Space Telescope Imaging Spectrograph

Science Data Management and Analysis Software Requirements Document

Version 1.0: March 7, 1995

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for

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Prepared under contract NAS5-29370 between Goddard Space Flight Center and Ball Aerospace and Communications Group, Boulder, Colorado.

Mode Identification

Mode *n.m*

n is the band number

Band *n*	Wavelength Range	Detector
1	115 - 170 nm	MAMA/CsI
2	165 - 310 nm	MAMA/Cs_2Te
3	305 - 555 nm	CCD
4	550 - 1000 nm	CCD

m is the dispersing mode

Mode *m*	Dispersing Element	Relevant Bands			
		1	2	3	4
1	Low Resolution grating				
2	Medium Resolution grating				
3	Medium Resolution echelle				
4	High Resolution echelle				
5	Prism				
6	Mirror				
7(x3)	Mode 3 cross-disperser				
7(x4)	Mode 4 cross-disperser				

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Section 1
Introduction

1.1 Scope

The purpose of this document is to define the requirements of the ground system of the Space Telescope Imaging Spectrograph (STIS) needed to:

- Assist the astronomer in specifying the observational parameters (e.g. exposure time) needed to acquire data.

- Acquire, archive and manage, the STIS science data

- Convert raw data to a form which is directly useful to the astronomer for analysis and interpretation.

The required functions that the ground system must conduct from the time of receipt of raw observational data through delivery of processed data to the astronomer include:

- Acquisition, archival, and cataloging the raw telemetry data (section 3)

- Quick-look analysis of the incoming data to verify quality and direct latter processing (section 4)

- Calibration of the instrument (section 6)

- Analysis of the instrument performance (section 7)

- Routine reduction of science data (section 5)

- Analysis of the reduced data and generation of final outputs (section 8)

1.2 Instrument Description

STIS is a second generation Hubble Space Telescope (HST) instrument currently scheduled for launch in 1997. STIS will have 13 spectroscopy and 4 imaging science modes covering the wavelength range of 115 to 1000 nm (ultraviolet to near infrared). Data will be collected with two 1024 x 1024 Multi-Anode Micro-channel Arrays (MAMA) and one 1024 x 1024 Charge-Coupled Device (CCD). STIS will provide spectral resolutions from R~100 to R~100,000. The two dimensional detectors will allow spatially resolved spectra to be obtained for extended astronomical objects. Observing modes include:

1) Low resolution spectral imaging; R~1000, long slits, 115-1000 nm.
2) Medium resolution spectral imaging; R~10,000, long slits, 115-1000 nm.
3) Medium resolution echelle spectroscopy; R~23,000, short slits, UV only.
4) High resolution echelle spectroscopy; R~105,000; short slits, UV only
5) Objective Spectroscopy; R=26 (at 310 nm)-165 (at 122 nm), Wide Field, 115-310 nm.
6) Broadband imaging - Wide Field, 115-1000 nm

1.2.1 Detectors

STIS will have two MAMA detectors and one CCD detector. The first MAMA detector will have a CsI photocathode and supply wavelength coverage from 115-170 nm (Band 1) and the second MAMA detector will have a Cs_2Te photocathode and will provide coverage from 165-310 nm (Band 2). In the objective spectroscopy mode, Band 2 coverage will extend from 115 nm to 310 nm. The MAMA detectors have a 1024 x 1024 pixel format with 25 μm pixel separation. These can be read out in a high resolution (Hi-Res) mode which separates the odd and even fold anode events giving 2048 x 2048 pixels with an effective separation of 12.5 μm. Important characteristics of the MAMA detectors in the data reduction process are;

1) Cosmic rays show up as a single event or count and only form part of a general detector background.
2) Cherenkov events resulting from passage of cosmic rays through the detector window will be automatically rejected by the intrinsic anti-coincidence properties of the MAMA readout.
2) The detectors show a significant non-linear response at higher count rates. The non-linearity is a function of both the local counts/pixel and the global total counts per detector.
3) There is no read noise.
4) Data from the MAMA can be collected in a time-tagged mode. The pixel location and time of each detected photon event can be recorded.

A single CCD will provide wavelength coverage from the near UV to the near IR for wavelength Band 3 (305-555 nm) and Band 4 (550 - 1000 nm). The CCD will have a 1024 x 1024 array with a pixel size of 21 x 21μ. A shutter will control exposure times from 0.1 to 3600 seconds. The CCD can be read out with 1, 2, or 4 amplifiers with corresponding readout times of 27, 14, and 7 seconds. Shorter time resolved spectroscopy can be achieved by a parallel shift and dwell mode. In this mode the shutter is left continuously open, data is alternately integrated for a short period followed by a parallel shift of a selectable number of rows. Other CCD options include a selectable gain from 1, 2, 4, or 8 electrons/DN and on-chip binning of any M x N pixels, limited by the well capacity of the serial pixels and summing well.

Both the CCD and MAMA detectors have sub-array modes where up to 8 equal size sub-arrays can be selected to increase time resolution or to decrease the amount of telemetry data.

Table 1.1 summarizes the design specifications for the STIS detectors.

Table 1.1
Detector Design Specifications

Detector	MAMA/CsI	MAMA/Cs_2Te	CCD
Array Size	1024 x 1024	1024 x 1024	1024 x 1024
Pixel Size	25 x 25μ	25 x 25μ	21 x 21μ
MTF	≥ 35% at 20 line pairs/mm	≥ 35% at 20 line pairs/mm	>50% at 24 line pairs/mm @632.8nm
Wavelength Range	115-170nm	120-310nm	305-1000nm
Quantum Efficiency(QE)	≥ 15% @121.6nm	≥ 10% @253.7nm	300nm >25% 500nm >60% 700nm >60% 900nm >20% 1000nm >5%
Dark Rate	<6.25 x 10^{-5} cnts/pixel/sec	<1.25 x 10^{-4} cnts/pixel/sec	<7x10^{-3} electrons/pixel/sec
Flat Field Uniformity per pixel	8% (1σ)	8% (1σ)	± 10 % peak to peak
System Readout Noise			<4 electrons (rms)
Full Well			170,000 electrons
Broken Electrodes in Anode Array	≤3	≤3	
Bright Spots (Note 1)	0	0	
Dark Spots (Note 2)	≤20	≤20	
Blemishes (Note 3)			<100
Maximum Count Rate (for 10% coincidence Loss) Each Pixel Total Detector	>50 counts/sec. (random) >3x10^5 counts/sec (random)	>50 counts/sec. (random) >3x10^5 counts/sec (random)	
Visible Light QE (above 400nm)	10^{-4} percent	10^{-1} percent	

Note 1: Bright spots defined as > 1 count/pixel/sec.
Note 2: Dark spots defined as regions with a response < 25% of the nominal plate performance. None allowed with diameters > 4 channels diameter.
Note 3: Blemishes are pixels with <50% of the average QE or >10 times the average dark current

1.2.2 Dispersive Modes

Table 1.2 gives a summary of the dispersive modes provided by STIS. The selection of dispersive mode is made by moving the mode select mechanism (MSM). Appendix A shows a pictorial representation of the various dispersive modes for both internal calibration lamp observations and external targets. Appendix B shows the spectral format at the STIS detector for each grating mode. Some of the grating modes require multiple observations to cover the entire wavelength range of the mode (scanned). In the case of the scanned first order gratings, only a representative format plots are shown in Appendix B.

Table 1.2
STIS Dispersive Modes

Mode	Wavelength Range (nm)	Resolving Power	Detector	Comments
1.1	115-170	770-1130	MAMA/CsI	1st order grating, 24".9 slit length
1.2	115-170	8,600 - 12,800	MAMA/CsI	1st order grating (scanned), 29".7 slit length
1.3	115-170	24,000	MAMA/CsI	Medium resolution echelle
1.4	115-170	100,000	MAMA/CsI	High resolution echelle
1.6	115-170		MAMA/CsI	Camera Mode, 24".9 x 24".9 field of view
1.7(x3)	115-170		MAMA/CsI	1.3 cross-disperser mode
1.7(x4)	115-170		MAMA/CsI	1.4 cross-disperser mode
2.1	165-310	415-730	MAMA/Cs_2Te	1st order grating, 24".9 slit length
2.2	165-310	7,500 - 13,900	MAMA/Cs_2Te	1st order grating (scanned), 29".7 slit length
2.3	165-310	23,500	MAMA/Cs_2Te	Medium resolution echelle
2.4	165-310	100,000	MAMA/Cs_2Te	High resolution echelle
2.5	115-310	165-26	MAMA/Cs_2Te	Objective Prism, 29".7 x 29".7 field of view
2.6	165-310		MAMA/Cs_2Te	Camera Mode , 24".9 x 24".9 field of view
2.7(x3)	165-310		MAMA/Cs_2Te	2.3 cross-disperser mode
2.7(x4)	165-310		MAMA/Cs_2Te	2.4 cross-disperser mode
3.1	305-555	445-770	CCD	1st order grating, 51".1 slit length
3.2	305-555	4,340 - 7,730	CCD	1st order grating (scanned), 51".1 slit length
3.6	305-1000		CCD	Camera Mode, 51".1 x 51".1 field of view
4.1	550-1000	425-680	CCD	1st order grating, 51".1 slit length
4.2	550-1000	3,760-6,220	CCD	1st order grating (scanned), 51".1 slit length
4.6	550-1000		CCD	Camera Mode, 51".1 x 51".1 field of view
Backup Modes				
1.1B	115-170	765-1115	MAMA/Cs_2Te	1st order grating, 29".7 slit length
1.2B	115-170	8,600-12,800	MAMA/Cs_2Te	1st order grating (scanned), 29".7 slit length
1.3B	115-170	24,000	MAMA/Cs_2Te	Medium Resolution Echelle, uses mode 1.3's cross-disperser with mode 2.3's echelle grating.

Mode	Wavelength Range (nm)	Resolving Power	Detector	Comments
1.4B	115-170	100,000	MAMA/Cs_2Te	High Resolution Echelle, uses mode 1.4's cross-disperser with mode 2.4's echelle grating.
2.1B	165-310	495-910	CCD	1st order grating, 51."1 slit length
2.2B	165-310	4,370-8,230	CCD	1st order grating (scanned), 51."1 slit length

Modes x.1 (where x is the wavelength band number from 1 to 4) are low resolution first order gratings. In these modes the entire wavelength range will fit on the detector in a single observation. Modes x.2 are medium resolution first order gratings. The entire spectral format will not fit on the detector at once. In these modes the grating angle must be changed (scanned) by moving the MSM to place the desired wavelength range on the detector.

Modes 1.3 and 2.3 are medium resolution echelle modes. The entire spectral range for mode 1.3 will project onto the MAMA detector. Mode 2.3 requires two observations to capture the entire spectral range. The spectral orders incident on the detector are controlled by the MSM which can vary the angle of the cross-disperser. There are no echelle modes in bands 3 and 4.

Modes 1.4 and 2.4 are the high resolution echelle modes. Mode 1.4 requires three different positions of the MSM (three different cross disperser angles) to cover the entire wavelength range and mode 2.4 requires 6.

The objective prism mode, mode 2.5, has a wavelength coverage 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 cool 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. A spectrum which is visible all the way to Lyman alpha will extend across nearly 40% of the detector.

Modes x.6 are camera modes and are available in all wavelength bands. These modes will be used for target acquisition and for wide field imaging.

Modes x.7 are flat field calibration modes for the echelles. In these modes, the echelle grating is replaced by a mirror. Light is then dispersed by the cross-disperser grating only. For some science goals requiring a spectral resolution that is intermediate between the resolutions of the low-resolution x.1 mode and the higher resolution x.3 mode (medium resolution echelle), one may be able to obtain the desired resolution along with higher throughput by using a cross-dispersed, x.7, first order mode.

1.2.3 Apertures and Filters

The STIS has a slit/filter wheel containing spectroscopic slits, target acquisition apertures, and filters. A complete listing of the contents of the slit wheel can be found in Table 2.

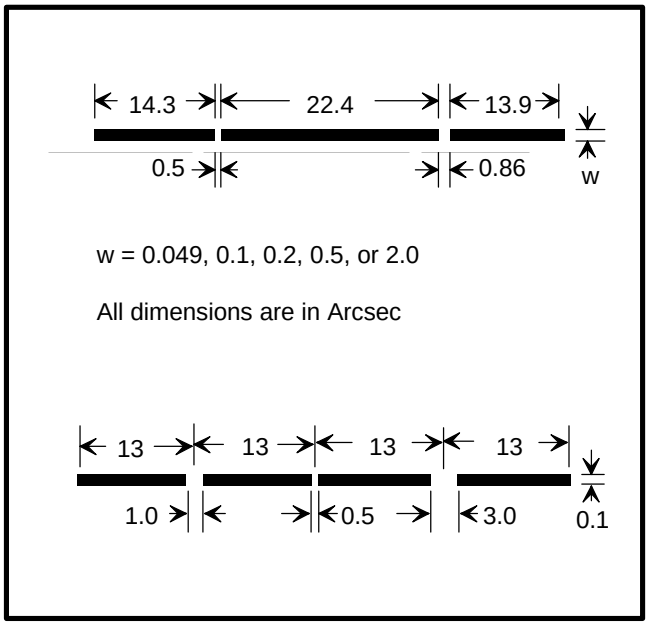


Fig. 1.1 Long Spectroscopic Slits with Occulting Bars

The 6 long slits (Figure 1.1) can be used for both extended objects and point source targets. For the first order grating modes, the long slits have two major advantages over the short slits for point source observations; the sky or background spectrum is observed simultaneously and the position of the star can be varied along the slit. Trailing the object along the slit can be used to decrease the fixed pattern noise resulting from inadequate flat field calibrations. Varying the position of a star in the slit can also be used to minimize hysteresis effects associated with repeated exposure of the same section of the detector. Each long slit has either 2 or 3 occulting bars of varying widths. In addition to the ability to place a target behind the occulting bar, these bars can be used as spatial fiducials when extracting spectra from external extended sources and internal calibration lamp observations.

Eleven standard echelle slits are available with widths of 0.063, 0.09 or 0.2 arcsec. The larger widths give higher throughput and better photometric accuracy at the cost of a slight loss of resolution. Four lengths are available: 0.1, 0.2, 0.33, and 1.0 arcsec. The first three were optimized to the echelle order separation. 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. 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.

Fig. 1.2 High Signal/Noise Offset Slits

There are two sets of high signal-to-noise slits (Fig. 1.2) with widths of 0.06 and 0.2 arcsec. Each set contains 5 equal sized 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 simultaneous computation of the fixed pattern noise and spectral flux distribution using techniques that have been successfully applied to data taken with the Goddard High Resolution Spectrograph (GHRS) and the Faint Object Spectrograph (FOS).

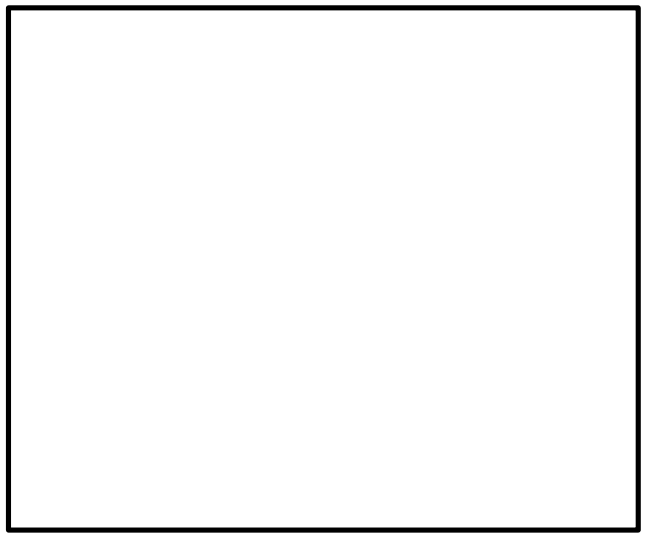


Fig. 1.3 Planetary Slits

Figure 1.3 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 to allow positioning of the target at a any specified angle. Selection of which slit of each pair will depend on the roll angle constraints of HST.

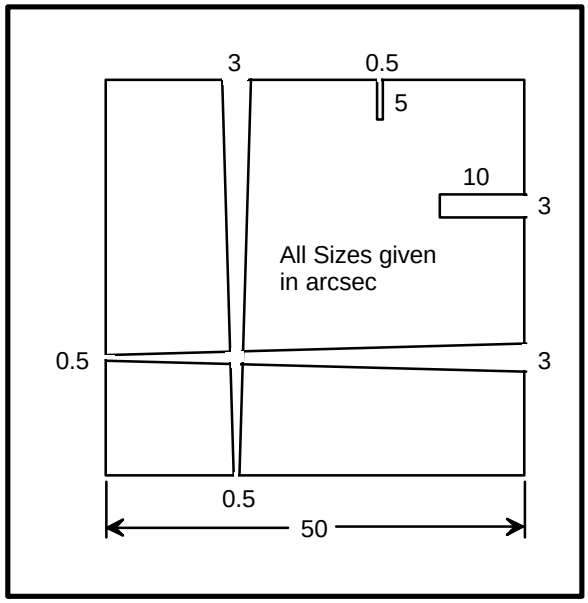


Fig. 1.4 Wedge/Finger Aperture

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 only dispersed by the cross-dispersers. Special long calibration slits rotated 90 degrees from the normal long science slits can be used for flat field calibration of the echelle modes. The length of the slit insures complete coverage of the detector. Dispersion of the light in the cross-dispersion direction insures that the wavelengths at each detector pixel is close to the wavelengths seen in the echelle modes (within one spectral order). Flat field variations with wavelength in the MAMA detectors are expected to be negligible over the wavelength range of a couple of spectral orders. Two of the cross-dispersed slits have neutral density filters to reduce the incident count rates.

There are 15 wide field camera apertures for use in target acquisition and imaging. The central wavelengths and widths of the filters are given in table 1.3. A selection of neutral density filters are available for acquisition 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 prism mode.

The final aperture is a 50 x 50 arcsec aperture with two perpendicular occulting bars varying in width from 0.2 to 3 arcsec. It also includes two "fingers", 0.5 x 5 and 3 x 10, arcsec. A diagram of this aperture is shown in Figure 1.4.

Table 1.3
Slits, Apertures, and Filters

Width (arcsec)	Length (arcsec)	Primary Mode(s)	Comments
Long Slit Spectroscopy (+ Occulting Bars)			
0.049	52	x.1, x.2	See Figure 1.1 (upper slit)
0.1	52	x.1, x.2	See Figure 1.1 (upper slit)
0.2	52	x.1, x.2	See Figure 1.1 (upper slit)
0.5	52	x.1, x.2	See Figure 1.1 (upper slit)
2	52	x.1, x.2	See Figure 1.1 (upper slit except that the occulting bars 0.5 and 0.82 arcsec)
0.1	52	x.1, x.2	See Figure 1.1 (lower slit)
Echelle Slits			
0.063	0.1	2.4	
0.09	0.1	2.4	
0.2	0.1	2.4	
0.063	0.2	1.4, 2.3	
0.09	0.2	1.4, 2.3	
0.2	0.2	1.4, 2.3	
0.063	0.33	1.3	
0.09	0.33	1.3	
0.2	0.33	1.3	
0.5	0.2	1.3, 2.3	Lower resolution, higher throughput
0.063	1	1.3, 2.3	Extended Sources
0.2	1	1.3, 2.3	Extended Sources
0.05	0.2	1.4, 2.3	With ND filter for use with continuum lamp
0.05	0.33	1.3	With ND filter for use with continuum lamp
Miscellaneous Sizes			
0.025	0.1	x.3, x.4	Super High Resolution
0.2	6	1.3, 2.3	Extended sources
0.5	6	1.3, 2.3	Extended sources
0.063	6	1.2, 1.3, 2.2, 2.3	Extended sources
0.5	0.5	x.3, x.4	
6	6	1.3, 2.3	
High Signal-to-Noise (Offset)			
0.063	0.2	x.1, x.2, x.3, x.4	set of 5 slits (Figure 1.2)
0.2	0.2	x.1, x.2, x.3, x.4	set of 5 slits (Figure 1.2)
Planetary			
0.05 - 0.2	35	x.1, x.2	at 45 degrees (Figure 1.3, upper slit)
0.05 - 0.2	35	x.1, x.2	at -45 degrees (Figure 1.3, upper slit)
0.6 - 2	35	x.1, x.2	at 45 degrees (Figure 1.3, lower slit)
0.6 - 2	35	x.1, x.2	at -45 degrees (Figure 1.3, lower slit)
2	2	x.1, x.2	Io

Width (arcsec)	Length (arcsec)	Primary Mode(s)	Comments
Crossed Dispersion			
29	0.054	1.7, 2.7	Cross-dispersed low resolution
29	0.09	1.7, 2.7	Cross-dispersed low resolution
29	0.2	1.7, 2.7	Cross-dispersed low resolution
Spectral Flat Field Calibration			
0.05	31	1.1, 2.5	+ND filter
0.05	31	2.1	+ND filter
0.05	31	1.2, 2.2	+ND filter
31	0.05	1.7(x3)	+ND filter "no echelle" flat field calibration for the
31	0.05	1.7(x4), 2.7	+ND filter echelle modes
Camera Apertures			
24.7	24.7	x.6, 2.5	Clear (also used with objective prism mode 2.5)
50	50	CCD	Clear
24.7	24.7	MAMA	ND5 (Bright Star, Flat Field)
24.7	24.7	MAMA	ND6 (Bright Star, Flat Field)
24.7	24.7	MAMA	UV ND step wedge (2-4 steps)
50	28	CCD	Visible Long Pass (Standard Target Acq.)
50	28	CCD	372.7 nm narrow band
50	28	CCD	500.7 nm very narrow band
Wedges/Fingers			
50	50		See Figure 1.4
UV Camera Filters			
24.7	24.7	MAMA	Lyman Alpha Filter
24.7	24.7	MAMA	Cystalline Quartz Filter
24.7	24.7	MAMA	182nm Continuum Filter
24.7	24.7	MAMA	C III Filter
24.7	24.7	MAMA	270nm Continuum Filter
24.7	24.7	MAMA	MgII Filter
24.7	24.7	MAMA	SrF_2 Filter

1.2.4 On-Board Calibration Subsystems

STIS will have 6 on-board calibration lamps (listed in table 1.4). These include three wavelength calibration line lamps and 3 flat field calibration continuum lamps. Non-repeatability in the MSM is expected to be of order ±6 pixels and will therefore require a wavelength calibration exposure with every motion of the MSM if accurate wavelengths are required. The on-board lamps will also be used for locating the slits and apertures in undispersed light during target acquisition.

Table 1.4
On-board Calibration Lamps

Number	Type	Wavelength Coverage	Subsystem
1	Krypton (continuum)	130-170 nm	CIM
1	Deuterium (continuum)	165-310 nm	CIM
1	Tungsten (continuum) (contains 4 bulbs, 1 or 2 of which can be on at one time)	305-1000 nm	CIM
1	Pt-Ne-Cr (spectral line lamp)	115-1000 nm	CIM
2	Pt-Ne-Cr (spectral line lamp)	115-1000 nm	HITM

STIS has two calibration subsystems. The "hole in the mirror" (HITM) and a calibration insert mirror (CIM) calibration subsystem. The HITM calibration subsystem is used principally for target acquisition and wavelength calibration. The wavelength calibration performed by this subsystem is required for identification of the spectral shift associated with the mode select mechanism (MSM) pointing inaccuracy. A wavelength calibration exposure is normally required with a movement of the MSM.

The HITM consists of two Pt/Cr-Ne lamps. The light at the cathode of either of these lamps can be imaged on the slit. The optical paths for the two sources differs only in the use of a VUV beamsplitter in either transmission or reflection. In the VUV, the reflectivity and transmissivity of the beamsplitter is comparable. However in the visible, the beamsplitter reflects ~60% of the incident light and transmits only ~20%. Thus, the wholly reflective path has higher throughput in the visible region of the spectrum.

This HITM system has an aperture stop located at the rear of the second corrector mirror (CM2). The beam then passes through the hole in CM2 and is imaged on the slit. There is no mechanism for blocking light from the telescope when you are operating in this mode. Consequently light from the target or any serendipitous source is imaged on the slit simultaneously with the Pt/Cr-Ne lamp.

