mbytes). This data volume amounts to approximately one-sixth of the full science capacity of the SSR. Similarly, for XDL ACCUM mode, 60 readouts would produce 1600 Mbits. Nominal daily downlink capacity is approximately 20,000 Mbits (2500 Mbytes - twice the full SSR capacity) and STIS rules for recorder management suggested no more than ~20% of SSR capacity (2000 Mbits) should be filled in any normal orbit. As with STIS, extended repeatobs observations at these maximum rates would require some special recorder management.

STIS repeatobs usage with exposure times less than 2 minutes comprises about 1% of all STIS exposures and only about 10% of STIS time-resolved spectra. FOS observations, which routinely read out at either two or four minute intervals, had only 20% of RAPID mode sample times longer than 30 seconds.

Given the general utility of TIME-TAG mode for most time-resolved observations, we expect that COS repeatobs ACCUM mode observations will be used rarely and only when necessary. Although there are data volume efficiency advantages to using ACCUM mode at rates somewhat slower than those limited by buffer memory dump times (recall that the maximum TIME-TAG rate produces 144 Mbits (18 Mbytes) every 192 seconds or about 2240 Mbits per 50-minute exposure), we do not anticipate that these efficiencies will be routinely exercised. Rather, since the repeatobs sampling times are substantially longer than the majority of historical HST time-resolved sampling times, we expect that only those time-resolved observations that absolutely can not be performed in TIME-TAG mode (exposure durations longer than 192 seconds for count rates higher than 24,000 counts per second) will be performed in repeatobs ACCUM mode.

We assume that, like STIS, only about one-tenth of COS time-resolved observations will be executed in repeatobs ACCUM mode.

Time-tag mode: TIME-TAG mode will generate a single science exposure (and dataset). These datasets can be very large, with 800 Mbits produced in roughly 1200 seconds (data volume limits the length of these exposures as buffer memory can accommodate ~4.7 million entries in the event list). At the maximum TIME-TAG rate - 24,400 counts per second - about 15,000 FUV counts are recorded per resolution element in a 50-minute visibility. Therefore, nominal Poisson S/N of 100:1 can be reached in one visibility at this maximum rate even allowing for instrument overheads and FPSPLITs. Since XDL detector non-linearity sets in at ~40,000 counts per second, only targets less than 0.75 magnitudes brighter than the TIME-TAG brightness limit would be candidates for repeatobs time-resolved mode.

A 50-minute visibility at the maximum TIME-TAG rate produces about 2240 Mbits of data volume, which is at the nominal limiting threshhold for orbital data volume. Several consecutive orbits at this rate would require downlink management. We therefore need to estimate how frequently COS programs will make time-resolved observations near the maximum TIME-TAG data rate.

Approximately 10% of FOS observations by number were made in time-resolved (RAPID) mode with sample times longer than one minute. The median sample time was approximately 7 seconds with 20% of samplings performed at intervals ≤1 second and 80% of sample times were 30 seconds or less. The brightness distribution of FOS RAPID targets was quite similar to the distribution of all FOS targets though truncated at the extrema. V magnitudes ranged from 5 to 17 with a median of 13, as compared to 13.9 for the entire set of FOS science targets. Most FOS RAPID targets were either eruptive binaries (CVs, etc.) or solar system targets engaged in some form of eclipse or occultation. Seventy percent of the FOS CVs were fainter than the median target brightness. None of the solar system targets and only 10% of 30 CVs in the FOS archive had ultraviolet fluxes that would produce COS countrates above the TIME-TAG rate limit.

By analogy we assume 90% of COS time-resolved programs will be monitoring variability on timescales shorter than 60 seconds and will be carried out in TIME-TAG mode. On the conservative assumption that the brightness distribution of COS CV targets is similar to that of FOS (it will actually be shifted to fainter levels), 1 in 10 would produce data volumes that could stress the system and another two in 10 could be within a factor of two of the maximum TIME-TAG data volume. We incorporate this distribution in the calculation of data volume for Table 11 in section 4.

