STIS GTO

OBSERVER'S HANDBOOK

Revision A

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1.0 INSTRUMENT OVERVIEW

A schematic layout of STIS, identifying its principal components, is shown in the accompanying figure.

Figure 1.1 STIS Schematic

STIS will carry out its observations in four spectral bands, using three detectors:

Band 1 115-170 nm	MAMA with CsI photocathode
Band 2 165-310 nm	MAMA with Cs_2Te photocathode
Band 3 305-555 nm	CCD with enhanced short wavelength performance
Band 4 550-1000 nm	Same CCD

The MAMA detectors are 1024 x 1024 with 25 x 25 micron pixels. *Throughout this document, "MAMA pixels" will be used to refer to this 25 micron pixel size.* The MAMA data will actually be read out in a 2048 x 2048 format, by using the event decode electronics to locate photon events to the nearest half-pixel position. This "high-resolution" readout for the MAMA provides better sampling and better final resolution. The corresponding 12.5 x 12.5 micron elements are referred to as "high-res" pixels. For historical reasons (and by virtue of the correspondence to the actual spacing of anode wires on the MAMA anode), when this document refers to MAMA pixels, it will mean the "low-res" 25 x 25 micron variety.

The CCD is a Scientific Imaging Technologies (SITe) backside-illuminated 1024 x 1024 device with 4-amp readout capability. Its pixels are 21 x 21 microns in size.

STIS will observe in the following modes:

a) low resolution spectral imaging
   -R ~ 500-1000; long slits; all 4 spectral bands

b) medium resolution spectral imaging
   -R ~ 5,000-10,000; long slits; all 4 bands

c) medium resolution echelle spectroscopy
   -R ~ 24,000; short slits; 2 UV bands only

d) high resolution echelle spectroscopy
   -R ~100,000; short slits; 2 UV bands only

e) objective spectroscopy
   -R = 26 (at 3000 Å)-930 (at 1216 Å); Cs_2Te detector only

f) broadband imaging
   -wide field; all 4 bands; several filters available (see Section 3.0)

2.0 SPECTROSCOPIC MODES/RESOLUTIONS

2.1 Summary of Mode Specifications

The following tables (Tables 2.1-2.3), based on the STIS CEI Specification, Part 2 (the requirements laid on Ball Aerospace), present the key information for the various STIS spectroscopic modes. The core observing modes for STIS are the n.1 through n.6 modes (that is, all those in Table 2.1 and the camera modes from Table 2.2).

NOTES FOR TABLES 2.1-2.3

1. The spectral resolutions shown are $\lambda/\Delta\lambda$, where $\Delta\lambda$ is the FWHM predicted for a monochromatic input uniformly filling a two-pixel wide slit (except for the high resolution echelle modes 1.4 and 2.4; for these, achieving the stated resolution of 100,000 will require the use of slits narrower than two pixels wide). When a range of resolving power is given, the first number refers to the short wavelength end of the band and the second number to the long wavelength end of the band. The predicted FWHM values range generally from about 2.25 to 2.45 pixels. For point sources, image quality in the spatial direction is also about 2-2.5 pixels FWHM.

2. Note that all of the medium resolution spectral imaging (long slit) modes and all of the echelle modes except mode 1.3 require more than one exposure to cover the full wavelength range of the band. The number of exposures required to cover the band with a bit of overlap and no gaps is shown in the table.

3. The STIS throughput values in the table refer to the specification laid on Ball for throughput at particular wavelengths. See Section 4.0 for the predicted effective areas for STIS (including the HST) as a function of wavelength.

4. The objective prism mode (2.5) is so named because it is directed toward the band 2 detector. However, the short wavelength cutoff is defined by the transmission of the MgF_2 prism and MgF_2 detector window, so the actual wavelength coverage extends through band 1. The predicted resolving power is shown in Figure 2.1.

Table 2.1: STIS Spectroscopic Modes

Mode	Band Wavelength Range (nm) Detector	Band 1 115-170 Det #1 (MAMA/CsI)	Band 2 165-310 Det #2 (MAMA/Cs_2Te)	Band 3 305-555 Det #3 (CCD)	Band 4 550-1000 Det #3 (CCD)
Low Resolution Spectral Imaging (first order)	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Slit Length (arcsec) Exposures/band	1.1 770-1,130 24.9 1	2.1 415-730 24.9 1	3.1 445-770 51.1 1	4.1 425-680 51.1 1
Medium Resolution Spectral Imaging (first order scanning)	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Slit Length (arcsec) Exposures/band	1.2 8,600-12,800 29.7 11	2.2 7,500-13,900 29.7 18	3.2 4,340-7,730 51.1 10	4.2 3,760-6,220 51.1 9
Medium Resolution Echelle	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Exposures/band	1.3 24,000-24,200 1	2.3 23,900-23,100 2	---	---
High Resolution Echelle	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Exposures/band	1.4 100,000 3	2.4 100,000 6	---	---
Objective Spectroscopy (prism)	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Field of View (arcsec)	---	2.5 (115-310 nm) 930-26 (@120-310) 29.7 x 29.7	---	---