The CIM calibration subsystem is used for flat fielding the detectors, echelle modes' wavelength calibration, and obtaining spectral line profiles for calibration. The light from sources in this subsystem is directed to the slit using the calibration insert mirror mechanism. When the mirror controlled by this mechanism is in the beam, light from the telescope is blocked from the slit. The light from the each of the sources has a different optical path upstream of the elliptical mirror and a common optical path downstream of this mirror. Light from the Kr continuum lamp is transmitted by the lamp's MgF2 window, and then reflected by two beamsplitters. The light transmitted by the D2 continuum lamp's MgF2 window is transmitted by two beamsplitters. Light from the tungsten lamps is transmitted by the first

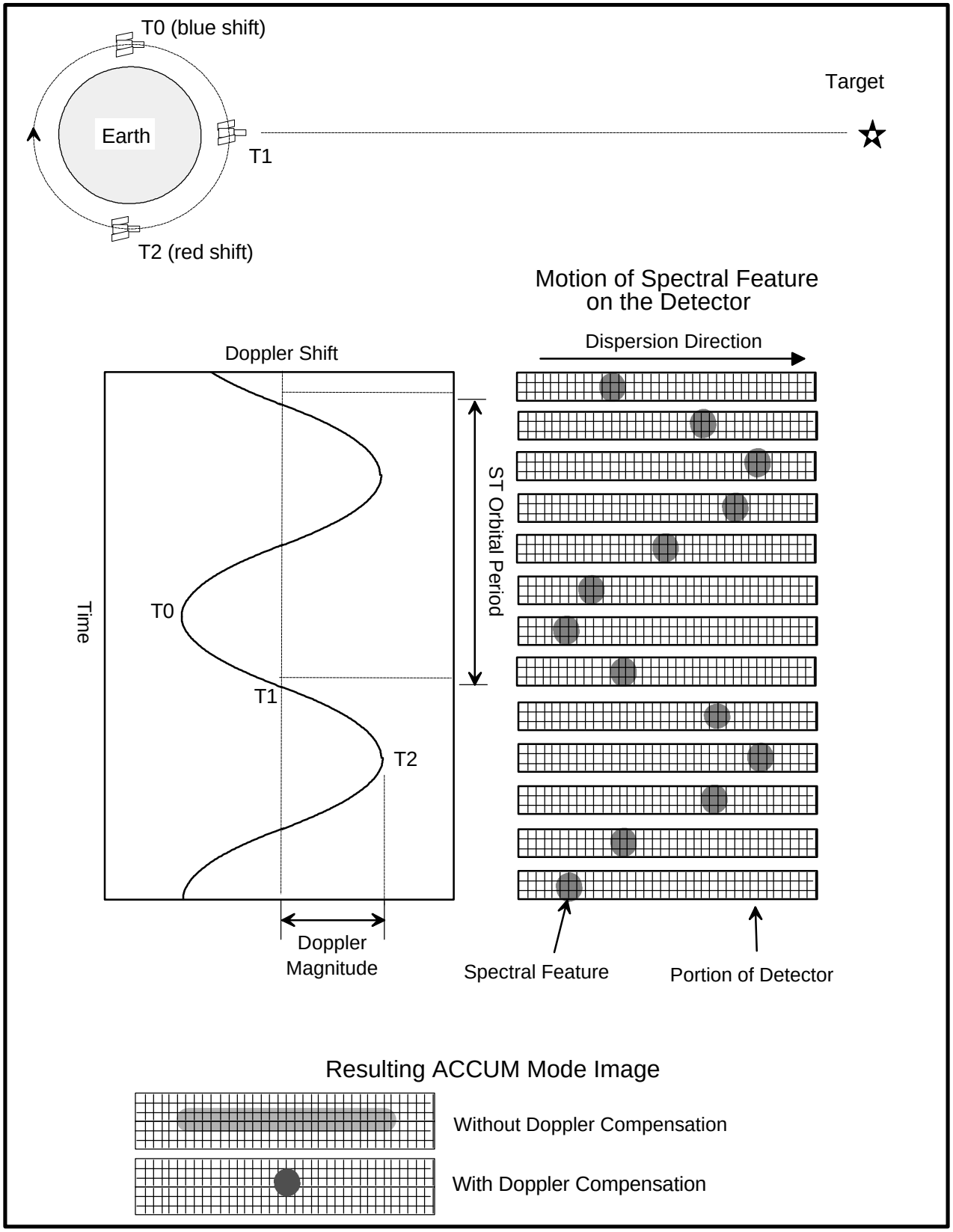


Fig. 1.5 On-board Doppler Compensation

beamsplitter and then reflected by the second. Light passed by the beamsplitters is collected by an elliptical mirror. This mirror images the source on a spherical mirror which images the light distribution on to the slit. In addition, four flat mirrors are required to direct this light. Thus the flat field sources utilize two beamsplitters, two powered optics, and four flat mirrors. The cathode in the Pt/Cr-Ne lamps is further from the MgF2 lamp window than the plasma of the flat field lamps. Therefore a powered optic is used to image the Pt/Cr-Ne lamp to the same source point as the flat field lamps. Light from this source is transmitted by the first beamsplitter, transmitted by the second beamsplitter, and then collected by the elliptical mirror. The tungsten lamp is actually a combination of four individual bulbs. These bulbs can be controlled to have either a single bulb lit or two bulbs lit simultaneously in a fixed configuration.

1.3 Observing Modes

1.3.1 Accumulation Mode

The most popular STIS observing mode will be the accumulate mode. In the accumulate mode, the data from both the MAMA's and the CCD are accumulated on-board and sent to the ground as an image. A full readout of the CCD will create an image of 1024 x 1024 pixels plus an overscan region for bias level determination. The full size of a MAMA image is 2048 x 2048 Hi-Res or 1024 x 1024 Lo-Res pixels.

In the image accumulation mode for the MAMA detectors, the integrating memory will accommodate an event rate of 300,000 counts/second with and a pixel count rate of at least 50 counts/second with less than 10% coincidence. The maximum accumulated counts per pixel is limited to a 16 bit word (65536 counts).

The STIS flight software will provide on-board Doppler compensation to within 12.5μ (one hi-res pixel) for MAMA echelle observations taken in the

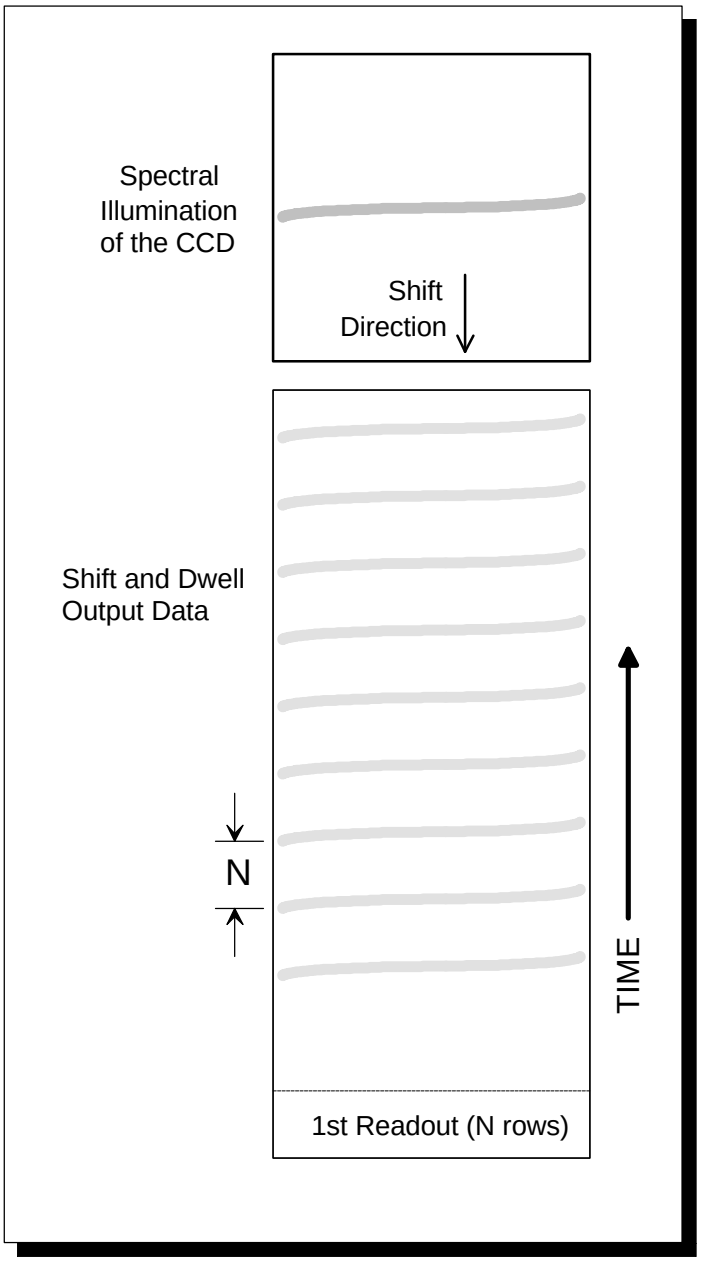


Fig. 1.6 Shift and Dwell mode, with a shift of N *rows between integration periods.*

accumulation mode. On-board Doppler compensation is illustrated in Fig. 1.5. As the telescope moves around the Earth, its velocity with respect to the target changes. As it moves away from the target, wavelengths are red shifted and as it moves toward the target, wavelengths are blue shifted. This will cause spectral features to move back and forth on the detector. Spectral features will be smeared in the resulting observed data if no compensation for this motion is made. The Doppler motion occurs in the dispersion direction only and can be described by a sine wave. The STIS flight software can compute the spectral shift at any time during the observation if given a magnitude and zero phase time for the sine function. This shift can then be subtracted from each pixel location before adding to the accumulated image. Data at any given wavelength will then always be accumulated in the same location resulting in no spectral smearing.

The CCD will have the capability to readout the full array using 1,2 or 4 amplifiers with corresponding readout times of 28, 14, and 7 seconds. CCD integration times can be specified in increments of 0.1 seconds up to a maximum of 60 minutes. On chip binning in both the parallel and serial directions can be performed (limited only by the signal intensity and by the capacities of the serial register and output summing wells). Onboard Doppler compensation is not available for the CCD.

Both the MAMA and CCD can be operated in a subarray mode. 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 by 8 pixels. 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. CCD sub-arrays that overlap in the parallel direction must overlap completely in the parallel direction.

1.3.2 MAMA Time-Tagged Mode

Very high time resolution data can be obtained from the MAMA detectors using a time-tagged mode. In this mode the photon events are not accumulated onboard the spacecraft. Instead, each photon event is recorded and transmitted to the ground as a x and y location (pixel) and event time (to within 150 microseconds). On the ground, the image or spectra can then be accumulated for any specified time interval(s). The maximum event rates in this mode are:

1200 events/sec. long term (until tape recorder is full or end of scheduled direct down-link time)

30K events/sec. with continuous access to the 1MB telemetry link

Subarrays can be used in the time-tagged mode but on-board Doppler compensation can not be used. Time-tagged data can be Doppler corrected on the ground.

1.3.3 CCD Parallel Shift and Dwell

A parallel shift and dwell (PSD) mode can be used for time resolved spectroscopy with the CCD. In this mode the CCD shutter is left in the open position. Data is integrated for a specified time interval and the accumulated charge is shifted N rows (the shift is perpendicular to the direction of dispersion). The integration and shifting are continually repeated with a readout of N lines during each shift. Both serial and parallel binning are available in this mode.

Figure 1.6 illustrates the PSD mode. N rows of the CCD image are shifted and read out after every dwell point. The resulting data show time resolved images of the spectrum separated spatially by N rows. The time resolution is the time between shifts (dwell time).

The PSD mode can be taken in conjunction with a telescope dwell scan. The shift of the charge on the detector will be synchronized with the telescope's motion such that each output spectra corresponds to a single telescope position within the one or two dimensional scan.

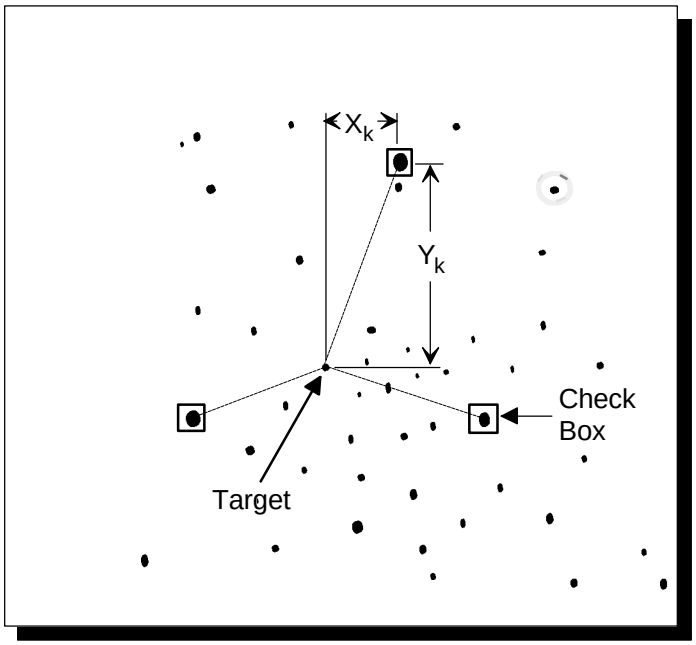


Fig. 1.7 On-board Crowded Field Target Acquisition

1.4 Target Acquisition Modes

The On-board STIS target acquisition modes can be divided into three types:

- Point Source
- Crowded field
- Diffuse source or planet

For the three types of targets the basic steps of target acquisition are:

1) locate the target acquisition aperture using an on-board calibration source to fully illuminate the aperture. This removes the non-repeatability of the MSM. The determined offset of the aperture from its expected position can be used as an offset for any other aperture or slit (assuming sufficient repeatability of the slit wheel).
2) locate the target within a target acquisition aperture.
3) Move the target to the expected position of the desired slit. Take an acquisition image for down-linking (optional). Move the slit wheel to the desired slit.

4) Peak-up the target within the slit
5) Peak-down the target behind an occulting bar

For a given target acquisition all steps or any subset of the steps may be selected.

1.4.1 Onboard Target Acquisition Image Processing

During any phase of target acquisition in which one or more images are required, the following steps can be performed on the image or selected sub-array.

1. Perform cosmic ray rejection (CCD only). If performed, two images are taken and compared pixel by pixel, with the final pixel value being the minimum of the two images.
2. Subtract a bias value (CCD only). The value will be stored in the onboard microprocessor. Subtraction will be done on a pixel-by-pixel basis.
3. Repair bad pixels (CCD only). A list of bad pixel locations will be stored in an onboard lookup table. The value of the bad pixel locations will be replaced with an average of the flux values recorded at the four adjacent pixels (in the X and Y locations). If a bad pixel is at an edge of the sub-array, the average of the flux values in the adjacent good pixels will be used.

1.4.2 Target Location

The target location phase of acquisition, locates the target within an image taken with a camera aperture in place. The location algorithm differs for the three types of targets. A point source is located by finding the point within the image or sub-array containing the largest total flux in a check box (square box with a selectable size) centered at the point. The target location is determined by the flux-weighted centroid of the values in the check box.

An object within a crowded field can be located by using three reference stars. An early acquisition image is normally used to identify the stars and their position with respect to the target. The reference stars should typically be the brightest in the field. The STIS flight software uses the following procedure to locate the target. Let X_k and Y_k (k=1,3) be the offsets to the 3 reference stars in pixels (as illustrated in Figure 1.7) and let X_k and Y_k be the same values rounded to the nearest integer. Then for each pixel (I, J) in the search sub-array, the total counts are summed in a square check box (selectable size) centered at locations ($I+\mathsf{X}_k$, $J+\mathsf{Y}_k$). A potential offset star is found if the sum in the check box is greater then a selectable threshold. A potential target star is found if offset stars are found in all three check boxes. If multiple positions (I, J) have potential targets, the position with the largest sum in the three check boxes is chosen. If no position (I, J) is found in which all of the three offset check boxes have sums above the threshold, the best position (the one with maximum total within the check boxes) with two offsets stars is chosen. The final target location is then given by the median value of the flux-weighted centroid of the offset star check boxes minus their offsets, X_k and Y_k. When only two offset stars are found, the position is the average between the two positions.

The brightest area of a diffuse source or solar system object is determined by either the geometric center, a flux-weighted centroid, or a thresholded centroid of the brightest check box location within the image. The size of the check box is selectable and will be typically larger than the size used for point source acquisitions. If the threshold centroid option is selected, the positions of the N brightest pixels in the image are centroided with equal weights (i.e. flux set to 1.0 for the N brightest points and 0.0 for all other points). N is the area of the object and is user selectable.

1.4.3 Determination of the Slit Position

The position of the projection of a slit or aperture on a detector will vary due to the non-repeatability of the MSM. If the slit wheel mechanism is highly repeatable (a projected position error on the order of a pixel), the flight software will find the edges of the camera aperture (illuminated by an on-board calibration lamp) on the detector and determine the projected slit position relative to the camera aperture edge using an onboard lookup table. If the slit wheel is not repeatable or if the edge of the camera aperture does not project on to the detector, the slit can be located directly using the thresholded centroid of the slit illuminated by an on-board calibration source.

1.4.4 Target Centering

Target centering is required if the positioning in the spectroscopic slit after the target locate step is not sufficiently accurate. There are two methods of target centering, spiral and linear. In a spiral search, a two dimensional scan is performed by moving the target in a spiral of specified size (odd number greater then 1). A flux measurement is made at each dwell point in the spiral by summing the counts within a selectable sub-array. The final position of the target is given by either the point in the spiral with maximum total flux or the centroid of the flux measurements at all points.

In the linear peakup method, the target is scanned in only one direction (perpendicular to the direction of dispersion) across the slit. Again, the target position is determined as the position of maximum total flux or the centroid of the flux measurements at all dwell points. Target centering can optionally be done in dispersed light. The only difference between the dispersed and undispersed light centering is the size and location of the sub-array.

Linear centering is also used to place an object behind an occulting bar. The object is scanned across the occulting bar and the position of the minimum total flux within a sub-array is chosen as the final target position.

Section 2
Simulations and Observation Preparation

The STIS science data management and analysis software must be completed before STIS ever views an astronomical target. Much of the calibration and reduction and STIS flight software algorithms must be tested without the benefit of real data. To alleviate this problem, both spectral and image simulation software can be used. This software can also be used to:

- Test the flight software target acquisition algorithms.
- Optimize observing parameters and techniques for both target acquisition and spectral observations.
- Verify that the spectral format and combined optical efficiency match predicted values.
- Diagnose problems by reproduction of the problem through simulation.
- Compute exposure times needed to achieve desired counts or signal-to-noise level.
- Test target acquisition algorithms for a particular target using early acquisition images and/or images of the target taken with another instrument.

The simulation and observation software can be divided into two groups, target acquisition (section 2.1) and spectral simulation (section 2.2).

2.1 Target Acquisition

It is difficult to fully test the STIS on-board target acquisition software in the pre-launch calibration and testing environment. Image simulation software and software that duplicates the functions of the on-board target acquisition algorithms can be used to evaluate and optimize the adjustable parameters of these algorithms. Software is required to generate test images and apply the algorithms described in section 1.4 to these images.

The input test images may be:

- images taken from ground telescopes and from other HST instruments.
- pre-launch calibration and test images taken with STIS.
- computer generated star fields and extended objects.

The image generation software should allow the input image from one of these three sources to be convolved with an estimated STIS point spread functions (PSF) and allow the addition of random noise (Poisson, CCD readout noise, flat field non-uniformities), artificial cosmic rays, hot pixels, and image motion due to spacecraft jitter. Execution in a batch mode should be available for executing Monte-Carlo simulations. Monte-Carlo simulations can be used to estimate the probability of target acquisition failure for particular target scenarios.

The first step in the target acquisition software is the on-board image processing. The simulation software should exactly duplicate the process used by the flight software to allow

evaluation of the on-board algorithms for cosmic ray removal and bad pixel repair. Typical evaluations will include; the impact the algorithms have on stellar profiles, flux levels, and centroids after cosmic ray removal, the effect of the bad pixel repair in very sharp point sources, and the effect unremoved cosmic rays or hot pixels have on latter target acquisition phases.

The algorithms used for target locate (isolated point source, crowded field, and diffuse source acquisitions) should be duplicated in the ground software to allow optimization of the selectable parameters including check box sizes, sub-array sizes, thresholds, and the centering/centroiding method. After launch, the simulation software can be used to test target acquisition scenarios using early acquisition images and to diagnose the causes of target locate failures. Typical investigations of the target locate algorithms will include:

- The impact of unremoved cosmic rays or hot pixels on the target location
- Target position accuracy in the presence of flat field non-uniformities and Poisson/readout noise
- Selection of optimal size check boxes for crowded field acquisitions depending on the accuracy of the positions of the offset stars relative to the target
- Comparison of the accuracy of the three algorithms (geometric center, flux weighted centroid, and thresholded centroid) for determining the center of different types of diffuse or planetary objects.

Slit location software will be used to evaluate the two methods of slit location (locating the edges of the camera aperture and thresholded centroid of a slit). Since the input images for this step are taken using the on-board calibration lamps, both simulated and actual pre-launch STIS images can be used to evaluate and optimize the selectable parameters. This software will be used to optimize the number of rows and columns to sum-over to generate the edge profile, the edge threshold, and the slit areas used for the thresholded centroid algorithm. The software can also be used to investigate the impact of unremoved cosmic rays and hot pixels on the computed location of the aperture edges or slit position.

The target centering algorithms (both peak-up and peak-down) must be evaluated to optimize the step size between scan positions for the various slit and occulting bar sizes. Software that duplicates the on-board target centering algorithms can also be used to determine when a centroid of the scan profile should be used instead of the position with maximum total. Other studies may include the impact of jitter and unremoved cosmic rays or hot pixels on computed target positions.

Table 2.1 summarizes the on-board target acquisition simulation software requirements and the input/outputs. Note: inputs from item numbers N and $N.J$ may be inputs (as required) to item number $N.K$ where $K>J$ but are not listed again in the input column.

Table 2.1
Target Acquisition Simulation Requirements

Item No.	Requirement	Inputs	Outputs
1	**Image simulation**		Simulated image
1.1	Generation of random star field	Pixel size (arcsec), Number of stars Magnitude distribution table, clustering parameter	Image of star field
1.2	Illuminated aperture or slit	Slit size and position, Optional slit illumination image, Optional target field to be added when pixels fall within the slit.	Image of illuminated slit
2	**Image formation**	image from step 1, from another source, or an actual STIS image.	image
2.1	Image resampling	input and output image pixel sizes in arcsec.	resampled image
2.2	Convolution with PSF	Model or observed PSF	blurred image
2.3	Sub-array extraction	location and size of the sub-array	sub-image
2.4	Addition of noise	Readout noise level, Flat Field non-uniformity, Exposure time (if input image is supplied in count rates).	image
2.5	Addition of cosmic rays and hot pixels	Number of random cosmic rays to add or a Cosmic ray image (e.g. from STIS or another CCD), Optional cosmic ray count distribution table Table of hot/dead pixel locations and count rate.	image
3	**On-board image processing**	one or two images from step 2	processed sub-image
3.1	Cosmic ray removal	2 CCD exposures	single image
3.2	Bad pixel repair	Table of bad pixels	repaired image
4	**Target Locate**	image from step 3	
4.1	Isolated point source	Check-box size	target position, and check-box sum
4.2	Crowded field	Check-box size, Threshold, Offsets to three stars	target position
4.3	Diffuse source	check-box size, Type(s) of centering (geometric, flux weighted centroid, or thresholded centroid), Area of target if threshold centroid	target center(s), flux of brightest checkbox
5	**Slit Position**		
5.1	Aperture Edge	Sub-array location, edge threshold number of rows and columns to sum	Edge locations
5.2	Slit location	Sub-array location, Area of the slit (in pixels)	Slit Position
6	**Target Centering**	Aperture size, Total counts in star. (Uses code from step 2 to generate image for each dwell point and most of those inputs apply).	
6.1	Linear scan peak-up or coronagraphic acquisition	step-size between dwell points, number of dwell points, direction of centering (x or y), Choice of maximum or minimum flux point, Centroid (yes or no)	Computed target position

Item No.	Requirement	Inputs	Outputs
6.2	Spiral search	x and y step-sizes between dwell points, order or the spiral	target position

2.2 Spectral Simulation

2.2.1 Spectral Format Display.

Software to generate spectral formats is required to assist in verifying optical alignment and to assist in the initial wavelength calibration. This software should compute and plot the spectral format projected on the detector using the grating parameters and STIS alignment information. The inputs include:

θ - grating blaze angle
d_g - groove spacing
δ - half angle between the angle of incidence and the angle of reflection (at the detector center) in the plane of dispersion
σ - out of plane angle between the angle of incidence and angle of reflection
$\Delta\theta$ - grating angle with respect to the blaze angle
f - the focal length of the camera mirror or focusing optic

Wavelengths, λ, at an arbitrary position on the detector can be computed by:

$$\lambda = d_g \cos\sigma(\sin\alpha + \sin\beta)/m$$
$$\alpha = \theta + \delta + \Delta\theta \qquad \text{angle of incidence}$$
$$\beta = \theta - \delta + \Delta\theta + \varepsilon \qquad \text{angle of reflection}$$
$$\varepsilon = \arctan(x/f)$$

where x is the distance in the dispersion direction to the center of the detector and m is the spectral order (1 for first order gratings). The routine should also have the provision for a rotation of the format on the detector. A prototype routine STIS_FORMAT is already available in IDL and was used to generate the plots in Appendix A. Other useful options include; overlaying the boundaries of the free spectral range (as thick solid lines), overlaying contours (thin solid lines) showing the theoretical grating efficiency, and marking the locations of significant astrophysical wavelengths.