Time-resolved Data Volume Limits: Time-resolved observations of bright sources are potentially the most stressful in terms of data volume. In order to assess worst-case downlink volume scenarios we assume ten 50-minute orbits as a representative maximum visit. In this case 22.4 Gbits would be the maximum TIME-TAG visit data volume. Alternatively, for repeatobs ACCUM mode 100 MAMA or 60 XDL readouts produce 16 Gbits in such a stressed visit. CVZ scenarios would produce 1.8 times these values.

Very Bright Target Observations

ACCUM mode recording uses 16-bit accumulation. Avoidance of numerical overflow can limit exposure duration for very bright targets by making use of multiple short exposures, but this should be an issue only for the very brightest targets. As in the STIS case, the use of multiple exposures should be self-limiting in the sense that the brightest sources should require the shortest total integration times, though astrophysical examples of faint lines on bright sources do exist. Perhaps more importantly, MAMA nonlinearity sets in at roughly 200 counts/pixel/second and XDL non-linearity at 1.25 counts/second/pixel, and users will typically want to choose a configuration which keeps them near the linear regime. At these MAMA count rates the 16-bit limit is reached after 5 minutes, but the 16-bit limit is not an issue for the XDL,.

Fixed-Pattern Split (FPSPLIT) Mode.

The FPSPLIT option is used to achieve the highest signal-to-noise on mostly brighter sources. FPSPLIT capability has been available to HST users of STIS and GHRS, but not with FOS. Only GHRS observers have made significant use of the technique. Nearly one-third of all GHRS science exposures used FPSPLIT, but this statistic is affected by heavy GHRS echelle mode usage - particularly for ISM studies. Therefore, we consider only the GHRS M modes, which had comparable resolution to the COS M modes.

Approximately one-fourth of GHRS M mode exposures, or about 12% of all GHRS science, were FPSPLIT and half of this number were in ISM programs. GHRS chemical abundance studies also substantially utilized high S/N spectra at M mode resolution.

Much of GHRS-type science can be done with great efficiency with STIS. However, COS has a definite FUV advantage over STIS at M mode resolutions. As discussed in section 2.3, COS M mode “discovery efficiency” is greater than that of either the STIS echelle modes after re-binning to COS resolution or the STIS M modes. The combination of this FUV advantage and the efficiency of simply staying with COS to execute the NUV portion of programs that require both regions may promote the movement of some programs from STIS to COS. Alternatively, we note that 70% of GHRS ISM observations already were in the FUV region.

We very roughly estimate that approximately 5% of COS exposures will involve FPSPLITs to obtain high S/N.

Due to the high S/N requirement, most FPSPLIT observations will be of bright targets. At the maximum XDL linear counting rate, 40,000 counts/sec, about 1000 seconds of exposure are needed to obtain Poisson S/N of 100:1 in an FPSPLIT series. With minimal overhead losses, a maximum of two such series (eight exposures) could be obtained in a single standard visibility. Alternatively, the maximum duration of each component of an FPSPLIT series would be limited to two orbits by typical SAA-free periods. These constraints impose a relatively narrow brightness range of a factor of 20 (about three magnitudes) for high S/N FUV targets with the XDL. (The equivalent range for the MAMA is much larger – a factor of ~400.) As this XDL brightness range is smaller than the attentuation factor of the BOA, a two magnitude “gap” exists in the range of fluxes that can be sampled at high S/N by the XDL. Implementation of the FUV G130MB backup grating with the MAMA and the PSA would cover this gap. We have included occasional baseline calibration of G130MB in our calibration estimates.

We will assume the two-series (8 exposures plus two wavecals) limit for the purpose of estimating the maximum orbital XDL FPSPLIT data volume as approximately 256 Mbits.