Table 2.2: STIS Imaging and Calibration Modes

Mode	Band Wavelength Range (nm) Detector	Band 1 115-170 Det #1 (MAMA/CsI)	Band 2 165-310 Det #2 (MAMA/Cs_2Te)	Band 3 305-555 Det #3 (CCD)	Band 4 550-1000 Det #3 (CCD)
Camera	Mode Number Field of View (arcsec)	1.6 24.9 x 24.9	2.6 24.9 x 24.9	3.6 51.1 x 51.1	4.6 51.1 x 51.1
Low Resolution Using Mode x.3 Cross Dispersers (first order)	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Slit Length (arcsec) Exposures/Band	1.7(x3) 768-1,123 29.7 1	2.7(x3) 838-1,504 29.7 2	---	---
Low Resolution Using Mode x.4 Cross Dispersers (first order)	Mode Number Resolving Power ($\lambda/\Delta\lambda$) Slit Length (arcsec) Exposures/Band	1.7(x4) 2,735-3,446 29.7 3	2.7(x4) 2,437-4,391 29.7 6	---	---

Table 2.3: STIS Backup Modes

Mode	Band Wavelength Range (nm) Detector	Band 1 115-170 Det #2 (MAMA/Cs_2Te)	Band 2 165-310 Det #3 (CCD)
Low Resolution Spectral Imaging (First Order)	Mode Number Spectral Resolving Power Slit Length (arcsec) Exposures/Band	1.1B 765-1115 29.7 1	2.1B 495-910 51.1 1
Medium Resolution Spectral Imaging (First Order)	Mode Number Spectral Resolving Power Slit Length (arcsec) Exposures/Band	1.2B 8,600-12,800 29.7 11	2.2B 4,370-8,230 51.1 10
Medium Resolution Echelle	Mode Number Spectral Resolving Power Exposures/Band	1.3B 24,300-24,000 1	---
High Resolution Echelle	Mode Number Spectral Resolving Power Exposures/Band	1.4B 100,000 3	---

2.2 Objective Prism Mode 2.5

The objective prism mode, mode 2.5, covers from the MgF_2 cutoff near 115 nm to the cutoff of the band 2 (Cs_2Te) detector near 330 nm. The typical spectrum of a cool object will be a relatively short (compared to the extent of the detector), low-dispersion spectrum ranging from the long wavelength cutoff of the detector to the intrinsic short wavelength cutoff of the object. In contrast, because of the rapidly increasing dispersion of the prism in the ultraviolet, a hot object's spectrum will extend across a significant fraction of the detector. The spectral format for the objective prism mode is represented pictorially in Figure 2.2. Quantitatively, the length of a prism spectrum, from the roughly 330 nm detector cutoff to some representative wavelengths, is as follows:

330 nm to 230 nm:	31 pixels
330 nm to 190 nm:	63 pixels
330 nm to 150 nm:	144 pixels
330 nm to 121.5 nm:	386 pixels
330 nm to 113.5 nm:	670 pixels.

Thus, a spectrum which is visible all the way to Lyman α will extend across nearly 40% of the detector. Stated another way, the size of the field of view for which the entire spectrum from 330 nm to Lyman α can be observed is only 60% of the nominal 29.7" x 29.7" field of view (whereas one can observe down to 190 nm for >90% of the field of view).

The nominal tilt of the prism will be such that the red tail of the spectrum will be directed toward the detector for all objects in the field. With that choice, a nominal one-exposure prism observation will provide spectra from 330 to <200 nm for >90% of the objects in the field, but the spectra will reach the edge of the detector before reaching Lyman α for 35-40% of the objects in the field. A tilted setting for the prism (using the scan capability of the grating wheel) will be determined to provide full coverage of the field at the Lyman α end of the spectrum. One can therefore obtain spectra of all objects in the field from 330 nm to Lyman α in two exposures, or concentrate exclusively on the Lyman α region in one exposure if desired.

2.3 Cross-Dispersed First Order Modes

The n.7(x3) and n.7(x4) modes are first-order spectroscopic modes with their dispersions perpendicular to the dispersions of the nominal first-order modes. The modes are generated by directing the beam from a cross-disperser on the grating wheel toward a fold flat and camera mirror instead of toward the corresponding echelle grating and camera mirror; these modes are used for flat-field calibration of the echelle modes.

In addition to their prime purpose of flat-fielding, the cross-dispersed first order modes are potentially useful for direct astronomical observations, because they can provide a spectral resolution capability intermediate between that of the low resolution n.1 modes and the higher resolution n.2 or n.3 modes. Though intermediate spectral resolution can always be obtained by binning up the data obtained in an echelle mode, the throughput in the cross-dispersed first order mode is naturally higher, because a fold mirror has been substituted for a relatively inefficient

echelle grating. Furthermore, a greater amount of detector background is added into a given wavelength range of a "binned spectrum", compared with observing at the desired resolution in the first place.

The penalty for obtaining higher spectral resolution from a cross-dispersed mode compared with the basic n.1 low resolution mode is a reduction in simultaneous wavelength coverage. While the n.1 modes cover an entire STIS band in one exposure, 3 of the 4 cross-dispersed modes require greater than one exposure to cover a given band. The simultaneous wavelength coverage of the cross-dispersed modes is presented in Table 2.5, while their effective areas can be found in Section 4.

It is important to note that the cross-dispersed first order modes are not considered prime scientific modes by the STScI in terms of maintaining a scientific calibration. Nor will they be characterized as thoroughly in the STIS ground calibration program.

2.4 Backup Modes

The backup modes in Table 3 are fallbacks in the case of detector failure. That is, either by employing a backup grating or an off-nominal pointing of the mode select mechanism (grating wheel), key band 1 spectral modes can be directed toward the band 2 detector, or band 2 modes toward the CCD (there is no backup for the one CCD).