The spectral format routine should also have the ability to plot positions of spectral lines to assist in the initial wavelength identification for spectra of a wavelength calibration lamp (see figure 2.1 which shows the spectral line positions as diamonds with the size indicating the relative line strengths).

Fig. 2.1 Echelle Spectral Format with locations of Pt-Ne Lamp Spectral Lines

After completion of the initial wavelength calibration of STIS, this routine should have the ability to use the dispersion solution (section 6.8) and spectral location files (section 6.6) to plot the spectral format. An option should be available to output the format plot into an image which can be used as an overlay on actual observed data.

2.2.2 Count Rate Estimation

Software is needed to estimate the count rates for a given dispersion mode and input source flux. This software will initially combine the efficiencies (either measured or predicted) of the individual optical components used by each mode. Tables 2.2 and 2.3 list the optical components for each mode when observing external targets. Tables 2.4 and 2.5 show the optical components for light from the two internal calibration subsystems prior to the slit wheel. The light enters the system through a hole in the second corrector mirror or is reflected off of a calibration insert mirror placed between the second corrector mirror and the slit wheel. The light then passes through the same slits used for external sources. The remaining optical path is then identical to the path used for external targets.

The inputs to the count rate estimation routine include:

- Input flux distribution versus wavelength (existing observed data or a model)
- A table of efficiency versus wavelength for each optical component
- Tables of the relative throughput for each applicable STIS slit.
- The STIS grating mode, slit identification, wavelength range and/or spectral orders that count rates are needed.

The output of the routine is count rate versus wavelength for the specified mode. The routine should also have the provision for generating a predicted combined efficiency curve or sensitivity curve (formatted as needed by the standard STIS pipeline calibration routine, section 5). Other capabilities of the program should include:

- Estimation and application the MAMA detector non-linearities (both local and global) using either a analytic function of interpolation in a lookup table (TBD).
- Resampling the output wavelength and flux onto the STIS wavelength grid (one data point per STIS detector pixel.
- Use of separate efficiency curves for each spectral order in the echelle modes or alternately use a theoretical or calibrated echelle ripple function
- When calibrated sensitivity functions become available, allow their use instead of combined component efficiencies.
- The HST optic efficiencies external to STIS.
- Support for the internal STIS calibration sub-system and the external calibration system used during pre-launch calibration and testing.

Table 2.2
Optical Elements for each Mode (External Targets)

Optical Element	Mode																				
	1.1	**1.2**	**1.3**	**1.4**	**1.6**	**1.7 x3**	**1.7 x4**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7 x3**	**2.7 x4**	**3.1**	**3.2**	**3.6**	**4.1**	**4.2**	**4.6**
first corrector mirror	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1	CM1
second corrector mirror	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2	CM2
Slit (see table 1.3)	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit	Slit
Collimator Mirror	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM	CLM
Mode Select Mechanism Optical Elements																					
order sorter								os21	os22	os23	os24			os23	os24	os31	os32		os41	os42	
Parabolic grating	ng11							ng21													
plane grating		ng12							ng22					ng23	ng24	ng31	ng32		ng41	ng42	
cross-disperser plane grating			ng13	ng14		ng13	ng14			ng23	ng24										
order sorter								os21	os22	os23	os24			os23	os24	os31	os32		os41	os42	
prism												Prism									
mode select parabolic mirror					nm16								nm26								
mode select fold mirror																		nm36			nm36
Post Mode Select Mechanism Optical Elements																					
echelle grating			eg13	eg14						eg23	eg24										
fold mirror		m1				m1	m1		m2			m2		m2	m2	m3	m3	m3	m3	m3	m3
camera mirror		k1a	k1b	k1b		k1a	k1a		k2a	k2b	k2b	k2a		k2a	k2a	k3	k3	k3	k3	k3	k3
detector window	dw1	dw1	dw1	dw1	dw1	dw1	dw1	dw2	dw2	dw2	dw2	dw2	dw2	dw2	dw3	dw3	dw3	dw3	dw3	dw3	dw3
CsI MAMA detector	MA1	MA1	MA1	MA1	MA1	MA1	MA1														
Cs2Te MAMA detector								MA2	MA2	MA2	MA2	MA2	MA2	MA2	MA2						
CCD detector																CCD	CCD	CCD	CCD	CCD	CCD

Table 2.3
Backup Grating Modes (External Targets)

Optical Element	Mode					
	1.1B	**1.2B**	**1.3B**	**1.4B**	**2.1B**	**2.2B**
first corrector mirror	CM1	CM1	CM1	CM1	CM1	CM1
second corrector mirror	CM2	CM2	CM2	CM2	CM2	CM2
Slit (see table 1.3)	Slit	Slit	Slit	Slit	Slit	Slit
Collimator Mirror	CLM	CLM	CLM	CLM	CLM	CLM
Mode Select Mechanism Optical Elements						
Parabolic grating	ng11b					
order sorter					os21b	os22b
plane grating		ng12b			ng21b	ng22b
order sorter					os21b	os22b
cross-disperser plane grating			ng13	ng14		
Post-Mode Select Mechanism Optical Elements						
echelle grating			eg23	eg24		
fold mirror	m2	m2			m3	m3
camera mirror	k2a	k2a	k2b	k2b	k3	k3
detector window	dw2	dw2	dw2	dw2	dw3	dw3
Cs2Te MAMA detector	MA2	MA2	MA2	MA2		
CCD detector					CCD	CCD

Table 2.4
HITM Calibration Subsystem Optical Path

Pt/Cr-Ne cathode lamp 1	Pt/Cr-Ne cathode lamp2
Beamsplitter (reflection) BS4	Beamsplitter (transmission) BS4
off-axis elliptical mirror (EL4)	
turning flat (TF4)	
turning flat (TF5)	
turning flat (TF6)	
slit	

Table 2.5
CIM Calibration Subsystem Optical Path

Source	Kryton Continuum	Deuterium continuum	Tungsten continuum	Pt/Cr-Ne spectral line
				spherical mirror (EL3)
				flat mirror (TF7)
beamsplitter	reflection (BS1)	transmission (BS2)	reflection (BS2)	transmission (BS1)
beamsplitter	reflection (BS3)	transmission (BS3)	transmission (BS3)	reflection (BS3)
elliptical mirror (EL1)				
flat mirror (TF1)				
flat mirror (TF2)				
flat mirror (TF3)				
spherical mirror (EL2)				
flat mirror (IM)				
slit				

2.2.3 Spectral Image Generation

The results of the count rate estimation routine in the previous section must be placed onto a simulated STIS image in order to simulate how the data will actually appear. A routine is required which takes the raw count rates versus wavelength and constructs a simulated image using the spectral formats as generated by the software described in section 2.2.1. The generated images will be useful for testing the calibration and reduction software, and investigating the sources and effects of scattered light.

The spectral image generation routines should have the capability to:

- place the spectrum onto a data array in the proper spectral format using a supplied cross-dispersion light profile,
- convolve the data with a grating scatter function (in the echelle modes with both an echelle and cross-disperser scatter function),
- create (or use existing calibration data) and apply flat fields, bias images, and darks,
- add a electronic bias and overscan region to a simulated CCD image,
- add Poisson and readout noise,
- add bad pixels (cosmic rays, hot spots, etc.),

and,

- convolve the data with the detector PSF.

Section 3
Data Acquisition and Management

Data acquisition and management tasks include:

- receiving raw data and reformatting the data into a more convenient form for subsequent processing
- cataloging the data
- archiving the data
- retrieval of archived data
- distribution of the data

During the pre-launch calibration period, data will be received in a packetized format (described in section 3.1). This format is not convenient for reduction and analysis. The packetized format must be converted to a form easily read and used by subsequent software tools. The formats that we currently plan to use are SDAS images and tables. These formats are easily read by both IDL and IRAF/SDAS and are the standard internal format used by the first generation HST instruments. Both IDL and IRAF/SDAS have tools for converting these formats into Flexible Image Transport System (FITS) format. FITS formatted data are in a machine independent form and can be read by most other major astronomical reduction and analysis packages.

After launch the raw data will be received from the ST ScI. The packetized data will already be reformatted during a process called generic data conversion and will be received by the STIS team as internal SDAS image/table (TBD) files or as FITS files.

As data is acquired and reformatted (section 3.2), it will be cataloged into a merged observing log
(section 3.3). This catalog will contain, instrument configuration, environmental, and target information for each observation. It will also contain the location of the data (if on-line), the archival status, and the location of the data in the archive. This observing log will be the users' primary source of information for determining what data is currently available and where to find it.

3.1 Raw Telemetry Format

During the pre-launch calibration of STIS, science and calibration data will be received in ST packetized format. A packet is composed of 16 bit halfword integers blocked into 64 word segments. The first two words of each segment contains a 24 bit sync word and an 8 bit segment number, the third word contains a packet counter, and the remaining 61 words contain data. The first segment of each packet contains a standard packet header (Table 3.1).

Table 3.1
Standard Packet Header

Word	Bit Positions	Description
0	0-15	Sync (Hi order 16 bits of 24-bit word)
1	0-7 8-15	Sync (Low order 8 bits of 24-bit word) Segment No. (0 for the first segment)
2	0-15	Packet Count (a running 16-bit counter)
3	0-7 8-15	Source ID (00 * for a standard header packet, ?? * for a STIS science data packet) Mission ID
4	0-7 8-15	Packet Length Code Secondary Header Length (number of 8-bit words in the secondary header, words 6-13 of segment 0)
5	0-7 8-15	Packet Format Code Source ID Parity (Coded, redundant specification of source ID)
6	0-15	Frame Start Count
7	0-15	Line Count
8	0-15	Time Code Bits 0-15 of 42 bit spacecraft time code
9	0-15	Time Code Bits 16-31
10	0-9 10-15	Time Code Bits 32-41 Spare
11	0-7 8-15	Spare Observation number (for a standard header packet, this value is 0 and the observation number is in segment 0, word 14 bits 8-15)
12	0-15	Number of packets per frame
13	0-5 6-15	Spare Number of 16-bit data words per packet

STIS science data will contain two types of packets; Standard Header Packets (SHP) and Science Data Packets (SDP). Note that the Standard Header Packet is not the same thing as the Standard Packet Header. The SHPs contain 965 words of data in a 16 segment packet and can be identified by a packet format code of 170. The SDPs also contain 965 words in 16 segment packets and can be identified by a packet format code of TBD.

An observation contains one or more SDPs and optionally one SHP. The packets associated with a STIS observation (which may contain more than one exposure) are identified by its programmatic information consisting of a program ID (3 characters), an observation set ID (2 characters) and an observation number or ID (2 characters). These ID's are found in words 803 through 806 of the SHP and in an Internal Header Packet of the SDP's.

The science data for a single observation are packed into multiple SDP's each containing up to 965 16 bit words of data. If required, the last packet associated with an observation may be packed with fill data to extend it to 965 words.

There are 3 basic types of STIS science data; a detector science exposure, a memory dump, or a engineering data (ED) diagnostic observation. The majority of the science data will be detector science exposures. Memory dumps will occur whenever it becomes necessary to verify the contents of the STIS microprocessors. Engineering data diagnostics will be used when the data from engineering telemetry stream has insufficient time resolution to diagnose problems in the STIS hardware or flight software. In all three types of science data, the science data packets contain the same basic structure given by the outline below (additional details can be found in Appendix C):

I. Internal Header Packet

- Program ID
- Obset ID
- Observation ID or Number

II Internal Unique Data Log

A. Data Unpacking Definition

- Flight observation number
- Number of bytes in the image

B. Image Definition

- HST time at the start of the observation

- Image Type (detector science data, memory dump, or ED diagnostic)

- Memory Dump Definition
  - Memory Dump source
  - Memory Dump starting address
  - Number of bytes in the memory dump

- ED Diagnostic Definition
  - Items to collect (up to 32)
  - Collection time
  - Collection frequency

- Detector Science Data Definition
  - Detector Number
  - Detector Science Data type
  - Subarray Definition (up to 8 subarrays allowed)

C. Calibration Information

D. ED Snapshots

Engineering snapshot number 1
Engineering snapshot number 2

III Image Data

Detector science , Memory Dump, or ED Diagnostic data.

The information in the internal header packet will be used to associate the SDP's with the proper observation. Word 11 in the SDP standard packet header will not be a reliable observation number indicator. The last word in the internal header packet contains the number of science data packets required for this image. If more than one packet is required for an Image, the first packet will contain the internal header packet and the internal unique data log. Subsequent packets will contain Image data. Any unused portion of the last packet will contain fill data.

The Internal Unique Data Log (UDL) contains information needed to unpack the Image data, exposure time information, calibration information, and engineering data snapshots. The Image type distinguishes the data as one of the three types:

- detector science data,
- microprocessor memory dump, or
- engineering data diagnostic information.

The detector science data definition gives the detector number, data type (accumulate, MAMA time tagged, or CCD parallel shift and dwell), and the subarray definition (locations and sizes for up to 8 subarrays)

The memory dump definition gives the memory dump source (which internal computer, CS or MIE), starting memory address, and the number of bytes in the memory dump.

The ED diagnostic definition defines the contents of engineering data diagnostic dump. There are two types of diagnostic modes (FAST and SLOW). In the FAST mode, the specified engineering items are sampled as fast as possible. In the SLOW mode, the collection frequency gives the sampling intervals in milliseconds. The collection time specifies the number of seconds during which the ED diagnostic data will be collected. Up to 32 can be collected simultaneously. A 16 bit word is used to identify each item to collect.

The final portion of the internal UDL are the ED snapshots. Two ED snapshots are included. In normal accumulate mode science observations, the first snapshot will be populated just prior to the beginning of the exposure and second just after completion of the exposure. For MAMA time-tagged and CCD parallel shift and dwell modes, both snapshots may be populated prior to the exposure start. The number of words in the ED snapshots are TBD. The calibration information and ED snapshots will contain configuration information (state of internal lamps, positions of all mechanisms, temperatures, and other engineering data items needed for interpretation and calibration of the detector science data).

3.2 Data Reformatting

The raw packetized data must be reformatted into data sets that are easily managed and convenient for further reduction and analysis. The primary format of these data sets will be SDAS image and table files. The SDAS image file format is the current format used by the HST Post Observation Data Processing System (PODPS). During Generic Data Conversion, PODPS converts the packetized data into Generic Edited Information Sets (GEIS) files. The GEIS files are formatted as SDAS image files. The formats for the current ST instruments are described in ICD-19: Post Observation Data Processing to Space Telescope Science Data Analysis Software Interface Control Document.

To the extent feasible, the software used to reformat the pre-launch STIS calibration and test data should convert the data into a format closely resembling the expected post-launch format from generic data conversion. Exceptions may be made for pre-launch specific requirements, and when significant improvements in data compression or data reduction throughputs can be achieved. When exceptions are made, care should be used to isolate the relevant input/output software so that a smooth transition to post-launch GEIS format can be made.

3.2.1 SDAS Image Files

Before continuing with details of STIS data acquisition, we should first review the basic formats and capabilities of SDAS images and tables. An SDAS image file is very similar to group formatted FITS files and contains three basic parts, a header, a set of one or more equal size data arrays, and a group header (or parameter block) for each array. The header is stored in one file and the group parameters and data are stored in a separate file. The last character in the 3 character extension of the header file is an *h*. The data file has the same name with the *h* changed to a *d*. For example, if the header file has the name *flux1.hhh* the associated data file would have the name *flux1.hhd*.

The header contains an ASCII description of the data in 80 character records. These records contain either keyword parameters in the form:

<name> = <value> / comment

or free form text or history when the first 8 characters have the value of "HISTORY ", "COMMENT " or are all blank. <name> gives the keyword name (first 8 characters of the record padded with blanks if required). The <value> can be integer, logical, floating point, or string. The final keyword of the header file is the "END" keyword. Prototype headers for STIS science data can be found in Appendix D.

Required keywords in the header are used to describe the number and sizes of the data arrays. These include:

SIMPLE Logical value which specifies whether the file conforms to the FITS standard. This normally has a value of false for SDAS image files.
BITPIX Number of bits in each data value (8, 16, 32, or 64)
DATATYPE Type of data values in the array ('REAL*4, INTEGER*2, etc.)
NAXIS The number of axis or dimensions of the data
NAXISi i = 1 to NAXIS, the length of each dimension
GROUPS If true, specifies that the data structure has a group format with parameter blocks
GCOUNT The number of arrays or groups
PCOUNT The number of group parameters in the group header
PSIZE The number of bits in the group parameter block.

for i = 1 to PCOUNT

PSIZE*i* Specifies the number of bits in each group parameter
PTYPE*i* Specifies the name of each group parameter
PDTYPE*i* Specifies the data type for each group parameter. Unlike standard FITS, each group parameter can have a different size and data type.

The data file contains the data arrays and the group parameters for each array as binary data. The format of the data is illustrated in Fig. 3.1.

Current IDL software available for reading and writing SDAS image files include:

SXOPEN - opens a data file and either reads (if input) or writes (if output) the header
SXREAD - reads a data group and its group parameter block
SXPAR - extracts keyword parameter values from the header
SXGPAR - extracts group parameter values from the group parameter block
SXGREAD - reads group parameter blocks without reading the data arrays
SXADDPAR - adds or updates a keyword parameter value in the header
SXADDHIST - adds line(s) of history to the header
SXWRITE - writes a data group and its group parameter block

One disadvantage of the current SDAS image file format is that the disk files can not be shared by computers that are not binary compatible. To alleviate this problem, we plan to enhance the format by adding an option for storing the data in IEEE format. The addition of a single keyword in the header could be used to indicate this new IEEE format and maintain compatibility with existing SDAS image files not in IEEE format.

Fig. 3.1 SDAS image files. N groups or data arrays and M group parameters

3.2.2 SDAS Table files

SDAS image files suffer from the restriction that all data arrays must be of the same type. You can not mix integer data with floating point data, etc. SDAS table files can be used to overcome this restriction. SDAS table files are used to store tabular data of varying types. Tables are two dimensional with an arbitrary number of rows and columns. All data with in a single column is of the same data type but different columns can be different types. An SDAS table contains a table description, a FITS-like header, and the tabular data stored in a single data file. The header can contain keyword parameter values and history lines. There are no required keyword parameters for a table and the header can be empty.

The SDAS table format to be used by STIS will be a modification of the current table format. There are three differences between this format and previous SDAS tables.

1. The file format is machine independent; i.e. integer values are not byte-swapped, and IEEE format is used for floating point values.
2. The column descriptor includes additional space for storing axis lengths for the case that entries are multidimensional arrays.
3. Lengths are specified in bytes rather than in units of two bytes.

In the following description of the table format, the word "entry" is used here to mean the value or array of values stored at one row and column, while "element" means a single value or element of an array. A character string is regarded as one element, and an array of strings can be stored as one entry.

There are four sections to a table:

(1) a size-information record which gives the number of rows, etc.
(2) optional header-parameter records
(3) a record for each column that describes the column
(4) the table data

1. The size-information record is 12 four-byte integers in length. Only the first ten are used at the moment, and these have the following meanings:

1 The number of header parameters that have been written to the table.
2 The maximum number of header parameters for which space has been allocated.
3 The number of rows that have been written to the table.
4 The allocated number of rows; this is irrelevant for this table type.
5 The number of columns that have been defined.
6 The maximum number of column descriptors for which space has been allocated.
7 The length in bytes of the portion of the row that is used by columns that have been defined.
8 The allocated row length in bytes. This is the spacing between values in the same column and in adjacent rows.
9 Table type: 10, which implies a row-ordered table that can contain array entries and 11 indicates a column-ordered table
10 Table software version number. For tables that can contain array entries, the version will be two or larger.
11 zero (currently not used)
12 zero (currently not used)

2. The header parameters are FITS-like records for storing information such as comments or numerical values. They are not used by the table routines at all. There need not be any

header parameters, and there need not be any space allocated for them; that is, words one and two of the size-information record may be zero. Each header-parameter record is 80 bytes in length and contains the following:

bytes	description
1-8	Keyword; from one to eight characters padded on the right with blanks. All letters will be in upper case.
9	Data type; a single lower-case letter: t, b, i, r, d indicating a type of text, Boolean, integer, real, or double precision respectively. The data type has little real meaning since the value is ASCII.
10-80	The value and optional comment, a left-justified ASCII string terminated by an ASCII null and followed by garbage. Boolean true and false are represented by one and zero respectively. Values of type text may optionally be enclosed in double quotes. The comment is described below.

A comment may follow the value of a header parameter, except for HISTORY, COMMENT or blank keywords. Anything that follows the value is interpreted as a comment, but if there is a comment, it is expected that there be one space between the value and the comment. For a text string parameter to include a comment, the value must be delimited by double quotes, and whatever follows the second quote is taken as the comment.

3. There is a column descriptor for each column that has been defined. Each column-descriptor record has a length of 24 four-byte integer words and contains the following:

word	description
1	The column number.
2	The offset in bytes from the start of the row. This will be an even number, and it is the sum of the widths of all previous columns, or zero for the first column.
3	The amount of space in bytes required to store one entry. This is the full width of the column, which may contain an array of values at each row. The column width will be an even number of bytes; if the entry is an array then each element will itself be an even number of bytes in length.
4	The number of elements in the first dimension of the array, or one if the column contains single elements rather than arrays.
5	The number of elements in the second dimension of the array. This will be one if the dimension is less than two.
6	The number of elements in the third dimension of the array, or one.
7	The number of elements in the fourth dimension of the array, or one.
8	(currently not used)
9	(currently not used)

10 (currently not used)
11 (currently not used)
12 The data type:
6 = single-precision real
7 = double-precision real
4 = integer
3 = short integer
1 = Boolean
-n = character string containing up to n characters
13-17 The column name, up to 19 characters left-justified, terminated by an ASCII null and followed by garbage. Upper and lower case are allowed.
18-22 The units, up to 19 characters terminated by an ASCII null and followed by garbage.
23-24 The format for printing the column, terminated by an ASCII null and followed by garbage. This is an SPP-style format without the leading %.

4. The table data are stored in row order if any table column contains arrays; that is, values in the same row and in adjacent columns are adjacent in the file. If all entries are scalar values, the table data may be stored in either row or column order. Floating point values are stored in IEEE format and may be single or double precision. Two-byte and four-byte integers are supported; integer values are not byte swapped. Boolean values are stored as two-byte integers, with one and zero representing true and false respectively. For character data type, each element will be terminated with an ASCII null if there is room for the null; if the string fills the space allocated for the element then the null will not be present. Undefined floating point elements are represented by IEEE NaN. Undefined two and four byte integers are represented by -32767 and -2147483647 respectively.

The following IDL routines are currently available for reading, writing, and manipulating SDAS table files. These routines will need to be modified to handle the changes made to the table formats. Routines with names in the form of TABLE_* require an existing table file name as input. Routines with names TAB_* require the table to be read into IDL variables.

TABLE_HELP - prints the table header, table size information, and a description of each column
TABLE_EXT, TAB_VAL - extracts and reads selected values from a table
TABLE_LIST, TAB_LIST - prints all columns for selected rows of the table
TABLE_PRINT, TAB_PRINT - prints selected columns of the table in an ASCII tabular format
TABLE_SORT, TAB_SORT - sorts the table in ascending order for a selected column.
TABLE_DELETE, TAB_DEL - deletes selected rows of the table.
TABLE_APPEND - appends two or more tables with the same columns into a single table

TABLE_CALC - creates new table columns which can be generated from a numerical expression from existing columns.

TAB_READ - reads a table and it's header from an existing file and places them into IDL variables

TAB_CREATE - creates a new table

TAB_VAL - extracts data values from the table

TAB_NULL, TAB_NULLROW - sets selected table values to null values.

TAB_PUT - inserts new values into the table

TAB_ADDCOL - adds a new column to the table

TAB_COL - returns a description of the specified column

TAB_SIZE - returns table size information

TAB_WRITE - writes a table to a disk file

TAB_MODCOL - modifies a table column description

TAB_TO_DB - converts a table to an IDL data base file

3.2.3 STIS reformatted raw data files.

Table 3.2 lists the proposed reformatted STIS data files for the reformatting of pre-launch data.

Table 3.2
Reformatted Raw Data Types

File Extension	SDAS File Type	Data Type
.shh, .shd	image	Standard header packets
.ulh, .uld	image	Internal Unique Data Logs
.d0h, .d0d	image	Accumulate mode images, CCD Parallel shift and Dwell data
.tle	table	bad pixel list
.d1h, d1d	image	MAMA time-tagged data
.ttc	table	MAMA time-tagged coarse time table
.deh, .ded	image	Engineering Diagnostic Data
.dmh, .dmd	image	Memory Dump Data

The data acquisition software will read a raw packetized data file and place the reformatted data into the data sets listed in Table 3.2. File names will be constructed as:

<rootname>.<file extension>

Unlike the rootnames expected for the post-launch data from PODPS which are constructed from the observation's programmatic information, the rootnames for the pre-launch data sets will be the entry number of the observation in the merged observing log (section 3.3). After launch, the programmatic information is unique for every observation. During pre-launch calibration, this may not be the case.