The higher maximum linear counting rate for the MAMA allows S/N of 100:1 to be reached in less than two minutes. Mechanism overheads are not yet established, but on the assumption of one minute for each grating motion and five mintues for the wavecal, no more than 4 full NUV FPSPLIT series could be fit in a 50-minute visilbility. The resultiant 16 ACCUM exposures and four wavecals would produce a maximum of 320 Mbits (40 Mbytes) of NUV FPSPLIT downlink data per orbit..

Calibration

We have budgeted pointed calibration exposures to use approximately 10% of the total time allocated for COS, although to date we have enumerated observations that require perhaps one-fourth of this amount. Since external calibration sources are usually bright, they will generate relatively large amounts of data. For FOS and STIS, approximately 25% of all pointed external SI exposures have been calibration-related, but have used only about 10% of the instrument observing time. GHRS, an instrument with relatively fewer modes than either FOS or STIS, required smaller fractions. We expect the number fraction of calibration exposures for COS to be similar to those for STIS and FOS (due to the relatively small number of science exposures) but the time fraction for COS should be smaller due to the relatively short calibration exposure durations that will be required.

8. References

COS IDT, "Cosmic Origins Spectrograph (COS) Science Operations Requirements Document (OP-01), 1999.

Ebbets, D. and Becker, I., 1998, SER COS-FSW-001.

Morse, J.A., “COS IDT DRM,” 1998.