In general, these modes have poorer performance than the nominal modes (either in throughput or spectral format [e.g. the backup echelle modes suffer from order overlap at the shortest wavelengths]). The one exception is that the CCD has higher quantum efficiency than the band 2 MAMA down to about 2500 Å, so observations in the longer wavelengths of band 2 can be better carried out with the 2.1B or 2.2B backup modes, for targets that do not demand a solar blind detector. See Section 4 for current estimates of the sensitivity of the Band 2 MAMA and CCD first order modes. *Because of this sensitivity advantage, the STScI has agreed to offer the band 2 backup modes using the CCD as prime, fully calibrated scientific modes.*

2.5 Dispersions/Plate Scales

There are three different focal lengths used by the STIS optical design. In addition, some of the modes employ gratings with relatively large blaze angles; the resulting anamorphic demagnification yields different angular plate scales in the dispersion and cross-dispersion directions. The following tables present the reciprocal dispersion in Å/pixel, the approximate wavelength range covered in a single exposure, and the angular scale per pixel in the dispersion and cross-dispersion directions, for each of the STIS observing modes.

Table 2.4 Dispersions/Plate Scales - Prime Modes

Mode	Å/pixel	Å per exposure	arcsec/pixel (along dispersion)	arcsec/pixel (cross-dispersion)
1.1	0.597	611	0.0244	0.0244
2.1	1.58	1616	0.0244	0.0244
3.1	2.73	2800	0.050	0.050
4.1	4.92	5030	0.050	0.050
1.2	0.0535	54.8	0.0306	0.0290
2.2	0.0875	89.6	0.0306	0.0290
3.2	0.279	286	0.054	0.050
4.2	0.559	572	0.054	0.050
1.3	λ/91,700	620	0.0358	0.0290
2.3	λ/60,000	808	0.0332	0.0290
1.4	λ/228,000	202	0.0466	0.0290
2.4	λ/228,000	277	0.0466	0.0290
2.5	variable	~1150Å-3100Å*	0.0290	0.0290
1.6	-	~700	0.0244	0.0244
2.6	-	~2000	0.0244	0.0244
3.6	-	~8000	0.050	0.050
4.6	-	~4500	0.050	0.050

*Objective prism spectra will cover roughly 3100 Å (where the sensitivity of the band 2 MAMA is dropping rapidly) to roughly 1150 Å (where the dispersion of the prism is increasingly rapidly and the MgF_2 transmission is dropping rapidly).

Table 2.5 Dispersions/Plate Scales - Backup/Cal Modes

Mode	Å/pixel	Å per exposure	arcsec/pixel (along dispersion)	arcsec/pixel (cross-dispersion)
1.1B	0.606	621	0.0290	0.0290
2.1B*	1.35	1381	0.050	0.050
1.2B	0.0535	54.8	0.0306	0.0290
2.2B*	0.152	156	0.061	0.050
1.3B	λ/60,000	620	0.033	0.0290
1.4B	λ/228,000	202	0.0466	0.0290
1.7(x3)	0.606	620	0.0290	0.0290
1.7(x4)	0.197	202	0.0290	0.0290
2.7(x3)	0.789	808	0.0290	0.0290
2.7(x4)	0.270	277	0.0290	0.0290

*Note that by virtue of their high efficiency at long wavelengths compared with that of the corresponding prime MAMA modes, these band 2 backup modes on the CCD will be supported by STScI as prime science modes.

3.0 SLITS/FILTERS

3.1 Slits - General Considerations

STIS offers a variety of slits and apertures to support its assorted observing modes: long slits for first-order imaging spectroscopy, small echelle slits that preclude order overlap, tilted "planetary" slits, perpendicular slits for use with the cross-dispersion modes, camera apertures (filtered and unfiltered), assorted occulting wedges and bars, flat-fielding slits (with ND filters), and quintets of "offset" slits for use in obtaining high signal-to-noise data through iterative methods. A few general points should be noted:

a) The nominal resolution of each mode, as shown in Tables 2.1-2.3 above, is obtained for a source uniformly filling a slit whose width corresponds to two pixels at the detector. As the various modes have slightly different plate scales, there does not always exist a slit with exactly that width in the STIS list. The closest available slit dimensions are these:

for modes 1.1 and 2.1: 0.049" wide long slit

for modes 1.2 and 2.2: 0.049" wide long slit; 0.063" wide echelle slits

for modes 1.3 and 2.3: 0.063" wide echelle slits

for modes 1.4 and 2.4: 0.063" wide echelle slits corresponds to 1.3 detector pixels; ensures >100,000 resolution
0.09" wide echelle slit corresponds to 2 detector pixels; offers ~90,000 resolution

for all band 3 and 4 modes: 0.100" wide long slit.

b) To avoid order confusion at all wavelengths in an echelle mode, choose an echelle slit with the following lengths:

mode 1.3: 0.33" long
mode 2.3: 0.20" long
mode 1.4: 0.20" long
mode 2.4: 0.10" long.

c) For extended sources observed through wider slits, the FWHM can be estimated by calculating the number of pixels corresponding to the width of the desired slit (using Table 2.1 "Dispersions/Plate Scales") and adding that in quadrature with 1.4 pixels (a typical value for the width of the detector point spread function plus aberrations).