The first step in processing the raw telemetry stream is to separate the packets into individual observations. It is assumed that all packets will be received in the correct time order during the acquisition of pre-launch calibration and test data. The end of one observation and beginning of a new observation will be detected by a change in the programmatic information (Program ID, observation set ID, and Observation ID). If the ground test system setup is not capable of insuring that consecutive observations have unique programmatic information, a backup method will be to use the Flight Observation Number in the Internal Unique Data Log to separate packets between observations. When the acquisition of an observation is completed, a new entry will be added to the merged observing log (section 3.3) describing the data and the location of the reformatted data files.

All Standard Header Packets will be placed into an SDAS image file with extensions *.shh* and *.shd*. The proposed header contents for this file can be found in appendix D. The data in each group consists of 965 INTEGER*2 data words (the raw packet data with the packet header and sync words removed). The format of this file is identical to the SHP files currently produced by PODPS for the first generation HST instruments. The rootname of the SHP file will be the current observation being processed. Not all observation will have an SHP file associated with them. The only item in the SHP that may be required for processing the science data is the time when the spacecraft time equals zero. For observations without an SHP file, the zero time from the most recent processed SHP can be used.

Internal Unique Data Logs (UDL) will be extracted from the science data packets and placed into a SDAS image file with extensions *.ulh* and *.uld*. The format of this data file matches the formats presently used by PODPS for the external UDLs of the first generation ST instruments. A prototype UDL header can be found in appendix D. Selected values will be extracted from the internal UDLs and placed into the .ulh header and/or the headers or group parameter block of the science data files. All STIS science observations will have at least one Internal Unique Data Log.

Image data from accumulate mode observations will be placed into SDAS image files with extensions *.d0h* and *.d0d*. These files may have multiple groups for sub-images or multiple readouts. The group parameter block will contain parameter values which change from one group to the next. A prototype header for this file can be found in Appendix D.

MAMA CCD time tagged data will be placed into an SDAS image file with extensions *.d1h* and *.d1d*. Each 32 bit word of the time tagged data set will contain a coarse time or a fine time with an X and Y location of the event. These words will be placed into the *.d1d* file without any unpacking. During acquisition of the time tagged data, a table (extension *.ttc*)

will be constructed containing the coarse time and the location of the coarse time words in the in the *.d1d* file. This file will allow random access of the .d1d file for any specified time interval and can also be used as a quick-look of total counts per time interval (where the time interval equals one coarse time unit). The columns of the table will be:

COARSE_TIME - coarse time value
POSITION - data word position of the coarse time in the *.d1d* file
EVENTS - number of events between this coarse time and the next coarse time marker

The present IDL SXREAD routine will need to be modified to allow it to read a subset of a single group. The time-tagged data will all be placed into a single group of the SDAS image file. It will not always be feasible to read the entire group simultaneously. The acquisition software should also construct an ACCUM mode image (extensions *.d0h* and *.d0d*.) for the time-tagged data.

CCD Parallel Shift and Dwell data will be reformatted into an SDAS image file with extensions *.d0h* and *.d0d*. Each group will contain a two dimensional array containing the data for one shift and dwell.

Memory Dump data will be placed into a single group SDAS image file with extensions of *.dmh* and *.dmd*. The memory dump source (CS or MIE) and the starting dump address will be placed into keyword values in the header. The number of bytes in the memory dump will be placed into the keyword NAXIS1.

Engineering Diagnostic data will be placed into a single group SDAS image file with extensions *.deh* and *.ded*. NAXIS1 will contain the number of items dumped and NAXIS2 will contain the number of times each item was dumped. The diagnostic mode (FAST or SLOW), collection time, the collection frequency, the ED item numbers, and ASCII names of the items collected will be placed in the header as keyword values.

After launch, data will be reformatted by the ST PODPS system during a process called generic data conversion. The outputs of this process will be files very similar to the format used during pre-launch calibration and testing. These data can be accessed from the ST ScI in the SDAS image or table format directly or as FITS files transferred via network or tape. The FITS files can be reformatted into internal SDAS image format using an existing IDL routine ST_TAPEREAD (which should require minimal modification).

3.3 Merged Observing Log

A catalog of STIS data must be maintained in order to manage the large amount of data that will be received both during pre-launch testing and calibration period and during post-launch calibration and scientific utilization. A merged observing log should be maintained on-line which allows fast searching for data with specific characteristics and gives information of where the data is archived. At a minimum, the pre-launch data catalog should include:

Observation file name
Observation date and time
Observation mode (ACCUM, time-tagged, parallel shift and dwell, memory dump, etc.)
Detector (MA1, MA2, or CCD)
Disperser (MSM disperser element)
MSM encoder positions
Slit - aperture, filter, or slit identification
Slit wheel encoder value
Identification of CCD amplifiers used for the readout
CCD gain values
Lamp status and currents for all internal lamps
Engineering data snapshot
Central Wavelength
Number of sub-images
Sub-image size
Position of each sub-image
Number of readouts
Exposure time
Shift and Dwell times for the PSD mode
X and Y Bin size for CCD on-chip binning
Average count rate
Target acquisition parameters
    Target locate method
    Slit locate method
    Target centering method
Image statistics, including a crude histogram
If data is currently stored on-line, its location
Disk Identification and location for optical disk archive
Tape Identification and file number for tape archive
External lamp identification
Test purpose
Comments

An observation will be added to the log as soon as the data is acquired (as described in section 3.2). All of the fields in the catalog except for the archive information, external lamp identification, test purpose, and comments can be added at the time of data acquisition. The archive information will be added when the data is archived to tape or optical disk by the software described in section 3.4. The external lamp identification, test purpose, and comments will require a special utility so that they can be added or updated by the data manager or librarian at a later time.

In addition to the contents of the pre-launch catalog, the post-launch catalog should also include:

Target type (point source, crowded field, diffuse field)
Right Ascension and Declination of the target
Proposal ID
Target Name
Target Alias
Target Description
The orbital ephemeris model parameters
Central wavelength(s) of the subarrays

This post-launch information can all be found as keyword values in the data headers generated by the ST PODPS.

The necessary IDL software for creating, updating, and using the described catalog has been developed by the GHRS instrument team and can be used with no modification. The relevant routines are:

DBHELP - on-line listing of available data bases and descriptions of the size and fields in the data base
DBOPEN - open a data base
DBCLOSE - close a data base
DBFIND - search catalog on any field(s)
DBSORT - sort all or any selection of entries (records) on any field(s)
DBEXT - extract data values for any selection of entries or fields
DBPRINT - print selected fields for all and any selection of entries
DBCREATE - create a new data base
DBRD - read an entry from a data base
DBWRT - write an entry to a data base
DBVAL - extract the value a specified field from an entry
DBPUT - place a value into an entry
DBINDEX - create an index file of a data base for very fast searches on selected fields

3.4 Data Archival and Retrieval

Three data archives are planned:

1) An on-line temporary archive for immediate access of the data.
2) An optical disk archive which will allow data retrieval within minutes.
3) A tape archive for long term storage of the data.

The on-line disk archive will have sufficient capacity to store the majority of the pre-launch data taken during the 1996 scheduled calibration period. This data will remain on-line until after launch and will only be removed if the space is needed for storage of post-launch data. Once removed, the data can still be accessed within minutes from an optical disk archive.

The format of the files stored on the optical disks will be identical to the internal on-line formats (SDAS images and tables). This has the advantage that data can be quickly restored or used by the reduction and analysis software directly from the disk. A disadvantage of using an internal format for the optical disks is that the format is machine dependent. Future changes in hardware and optical disk formats may make these disks obsolete. To avoid this problem, data will also be archived on magnetic tape cartridges in a machine independent format (e.g. FITS). Current IDL software, ST_TAPEWRITE, (with minimal modification) can be used to archive the data to tape.

Nothing in the design of the STIS archival and retrieval software should prohibit the use of new archival technology. Sufficient spare space should be added to the merged observing log to allow additions of new archival media.

3.5 Data Distribution.

The current plan during pre-launch calibration and test is to have two large file servers, each with at least 10 gigabytes of on-line storage. During the 1996 calibration period at Ball, one of the file servers will be installed at Ball and the other installed at Goddard Space Flight Center (GSFC). The file server at Ball will acquire the calibration data, update the log, and archive the data to optical disk and tape. The data will be transferred to GSFC via internet and/or overnight delivery of an archive tape. The on-line data at GSFC will then be available to local GSFC users and remote STIS Internet users. Data can be copied directly to a user's computer via network. Both file servers will be equipped with optical and tape drives for distribution of data via optical disk or tape. FITS tape distribution will be available using a modified version of the current IDL routine ST_TAPEWRITE.

After completion of the pre-launch calibration, both file servers will be located at GSFC. Post-launch data will be installed on the servers and can be distributed to remote user's in the same manner as pre-launch data.

Section 4
Quick-Look Analysis

Once the data from a new observation is received, it should be immediately examined. Easy to use, interactive quick-look software is required. It is anticipated that the implementation of this software will be an X-window cursor and widget controlled package.

During quick-look analysis, the user will;

- determine that the data was properly received.
- determine that the data was taken with the proper configuration and target.
- locate anomalies.
- verify that the data is satisfactory (e.g. sufficient counts) for the calibration or test it was taken for.
- supply inputs to the routine reduction procedure (section 5).

Quick examination of data is particularly important during the pre-launch calibration period. This period will only last a few weeks. Any data that is not sufficient for the purpose that it was taken must be quickly identified so that, if necessary, the test can be modified and rescheduled.

The quick-look software should allow the user to select observations to examine from the merged observing log (section 3). In addition to quick-look analysis, this will allow the software to be used as a browse utility for the data archive.

The quick-look software can be categorized into three groups:

1. Image display and measurement
2. Spectral extraction, display, and measurement
3. Display of target, configuration, and environmental parameters

4.1 Image Display and Measurements

Image display and measurement software is required for both camera mode images and spectral images. Software for interactive manipulation and measurement of images should include the following capabilities and options:

1. Display of the full image (rebinning may be required to display images larger than the display capabilities of the computer's display)
2. Conversion to count rates
3. Subtraction of the bias determined from the CCD overscan region, subtraction of a bias and/or dark image, and division by an appropriate flat field image.
4. Intensity transformation (display with logarithm, square root, histogram equalized intensity transfer functions)

5. Selection of pseudo-color tables.
6. Linear contrast enhancements between selectable minimum and maximum.
7. Image zoom and roam.
8. Interactive measurement of cursor position and pixel intensity.
9. Cross sectional plots between any two selected points in the image.
10. Row or column sums of any user selected box with in the image.
11. Plot of the image's intensity histogram.
12. Display of image statistics for any user selected region (e.g.. mean, standard deviation)
13. Feature measurement (total flux, centroid, widths)
14. Image filtering (mean, median, low and high-pass band fourier filtering, convolution with a user supplied kernel)
15. Adding comments to the data's header file

The software should allow the user to generate annotated hardcopy output of the displays, plots, or measurements.

4.2 Spectral Extraction and Display

To evaluate spectral observations, the quick-look analysis software should have the capability of performing a crude (or full) reductions, spectral extraction and assignment of wavelengths (section 5). Once spectra have been extracted, the user should have the capability to:

1. Plot the spectrum (either on a linear or log scale) for any spectral order (echelle modes) or spatial position (long slit modes) versus pixel position or wavelength.
2. Zoom in on any selected region of the spectrum.
3. Interactively measure positions (wavelength, pixel, flux).
4. Analyze spectral features (equivalent widths, FWHM, total flux, centroids, etc.)
5. Overlay spectral line identifications from a spectral line library or table.
6. Filter the data (median, mean, convolution with user specified kernel)
7. Measure statistics in a user specified region (mean, standard deviation, estimated S/N)
8. Interactively annotate the plot.
9. Generate hardcopy of any displayed plot.

4.3 MAMA Time-Tagged Data

The accumulated image constructed from the time-tagged data during data acquisition can be examined using the software described in sections 4.1 and 4.2. However, this image was constructed for the entire observation period and gives no information of changes in the source with time. To allow examination of time variability, additional capabilities required for quick-look examination of time-tagged data include:

1. Plots of the total count rate versus time. (data quality masks should be an option which allow the user to exclude selected "hot" pixels from the analysis).
2. Constructions of an image for a user specified time interval. The software in sections 4.1 and 4.2 can then be used to provide a crude reduction or to examine the image.
3. Construction of data cubes with by having multiple images over user time intervals. The software should allow this data cube to be displayed as a "movie" or allow the user to examine the data cube with the IDL Slicer routine.
4. Plots of the count rate versus time for any subset region specified in pixels or wavelength. The user should be allowed to identify the region on the ACCUM mode image. The software should allow simultaneous display of the plots for multiple regions.
5. Generation of stacked plots showing extracted spectra for multiple time intervals.
6. Reformatting extracted spectra over a user specified time interval into a 2-dimensional image which can be analyzed using the software described in section 4.1.

4.4 Parallel Shift and Dwell Data

Quick-look analysis of Parallel Shift and Dwell Data can be best accomplished by combining the data from all (or a selected range) of dwell points into a two dimensional image with time running in the Y-direction. To decrease the size of the image, the software should allow binning in either or both the wavelength or time direction. Normally binning the data in the time direction in a bin size equal to the shift size between dwell points will allow the quickest way to examine time variability. For quick-look purposes, routine data reduction can be limited to overscan subtraction and generation of an approximate wavelength scale. Once the two-dimensional image is constructed, the software described in sections 4.1 and 4.2 can be used examine the image. Examination of row sums and vertical cross-section plots will allow analysis of time variability.

4.5 Display of Target, Configuration and Environmental Information

In addition to display of the image and spectral data, the quick-look software should allow examination of the configuration and environmental parameters of the data. Although much of this information can be found in the image headers, printout of the headers does not display the data in a convenient form for fast information retrieval. Display pages should be constructed for each class of parameters. Typical display pages will include:

1) Instrument configuration
2) On-board target acquisition parameters and results
3) Environmental parameters (selected temperatures, voltages, currents)

Figure 4.1 shows what a typical display page might look like. The software should be written to allow new display pages to be easily added. Users may even want to construct there own private display pages and add them to the options.

```
Observation Number   1234                    Calibration Lamps                Subarray Size
            Detector:  MA1                   Pt-Ne1 :     off                   128 x 128
             Grating:  1-4                   Pt-Ne2 :     off              Subarray Locations
 Central Wavelength:  1450 A                 Pt-Ne3 :     ON  18.4 mA          1     100,   124
               Slit:  0.063 x 0.2            Krypton :    off            2     500,   124
                                             Deuterium :  off                  3     100,  1800
                                             Tungsten1:   off            4     500,  1800
Observation Mode:     ACCUM                  Tungsten2:   off            5
    Exposure time:    5.00 Min               Tungsten3:   off            6
   Exposure Start:    12-JUL-1996 22:10:13   Tungsten4:   off            7
                                                                        8
Mechanism Positions:                                                          CCD binning  1 x
1
  MSM1:   12345
  MSM2:    3456
  MSM3:   32211          Parallel Shift & Dwell:  Shift = 0  Dwell = 0 sec
  SW:      8231                Doppler Zero:  12-Jul-1996 21:49:04     Mag: 0
```

Fig. 4.1 Sample Quick-look Display Page

After launch, display page(s) will also be required for display the external target and telescope pointing information available in the support schedule sections of the data's header (appendix B).

On-board ephemeris model parameters should also be used to construct the orbital path during the observation (Fig. 4.2) and list significant events (e.g. terminator crossings).

Fig 4-2 Display of the HST Orbital Path During an Observation

Section 5
Routine Reduction

5.1 Introduction

The purpose of routine reduction is to convert detector counts per pixel to a finished product of flux versus wavelength using the calibration reference tables, coefficients, and files that will be described in section 6. In the ST ScI Post Observation Data Processing System (PODPS) this process is referred to as Routine Science Data Processing (RSDP). Table 5-1 summarizes the corrections or calibrations required for this task. The information in this table is described in detail in the subsequent sections.

A quality estimate for the reduced wavelength and flux values is required in order to make meaningful scientific interpretations. The reduction process should generate this information. The quality of the data should be described by:

- a processing log
- propagated statistical errors
- data quality flags

The processing log should completely describe the reduction process with sufficient information to allow the reduction procedure to be repeated with identical results. At minimum the processing log should contain:

- The version number of the reduction software. Changes to the reduction routine should be documented and this version number incremented whenever the reduction software is modified.
- Identification of calibration reference files, tables or coefficients used to reduce the data.
- The values of any user selectable parameters or reduction methods

A FITS-like ASCII header is associated with each raw data file. The reduction process can add keyword values and free-form history records to this header to create the output processing log.

A statistical error model (Poisson and readout noise) should be propagated through the reduction process to give an error estimate for each output flux value. Data quality flags should be used to flag data points where the propagated statistical error does not give a reliable error estimate for the output flux value (e.g. hot pixels).

Table 5-1
Summary of Routine Reductions Steps

Reduction Step	Selectable Parameters	Calibration Reference Data	Comments
Data Quality Initialization		Bad Pixel Table	Flags Hot/Cold pixels. Special requirements when on-board Doppler compensation is used.
Bias Overscan Subtraction	Location of overscan region, overscan smoothing function		CCD only
Bias Image Subtraction		Bias Image	CCD only
Conversion to Count Rates		CCD gain factor(s)	
Non-linearity Corrections		Non-linearity coefficients or non-linearity lookup tables	Both local and global count rate correction for MAMA detectors
Dark Subtraction		Dark Image	Special requirements when on-board Doppler compensation is used.
Flat Fielding		Flat Field Image(s)	Special requirements for Doppler Compensation and objective mode prism
Spectrum Location (Point source)	Location Method (constant shift of reference location or full order tracing)	Approximate Spectral location file (order tracings). Detector distortion file.	May require interactive input for difficult cases.
Spectral Extraction (point source)	Slit width, Extraction method, unweighted slit or optimal extraction		

Reduction Step	Selectable Parameters	Calibration Reference Data	Comments
Wavelength Assignment		Previous dispersion solution for the configuration, may require detector spatial distortion file. Incidence Angle Correction Table. Spectral calibration lamp line library or template spectrum.	Will use spectral cal. obs. taken before and/or after the science data to adjust dispersion coefficients
Spectral Extraction (long slit mode)	Interpolation method.	Dispersion file Spatial Position file (Spectral location file)	
Background/Sky Subtraction	Background position, slit width, smoothing parameters	Echelle Scattered Light coefficients	
Echelle Ripple Correction		Echelle Ripple coefficients, or separate tabular curve for each spectral order	
Conversion to Absolute Flux Units		Inverse sensitivity table, Low Frequency detector variations and Vignetting file.	
Conversion to Heliocentric Wavelengths			Corrects for Earth's Motion around Sun

5.2 Statistical Error Propagation and Data Quality Flags

The STIS reduction software must have the ability to propagate statistical errors throughout the reduction process. The error of the raw data can be modeled by:

$$\sigma = \sqrt{R/g + \sigma_c^2}$$

where:

R is the observed DN minus electronic bias for the pixel

g is the CCD gain factor (1 for MAMA detectors)
σ_c the white noise component (e.g. readout noise)

Certain conditions including saturated pixels, photocathode blemishes, etc. can not be adequately modeled by the propagated statistical errors. A data quality flag (often referred to as an epsilon value) describing these conditions should be assigned to each data value. This flag should be an 8 bit integer (0 to 255) with the more serious conditions having a larger value. When a data point suffers from multiple conditions, only the flag for the more serious condition needs to be retained. To maintain compatibility with the FOS and GHRS, data quality flags should use the following convention.

value	condition
0	no special conditions
1-99	data quality impaired but the quality is reflected in the propagated statistical error
100-199	data is uncertain; uncertainty is not reflected in the statistical error computation, data may not be usable.
200 - 255	data is total useless

Table 5.2 gives some prototype quality conditions. Additional flags can be added as new conditions are discovered. Where possible, these correspond with FOS and GHRS data quality flags (note: GHRS and FOS data quality flags are 16 bits, values above 255 have been adjusted to restrict the flags to 8 bits).

Table 5.2
Data Quality Flags

Flag Value	Condition
255	Fill data (e.g. telemetry dropout)
240	Dead detector element or CCD column
230	Complete saturation (value unusable)
200	Inverse sensitivity correction invalid (outside usable wavelength range)
195	Cosmic ray detected (but not removed)
190	More than 20% uncertainty in non-linearity correction
185	Data masked by occulting bar or beyond edge of entrance aperture or slit
180	Large blemish (depth > TBD percent of average flat field)
175	Objective mode prism spectrum contaminated by nearby source
170	Noisy or hot pixel
160	Intermittent dead pixel

Flag Value	Condition
150	Blemish with depth < TBD percent
145	No flat field non-uniformity correction available for the pixel
140	Data has been repaired by interpolation from neighbors (eg. cosmic ray removed)
130	Moderate saturation. Up to 5% uncertainty in non-linearity correction
100	Reed-Solomon telemetry decoding error
40	Some data rejected during coaddition of multiple images. (eg. bad pixel or cosmic ray).

In many cases very few pixels in an image will have a non-zero data quality value. In these cases, it is not efficient to store an entire data quality image (which can be as large as 2048 by 2048 pixels). An alternate method is to store a table listing the data quality for only the bad pixels. Two types of tables will be used. The first type will have three columns giving the pixels row position, column position, and data quality or epsilon value. This table requires 5 bytes of storage for each pixel flagged and will take less storage if less than 1/5 of the pixels are flagged. Data quality flags for the raw data consists of only flags for fill data (lost telemetry) and Reed-Solomon decode errors (data may not be valid). These errors will occur in large contiguous areas of the raw image. An optimal method of flagging these conditions is to use a second type of data quality table with columns: starting row, starting column, number of rows, number of columns, and data quality value. Each entry in the table can be used to flag a rectangular region of the image with the same data quality value.

5.3 Data Quality Initialization

The first step in the routine data reduction of STIS images is the data quality initialization. In this step the data quality flags for the raw data are combined with a bad pixel table containing a list of detector dependent bad pixels (hot pixels, bad CCD columns, etc.). The bad pixel table will contain columns giving the anomalous pixels position and data quality indicator. Selection of which bad pixel table to be used will be based on the detector (MAMA1, MAMA2, or CCD) and the time of the observation.

The user should have the ability to also supply an observation specific bad pixel table that pertains only to the particular observation being processed. The user's table can be used to flag conditions such as cosmic rays that have been identified by preprocessing of the data.

When multiple data quality conditions are found for the same pixel, only the largest (worst condition will be retained).

When on-board Doppler compensation is used in the echelle modes (MAMA detector only), a pixel's data value is accumulated from multiple MAMA pixel positions. Doppler Motion due

to the HST motion around the Earth results in motion of the spectrum on the detector. This motion is modeled by:

$$\Delta x = C \sin[2\pi(t-t_0)/P]$$

where

Δx is the motion of the spectrum in pixels (in the dispersion direction)
C is the Doppler magnitude in pixels
P is the HST orbital period
t is the time
t_0 is the time of zero Doppler compensation.

The value of C and t_0 used by the flight software can be found in the science data telemetry.

Since the STIS flight software tracks this motion, the reduction software must determine what detector pixels were used in accumulation of each image value. The data quality value for each image value must be constructed as the combined quality for all pixels contributing to it.

Special requirements for data quality flagging for the Parallel Shift and Dwell mode are discussed in section 5.18.

5.4 Overscan Subtraction (CCD only)

The first step in processing CCD data is subtraction of what is commonly referred to as the "overscan" region. The overscan data is used to measure the electronics bias level by continuing the readout of a line of the CCD past its real physical extent. This bias level may vary with time and temperature and must be estimated using the overscan region of the particular observation being processed. The bias level may be a function of position on the CCD chip, varying primarily along columns. In the multi-amplifier readout mode, the overscan region for each amplifier should be processed separately.

The STIS CCD overscan will be included in both the serial and parallel directors for all full image readouts. Overscan will also be included in the parallel shift and dwell mode. At a minumum, the amount of overscan will be as follows:

Unbinned, single-amp readout:

20 rows of virtual parallel overscan.
The leading 20 pixels and 20 trailing pixels of physical serial overscan.

Unbinned, two-amp readout:

20 rows of virtual parallel overscan for each half-image.
The leading 20 physical pixels and 20 trailing virtual pixels of serial overscan for each half-image.

Unbinned, four-amp readout:

20 rows of virtual parallel overscan for each quarter-image.

The leading 20 physical pixels and 20 trailing virtual pixels of serial overscan for each quarter-image.

This implies that the size of single amp CCD images will be 1064 (serial) x 1044 (parallel). Two-amp readout images will be 1104 (serial) x 1044 (parallel). Four-amp readout images will be 1104 (serial) x 1064 (parallel).