Figure 1: COS and STIS Sensitivities

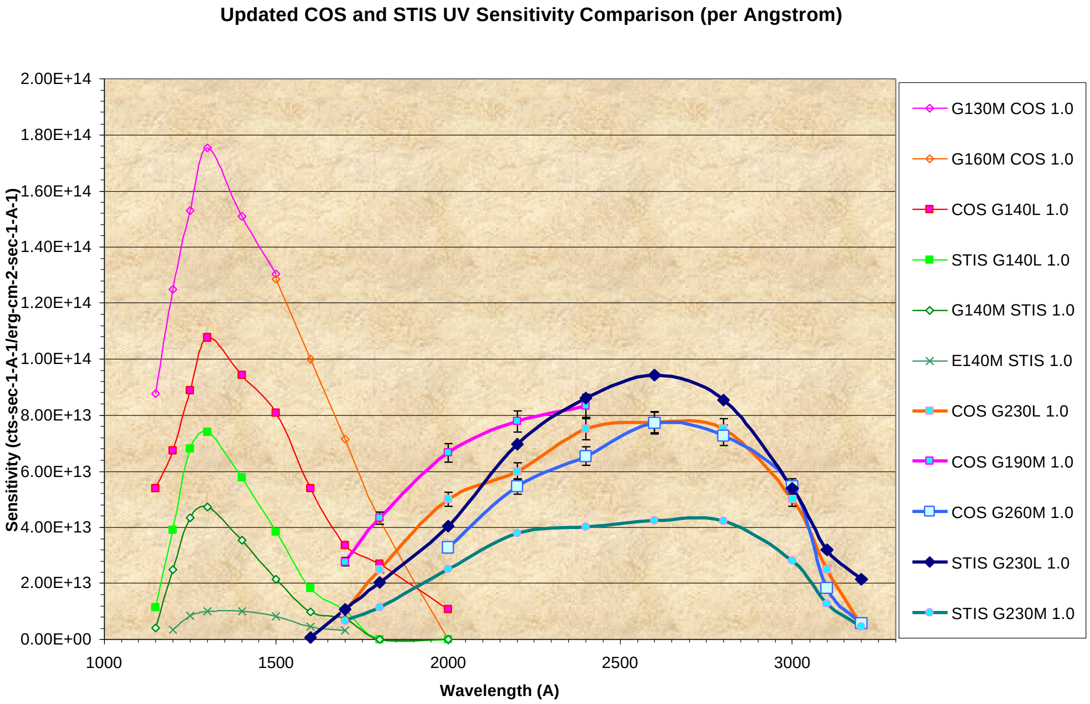

Figure 2: COS and STIS Limiting Fluxes for Typical Spectral Binnings

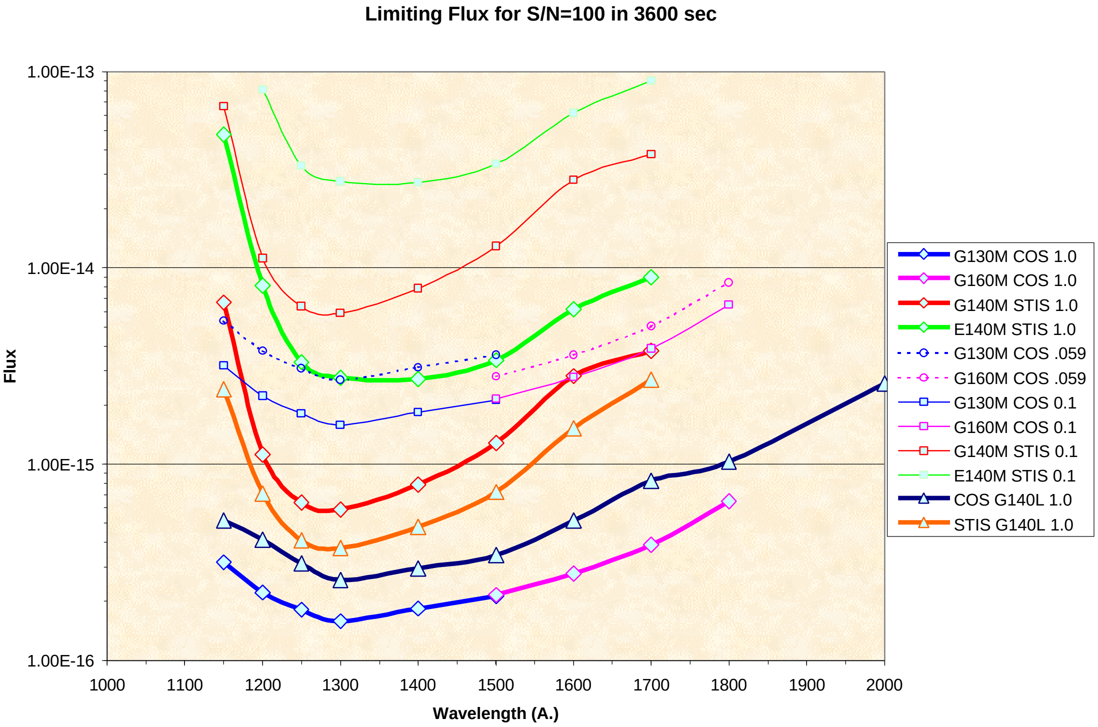