3.2 Slits - Details

The six long slits (Figure 3.1) can be used for both extended objects and point source targets. For the first order grating modes, the long slits have a major advantage over the short slits for point source observations: the sky or background spectrum is observed simultaneously. Furthermore, the position of the star can be varied along the slit to decrease the fixed pattern noise resulting from uncertainties in the flat field calibration and to prevent degradation of the flat-field uniformity of the detector through over-exposure of particular regions. Each long slit has either two or three occulting bars of varying widths. In addition to offering the capability of placing a bright target behind the bars, these bars serve as spatial fiducials to be used when extracting spectra from external extended sources and internal calibration lamp observations.

Figure 3.1 Long Spectroscopic Slits
with Occulting Bars/Fiducials

Eleven standard echelle slits are available with widths of 0.063, 0.09 and 0.2 arcsec. The larger widths give higher throughput and better photometric accuracy at the cost of decreased spectral resolution. Four lengths are available: 0.1, 0.2, 0.33, and 1.0 arcsec. The first three were chosen to provide echelle order separation in the different echelle modes. The 1.0 arcsec slit can be used to obtain limited spatial information for extended objects in the echelle modes at the cost of some order overlap complications. A very narrow (0.025 x 0.1 arcsec) slit is available for obtaining the highest resolutions. A relatively wide (0.5 x 0.2 arcsec) slit is available, providing higher throughput at degraded spectral resolution. Two small echelle slits (0.05 x 0.33 and 0.05 x 0.2) have neutral density filters to limit the throughput of the onboard continuum lamps when performing an echelle ripple calibration.

There are two sets of high signal-to-noise slits (Figure 3.2) with widths of 0.06 and 0.2 arcsec. Each set contains 5 equal size slits with varying x and y offsets. These offsets allow a target to be moved from one slit to another (with a corresponding repositioning of the slit wheel) such that the resulting motion of a spectrum on the detector is in the dispersion direction only. Five

observations can then be obtained that illuminate the same pixels spatially but with small wavelength shifts. This allows techniques that have been successfully applied to data taken with the Goddard High Resolution Spectrograph (GHRS) and the Faint Object Spectrograph (FOS).

Figure 3.2 High Signal/Noise Offset Slits

Figure 3.3 shows the shape of 4 planetary slits which are narrow in the center and wider at each end. There are two slits of each size; one rotated 45 degrees and the other rotated -45 degrees. These orientations facilitate making observations of solar system objects with the slit laid pole-to-pole or along lines of constant latitude, orientations which can be problematic for objects in the ecliptic plane, given the roll angle constraints of the HST.

Figure 3.3 Planetary Slits

In modes 1.7(x3), 1.7(x4), 2.7(x3), and 2.7(x4), the echelle grating is replaced with a mirror and the light is dispersed only by the cross-dispersers. Special long calibration slits rotated 90 degrees from the normal long science can be used for flat field calibration of the echelle modes. The length of the slit ensures complete coverage of the detector. Dispersion of the light in the cross-dispersion direction ensures that the wavelength incident on each detector pixel is close to the wavelength seen in the corresponding echelle mode (within one spectral order). Flat field variations with wavelength in the MAMA detectors are expected to be negligible over the wavelength range of single spectral orders. Two of the cross-dispersed slits have neutral density filters to bring the count rates produced by the continuum calibration lamps within the count rate limits of the MAMA detectors.

There are 15 wide field camera apertures for use in target acquisition and imaging, a number of which are associated with bandpass or cutoff filters (see Section 3.3). A selection of neutral density filters are also available for acquisition or spectral observation of bright targets with the MAMA detectors. The 24.7 x 24.7 arcsec clear aperture will also be used for multi-object spectroscopy in the objective prism mode.

The final aperture is a 50 x 50 arcsec aperture with two perpendicular occulting bars varying in width from 0.5 to 3.0 arcsec. It also includes two "fingers", 0.5 x 5 and 3 x 10 arcsec. A diagram of this aperture is shown in Figure 3.4.

Figure 3.4 Wedge/Finger Aperture

The complete list of STIS slits and apertures is given in Table 3.1.

3.3 Filters

STIS incorporates a small number of filters for use with its imaging modes. These include:

a) UV cutoff filters (SrF_2--128 nm cutoff, rejects Lyman α; crystalline quartz--145 nm cutoff)
b) UV bandpass filters (Lyman α; 182 nm medium; 191 nm--CIII]; 270 nm medium, 280 nm--MgII)
c) visible narrowband filters (373 nm narrow--[OII]; 500.7 nm very narrow--[OIII])
d) visible longpass filter (550 nm cutoff, distinguishes mode 4.6 from mode 3.6).

The primary function of the visible narrowband filters is actually to provide attenuation of bright targets for target acquisition. Narrowband filters were chosen rather than ND filters in order to offer a very modest emission line imaging capability in the visible. Neutral density filters are available in the UV, permitting imaging of bright targets otherwise beyond the count rate capability of the MAMA detectors.