Binned data will also include at least 20 rows of virtual overscan in the parallel direction and 20 leading and 20 trailing pixels of overscan in the serial direction. The 20 here refers to the number of extra row transfers and the number of leading and trailing serial pixel transfers that are done in acquiring the image. In the resulting image, there are thus roughly 20/n (binned) overscan rows and 20/n (binned) leading and 20/n (binned) trailing overscan pixels in each row. The exact numbers of overscan transfers will be chosen so that the total number of serial transfers per row is a multiple of the serial binning factor, and the total number of parallel row transfers is a multiple of the parallel binning factor.

The parallel shift and dwell mode (whether binned or unbinned) will follow the same rules as for normal full image readouts, providing the same amount of final virtual parallel overscan after the full image array is cleared at the end of the observation.

The algorithm which computes the bias as a function of row number is:

1) For each row, compute the average or median bias level for selected columns of the overscan region. If an average is taken, iteratively reject bad pixels greater than a selectable number of sigma from the average.

2) Optionally filter the bias vector from step one with a median filter to remove and remaining bad pixels or cosmic rays.

3) Compute the bias level as a function of line position by one of three methods:

- Average the bias levels for all lines and use it for the entire image.
- Smooth the results of step 1 by fitting a low order polynomial or spline curve.
- Use the results from step 1 as is (a separate bias for each row)

4) For each pixel of the CCD image, subtract the bias from step 2 appropriate for the pixel (either a constant value used for all pixels, or a value which varies with row number).

5) At this point, the overscan region of the image is removed and only the part of the image containing the useful data is retained.

5.5 Bias Image Subtraction (CCD only)

It is possible for the electronic zero point to have a 2-dimensional additive stationary pattern that is repeated for each CCD readout. In this case it is necessary to subtract a bias image (sometimes referred to as a "superbias") in addition to subtraction of the bias computed from the overscan region. This bias image is what you see when you readout an image with zero exposure time. The creation of the bias image is discussed in section 6.1. Selection of which bias image to subtract depends on the amplifier(s) used for readout.

If on-board binning in either or both the serial and parallel direction is used during data collection or data is collected only for selected sub-array(s), the correct portion of the bias image must be extracted and binned to match the observed data.

Special requirements for bias image subtraction for the Parallel Shift and Dwell mode are discussed in section 5.18.

5.6 Conversion to count rates

Conversion from observed Data Number (DN) to count rates is done by dividing by the exposure time and by multiplying by the CCD gain factor. The actual exposure time (not the planned) as reported in the telemetry from the STIS flight software should be used. The STIS CCD will have a selectable gain (1,2,4 or 8) which is reported in the telemetry. Actual calibrated gain factors should be used in the conversion to count rates (not the commanded integer value).

5.7 Dark Rate Subtraction

Unlike the CCD bias, the CCD and MAMA dark rate is an additive noise component which is proportional to the exposure time. Creation of the dark rate reference file is described in section 6.2. The correct dark file is selected by detector (CCD, MAMA1, or MAMA2), observation time, and possibly detector temperature. If sub-image(s) are taken or onboard data binning is used, the proper portion(s) of the dark frame should be extracted and binned in the same fashion.

In the echelle modes where Doppler compensation is used, the reduction software must determine what detector pixels were used in accumulation of each image value and what percentage of time the detector pixels were used. The percentage of time at each pixel can be used to compute a weighted dark rate for the pixels contributing to each image value.

Special requirements for dark image subtraction for the Parallel Shift and Dwell mode are discussed in section 5.18.

5.8 Correction of Detector Non-linearities

MAMA detectors a have non-linear response. As the input count rate increases the counting efficiency decreases. The non-linearity depends both on the local pixels count rate and on the global count rate for the entire image. The correction will be as follows:

1) Compute the total count rate for the entire image.

2) Using either an analytic or tabular function (TBD) determine a global correction factor.

3) Multiply all image pixels by this factor.

4) For each pixel, compute a corrected count rate using either an analytic or tabular function (TBD) of observed count rate.

Note: the local correction function may vary with pixel. However, it is unclear whether a separate function could be calibrated for each pixel. Present plans are to use a single function for all pixels.

In addition to corrections for non-linearities, the software must flag pixels that are saturated or have large uncertainties in the non-linearity correction. The data quality flags are:

130	More than 5% uncertainty in the non-linearity correction
190	More than 20% uncertainty in the non-linearity correction
230	Saturated pixel (data is basically useless)

Only a local non-linearity correction for the CCD is required. For each pixel, a corrected count rate must be computed using either an analytic or tabular function (TBD) of observed count rate.
The correction function must be selected by the amplifier and commanded gain setting.

5.9 Flat Fielding

Each pixel of a CCD or MAMA detector has a different quantum efficiency. To correct for these differences, the detector data must be divided by a flat field image which contains the relative efficiency for each pixel. Construction of the flat field reference files are described in section 6.9.1. Selection of which flat field file to use is based on detector, disperser, and central wavelength or spectral order. If sub-image(s) are taken or onboard data binning is used, the proper portion(s) of the flat field image must be extracted and binned in the same fashion as is done on-board for the science observation. Since the flat field response varies from pixel to pixel, on-board Doppler compensation requires computation of an effective flat

field response for each data value as the weighted average (described in section 5.3) of the response of all detector pixels contributing to the data value.

Special processing is required for a multi-object prism or grating mode when a camera aperture instead of a slit is used (Section 5.19). Special processing is also required for the CCD parallel shift and dwell modes (section 5.18).

5.10 Spectral Location (Point Source Observations)

The position of a spectrum for a given observing configuration will not fall always fall on the same place on the detector due to non-repeatibility in the mode select and slit wheel mechanisms
and due to intentional distribution of position usage on the MAMA detectors. The center of the spectrum or each spectral order in the echelle mode must be traced. Figure 5.1 shows a spectral order with the center of it marked by a dotted line. The positions along the center dotted line are used as the centers of an extraction slit when integrating the flux at each wavelength. Two methods can be used for spectrum or order tracing. The first method (which will be the default method) will use an existing tracing of the spectrum (stored in a reference table and selected for the given aperture and central wavelength or order). The existing tracing will be adjusted in the y (cross-dispersion direction) to maximize the flux under it. This can be accomplished by using the existing tracing as a cross-correlation template. The position of maximum correlation gives the optimal position of the tracing. Quadratic refinement using the position of maximum correlation and the two neighboring correlation values can be used to position the tracing to sub-pixel precision.

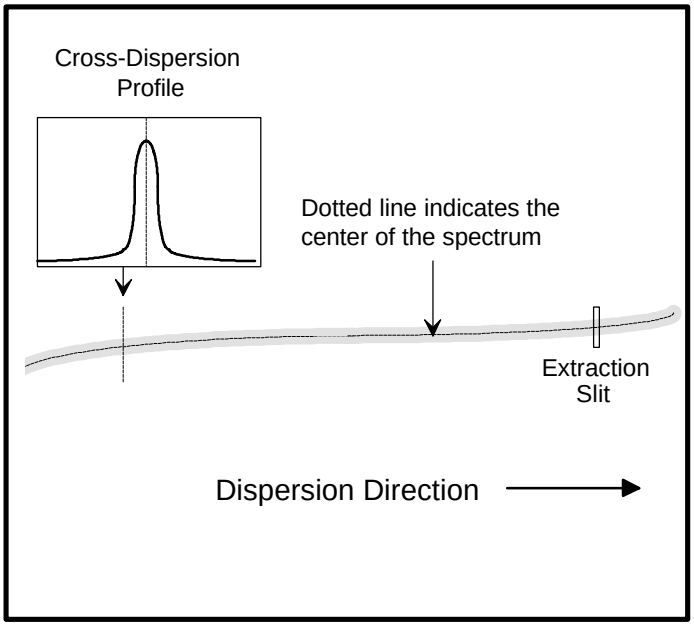


Fig 5.1 Spectral Location

In the second method, a full-tracing is computed. This method allows adjustment of the spectral curvature as well as the position. The spectral position versus wavelength (or pixel number in the dispersion direction) is determined by examining the cross-dispersion profiles (see Fig. 5.1). The profile can be constructed from a single column or by averaging multiple neighboring columns to increase the signal to noise. The approximate position to search for the center of the profile can computed from an earlier reference tracing for the given mode and central wavelength or an earlier tracing updated with the first location method. If no tracing is available, the routine should allow the user to interactively locate the approximate

position of the spectral orders The updated center of the profile is then determined by one of three methods:

1. Center of a Gaussian function fit to the profile
2. Cross-correlation with a template profile (with quadratic refinement for sub-pixel accuracy)
3. Average of the two edges (position where the flux is one half the maximum plus minimum flux)

A least squares polynomial or spline function can be fit to the computed profile positions versus pixel location in the dispersion direction to give a smooth tracing. The least squares fitting should allow iterative rejection of bad data points (residuals greater then a user selectable factor times the standard deviation of all residuals). The fitting function should also allow automatic rejection of points where the flux in the spectral order is below a selectable threshold to allow interpolation over absorption regions. In some cases, entire spectral orders in the echelle mode may have insufficient flux to trace the order with method 2. For these orders the input tracing (or the results of method 1) should be should used.

In summary, the user should have the following choices:

1. Use an input order tracing without modification. This allows the user to run order tracing software ahead of time or use the tracing from another observation.
2. Run method 1 using an existing order tracing as the approximate location of the spectrum. This method is the default.
3. Interactively identify the spectral orders optionally followed by location method 1 and/or method 2.
4. Use a previous order tracing as the approximate spectral location updated using method 1 and/or method 2.

Small scale distortions or geometric discontinuities in the detectors may not be adequately modeled by a smooth order tracing. It may be necessary to adjust the center of the spectrum using a distortion reference map containing an x and y distortion for every pixel. The positions of the order tracing (used as the center of the extraction slit in the next section) should be adjusted by the offset in the distortion map in the direction perpendicular to the direction of dispersion.

The spectral location software and all other spectral processing software must be able to process spectra taken in the cross-disperser x.7 modes. In these modes, the direction of dispersion (in detector coordinates) is approximately perpendicular to the direction of dispersion for the other modes. The same algorithms used for the other (x.1, x.2, x.3, x.4, and x.5) modes can be used in the x.7 mode by simple reversal of the line and sample directions.

5.11 Spectral Extraction (Point Source Observations)

Spectral extraction for point source targets is the process of transforming the two dimensional image data into one dimensional flux vectors. Two methods can be used for this extraction: unweighted and optimal.

In the unweighted method, we add the total counts within an extraction slit to obtain the extracted data value (Figure 5.2). There are two ways to handle the end pixels of the slit. In the first, the slit is chosen with a width equal to an odd integer number of pixels. The slit is then centered on the nearest integer pixel and all pixels within the slit are coadded. Alternately we can use an extraction slit of arbitrary width which is centered to sub-pixel accuracy. The data values in the end-points of the slit are coadded by weighting them by the area within the portion of the pixel covered by the slit.

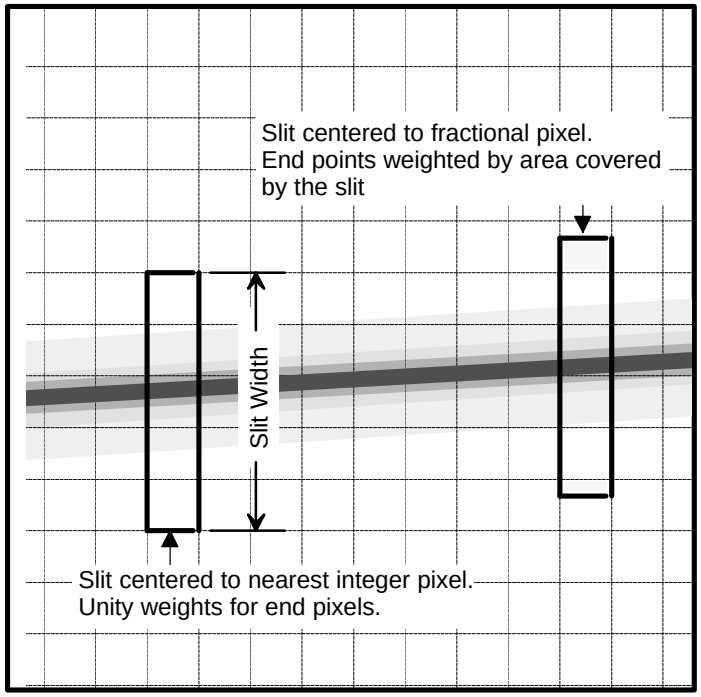


Fig. 5.2 Point Source Extraction Slit

In optimal extraction, the data values in the slit are coadded with weights selected to maximize the signal to noise of the result. The critical components in optimal extraction are determination of an accurate model for the cross-dispersion profile, P_i, and an accurate model for the noise within the image, σ_i, where i is the position of the pixel along the slit. The optimal value of the extracted flux can then be computed by minimizing chi-squared:

$$\chi^2 = \sum \left(\frac{f_i - FP_i}{\sigma_i} \right)^2$$

where f_i is the background-subtracted data value for pixel i (see section 5.14 for information on background subtraction) and F is the optimal value for the flux. The solution of F which minimizes chi-squared is given by:

$$F = \frac{\Sigma(f_i P_i / \sigma_i^2)}{\Sigma(P_i^2 / \sigma_i^2)}$$

The error estimate of F is given by:

$$\sigma = \sqrt{\frac{1}{\sum P_i^2 / \sigma_i^2}}$$

The major difference between current optimal extraction techniques is in the method of determining the cross dispersion profile *P*. Typical techniques include:

- Fitting functions (e.g. Gaussians) to data combined for a large number of wavelengths
- using library profiles that have been modeled from multiple data sets
- fitting low order polynomials in the dispersion direction to each row in the order previously normalized along the slit with an unweighted extracted flux.

The best selection for STIS data will depend on how much the PSF varies with wavelength or position on the detector and how much the PSF changes from one observation to another taken in the same observing mode.

5.12 Wavelength Assignment

The following steps summarize the wavelength assignment for a STIS science observation.

1. Find the reference dispersion solution appropriate for the observation. The dispersion coefficients are selected by grating mode, central order and central wavelength. For echelle observations multiple sets of coefficients (which vary with spectral order) may be required.
2. Apply an incidence angle correction if the observation's slit is different than the slit used to calibrate the reference dispersion coefficients.
3. If wavelength calibration observation(s) were taken with the science observation, compute an average pixel shift between the reference dispersion solution and measured spectral locations in the wavelength calibration observation(s). Apply this shift to the dispersion solution used for the science observation.
4. For each extraction position, optionally apply a distortion correction to its position in the direction of dispersion.
5. Compute the wavelength for each flux value using the position of the center of the extraction slit adjusted for distortion in step 4 and the dispersion coefficients adjusted in steps 2 and 3.

The dispersion relation for the grating modes (image pixel *i*,*j*) can be modeled by:

$$x_{ij} + \Delta_{ij} = A_0 + A_1 m\lambda + A_2 m^2\lambda^2 + A_3\lambda$$

and for the prism mode by:

$$\lambda = A_1 + \frac{A_2}{(X - A_0)} + \frac{A_3}{(X - A_0)^2} + \frac{A_4}{(X - A_0)^3} + \frac{A_5}{(X - A_0)^4}$$

$$X = x_{ij} + \Delta_{ij}$$

where x is the detector position in the dispersion direction, Δ_{ij} is an optional pixel shift from a distortion map (see section 6.10), m is the spectral order (1 for first order gratings), λ is the wavelength and A_i are the dispersion coefficients. Other terms may be needed depending on the optical and detector distortions present. A_3 is used only for the echelle modes (it is redundant with A_1 for first order gratings). Newton's iterative method can be used to compute the wavelength for the grating modes for a given order number and x location.

The coefficients, A_i, are selected by grating mode and central order/wavelength. In the echelle modes, optical/detector distortions may prohibit the use of a single set of coefficients for the entire spectral format visible on the detector. In this case, separate dispersion solutions (which vary with spectral order) may be required. For example, the reference file may have solutions for groups of every 9 orders tabulated according to the central order of the fit. Linear interpolation of the coefficients between the tabulated orders can be used. In the long slit modes, the dispersion solution will vary with position along the slit. Linear interpolation between solutions for tabulated line (cross-dispersion direction) positions can be used to find the coefficients for each line position along the slit.

To avoid maintaining a coefficient table for every grating mode, central order/wavelength, and every entrance slit, A table of relative slit positions and a table of incidence angle coefficients will be used to compute an offset between the reference dispersion solution (generated for one slit) and an observation taken with a different slit. The required coefficients of the incidence angle correction are TBD. The initial approach will be to define the incidence angle correction as:

$$A_0' = A_0 + a_1\delta + a_2\delta^2$$
$$A_1' = A_1 + b_1\delta$$

where, A_1' and A_1' are the incidence angle corrected dispersion coefficients, δ is the offset between the apertures in arcsec. and a_1, a_2, and b_1 are the calibrated incidence angle correction coefficients. A correction for both wavelength offsets, and small changes in linear dispersion can be modeled with these coefficients.

The accuracy of the reference dispersion solution and incidence angle correction is limited by the repeatability of the mode select and slit wheel mechanisms and any thermal changes that may cause the spectral format to move on the detector. To obtain accurate wavelengths, a wavelength calibration observation (WAVECAL) must be taken before and/or after the science exposure without movement of the mechanisms. In the routine pipeline processing these WAVECAL(s) can be used to compute an offset to be applied to the reference dispersion solution. Alternatively, the WAVECALs can be used to generate a completely new set of dispersion coefficients (section 6.7) prior to execution the routine reduction routine.

The following procedure will be used to generate an offset for the reference dispersion solution.

1. Perform the routine image processing (bias subtraction, flat fielding, etc.) on the WAVECAL and extract the spectrum. Subimages may be used to limit the size of the down-linked data resulting in only portions of the spectral format being available.
2. Use the reference dispersion solution and incidence angle correction to generate a reference wavelength scale for the WAVECAL.
3. Use a reference spectrum as a template or create a template spectrum with this wavelength scale using spectral line positions and relative intensities given in a reference line library appropriate for the given spectral calibration lamp and observing mode. The profile of the lines in the template spectrum will depend on the width of the slit.
4. Cross-correlate the template spectrum with the extracted WAVECAL spectrum to obtain an average spectral shift. Apply this shift to the A_0 term of the dispersion relation before applying the solution to the science observation.

An alternate approach, which can be applied instead of (or after) the cross-correlation of the template spectrum is to locate each line in the line library using centroiding, cross-correlation, or line fitting. The median of the offsets computed for the individual lines can then be used to adjust the A_0 coefficient.

The HITM calibration sub-system will normally be used for the first order grating mode WAVECALs. Light from the external target is not blocked and will be overlayed on the wavelength calibration observation. If the brightness of the external target is comparable or brighter then the spectral calibration lamp, wavelength calibration will become difficult. To combat this problem the scaled external target observation (in count rates) should be subtracted from the WAVECAL image (also in count rates) before extraction of the WAVECAL spectrum. For point sources observed in a long slit, further improvements can result if the WAVECAL spectra are extracted above and below the location of the target spectrum. The wavelength calibration results from the two locations can then be averaged.

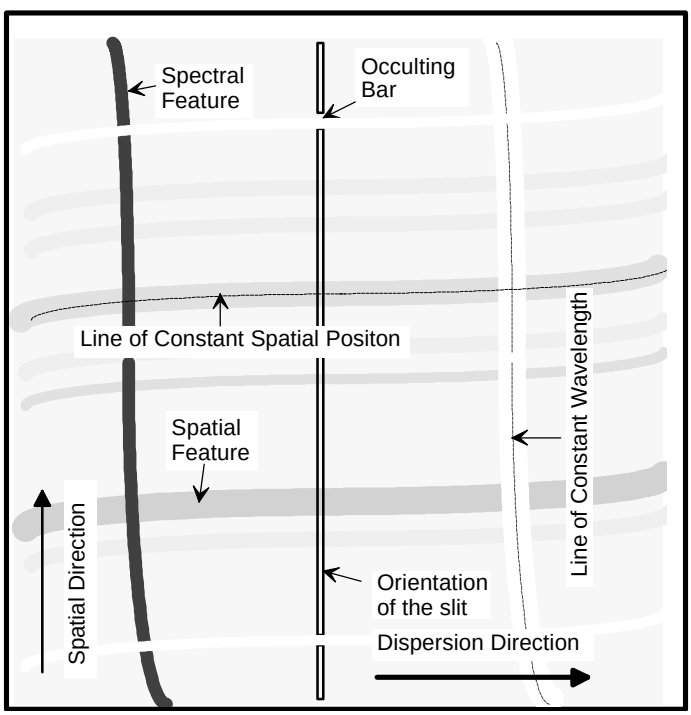


Fig. 5-3 Extended Source Spectral Format

5.13 Extended Source Extraction

Extended source spectral extraction is used to create a two dimensional map with wavelength in one dimension and position along the slit in the other dimension. Extended source extraction is appropriate for both extended sources

observed in a long slit or a point source trailed along a long slit. Fig. 5-3 illustrates a spectrum taken in the long slit mode. Optical/detector distortions have been exaggerated. Pixels of constant wavelength and pixels of constant spatial position do not lie in a straight line due to optical and detector distortions.

Two methods of reducing the data can be used. In the first method, no interpolation of the flux values in the image is required. Each pixel in the image is assigned a wavelength and a position along the slit. Wavelengths are assigned as described in section 5-12. Assignment of spatial positions along the slit require a spatial map constructed as described in section 6.10. This map may be either a full image containing the position of each pixel, a set of order tracings for various Y-positions, or a set of coefficients which vary with Y-position (cross-dispersion direction). The coefficients give the spatial position as a function of x-pixel. The spatial position function at each Y-location is identical to the spectral tracing function for a point source located at that Y-position along the slit. If the occulting bars are visible in the long slit spectrum, their position can be used in post-pipeline processing to adjust the spatial positions to an absolute position within the slit. The absolute position of the slit is useful for relating the spatial positions in the spectral mode to spatial positions in a camera mode image taken with the slit in place or to the spatial positions of an image taken with a different central wavelength or grating mode.

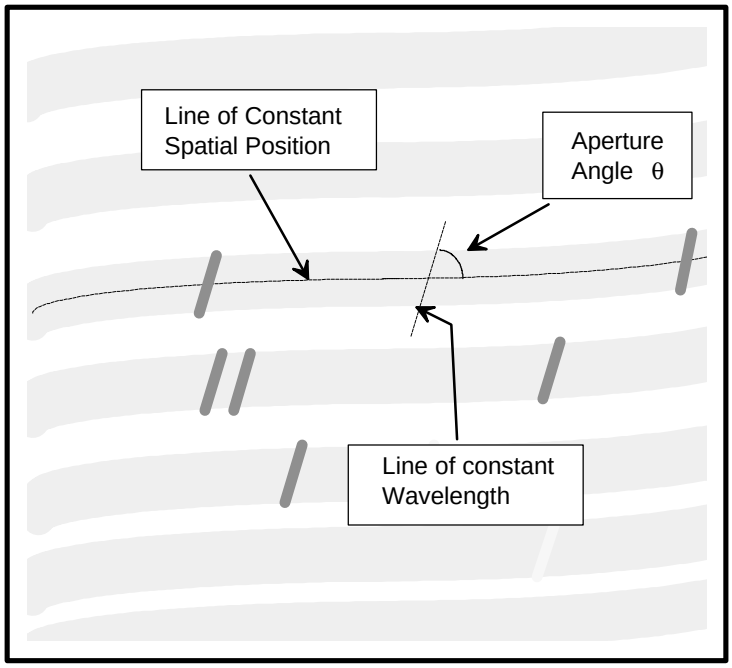


Fig. 5-4 Extended Source Echelle Extraction

In the second method of extraction, the flux values of the image is interpolated onto a square wavelength grid, F(i,j), such that:

- data points F(i1,j) and F(i2,j) are at the same spatial position for any i1, i2, and j.
- data points F(i,j1) and F(i,j2) are at the same wavelength for any i, j1, and j2.

Possible interpolation methods include, bi-linear, quintic, or sinc interpolation.

A slightly simpler approach may be applicable to the echelle modes where much shorter slits for extended sources are required to avoid order overlap. In this case, the wavelength solution and spatial distortion map at the center of the aperture can be used along the entire slit (Fig. 5.4) The positions along the slit at a constant wavelength are then defined as the positions

along a line at an angle θ from the center of the slit. The pixel position of a point at spatial distance *d* from the center of the order tracing at pixel *x,y* at the same wavelength is given by:

$$x_d = x + d\cos(\theta)$$
$$y_d = y + d\sin(\theta)$$

Calibration of θ is described in section 6.6. θ may vary with spectral order or wavelength.

5.14 Background and Scattered Light Correction

The extracted flux values at any point within an image will contain a contribution from scattered light from other wavelengths, inadequately removed dark current or bias, particle background, light from neighboring echelle orders due to order overlap, MAMA detector halos, and sky light. The contribution of these background sources can be estimated from measurements made on either side of the spectrum. In the echelle modes the measurements are made between the spectral orders (interorder).