Figure 3: COS and STIS FUV Limiting Fluxes

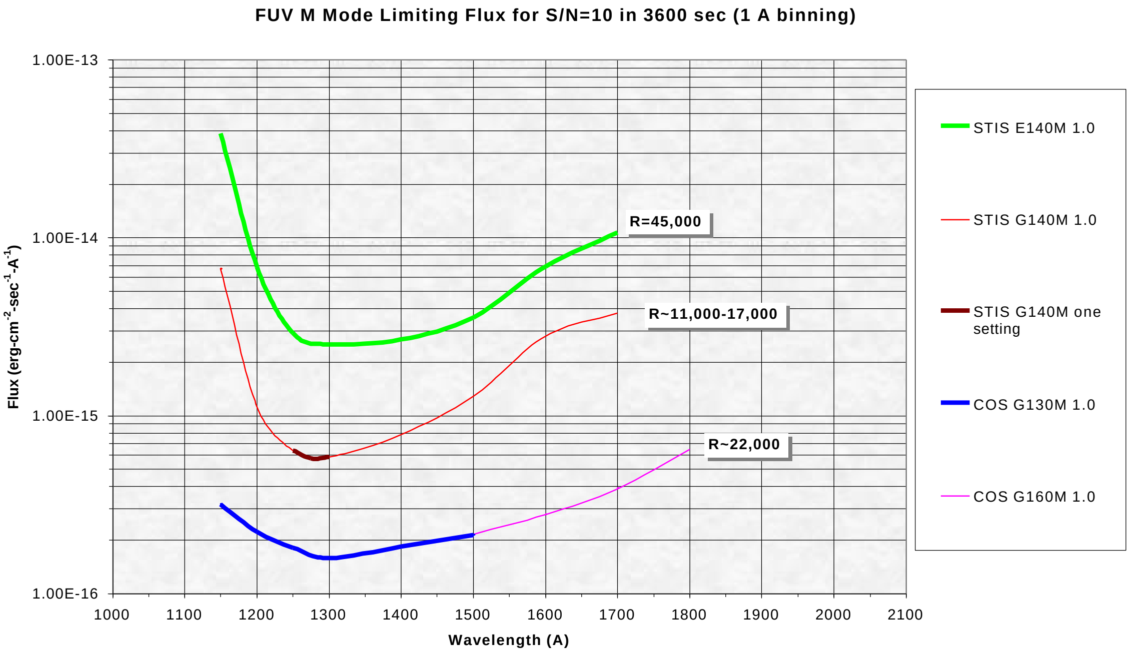

Figure 4: COS and STIS NUV Limiting Fluxes

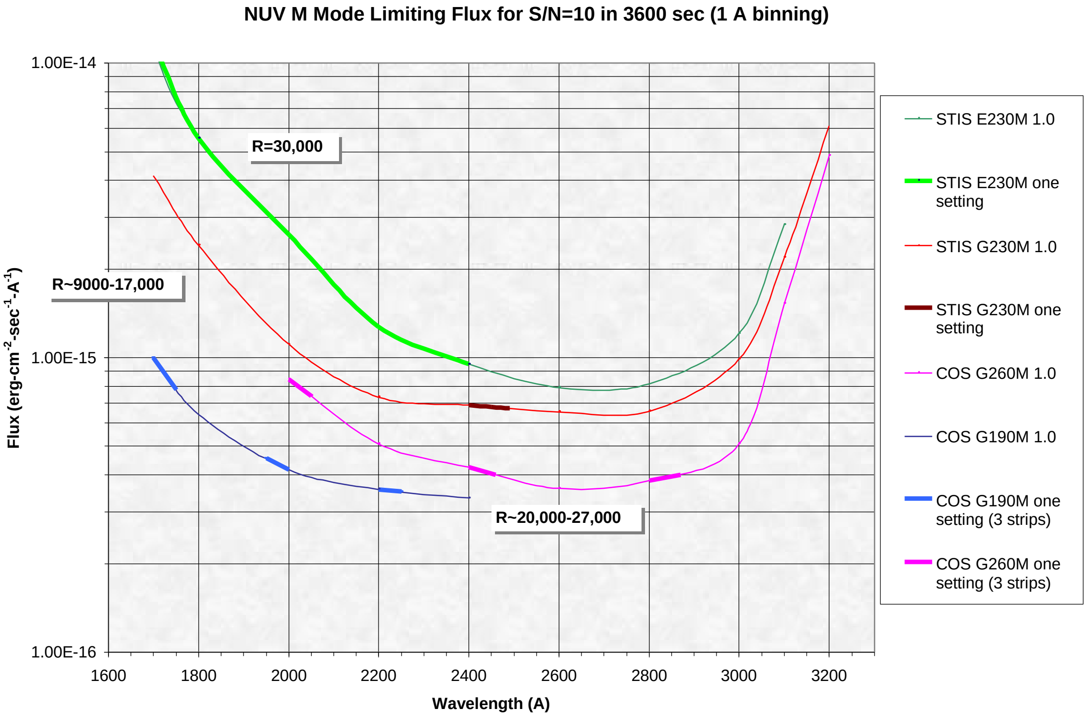

Table B1: Morse GTO Table:

	Aperture	G130M	G160M	G140L	G190M	#	G260M	#	G230L	Targets	FUV exp	NUV exp	Total exp	exp %	cts/s/resel	FUV cts	NUV cts	Total cts	data %	# orbits	orb %	cts/orbit	kBytes/orbit
HeII Gunn-Peterson	PSA	45000	0	0	0	0	0	0	0	3	135000	0	135000	9.6%	0.003	1620000	0	1620000	0.7%	50	9.6%	32400	129
D/H	PSA	20000	20000	0	20000	1	20000	1	0	4	160000	160000	320000	22.9%	0.1	64000000	2.4E+07	88000000	40.2%	118	22.7%	745763	2983
Ly-a forest/hot gas	PSA	10000	10000	0	10000	3	10000	3	0	4	80000	240000	320000	22.9%	0.08	25600000	2.9E+07	54400000	24.9%	118	22.7%	461017	1844
Local Starbursts	PSA	10000	10000	0	10000	2	10000	1	0	4	80000	120000	200000	14.3%	0.02	6400000	3600000	10000000	4.6%	74	14.2%	135135	540
Young SNRs	PSA	0	0	15000	0	0	0	0	15000	2	30000	30000	60000	4.3%	0.03	36000	45000	81000	0.0%	22	4.2%	3682	14
Cold ISM	PSA	10000	10000	0	10000	2	10000	1	0	3	60000	90000	150000	10.7%	0.05	12000000	6750000	18750000	8.6%	55	10.6%	340909	1363
UV extinction	PSA	0	0	8000	0	0	0	0	8000	4	32000	32000	64000	4.6%	0.1	1280000	480000	1760000	0.8%	23	4.4%	76522	306
UV extinction: STDs	BOA	0	0	100	0	0	0	0	100	5	500	500	1000	0.1%	10	2000000	750000	2750000	1.3%	5	1.0%	550000	2200
Planet occultations	PSA	0	0	3000	0	0	0	0	3000	5	15000	15000	30000	2.1%	5	30000000	1.1E+07	41250000	18.9%	11	2.1%	3750000	15000
Pluto and Triton	PSA	0	0	0	20000	2	20000	1	0	2	0	120000	120000	8.6%	0.01	0	180000	180000	0.1%	44	8.5%	4091	16
Totals:		3E+05	2E+05	77500	4E+05		3E+05		77500	36	592500	807500	1E+06		1.5393	1.43E+08	7.6E+07	2.19E+08		520		609952	2439.5
		sum	sum	sum	sum		sum		sum	sum	sum	sum	sum	sum	average	sum	sum	sum		sum		average	average
															0.065								951.5
															median								median
percent usage		0.23	0.14	0.06	0.30		0.22		0.06		0.42	0.58				FUV cts	0.65						
																NUV cts	0.3467						

Table B2. Community info - includes GTO programs in totals (from Morse)