Flight candidate filters are now in hand for several of the STIS filter types. The performance of these flight candidates is as follows:

Measured Transmissions (vendor data)	Lyman α:	10.4% peak transmission at 121.6 nm, 8.5 nm FWHM
	SrF_2:	128 nm cutoff, 83% peak transmission out to 200 nm
	270 nm:	72.0% peak transmission at 269.4 nm, 22.8 nm FWHM
	280 nm:	65.4% peak transmission at 280.3 nm, 5.6 nm FWHM
	373 nm:	52.8% peak transmission at 373.6 nm, 7.1 nm FWHM
	500.7 nm:	73.2% peak transmission at 500.6 nm, 0.6 nm FWHM

Predictions for the remaining filters are based on the performance achieved for UV bandpass filters for the *Ultraviolet Imaging Telescope (UIT)* or on vendor modelling:

Predicted Transmissions	crystalline quartz:	145 nm cutoff, 90% peak transmission
	182 nm:	35% peak transmission, 40-46 nm FWHM
	191 nm:	15-20% peak transmission, 12-15 nm FWHM
	550 nm:	550 nm cutoff, 98% peak transmission

The measured and predicted transmission curves for the ultraviolet filters are shown in Figures 3.5 and 3.6.

4.0 SENSITIVITY

4.1 Effective Areas

The current best estimates for the effective areas of the STIS observing modes are shown in Figures 4.2-4.7. These have been generated from databases in which Chuck Bowers is keeping track of measured or theoretically estimated performance for all of the STIS optical components. The first draft of this Handbook presented exclusively estimated performance data. The status of the input data for this Revision (A) is as follows:

1. Measured mirror reflectivities are employed in most modes. There is little difference between these and the previously estimated values.

2. Measured grating efficiencies are incorporated for modes 1.1, 1.3, 2.1, 2.2, 2.3, and 2.5 (prism). The biggest differences compared with the previously predicted values are the relatively disappointing performance of the mode 1.3 echelle grating and the mode 2.2 holographic first order grating, and the good performance of the mode 1.1 parabolic first order grating and the superb performance of the mode 2.1 parabolic first order grating.

3. Though the databases have not yet been fully updated, the efficiencies have been measured for all gratings used in modes 1.2, 1.4, 2.4, 3.1, 3.2, 4.1, and 4.2. All are in good agreement with previous estimates.

4. For all CCD modes, the effective areas are now based on measured quantum efficiency data for the flight CCD.

5. For the MAMA modes, the detector efficiency curves employed are curves which are set to the CEI specification level at the specified wavelengths (15% at 121.6 nm for Band 1; 10% at 253.7 nm for Band 2), with spectral shapes as seen for engineering model detectors. **The band 1 flight candidate detectors significantly exceed the specification, by an amount dependent on whether or not the internal repeller is biased to collect MCP web-generated photoelectrons.** (This last issue is currently under investigation; the choice is between optimal quantum efficiency and optimal PSF performance for the detector.) For band 2, the estimated performance in the current database is likely to be in good agreement with the flight detector performance.

6. For the echelle modes, the effective areas plotted represent averages over the echelle ripple function; i.e., at the blaze peak for each order, the effective area will be somewhat larger than shown here, while at the end of the free spectral range in each order, the effective area will be somewhat lower. The curves plotted for modes 1.3 and 2.3 are based on measured grating data. For modes 1.4 and 2.4, the estimated curves plotted assume that the average echelle efficiency over the free spectral range will be ~70% of the efficiency at the blaze peak; in fact, for the 1.4 and 2.4 modes, the average is closer to 85% of the blaze peak, so the estimated curves plotted for the n.4 modes are somewhat conservative.

4.2 Slit Losses

For extended sources, the effective area curves shown here can be multiplied by the solid angle of the appropriate slit and the surface brightness of the source to yield observed count rates for STIS. For point sources, however, there will be in addition substantial slit losses when observing through narrow (i.e. two-pixel wide) slits.

The magnitude of the effect can be estimated from Figure 4.1, which presents the plots of encircled energy vs. image radius for the nominal HST + jitter from Dan Schroeder's book *Astronomical Optics*. Image quality at the STIS slit plane (after the STIS correction for spherical aberration and the off-axis astigmatism) should correspond roughly to this, with modest degradation from the two STIS corrector mirrors (negligible in band 4, perhaps 20% loss compared to the nominal HST in band 1).

As very rough numbers, for nominal two-pixel wide slits, integrating about three pixels along the spatial direction, one could use:

for band 1: 30-35% slit throughput	for band 3: ~60% slit throughput
for band 2: 40-55% slit throughput	for band 4: ~55% slit throughput
(strong wavelength dependence in the UV)	

In addition, just as this revision was about to go to press, we have received model PSF data for STIS, kindly generated by Mark Clampin and Chris Burrows of the STScI. The predicted PSF's are based on the most complete data available for performance of the HST Optical Telescope Assembly, including scatter and mid-frequency error terms. Based on these data, Don Lindler has integrated over the area of representative STIS slits to derive transmitted energy percentages. The results as a function of slit size and wavelength are presented in Table 4.1. These results should be considered preliminary, but the agreement with the Schroeder curves appears to be reasonably good. We will continue to work with the STScI to generate additional slit throughput data at more closely spaced intervals in the UV, where the variations with wavelength are most rapid, and to ensure that we have a complete understanding of exactly what contributions to image blur are being modelled.

Figure 4.1 Encircled energy for the HST + nominal pointing jitter, from Schroeder's *Astronomical Optics*. These curves include as-built data on surface roughness and measured figure errors. They

are thus appropriate for the case of perfect correction of the spherical aberration (STIS should give reasonably close to that, like COSTAR).