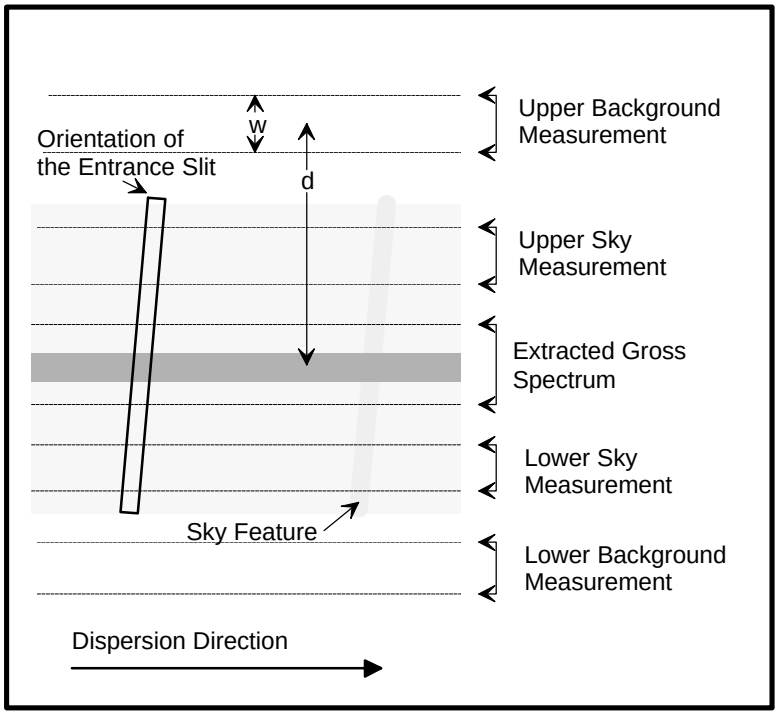


Fig. 5-5 First order grating Background Measurements

Fig. 5-5 illustrates the background measurements for the first order grating modes for observations of a point source. Measurements made within the slit will include the sky contribution. For the longest slits, no measurements of scattered light outside the slit may be possible. For the very small slits, no estimate of the sky can be made. Measurements of the background will be made at a distance d above and below the center of the position of the target spectrum using an vertical extraction slit with width w. Although both a background and sky measurement are shown in Fig. 5-5, only one or the other will be used in a single reduction. The extracted sky spectra must be shifted to account for the angle of the entrance slit to ensure that the sky features match. The upper and lower background spectra will be averaged and normalized to the extraction width of the gross spectrum. Before subtraction, the background can be optionally smoothed. Possible techniques include median filtering, mean filtering or fitting the background with a low order polynomial or spline function.

Smoothing will not be appropriate for a sky background when significant spectral features are present.

Background subtraction will not be performed in routine pipeline processing for extended source extractions. Post reductions utilities can be used to define a region (in spatial position) to measure the background and subtract it from the data.

Background measurements in the echelle mode will be made by measuring the level of the interorder background extracted halfway between neighboring orders. A first approximation of the background for an echelle order is an average the interorder spectra on each side of the order. The average interorder spectrum is optionally smoothed, normalized to match the extraction slit width for the spectral order, and subtracted. Some short comings of this method which must be investigated include: the presence of echelle "ghosts" in the interorder spectrum and the contamination of the interorder spectrum from neighboring spectral orders. The background for Each order has a flux contribution from the neighboring orders, but to a lesser extent than what is measured in the interorder spectra.

5.15 Echelle Ripple Correction and Conversion to Absolute Flux Units.

To avoid maintaining a library of sensitivity files with a separate sensitivity curve for every grating mode, grating scan angle, aperture or slit, and position within the aperture, we can divide the sensitivity function into four components:

1. An aperture throughput function.
2. Low frequence response variations across the detector and vignetting.
3. Echelle ripple function (echelle modes only).
4. Overall grating mode sensitivity function.

Separation of the sensitivity into components also has the added advantage that some of the components can be calibrated with internal lamps. This reduces the calibration time needed on external absolute photometric standard stars. Calibration of the components are discussed in section 6.

The aperture throughput function gives the throughput of an aperture or position within an aperture relative to some reference aperture. The throughput can be modeled as a low order polynomial of wavelength. An aperture's throughput function is applicable to all grating modes. If this function is calibrated for a low resolution grating mode, it can be applied to the high resolution grating modes. Calibration of the throughput function is discussed in section 6.9.4.

Ground calibration will determine how well the overall sensitivity function of a grating mode (which depends only on wavelength) can be separated from the other components. Fig. 5-6 illustrates a combined sensitivity function for a scanned grating. The sensitivity function for a

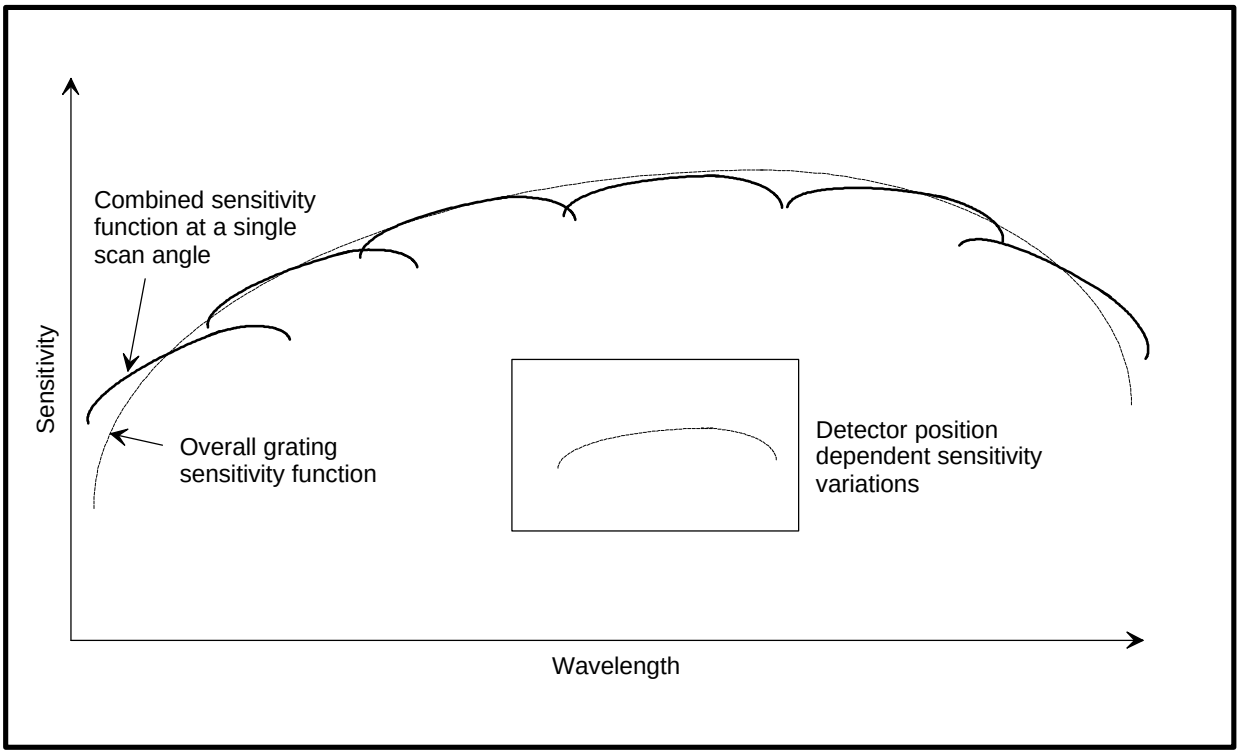


Fig. 5-6 Combined sensitivity for a scanned first order grating mode

single scan angle is a combination of an overall sensitivity and a sensitivity function which varies across the detector. The sensitivity which varies across the detector is normalized to 1.0 at the center of the detector and is expected to gradually change shape with grating scan angle and position along the slit. This function includes low frequency variations in the detector response from one side to the other and any vignetting.

A theoretical echelle efficiency (ripple) function is given by:

$$efficiency = \frac{\cos(a)}{\cos(b)}\left(\frac{\sin(t)}{t}\right)^2$$

where:

$$t = m\pi\cos(a)\frac{\sin((\alpha-\beta)/2-\theta)}{\sin((\alpha+\beta)/2)}$$

$a = \alpha$, $b = \beta$ when $\alpha \geq \beta$
$a = \beta$, $b = \alpha$ when $\alpha < \beta$
m is the spectral order number
θ is the echelle blaze angle
$\alpha = \theta + \delta + \Delta\theta$ (angle of incidence)
$\beta = \theta - \delta + \Delta\theta + \varepsilon$ (angle of defraction)
d is 1/2 the angle between the angle of incidence and angle of defraction (at the detector center) in the plane of dispersion

$\varepsilon = \arctan(y/F)$

$\Delta\theta$ is grating angle with respect to the blaze angle computed from the encoder positions or the central wavelength and order

y is the distance from the center of the detector in the dispersion direction

F is the focal length

It may be necessary to modify the theoretical formulation to match the observed data. One such modification is to replace t with t' where:

$$t' = f_0 + f_1 t$$

f_0 varies the center of the sinc function and f_1 varies the width. f_0 and f_1 may need to be order dependent. Other repeatable deviations from this model can be included in the sensitivity component having the low frequence response variations across the detector.

5.16 Heliocentric wavelength corrections.

A Heliocentric wavelength correction is required to account for the earth's motion around the sun. The correction is given by:

$$\lambda_{hel} = \lambda(1 + v/c)$$

where v is the earth's velocity component towards the object and c is the speed of light. Code from the current GHRS IDL routine CALHRS_HEL can be used to compute v from the observation time and the right ascension and declination of the target.

5.17 Time-Tagged Mode

When data taken in the MAMA time-tagged mode is acquired (Section 3), an image file is also constructed which contains the image accumulated for the full time period. The default pipe-line processing will be to calibrate the reconstructed image in the same fashion as if the image was taken in the on-board ACCUM mode. However, the user must have the option to generate image(s) over user specified time interval(s) and optionally perform some or all of the standard pipeline reduction steps. Because of the volume of data involved, the user should have the control of what outputs of the reductions are to be retained. These may include any or all of the following:

- Reconstructed raw images.
- Calibrated images after any reduction step.
- Extracted and calibrated spectral data
- Total counts or calibrated flux (in any image or wavelength regions) versus time for any specified time interval(s).

In the time tagged mode, on-board Doppler compensation is not performed. This correction must be made by the pipe-line processing during the reconstruction of echelle mode images. Future enhancements may also include the use of spacecraft jitter file during image reconstruction to increase the resolution of the images.

5.18 Parallel Shift and Dwell

A number of complications must be considered when processing CCD Parallel Shift and Dwell (PSD) data sets. As the image is shifted, each output image value becomes the sum of data collected at a number of detector positions (Fig. 5-7) . Charge is shifted down the CCD and remains at various detector pixels for the specified dwell time. The dark rate for a PSD data value must therefor be computed by averaging the dark rates all all dwell positions contributing to the PSD data value. This is also the case for the bias image removal and data quality flagging.

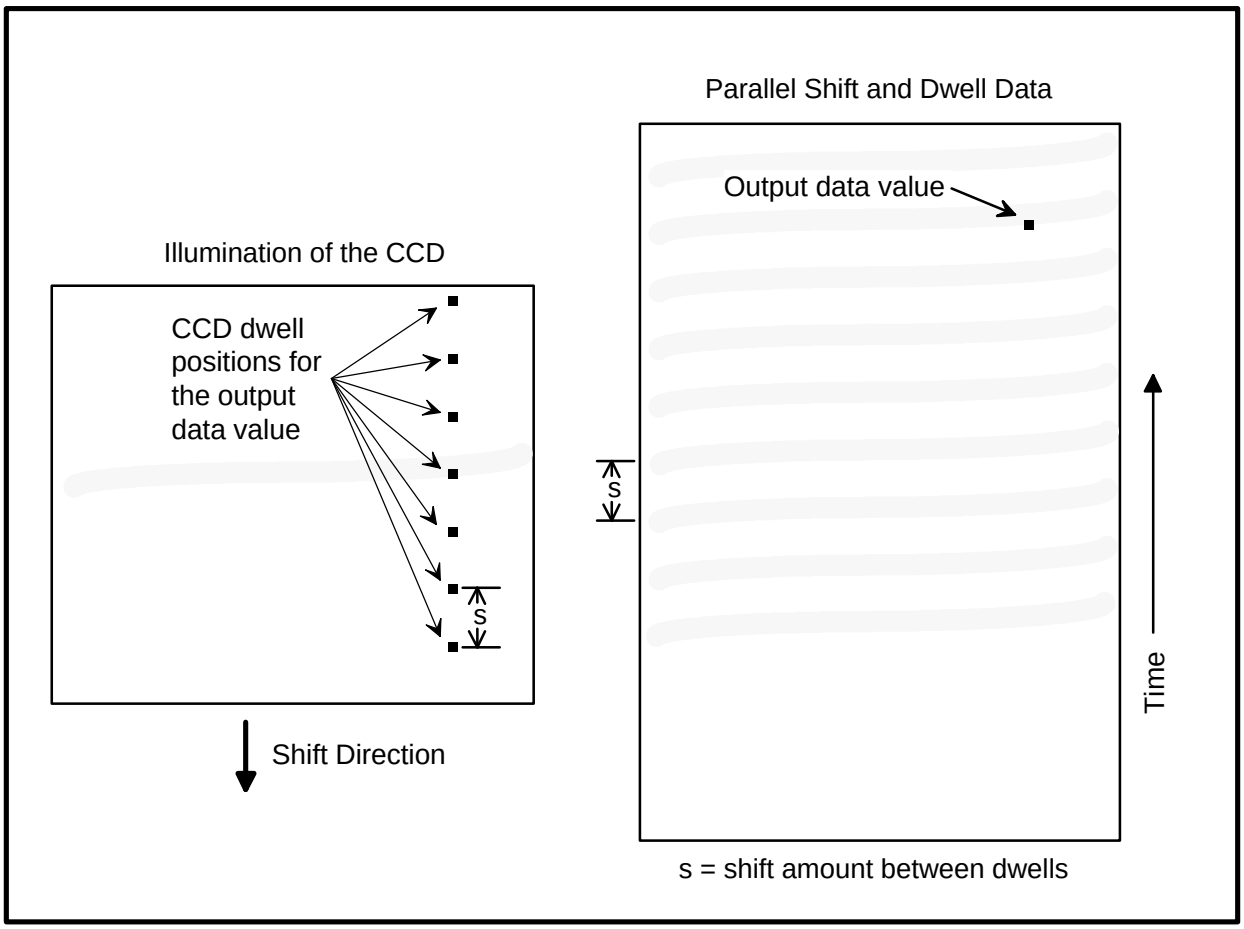


Fig. 5-7 Parallel shift and dwell detector dwell positions for a single output data value

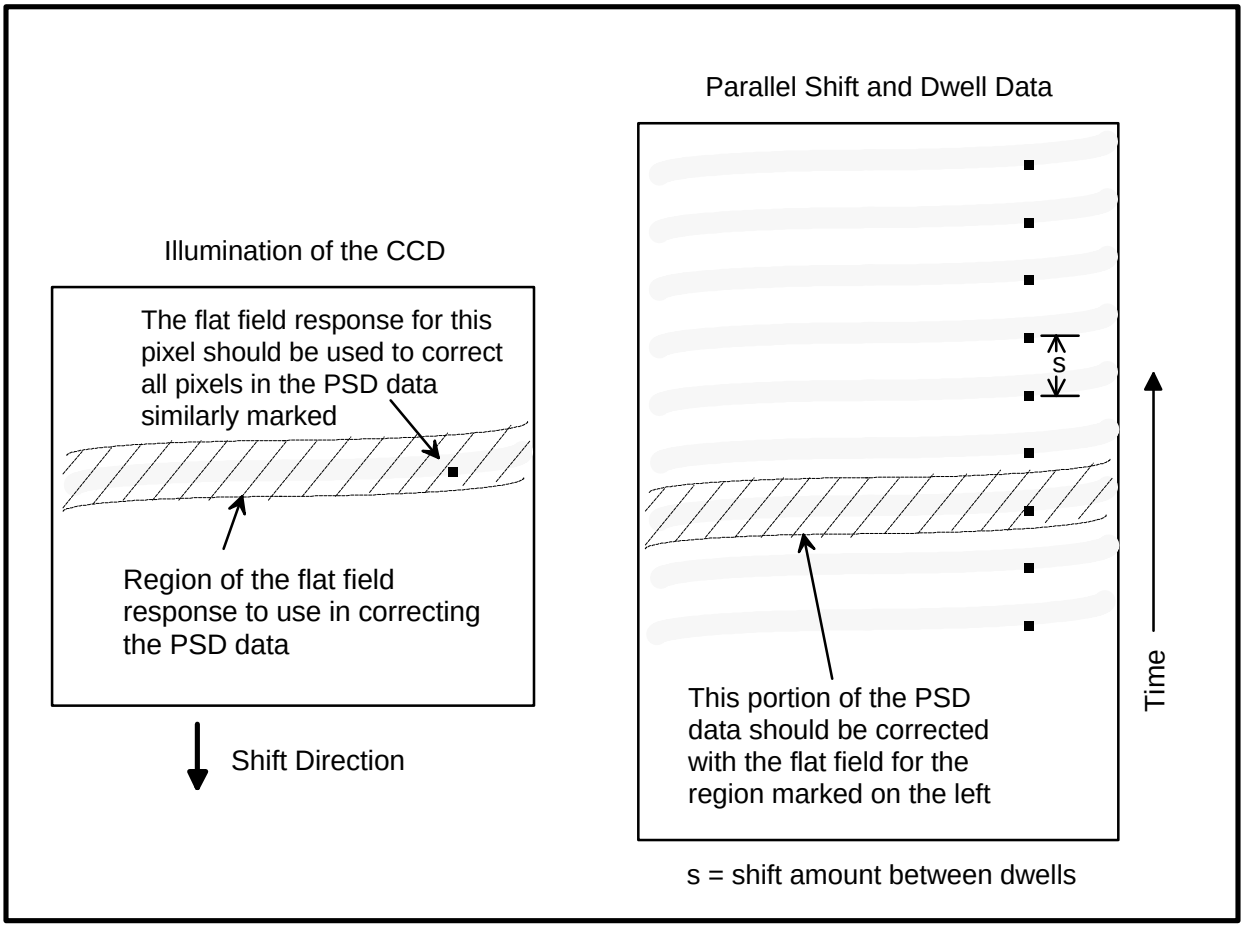


Fig. 5-8 Flat Field Pixel Position applicable to PSD data values

Selection of a flat field response for correcting an PSD data value is more complicated. The flat field response of detector pixels is only important when the pixel is being illuminated by light. Although an output PSD data value may be illuminated by some light at all dwell positions, the majority of the light is at the position of the spectrum. The general procedure would be to observe through a very short (point source) slit. We must therefor locate the portion of the detector illuminated by the spectrum to determine appropriate flat field values (Fig. 5-8). To locate the portion of the detector (Fig 5-9), we must find the location of the first occurrence of the spectrum in the PSD data. The position of the first spectrum in the PSD data corresponds to the position of the spectral illumination on the CCD. This means that a previous reference spectral order tracing for the given grating mode and central wavelength will give a good starting guess. The same method used in spectral location described in section 5.10 can be used. However, several problems can occur:

1. If the position variation resulting from the mode select mechanism non-repeatability is greater the the parallel shift size, the second spectrum in the PSD data may be found resulting in utilization of wrong location in the flat field image.

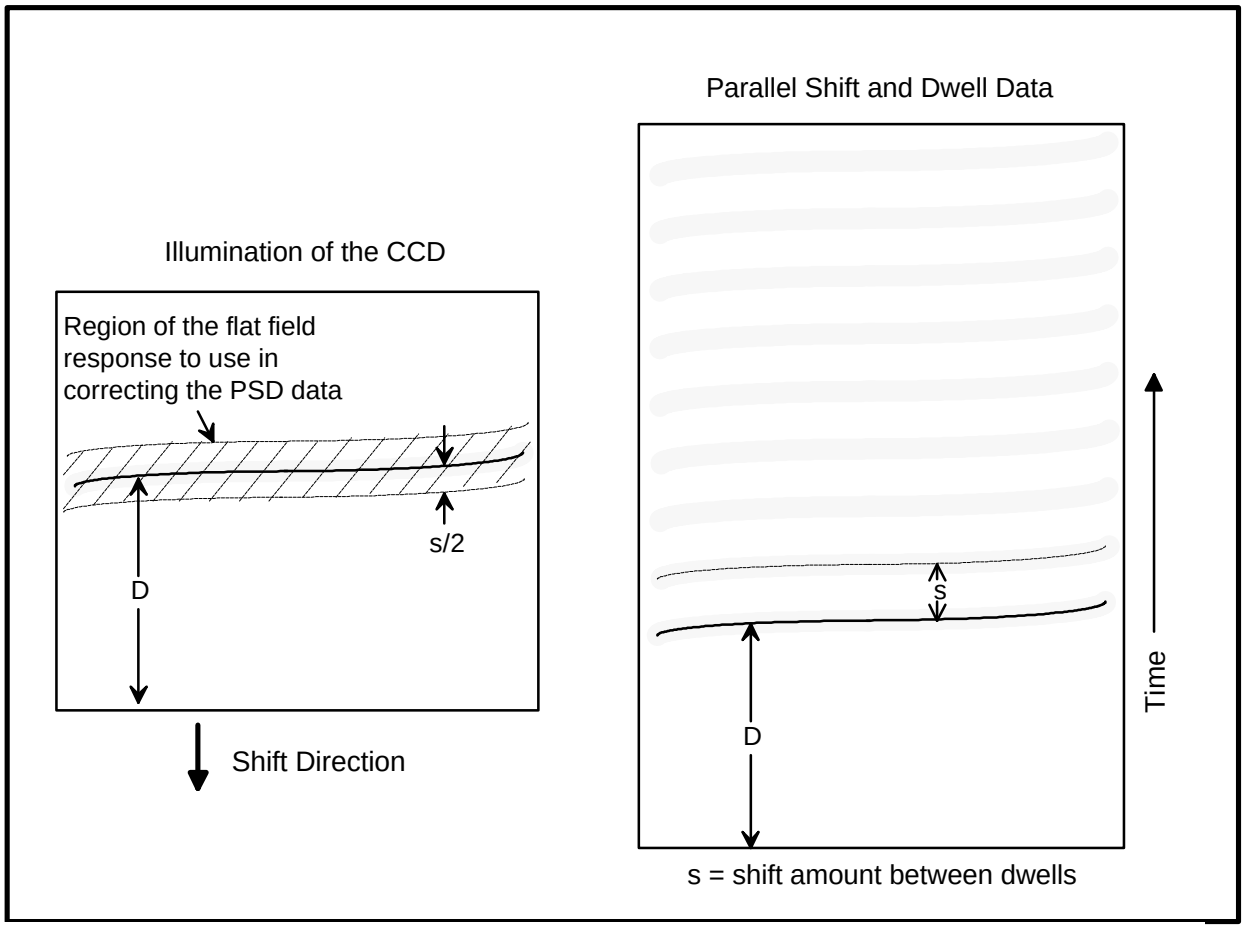


Fig. 5-9 Locating the position a PSD spectrum on the CCD

2. If the spectra have very few counts due to the short dwell time, statistical errors or couple of cosmic ray hits could result in failure of an automated location routine.
3. If a non-uniform extended source is observed in PSD mode using one of the shorter extended source slits, more sophisticated location techniques may be required. This is particularly true if the parallel shift size is comparable to the projected slit size.
4. If very small shifts are used, the spectra will overlap in the cross-dispersion direction (Fig. 5-10)

Manual registration of the spectrum with the order tracing can be used for these special cases. Once the first spectrum is located to within a pixel or two, the location can be refined by shifting and coadding all of the spectra in the PSD data set. With an accurate tracing of the first spectrum in the PSD data set, the portion of the flat field image used to correct the data can be selected by using the region within s/2 pixels on either side of the tracing where s is the parallel shift size.

For very small shifts, (e.g. Fig 5-10) a background value for each data must be a weighted average of background values for pixels contributing to the data point. In this case the cross-dispersion profile must be used to determine the weights. The position of the spectrum on the detector must be computed using the edge where spectral data is first received.