Scientific Program	Aper-ture	G130M	G160M	G140L	G190M	#	G260M	#	G230L	Targets	FUV exp	NUV exp	Total exp	%	cts/s/resel	FUV cts	NUV cts	Total cts	%	# orbits	cts/orbit	kBytes/orbit	n Tacq
HeII Gunn-Peterson	PSA	45000	0	0	0	0	0	0	0	5	225000	0	225000	0.78%	0.003	2700000	0	2700000	0.08%	83	32530.1205	130	15
D/H	PSA	20000	20000	0	20000	1	20000	1	0	10	400000	400000	800000	2.79%	0.1	160000000	60000000	220000000	6.45%	296	743243.243	2972	50
Ly-alpha forest	PSA	20000	20000	0	20000	3	20000	3	0	20	800000	2400000	3200000	11.14%	0.08	256000000	288000000	544000000	15.94%	1185	459071.73	1836	200
Hot Gas in Halos	PSA	20000	20000	0	20000	3	20000	3	0	20	800000	2400000	3200000	11.14%	0.08	256000000	288000000	544000000	15.94%	1185	459071.73	1836	200
Local Starbursts	PSA	25000	25000	0	25000	2	25000	1	0	10	500000	750000	1250000	4.35%	0.02	40000000	22500000	62500000	1.83%	462	135281.385	541	80
Young SNRs	PSA	0	0	15000	0	0	0	0	15000	3	45000	45000	90000	0.31%	0.03	54000	67500	121500	0.00%	33	3681.81818	14	6
Cold ISM	PSA	10000	10000	0	10000	2	10000	1	0	6	120000	180000	300000	1.04%	0.05	24000000	13500000	37500000	1.10%	111	337837.838	1351	24
UV extinction	PSA	0	0	8000	0	0	0	0	8000	10	80000	80000	160000	0.56%	0.1	3200000	1200000	4400000	0.13%	59	74576.2712	298	10
UV extinction: STDs	BOA	0	0	100	0	0	0	0	100	5	500	500	1000	0.00%	10	2000000	750000	2750000	0.08%	5	550000	2200	5
Planet occultations	PSA	0	0	3000	0	0	0	0	3000	5	15000	15000	30000	0.10%	5	30000000	11250000	41250000	1.21%	11	3750000	15000	5
Pluto and Triton	PSA	20000	20000	0	20000	2	20000	2	0	2	80000	160000	240000	0.84%	0.01	320000	240000	560000	0.02%	88	6363.63636	25	16
QSO Legacy Proj	PSA	33000	33000	0	33000	3	33000	3	0	50	3E+06	9900000	1.3E+07	45.96%	0.03	396000000	445500000	841500000	24.66%	2444	344312.602	1377	450
Local Group PNe	PSA	12500	12500	0	12500	3	12500	2	0	30	750000	1875000	2625000	9.14%	0.01	3000000	2812500	5812500	0.17%	972	5979.93827	23	180
Variability in AGN	PSA	2500	2500	0	0	0	0	0	0	250	1E+06	0	1250000	4.35%	0.1	500000000	0	500000000	14.65%	462	1082251.08	4329	250
UV upturn in E gals	PSA	40000	40000	0	0	0	0	0	0	10	800000	0	800000	2.79%	0.01	32000000	0	32000000	0.94%	296	108108.108	432	50
UV lines of YSOs	PSA	5000	5000	0	5000	1	5000	1	0	10	100000	100000	200000	0.70%	0.1	40000000	15000000	55000000	1.61%	74	743243.243	2972	20
SN1987A impact	PSA	3000	3000	0	3000	3	3000	4	0	1	6000	21000	27000	0.09%	1	2400000	3150000	5550000	0.16%	10	555000	2220	2
Variability in CVs I	PSA	0	0	9000	0	0	0	0	0	5	45000	0	45000	0.16%	5	90000000	0	90000000	2.64%	16	5625000	22500	5
Variability in CVs II	PSA	10000	0	0	10000	1	10000	1	0	30	300000	600000	900000	3.13%	0.2	240000000	180000000	420000000	12.31%	333	1261261.26	5045	60
Hibernating novae	PSA	0	0	0	0	0	0	0	10000	3	0	30000	30000	0.10%	0.01	0	45000	45000	0.00%	11	4090.90909	16	3
MW Halo (parallel)	PSA	75000	75000	0	0	0	0	0	0	1	150000	0	150000	0.52%	0.005	3000000	0	3000000	0.09%	55	54545.4545	218	10
Totals:		5E+06	5E+06	2E+05	1E+07		9E+06		2E+05	486	1E+07	1.9E+07	2.9E+07		1.0447	2.081E+09	1.332E+09	3.413E+09		8191	777878.589	3111.19048	1641
		sum	sum	sum	sum		sum		sum	sum	sum	sum	sum		average	sum	sum	sum		sum	average	average	sum
														median	0.08							1377	
	fract	17.59%	15.76%	0.65%	33.89%		31.51%		0.59%		34.00%	66.00%	100.00%							FUV cts	0.60968755		
		G130M	G160M	G140L	G190M		G260M		G230L		FUV exp	NUV exp	Total exp							NUV cts	0.39031245		