Table 4.1 Slit Transmission Based on Model PSF's

Aperture Size (Arcsec)	**120 nm**	**200 nm**	**280 nm**	**360 nm**	**440 nm**	**520 nm**	**600 nm**	**632.8 nm**	**680 nm**	**760 nm**	**840 nm**
0.025 x 0.1	20*	38	42	39	34	31	29	28	26	23	21
0.063 x 0.1	30	52	59	59	57	56	54	53	52	48	45
0.09 x 0.1	33	55	66	64	60	59	59	59	59	56	54
0.2 x 0.1	40	58	69	71	70	69	68	67	66	63	61
0.063 x 0.2	34	55	60	62	63	62	59	58	55	51	48
0.09 x 0.2	38	58	68	69	68	68	67	66	64	61	58
0.2 x 0.2	49	65	73	77	80	82	81	80	78	74	69
0.5 x 0.2	55	70	77	80	82	84	84	83	82	80	77
0.063 x 0.33	36	56	61	63	64	63	60	59	57	54	52
0.09 x 0.33	41	60	69	70	69	69	68	67	67	64	63
0.2 x 0.33	54	68	76	80	81	83	82	82	81	79	77

*Percentage of incident light transmitted by the given slit at the tabulated wavelength.

4.3 Detector Backgrounds/Noise

The other key factors in determining instrumental sensitivity in addition to throughput are detector background and read noise. For these parameters, the specifications (which we expect to meet) for the STIS detectors are these:

MAMA Detectors

Specifications

Band 1: $<6.25 \times 10^{-5}$ counts/pixel/second (=10 counts/cm^2/second)

Band 2: $<1.25 \times 10^{-4}$ counts/pixel/second (=20 counts/cm^2/second)

Flight Candidate Performance

The flight candidate detectors all exhibit dark count rates substantially below the specifications. Both band 1 and band 2 flight candidates show dark currents ranging from 0.8-1.6 counts/cm^2/second.

Outside of the SAA, these background rates should increase by <1.0 counts/cm^2/second from high energy particles. Within the SAA, the rates will likely increase by 10-100 times, precluding observations of faint targets during those periods.

There is no additional read noise component for the MAMA photon counters.

CCD Detector

Specifications

Dark current: 25 electrons/pixel/hour at -80°C (=0.007 electrons/pixel/second)

Read noise: 4.0 electrons rms

Flight Candidate Performance

The flight candidate CCDs show dark current performance at or just below the specified level. Furthermore, current thermal predictions indicate that the CCD subsystem should be capable of running the CCD at -83°C, providing a significant reduction in dark current compared with the specified operating temperature. At this temperature, a flight dark current of 10 electrons/pixel/hour can be anticipated.

Outside of the SAA, the CCD will accumulate cosmic ray events at the rate of ~1/cm^2/second or 4.4 events/second, each typically affecting one to ten pixels. These will set the practical limitation on maximum exposure time.

5.0 OTHER DETECTOR CHARACTERISTICS/READOUT MODES

5.1 MAMA Characteristics/Readout Modes

The MAMA will become non-linear at high local or global count rates:

local count rate (at 10% coincidence loss): >50 counts/pixel/second
(flight candidate detectors surpass this specification comfortably, with 10% rolloff points at >100-200 counts/second/pixel)

global count rate (at 10% coincidence loss): >300,000 counts/second.

Observations in camera mode or objective prism mode can easily exceed the local count rate limit. For echelle mode observations, the global count rate limit will always be reached first, while for first order observations of point sources, the local count rate limit will be reached first.

Note that several of the STIS calibration slits have associated UV filters with rather high ND values. Observing through the appropriate ND filter (we have as great as ND6!), any star (except the sun!) can be observed spectroscopically with STIS. The exact throughput vs. wavelength for the high ND values is likely to be poorly determined, however, so the absolute calibration of the observed spectrum would have significant uncertainty.

Typical MAMA observations will be carried out in "accumulate mode", in which a 2048 x 2048 image array is incremented as photons arrive. The pixel counters in buffer memory are 16 bits (65,535 counts) deep.

The STIS flight software will provide on-board Doppler compensation to re-register detected photon events to the proper half-pixel bin before they are accumulated in memory. This is necessary only in the echelle modes. Note that the small amount of blurring resulting from this effect is not included in deriving the spectral resolution specifications shown above. However, convolving a half-pixel wide smearing with a typical FWHM resolution element of 2.4 pixels only affects the achievable resolution by a few per cent.

MAMA data can also be collected in time-tag mode. In this case, the location and time of individual photon events are recorded and transmitted to the ground. The time resolution is better than 150 microseconds. The maximum sustainable rates in this mode are:

1200 events/second long term (until tape recorder is full or end of scheduled direct down-link time)
30,000 events/second with continuous access to the 1 Mbit/second telemetry link.

Both the MAMA and CCD can be operated in a subarray mode. Subarrays can be used to decrease the volume of data being sent to the ground and/or decrease the amount of time between image readouts. For the MAMA, up to eight equal size sub-arrays can be specified, where each

subarray is rectangular, does not overlap another subarray, and is not less than 8 x 8 pixels in size. Constraints on CCD subarray distributions are still TBD.

5.2 CCD Characteristics/Readout Modes

Full well (before blooming along the column) is specified at 170,000 electrons/pixel. The CCD will retain good linearity to at least 100,000 electrons/pixel.

The minimum exposure time for the CCD shutter is 0.1 seconds, so count rates need to stay below 10^6 detected photons/pixel/second to stay in the linear regime. This is not a severe constraint. With the available filters, the CCD can observe any star but the sun even in camera mode.