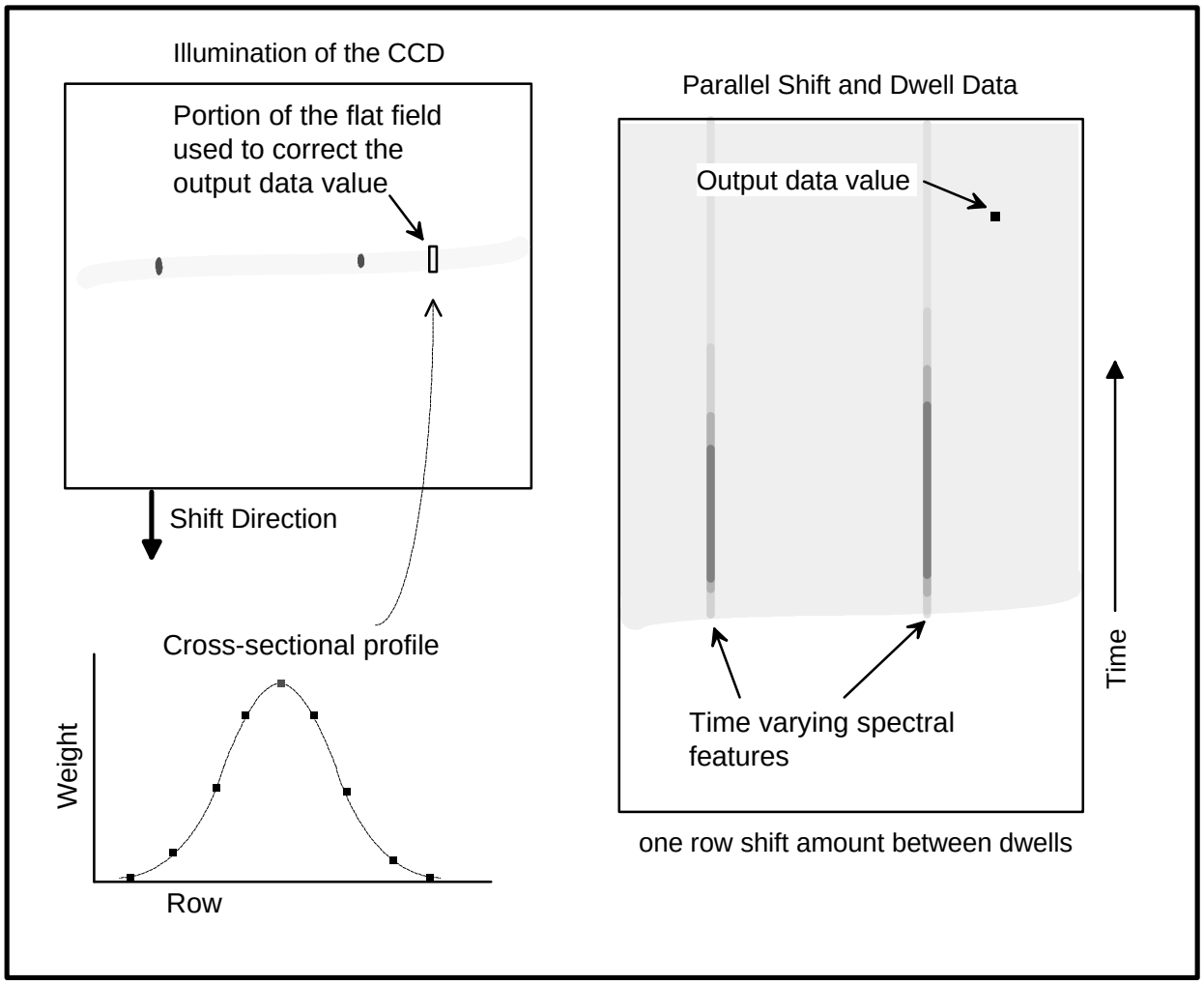


Fig. 5-10 Parallel Shift and Dwell observations with very small shifts. To flat field data, the cross dispersion profile must be used to compute a weighted average of the flat field pixels where the data received spectral illumination.

Alternately, a user may want to take a separate exposure prior to the PSD exposure to allow accurate location of the spectrum on the detector.

We must consider two types of conditions when applying data quality flags to PSD data. For conditions such as hot pixels (elevated dark counts), the quality of the PSD data value must be assigned by tracking the position of the data value at each dwell point. The second type (e.g. flat field blemishes) the PSD data value is only affected in the region of spectral illumination.

Spectral extraction, wavelength assignment, and background processing in the PSD mode can proceed in the same manner as in the standard ACCUM mode. The spectral order tracing for the second through the last spectrum in the PSD data set can is simply the tracing for the first spectrum offset by integer multiples of the parallel shift size. Background spectra can be extracted at the midpoint between successive spectral position provided a large enough shift

size is used. The length of the background extraction slit will depend on the size of the parallel shifts.

5.19 Slit-less Spectroscopy

In the slit-less spectroscopy modes, light enters through a camera aperture and is dispersed by a prism or grating. The position of the spectra on the detector varies with the positions of the objects within aperture in both the dispersion and cross-dispersion directions (as illustrated in figure 5-11).

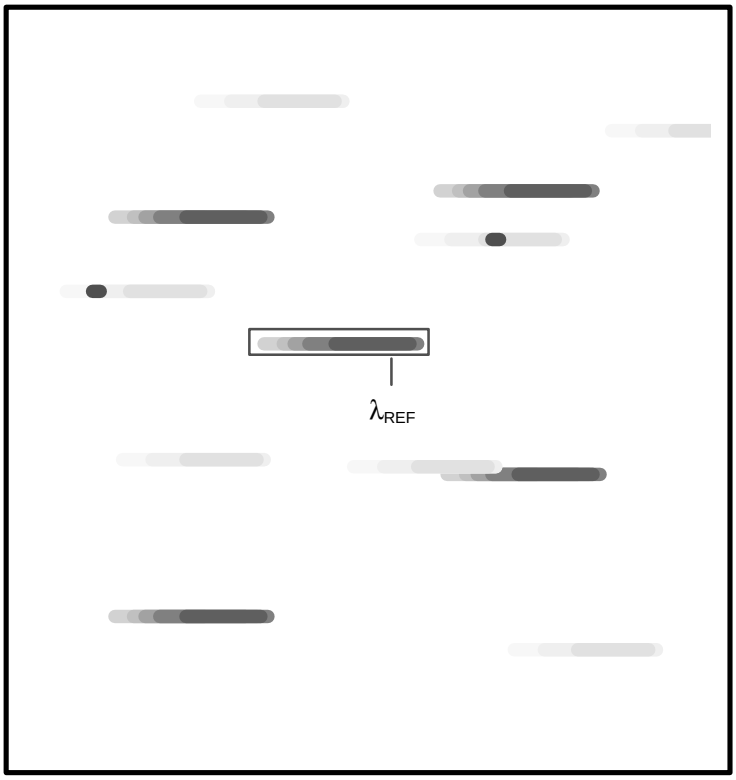


Fig 5-11 Objective Prism Mode

For slit-less spectroscopy, conversion to count rates, dark rate subtraction, and correction for non-linearities can be done exactly in the same manner as for other ACCUM mode observations. However, flat fielding is complicated because the wavelength of light striking a detector pixel depends on the object's location in the field of view. Before flat fielding can be accomplished, objects must be identified and wavelengths assigned to each pixel in the spectra.

There is no single algorithm that can be used to locate the spectra in all types of targets or dispersion modes. It is impractical to expect a standard pipe-line routine to decide which algorithm to use and automatically locate the spectra. The approach we will take, will be to require the user to supply a list of spectral locations to the pipe-line reduction procedure. Four values are required to completely specify the location of each spectra; an *x* (dispersion direction) and *y* location, the wavelength at that location (λ_{REF}), and the slope or shape of the spectrum. It is highly unlikely that the direction of dispersion will be exactly along the image axis and distortions will cause the spectral shape to vary with image position. Pre-calibrated reference values can be used for the slope or shape of the spectra and do not need to be supplied by the user. The cross-dispersion location, *y*, should be supplied at the center of the spectrum to be extracted.

Prior to pipe-line reduction, various methods can be used to identify spectra and measure their location.

Method 1: Interactive identification.

The first and simplest method, is interactive visual detection. The user displays the image and interactively identifies spectra with a cursor. For each spectra identified, the user must point to a position in the spectrum with a known wavelength. This can be a known spectral feature or a sharp cut-off at the end of the spectrum (the "heads" of the prism spectra). Centroiding, cross-correlation, or fitting a model to the cross-dispersion profile at the selected wavelength can be used to increase the accuracy of the central *y* positions.

The interactive method can also be used to edit the results of automated methods.

* * * *

Method 2: Automatic Detection of the "heads" of the spectrum.

In this method, a 1-D median filter is applied to the image in the direction of dispersion to remove spectral lines. An edge detection algorithm (e.g. Sobel filter) is then applied to detect the positions of the sharp gradient at the "heads" of the spectra. This method is only applicable to the prism mode. The success of this method will depend on how sharp the cut-off will be. For the Cs_2Te MAMA, the QE cutoff will kick in before the prism runs out of dispersion.

* * * *

Method 3: Object detection and location in a camera mode image.

In this method, objects are located in a image taken in a camera mode (not necessarily with STIS). Objects can be located in the image interactively or by automated procedures such as DAOPHOT (Dominion Astrophysical Observatory Photometry package). The object locations must then be converted to the plate scale and orientation of the STIS slit-less spectroscopy image. (this requires that the plate scale and orientation of the camera mode image is known). Once the locations are converted to the spectral image's coordinate system, the only other required information is a x and y offset for some particular wavelength. This offset is the same for all spectra and can be determined by identification of a single wavelength feature in one spectrum or by averaging known wavlength positions (e.g. the spectral "heads") in multiple spectra.

An alternate method of measuring the offset between a camera mode image and the spectral mode image is to use an artificial object (created using an internal calibration lamp observed through a small slit). This requires that the camera mode image and two internal calibration lamp images be taken with STIS prior to or after the spectral observation. The following sequence of observations are required (Figure 5-12):

1. Take a camera mode image of the field (with the large camera aperture).

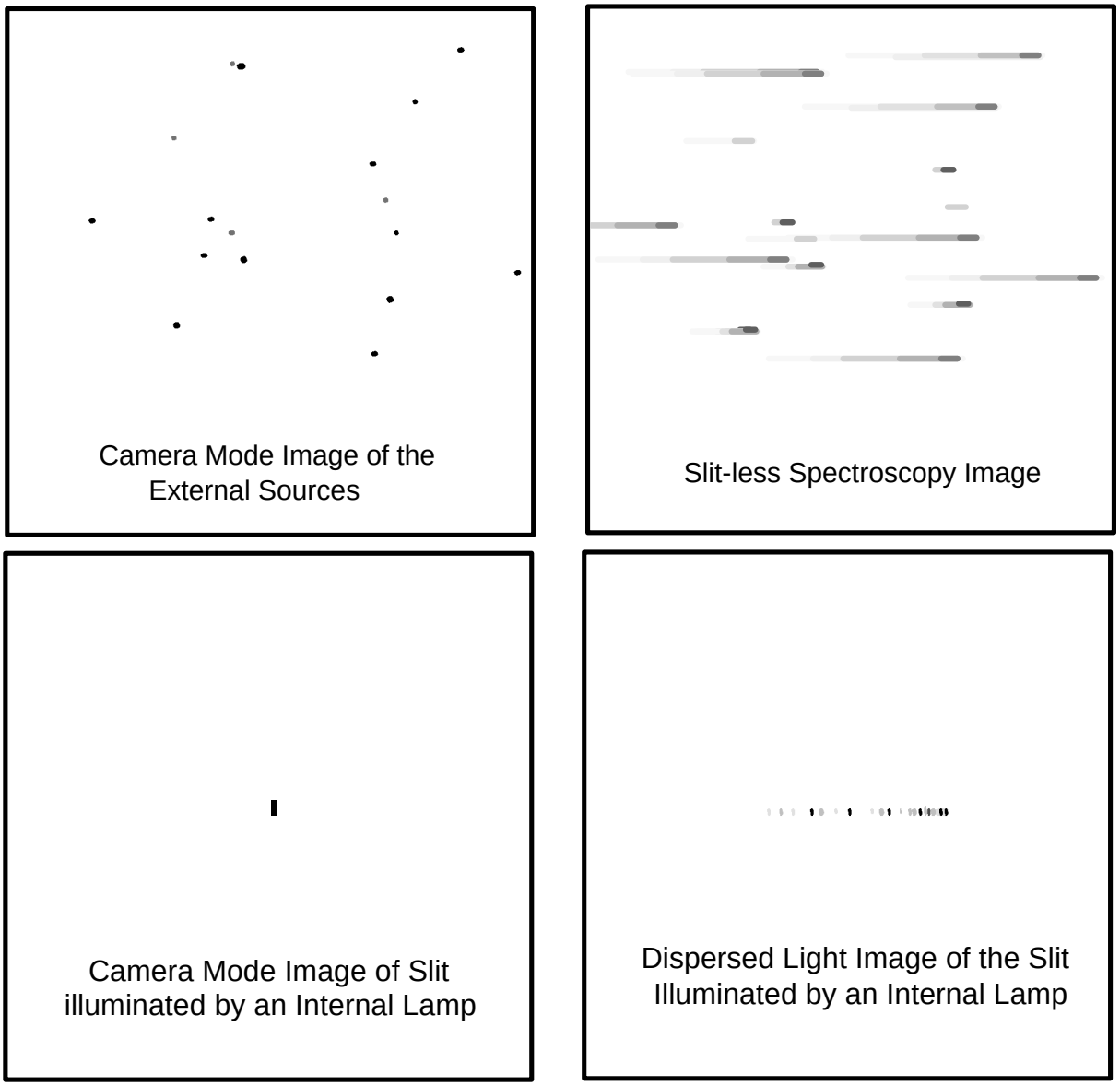


Fig. 5-12 Method for using a camera mode image to locate spectra in the multi-objective prism mode.

2. Move the slit wheel to place a small slit into the field of view. Take an image of the slit illuminated by an internal calibration lamp.
3. Move the mode select mechanism to the grating or prism mode and take an observation of an internal spectral calibration lamp (the small slit is still in place).
4. Move the slit wheel back to the large camera observation and take the desired slit-less spectroscopy observation.

Only small sub-images are required to be down-linked for steps 2 and 3. The images from steps 2 and 3 can be used to compute the offset necessary for relating positions of the objects from step 1 with the positions and wavelengths of the objects' spectra observed in step 4.

* * * *

Now armed with an *x*, *y*, λ_{REF} and a slope or shape for each spectrum, the wavelength dispersion solution can be shifted and the center y position for the entire spectrum between the wavelength limits of the prism can be computed. A wavelength can be assigned to every pixel within the region covered by the spectrum. This wavelength is then used to determine which flat field file (both high frequency non-uniformities and low frequency variations) to use to calibrate each pixel from a set of flats taken at different central wavelengths (these flats will normally be taken using a first order medium resolution grating). The same type of extraction techniques used for point source grating mode observations can then be applied to extract the flat fielded spectra and to convert to absolute flux units. Data points occurring in more than one spectrum should be identified by a flag of 175 in the output data quality vector.

5.20 Cosmic Ray Removal

Various methods for flagging or removing cosmic rays in the CCD images should be available during or prior to the routine reduction process. When a cosmic ray is detected it should be flagged with a data quality value of 195. If removed by interpolation from neighboring pixel values it should be flagged with a value of 140. If the data point is ignored (due to a suspected cosmic ray hit) when coadding multiple exposures, the coadded pixel value should be flagged with a data quality of 40.

Prior to pipe-line reduction cosmic rays can be flagged or removed using an automated procedure or using interactive identification. Preprocessing flagging or removal should be properly flagged in an input data quality table supplied to the pipe-line reduction procedure. This insures that the pixel's condition is properly propagated to the output spectral results.

During routine reduction, the following methods should be available for detecting or removing cosmic rays. The user should have the option of either just flagging the cosmic rays, or flagging and removing them.

Method 1: Combining multiple exposures:

A common practice in observing with the CCD is to divide an exposure into shorter sub-exposures. Comparing the same pixel in each of the sub-exposures can be used to detect a cosmic ray hit. If two exposures are available the difference in the values for a pixel should be less then N times the estimated statistical error of the difference where N is user selectable (typically around 3.0). When the difference is too large, the pixel with the larger value should be flagged or removed. The statistical error of the difference can be estimated as the

statistical error of the pixel with the lower value times the square root of 2 (the statistical error of the pixel with the larger value may be corrupted by a cosmic ray). If the data has not yet been flat fielded, errors due to flat field non-uniformities should be included in the error estimate for the difference. When more then two images are available, the median value (instead of the pixel with the lowest value) can used for estimating the statistical error threshold and locating cosmic rays. Once the cosmic rays have been identified, the remaining good pixels should be averaged. Note: if the images have different exposure times, the comparison should be done in count rates with the statistical error in the difference adjusted for the different exposure times.

When multiple exposures are present, the user should have the option to:

- flag the cosmic rays without averaging the images. Each image is then reduced separately.

or,

- Averaging the images, with cosmic ray pixels ignored in the averagw. The images should be properly weighted if exposure times vary. The propagated statistical error for the combined image should reflect the fact that some points have been rejected.

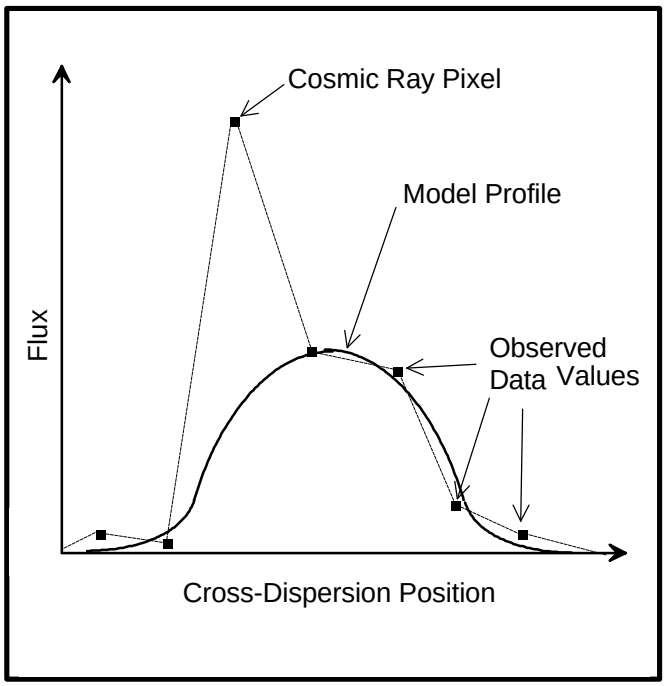


Fig. 5-13 Cosmic Ray Detection in Optimal Extraction

Method 2: Filtering

Filtering procedures can be used to find cosmic rays by comparing image values with neighboring values. The success of this method depends on whether the profiles of cosmic rays differ from actual objects in the image (e.g. stars). The construction of the proper filter depends on the point or line spread function of the observing mode. The filter will vary for the different imaging modes, point source spectral modes, and extended source spectral modes.

Method 3: *Optimal Extraction*

During optimal extraction, a model profile is used to weight the observed flux along the extraction slit. Deviation of individual data points from the fitted profile can be used to detect cosmic rays (Fig. 5-13). For broader profiles, a fit can be performed to all observed data values, followed by rejection of the outliers. For narrow profiles, a cosmic ray can

significantly affect the fit and will not be detected as an outlier. In this case, it may be necessary to fit the data multiple times with each data point removed. The removed data point is then compared to the fit to the other data points to determine if it is a cosmic ray.

Method 4: Parallel shift and dwell data.

Detection of cosmic rays in parallel shift and dwell data sets can be done by examination of the time history of the spectrum. Pixel values can be compared to the equivalent location in preceding and succeeding dwell points. One complication that must be considered is the time variability of target. If the target varies so rapidly that cosmic rays can not be distinguished from time variable spectral features, cosmic ray removal is not possible. However, this will not typically be the case.

The simplest approach is to compare each pixel value to the value in the same pixel value in dwell points immediately prior and immediately after it. If the value is greater than **both** of the values in the neighboring dwells by more than a statistical threshold, it can be considered a cosmic ray hit. Since it must pass the test for both neighboring dwell points, large gradients in the time variability of the target's flux can still occur without incorrect flagging of the time change as a cosmic ray.

5.21 Standard Outputs of the Routine Reduction

The standard outputs of the reduction process should include the following:

1) Calibrated Images: this will be an SDAS image file containing the input reduced image(s) after overscan, bias image subtraction, conversion to count rates, dark count subtraction, and flat fielding. The processing log describing the calibration should be appended to the image header.

2) Data Quality: This file is an SDAS table containing a list of pixel locations and data quality values for all pixels with non-zero data quality or an SDAS image (same size as the calibrated image) containing the data quality value for each pixel.

3) Propagated Statistical Error Image: This SDAS image file contains propagated statistical error image(s) for each image in the calibrated image file.

4) Extracted Spectral table: This is an SDAS table file containing the extracted and reduced spectra. It will have one row for each extracted spectrum. Table elements will be vector(s) or image(s) depending on the type of extraction (point source or extended source). Table columns are listed below. Some columns are only applicable to specific modes. For time resolved modes (parallel shift and dwell and time-tagged modes), two tables will be output. The first table contains the columns that do not change with time (e.g. wavelengths) and will have one row per sub-image. The second table will contain the time varying spectra. One

row for each time interval and sub-image. For extended source modes, the spectra will be two-dimensional arrays.

SCALAR COLUMNS

group number - image group number in the calibrated image file
sub-image number - number of the subimage (from 1 to 8)
spectral order - echelle order number (1 for first order gratings and prism)
start time of the integration
stop time of the integration
exposure time (total time actually spent integrating)

VECTOR/IMAGE COLUMNS

Wavelengths - it will be an image for the long slit modes when the spatial file is not interpolated onto a square wavelength/spatial position grid.
X or Y center of the spectrum - this is the spectral order tracing. Either x-position or Y-position is supplied depending on the orientation of the spectrum on the detector
Xref, Yref, Wref - object location at the reference wavelength for objective mode prism spectra.
Spatial position vector or image for extended source extractions. It will contain the relative spatial positions along the slit. It will be a vector if the extended source data is interpolated onto a square grid.
extracted gross spectrum.
data quality vector for the gross spectrum.
propagated statistical errors for the gross spectrum.
extracted background spectrum.
data quality vector for the background.
propagated statistical errors for the background spectrum.
smoothed background spectrum.
net spectrum (gross-smoothed background)
ripple corrected net
flux (absolute units)
data quality for the flux vector

5.22 User Control of the Reduction Process

A goal of the pipe-line reduction system is to be able to process any STIS observation without user intervention. The reduction process must determine what reductions steps to perform based on the observing mode, automatically select proper calibration reference files, tables

and reduction parameters, and make adjustments to the reference data based on the observed data (e.g. order tracings, dispersion solutions). However, user control of the reduction process should be available to handle anomalous conditions or to customize a reduction to improve the quality of the results. User control of the reduction process should include:

- Selection of what processing steps to perform

- Selection of alternate calibration reference files. Examples include:

- Selection of processing algorithms when alternates are present. Examples include:

  1) Optimal versus un-weighted slit extraction.
  2) Extended source versus point source extraction and processing.
  3) Method of cosmic ray flagging or removal.

- Specification of any adjustable reduction parameters. Examples include:

  1) Selection of the overscan region and smoothing method.
  2) Widths of extraction slits, and position of the background.
  3) Cosmic ray detection thresholds.
  4) Method for interpolation of extended source data onto a square grid.

- The ability to supply optional inputs. Examples include:

  1) Object location table in the objective prism mode
  2) Time interval(s) or resolution for reduced time-tagged data.
  3) A data quality table flagging cosmic rays or other observation specific conditions.

- Selection of what final outputs to generate, including the ability to write intermediate outputs after any processing step.

- Selection of special processing techniques including:

  1) Conversion of MAMA Hi-Res data to equivalent Lo-Res mode before reducing it.
  2) Multiple readout coaddition with cosmic ray removal instead of processing each readout independently.

- The ability to begin the reduction process after the image processing steps and before the spectral reduction steps using the intermediate results from a previous execution of the software.

5.23 Spectral Co-addition and Merging

Once routine pipe-line reduction is complete, spectra from multiple observations, readouts, or spectral orders may need to be merged or co-added to generate a final combined spectrum of flux versus wavelength. In overlap regions, when wavelengths scales do not match, the following options should be available:

- Interpolate spectra to match the wavelength scale of the first spectra having coverage in a particular wavelength region.
- Interpolate or bin (e.g. trapezoidal integration) all spectra to a user defined wavelength scale. This option can also be used with only a single input spectrum to produce a spectrum with a linear wavelength scale or to re-bin a spectrum to lower resolution.
- Retain all data points by sorting/merging the data from all observations. The output spectrum will have more data points per unit wavelength in regions of overlap.

In all cases, the data quality flags should be used to optionally ignore bad data during the co-addition process. Input statistical errors should be used for computing weights during coaddition and for computing a propagated error for the merged spectrum.

Routines are also required to process data taken the FP-SPLIT (fixed pattern) mode. Multiple observations can be obtained of the same target using the High Signal-to-Noise (offset) slits (section 1.2.3). These observations can be processed using algorithms currently used for processing GHRS FP-SPLIT observations to simultaneously compute the targets flux distribution and a fixed pattern noise solution. The best algorithms for processing FP-SPLIT data is TBD.