CCD data can be read out of 1, 2, or 4 amplifiers. Readout times are 27, 14, and 7 seconds, respectively. The typical readout will be a one-quadrant readout through the lowest noise amplifier. The four amplifiers of the flight CCD will all be low noise, however.

For faint targets, the deleterious effects of CCD read noise can be reduced (at the expense of spectral or spatial resolution) by binning the data on-chip. The data can be binned as much as desired in either or both dimensions. The serial pixels have only twice the full well capacity of the parallel pixels, so at some point well capacity will limit the ability to bin, but that limit is not particularly relevant to the faint-target application.

The CCD can obtain high time resolution through use of a parallel shift and dwell mode. In this mode, the CCD shutter is left in the open position. Data is integrated for a specified time interval and the charge accumulated is shifted N rows (the shift is perpendicular to the direction of dispersion). The integration and shifting are repeated with a readout of N lines during each shift. Both serial and parallel binning are available in this mode. With unbinned row read times of 24 msec and roughly 2 row wide point source resolution in the spatial direction, time resolutions as low as ~50 msec can be achieved.

Figure 5.1 illustrates the PSD mode. N rows of the CCD image are shifted and read out after each dwell point. The resulting data show time resolved images of the spectrum separated spatially by N rows. The PSD mode can also be used in conjunction with a telescope dwell scan in order to smooth out

flat field variations in the CCD. In this case, the shift of the charge on the CCD will be synchronized with the telescope's motion.

6.0 OPERATIONAL ISSUES

6.1 Observing Overheads

Observing overheads that will be incurred in using STIS are still somewhat uncertain, for several reasons. Detailed timing models for various functions are still being worked out, as the details of the flight software procedures continue to evolve. Potential efficiencies of the system are still being assessed for compatibility with ground operating procedures (e.g., there are some STIS configuration steps which in principle can be carried out in parallel with other spacecraft activities such as guide star acquisition, but which may not be able to do so due to the structure of the ground scheduling). Finally, key aspects of target acquisition (e.g. the number of steps required in target centering "peak-up" procedures may remain uncertain until the procedures can be run in orbit to see how well they really work).

Those excuses aside, some observing overheads can be identified and roughly estimated:

Guide star initial acquisition: 8-12 minutes

Guide star reacquisition after earth occultation or SAA passage: 6 minutes

Initial target identification and centering within STIS long slit: 10-15 minutes

Initial target identification and centering within small echelle slit: 15-20 minutes

Mode Select Mechanism motions: <2 minutes

Slit Wheel motions: <1 minute

Wavelength calibration exposures: ~100 seconds (required whenever the MSM has been moved)

CCD single-amp full frame readout times: <27 seconds

Note also that to permit cosmic ray rejection, CCD observations should routinely be made with at least two exposures.

6.2 MAMA Bright Object Protection

Protection of the MAMA detectors from over-light conditions is a complex subject which will not be given its full due in this edition of the *STIS GTO Handbook*. A few general remarks can be made, however.

The MAMA detectors will be protected from both global and local over-light conditions, both by ground screening of proposals and by on-board software and hardware monitoring. Observations will not be scheduled in configurations for which the predicted count rate is >500,000

counts/second global or >100 counts/second local on a MAMA detector. On-board protections will safe the detector if threshold rates (set somewhat higher than these screening limits) are exceeded.

As noted above, imaging and first order spectroscopy modes will generally run into the local count rate limit before the global count rate limit, while the echelle modes will do the opposite. In fact, for all but "pathological" input spectra, the peak count rate per pixel in an echelle mode is only ~10 counts/pixel/second when the global count rate is at the 10% coincidence loss point of 300,000 counts/second.

In comparing these limits with output from the STIS on-line simulation program "sim_stis", note that the simulation routine reports both a total count rate on the detector and a "counts/pixel/second" array over the spectrum. Bear in mind that this latter local count rate is in fact summed over the spread of the spectrum in the cross-dispersion direction. For a typical FWHM in the spatial direction of ~2.5 pixels, the peak pixel will actually be counting at roughly 30% of this reported "counts/pixel/second" rate. Hence, sim_stis count rates up to 330 counts/pixel/second are consistent with the 100 counts/actual pixel/second screening limit.

Similarly, when considering the signal-to-noise capabilities of STIS echelle modes, recall that the peak local count rate of ~10 counts/pixel/second corresponds to roughly 70 counts/second per spectral resolution element (i.e. summed in the cross-dispersion direction and over the 2.4 pixel FWHM spectral resolution element). Hence, even for regions of the spectrum significantly away from the peak count rates, high statistical precision can be achieved in reasonable amounts of time.

Coronographic observations with the MAMA are potentially problematic, due to the gross violations of count rate limits that could occur if telescope pointing drift should bring the target out from behind the occulting bar. A significant program of testing has taken place in the Ball MAMA laboratory to assess the risk of damaging the detector in such an eventuality. The results to date are very positive. No damage is observed for local inputs enormously in excess of the local rate screening limits, over time scales sufficiently long for on-board software monitoring protections to operate. It is thus anticipated that coronographic observations of very bright targets will be permitted with the MAMAs, with appropriate care in setting up the observation.

6.3 Roll Constraints

The long slit spectroscopic capability provided by STIS can be expected to generate an unprecedented demand for observations at scientifically chosen position angles. There are, however, at least two constraints on observing at particular position (roll) angles.

Date Restrictions

The nominal spacecraft roll angle required for a particular observation depends on the location of the target and the date of the observation. The maximum permitted deviation from that nominal roll angle depends on the angle between the sun and the target at the time of the observation. For sun angles between 50 and 90 degrees, off-nominal orientations are restricted to +/-5 ^{o}; for sun

angles between 90 and 178 degrees, +/-30° deviations from the nominal roll angle are permitted. Only for anti-sun pointings with sun angles between 178 and 180 degrees is the roll angle completely unconstrained.

Hence, placing a roll angle constraint on an observation will place additional restrictions on the times during the year in which the observation can be made. In rare cases, a particular combination of position angle and target position in the sky will not be observable for any period during the year. We are pursuing with the STScI the question of just how rare that case will be.

Guide Star Availability

Even if spacecraft roll constraints are satisfied, it is still possible that there will not be suitable guide stars available to support the most accurate (two-FGS [Fine Guidance Sensor]) guiding mode for the HST. At high galactic latitudes, the probability of finding a valid guide star within a given FGS "pickle" field of view is not unity. As two of the three FGS's are required for standard guiding, there is a significant probability that at a given position angle, there will be no suitable guide star pair available. Because the STIS field of view is off-axis, as the acceptable position angle range is opened up, the FGS pickles sweep out a larger area of sky, increasing the probability of finding a suitable guide star pair.

Rodger Doxsey of STScI has made a study of the probability of finding guide star pairs as a function of allowed roll angle range for the STIS field position. His results are summarized in Figure 6.1, extracted from his memo "Use of orientation restrictions for WFPC-II, NICMOS, and STIS", dated 3/13/95. Note that at high galactic latitudes, demanding a specific roll angle (0 ^{o} roll range) leads to a 45% probability that no suitable guide star pair will be available, and it requires a significant deviation from the desired roll angle to significantly reduce the failure probability.

Fortunately, for most STIS observations, there is no reason to distinguish between position angle θ and angle $\theta + 180^o$, and the STIS field of view is sufficiently far off-axis that rolling the telescope by 180° yields a nearly independent piece of sky for the FGS fields. The probability of failing to find guide stars at both θ and $\theta + 180^o$ is thus approximately $(0.45)^2 = 20\%$, significantly lower.

For those 20% of high latitude cases with scientifically chosen position angles and no guide star pair, it is possible to observe in a single FGS plus gyro mode. In this case, the single FGS constrains the line of sight of the telescope in two axes, while the on-board gyros control the roll. Because the STIS field of view is offset from the field of view of the FGS in control, the accumulating gyro error over the course of the observation will lead to a growing drift in position of the target with respect to the STIS slit.

The drift rate can be estimated as follows. The gyro error accumulates at roughly 1 milli-arcsec/second. The lever arm between the STIS field and the FGS field ranges from 5 to 18 arcminutes, i.e. 0.0015 to 0.0053 radians. The drift of the target will therefore accumulate at the rate of 1.5-5.3 milli-arcsec per 1000 seconds of observing time. Over the course of an extended observation, this drift rate is not negligible compared with the narrower STIS slits. Hence, an occasional re-centering will be required for observing in the single FGS plus gyro mode. The

frequency required for the re-centering scans will depend on the width of the slit in use and on the separation of the particular guide star from the STIS line of sight. With the single FGS mode available, the probability of being unable to observe a given target and position angle due to guide star failure (at both θ and $\theta + 180^o$) is <1%.

6.4 Continuous Viewing Zone Observations

Objects located near the poles of the HST orbit are not occulted by the earth at any time during the 96 minute orbital period of HST and thus are in principle available for "continuous viewing". As the spacecraft's orbital plane precesses (with a period of 56 days), the poles of the 28.5^o inclination orbit sweep out a significant fraction of sky around declinations $\delta = +/-61.5^o$. Over the course of the year, there exist substantial opportunities for continuous viewing zone ("CVZ") observing in the declination zones $57^o \leq |\delta| \leq 72^o$ and limited opportunities in the 53°-57° and 72°-77° zones.

When a target is in the CVZ, it can potentially be observed continuously for as long as 9 consecutive 96 minute orbits. The next 7 orbits will contain SAA passages that will interrupt the observation. After each SAA passage, guide star reacquisition is required, taking 6 minutes.

Appended are continuous viewing zone tables extracted from the *HST Phase 1 Proposal Instructions* for Cycle 5, issued June 1994 (a new edition for Cycle 6 is imminent). These tables indicate, for a representative year, 1) the total duration in hours of all CVZ opportunities as a function of RA and Declination, 2) the maximum duration in hours of any single CVZ interval, and 3) the total number of CVZ intervals.

CVZ observing is an extremely efficient way of utilizing GTO observing time, particularly in light of the accounting system which tracks orbits used, rather than on-target time. However, the STScI has pointed out that various scheduling constraints do place some limitations on how much CVZ observing is in fact available during any one cycle. Even in the remarkable event that all of our targets happened to lie within the available CVZ declinations, it would not be possible to arrange for the bulk of the GTO program to take place in CVZ time. Furthermore, for targets requiring observation at specific position angles, it should be noted that the roll constraints on the spacecraft define restricted observing windows over the year during which a particular position angle can be achieved for a given target, windows that are unlikely to coincide with passage of the target through the continuous viewing zone.