Routine processing of extended source spectra will generate a two-dimensional data set with a wavelength axis and a spatial position (position along the slit) axis. Post routine processing routines should allow generation of 1-dimensional extractions between user specified spatial positions (either interactively or manually entered). Additionally the user should be able to define some spatial regions as background to be subtracted from the extracted spectra or the from the two-dimensional extended source data set.

Section 6.
Calibration

This section describes the software needed to generate the calibration reference data required for routine reduction (section 5), instrument configuration, and on-board target acquisition. A summary of the tables needed for the routine pipe-line reduction process is given in table 6.1. The third column of the table gives the anticipated criteria that will be used by the reduction process for selecting the correct reference file or table entry. During pre-launch and post-launch calibration it may be discovered that additional environmental parameters may need to be added to the selection criteria. Most calibration reference data are expected to vary with time. Observation time will be a selection criteria for all reference files and tables and is not included in the 3rd column of table 6.1.

Table 6.1
STIS Calibration Reference Files and Tables needed for pipe-line reduction

Item	Description	Selection Criteria
Bad Pixel Tables	Gives locations of dead pixels, blemishes, hot pixels, ect.	detector
CCD parameters	Table giving location of overscan region to use for electronic bias computation, and the calibrated gain values.	CCD amplifier
Bias Image	CCD two-dimensional bias images in units of counts. Not applicable to the MAMA detectors.	amplifier
Detector Non-linearities	Coefficients or lookup table giving the non-linearity functions.	detector
Dark image	Gives the dark count rate for each pixel	detector, CCD amplifier
Flat Fields	Gives the pixel-to-pixel non-uniformities in the detector's response.	detector, dispersion mode, central order and wavelength
Spectrum Location file (order tracings)	Gives the position tracing of the spectrum or spectral order. It gives tracings of constant spatial position for extended source spectra.	dispersion mode, central wavelength and order, spectral order, position within slit.
Wavelength Dispersion coefficients	Coefficients relating detector pixel position to spectral order and wavelength tabulated for a reference aperture.	dispersion mode, central wavelength and order, spectral order, position along slit.

Item	Description	Selection Criteria
Relative Aperture Positions	Gives the aperture positions relative to a reference aperture. These are used to offset spectral location and dispersion coefficients from one aperture to another.	aperture number
Incidence Angle Offset Coefficients	Table of coefficients (function of order and wavelength) which allow correction of the dispersion coefficients for the aperture offsets.	dispersion mode, central wavelength and order, spectral order, position along slit.
Spatial Distortion File	This file will give the detector distortions which cannot be adequately modeled in the order tracings or dispersion coefficients. It will contain An x and y offset for every pixel.	detector
Slit Sizes	This file gives the sizes of each slit and position and sizes of the occulting bars.	Slit
Plate Scales	plate scales for each disperser mode for converting slit sizes to detector coordinates.	dispersion mode
Extraction parameters	Default extraction point source extraction slit widths, background extraction positions, background smoothing parameters	dispersion mode, spectral order
Echelle ripple parameters	Echelle ripple coefficients.	echelle mode, spectral order.
Vignetting, Low frequency detector non-uniformites	Contains low frequency response variations across the detector, vignetting, and corrections for inadequacies in the echelle ripple model.	dispersion mode, centeral wavelength and order, Detector position in cross-dispersion direction
Aperture throughput	Contains the relative aperture throughput function versus wavelength relative to a reference aperture and position within the aperture	Aperture
Absolute sensitivity	Absolute sensitivity function versus wavelength for a reference aperture	Dispersion mode

6.1 CCD Bias Images

The software to construct a CCD bias image used by the pipeline reduction requires at least two bias images taken with the same detector and amplifier(s). Normally for best results, 20 or more bias images should be combined to reduce the effective readout noise level in the final averaged bias image (Superbias). The routine to combine the bias images should:

1. Verify that all bias images are taken with amplifier(s) and are all taken with a zero exposure time.
2. Subtract the electronic bias from each image as determined from the overscan region (Section 5.4).
3. Average the images with cosmic rays removed (as described in section 5.20) to generate the Superbias. Also ignore bad pixels as given in optional input data quality tables for each image. Data with a data quality value above a user selectable epsilon (i.e. data quality value) should be ignored.
4. Locate "hot" pixels in the average bias image with counts than a user specified threshold.
5. Optionally compute the following statistics:

    Mean and standard deviation of the average Superbias image
    Average number of cosmic rays detected in each image
    Number of detected cosmic ray pixels in each image
    Number of bad pixels in each image (i.e. telemetry drop outs)
    Average bias level (after subtraction of the computed overscan level) and
        the standard deviation for each input image (with cosmic
        rays and bad pixels not included)
    Average overscan level for each image

The SuperBias image should be written out into an SDAS image file. The following minimum information should added to the header of the image and other output files.

Detector Identification
Amplifier(s)
CCD offsets
CCD gain factors
Detector temperature
Observation time of the earliest input bias image
Observation time of the latest input bias image
Mean observation time
Number of images averaged
Cosmic ray detection threshold value
Mean level and standard deviation of the SuperBias.
Average number of cosmic rays removed from each image.
A list of file names (rootnames for all observations)

If any hot pixels are detected, an output bad pixel table containing locations of detected hot pixels should also be written. The hot pixel detection threshold should be included in its header.
An optional output table containing the statistics should be written into an SDAS table file with one row per input image and the following columns:

File name
detector temperature
observation time
Average overscan value
Number of bad pixels rejected
Number of detected cosmic ray pixels
Average bias level
standard deviation of the image.

6.2 Detector Dark Rate

To construct a dark image for use by the pipeline calibration, one or more raw dark images are required. For the CCD, at least two should be used to allow cosmic rays to be removed. Since the exposure time of the darks may be long, more than 2 images should normally be used to avoid cases where cosmic rays occur in two images at the same pixel location. Before combining the raw dark images the following preprocessing should be done.

- Subtraction of the overscan electronic bias (section 5.4); CCD data only
- Subtraction of a CCD bias image (section 5.5); CCD data only
- Conversion to count rates (section 5.6)

After preprocessing the routine should:

1. Verify all images are for the same detector. For CCD images also verify that the images are taken with the same amplifier(s).
2. Compute a weighted average (by exposure time) of the dark rate images with cosmic ray rejection (CCD images only) as described in section 5.21. Data with a data quality value above a user selectable epsilon (i.e. data quality value) should be ignored.
3. Locate "hot" pixels in the average dark image with counts than a user specified threshold.
4. Optionally compute the following statistics:
   Mean and standard deviation of the average dark image
   Average number of cosmic rays detected in each image
   Number of detected cosmic ray pixels in each image
   Number of bad pixels in each image (i.e. telemetry drop outs)
   Average dark level for each image

The average dark image should be written out into an SDAS image file. The following minimum information should added to the header of the image and other output files.

Detector Identification
Amplifier(s) (CCD images only)
CCD offsets (CCD images only)
CCD gain factors (CCD images only)
Detector temperature
Observation time of the earliest input dark image
Observation time of the latest input dark image
Mean observation time
Number of images averaged
Total exposure time of all images averaged
Cosmic ray detection threshold value
Mean level and standard deviation of the average dark image
Number of detected cosmic rays.
A list of file names (rootnames) for all observations

If any hot pixels are detected, an output bad pixel table containing locations of detected hot pixels should also be written. The hot pixel detection threshold should be included in its header.
An optional output table containing the statistics should be written into an SDAS table file with one row per input image and the following columns:

File name
Detector temperature
Observation start time
Observation stop time
Exposure time
Average overscan value
Number of bad pixels rejected
Number of detected cosmic ray pixels
Average dark level for the image
Standard deviation of the dark image

6.3 CCD Gain Determination

The STIS CCD has selectable gain factors of 1, 2, 4, or 8. These factors are approximate and the actual values must be calibrated for each CCD amplifier. More important than absolute gain factors at each setting is accurate relative gain settings. Without accurate relative gain settings, a separate set of flux sensitivity files would be needed for each gain setting and amplifier (increasing the number of sensitivity files by a factor of 16). The absolute gain factors are not needed to the same precision as the relative gain factors. They are used only for estimation of the counting statistics.

The computation of the relative gains is a simple procedure and does not require development of any additional software than what is already described in the routine reduction section or is already available in IDL. The relative gains can be computed by observing a constant flux source (the actual incident intensity is not required) in each gain/amplifier mode. Ratios of the integrated flux of the same region of the images (after bias removal) will give the relative gain factors. If internal calibration lamps are used for the analysis, the lamp output may vary slightly with time. The first amplifier/gain setting should be repeated throughout the sequence of observations to monitor and allow correction for changes in the lamp intensity.

Calibration of the absolute gain setting is more difficult and can not be easily done and is not required to be done to the same precision as the relative gain settings. Since the only impact the absolute gain setting has on the reduction process is estimation of statistical errors, examination of the errors can be used for estimating the gain. Consider an exposure of a flat field source. The observation has three significant noise sources: readout noise, counting statistical Poisson noise, and flat field non-uniformities. The noise in the exposure can be estimated by:

$$\sigma^2 = \sigma_p^2 + \sigma_r^2 + \sigma_f^2$$

where σ_p is the Poisson counting statistical error, σ_r is the readout noise, and σ_f is the noise from the flat field non-uniformities. This noise can be estimated by computing the standard deviation of a region of the flat field image with approximately constant illumination. However, this estimate is not valid if any of the errors sources are spatially correlated. Since this may be the case for the flat field non-uniformities, the data should be flat fielded. σ_f in the above equation will then be the residual error in the calibrated flat field. As the exposure time approaches 0, the estimate noise approaches the readout noise. A zero exposure time image can be used to estimate σ_r. An error for the flat field, σ_{FLAT} can be estimated by comparing the two or more flat field images. With estimates of σ_r and σ_{FLAT}, $\sigma_p$can be estimated by:

$$\sigma_p^2 = \hat{\sigma}^2 - \sigma_r^2 - \sigma_f^2$$

where:

$\hat{\sigma}$ is the standard deviation a region of the image with uniform illumination.
$\sigma_f = \hat{\mu}\sigma_{FLAT}$ is the estimated flat fielding error
$\hat{\mu}$ is the average observed counts for the region
σ_{FLAT} is the estimated error in the flat field file
σ_r is the estimated readout noise

The CCD gain can then be estimated by:

$$Gain = \hat{\mu}/\sigma_p^2$$

The gain computation should be repeated for different portions of the image and for images with varying exposure time. A better estimate for $\hat{\mu}$ for shorter exposures can be computed from the longer exposures scaled by exposure time. The gain estimate should be consistent at all count levels. If it shows significant deviations at lower count levels, the readout noise estimate is probably in error and should be adjusted. If the gain shows a trend of continuing to increase or decrease as the counts increase, the flat field error estimate is probably incorrect and should be adjusted.

Once the gain has been computed for amplifier and gain setting, the others can be computed using the relative gain calibration.

6.4 Detector Non-linearities

The MAMA detectors have a non-linear response which depends on both the local count rate and on the global count rate. Non-linearities in the CCD will depend only on the local count rate. The exact approach to calibration of the non-linearities is TBD. The success of any approach depends on the ability to determine the input count rate. Various approaches that have been successfully used for calibration of Digicon non-linearities for the GHRS and FOS include:

1) The relative throughputs of various slits are calibrated with a low intensity source where the non-linearity is minimal for all slits. The true count rate of a high intensity source is computed for a small slit where non-linearities are insignificant. The expected count rate for the larger slits can then be estimated by scaling the count rate for the small slit by the relative throughput factors. The expected count rate can then be compared to the observed count rate. The intensity of the source using internal calibration lamps can be controlled by using gratings with different dispersions. High resolution gratings can be used to obtain a low intensity signal and low resolution grating modes (or prism) can be used to obtain a high intensity signal.

2) The sensitivity of various dispersion modes are cross-calibrated using a low intensity source where non-linearities are minimal. A high intensity source is then observed in a high dispersion mode where non-linearities are minimal and in low resolution modes where the non-linearities are significant. The cross calibration is used to estimate the expected count rates in the low resolution modes from the high resolution observation. These can then compared with the observed count rates in the high resolution observations. For calibration using external astronomical sources, the low intensity source can be a dim star and the high intensity source can be a bright star. For internal calibration, the low intensity source can be an internal lamp through a very small slit or a slit with a neutral density filter and the high intensity source can be a lamp observed through a larger slit.

6.5 Relative Aperture Locations

The relative locations of the apertures are required for the wavelength incidence angle correction and for on-board target acquisition. The relative positions of the apertures can be

located in any of the four camera modes by illuminating the aperture with an internal calibration lamp or an external extended object. To obtain accurate relative positions, the mode select mechanism must not be moved between observations.

Different methods are required for the different types of slits or camera apertures. The slit location software should allow previous results or interactive user input via cursor to assist in approximate location of positions. Input images to the slit-location routine should normally be pre-processed by the pipe-line reduction software to remove detector bias, dark, non-linearities, and flat field non-uniformities.

The following methods should be available for locating the center of the aperture for the small slits in both the vertical and horizontal directions:

1. Flux weighted centroid
2. Thresholded centroid
3. Cross-correlation with a template
4. Location of the edges (50% flux level)

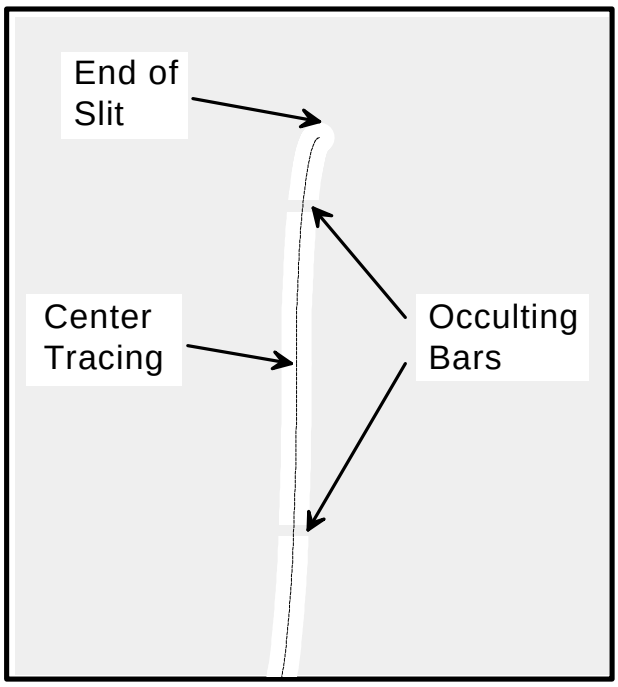


Fig. 6-1 Slit Tracing for the Long Slits

Methods 1 and 2 are identical to algorithms used by the STIS flight software.

For the long slits the software should locate the center of the slit as a function of position along the slit as shown by the dotted line in Fig. 6-1. The center should be computed from the profile across the slit by one of the following user selected methods.

1. Centroid
2. Cross-correlation with a template
3. Center of a fitted Gaussian
4. Location of the edges (50% flux level)

The center tracing should then be optionally smoothed by fitting a low order polynomial or least-squares cubic spline curve. The slope of the slit as a function of position along the slit should optionally be computed. This slope is needed to trail a point source along the slit. The software should also locate the end(s) of the slit if visible (the 50% flux level) and the centers of the occulting bars by one of the four methods above applied to the occulting bar profile along the slit subtracted from the maximum of the profile (i.e. the profile flipped upside down).

Edges of the camera aperture should be located with the same algorithm used by the STIS flight software. In some cases only two of the four edges will be visible. These edges are not needed for routine pipe-line reduction but are very important for slit locations during on-board target acquisition (section 1.4). For the camera aperture with the fingers and wedges the routine should trace the two fingers and two wedges using the reversed profile across the finger or wedge with the same algorithms used to trace the center of the long slits.

A utility will be needed to convert the measured slit and aperture positions to different coordinate systems including:

- Detector coordinates for other camera modes
- Astronomical coordinates (e.g. V2/V3 coordinates)
- Physical coordinates of the apertures (e.g. millimeters)
- Detector coordinates for the spatial direction in a grating or prism mode.

The transformations should include plate scale changes, translation, and rotation.

A second utility is required to generate relative slit positions. For on-board target acquisitions the slit locations are needed relative to the camera apertures. For the pipe-line processing, the slit locations are needed relative to the location of reference slit with tabulated dispersion coefficients. The utility should allow a single slit to be divided into "pseudo-slits" with different slit numbers. For example, an occulting bar on one of the long slits will have a different slit number then the center of the slit.

6.6 Spectral Tracing

The location of the center of the spectral orders versus pixel number in the direction of dispersion is required for centering the spectral extraction slits. Tracings of constant spatial position as a function of position along a slit is also required for extended source extraction. Section 5.10 described the requirements for generating the tracing for point sources. For extended sources the spatial distortion is expected to vary along a long slit. Simple translation of a tracing at one position in the slit to another will not be sufficient. To generate the required tracings it will be necessary to observe point sources at various positions along the slit. One method is to use a single star observed multiple times at the different slit positions. The software described in section 5.10 can be used to reduce the data. The resulting tracings can then be combined to give a two-dimension spatial map for extended source extraction. Tracings for arbitrary slit positions can be computed by interpolating between the calibrated positions.

An alternate method is to observe multiple stars simultaneously (i.e. observe a star cluster). One of the wider long slits could be used to ensure there are plenty of stars in the slit. This technique is illustrated in Fig. 6.2. Automatic location of the stars in the cross-sectional profile should be performed with interactive editing of the results. A technique to produce tracings where stars are blended is to extract a the portion of the cross-sectional profile at one wavelength and use it as a cross-correlation template for other wavelengths. This technique

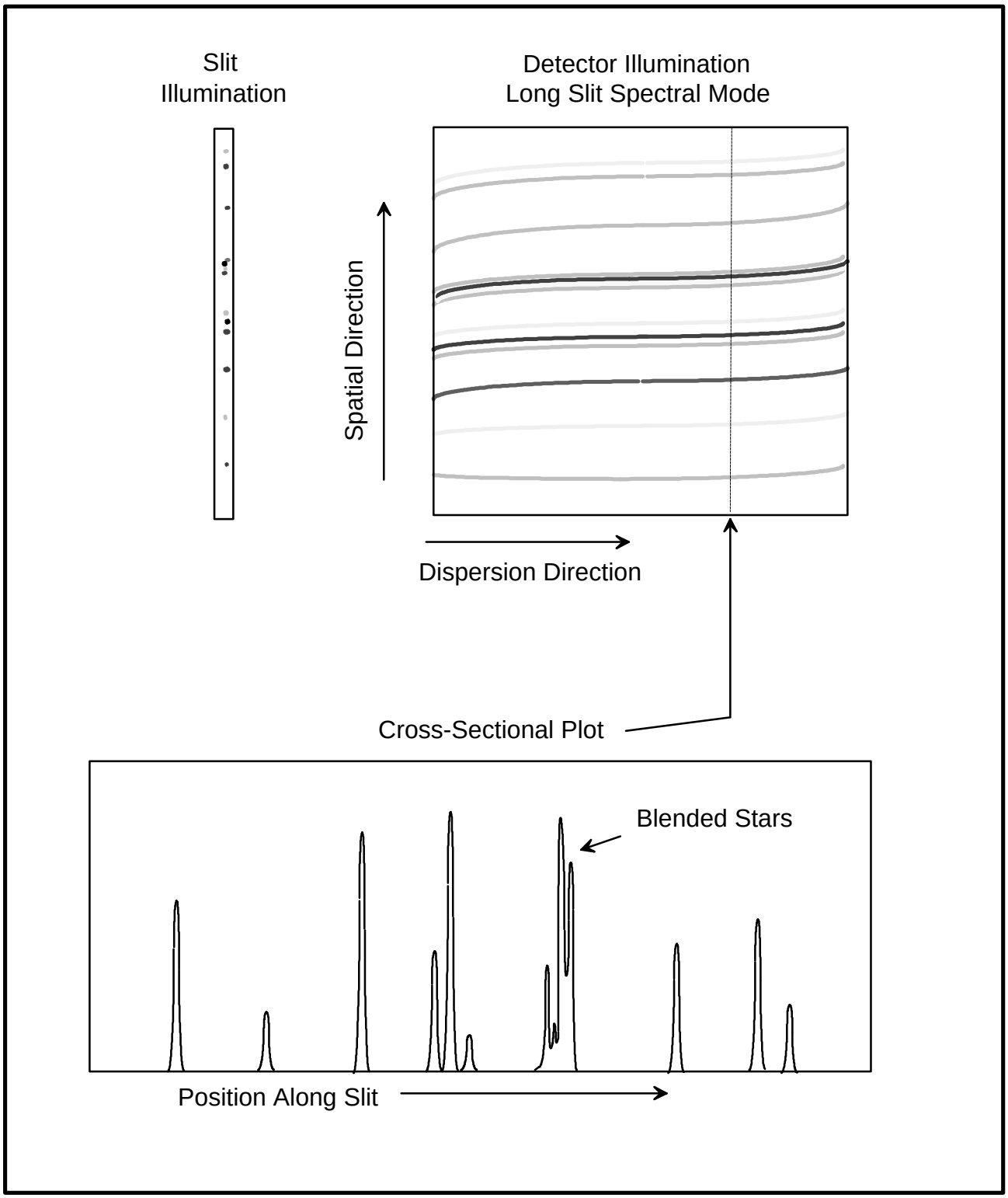


Fig. 6-2 Spectral Tracing in the long slit mode using an observation of a star cluster

may also give good results for non-stellar extended sources with a lot of structure.

Crude pre-launch tracings can be produced by tracing the locations of the occulting bars, the ends of the slits, or the centers of small slits illuminated by a calibration lamp.

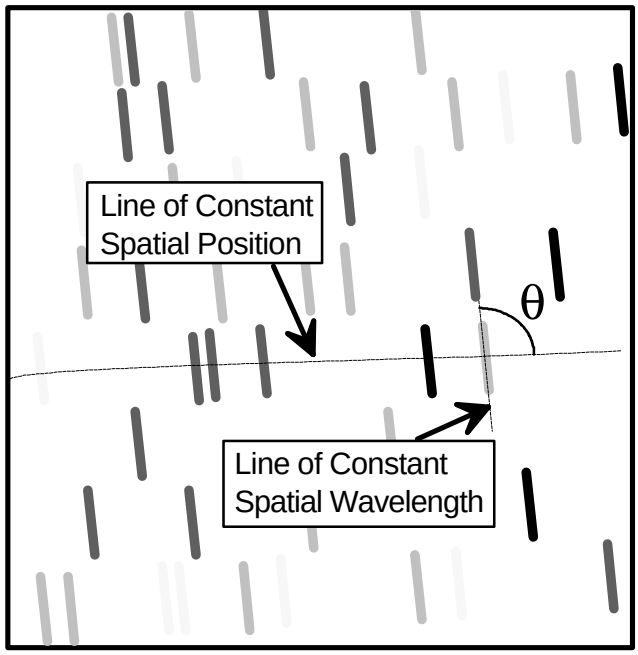


Fig. 6.3 Spatial Positions in an echelle extended source extraction.

For the short extended source echelle slits, a simplification can be made in the extraction process. Over the small spatial distances involved, the shape of the spectrum (tracing) will not significantly change from one end of the slit to the other. An order tracing made with a point source slit can be used for the entire length of the slit (with appropriate offsets in the cross dispersion direction). The only parameter needed is the slope of the line of constant wavelength. This slope can be measured by illuminating the echelle extended source slit with an internal calibration lamp (Fig. 6.3). The angle of constant wavelength can then be measured from the slope of the spectral features. This slope may vary slightly with wavelength and spectral order.

6.7 Wavelength Calibration

Wavelengths are calibrated using an internal spectral calibration lamp (Pt-Ne-Cr) observation (WAVECAL) with spectral lines of known laboratory wavelengths. The positions of lines in a spectral line library are found in the WAVECAL image and dispersion coefficients are determined by a least squares fit to the found locations. These coefficients relate detector position to spectral order and wavelength. The planned dispersion relations are:

$$x = A_0 + A_1 m\lambda + A_2 m^2\lambda^2 + A_3\lambda + \mathit{TBD\ Terms} \qquad \text{(Grating modes)}$$

$$\lambda = A_1 + \frac{A_2}{(x-A_0)} + \frac{A_3}{(x-A_0)^2} + \frac{A_4}{(x-A_0)^3} + \frac{A_5}{(x-A_0)^4} \qquad \text{(Prism)}$$

where:

λ is the wavelength
m is the spectral order
A_0, A_1, ..., A_5 are the dispersion coefficients determined by least squares and vary with disperser mode, and the mode select mechanism encoder positions (i.e. commanded central wavelength and order).

The following steps are used to compute the dispersion relation from a spectral calibration lamp observation:

1) Process the observation using the standard routine reduction procedure described in section 5. The minimal steps include overscan subtraction, spectral extraction and wavelength assignment using a previous dispersion solution for the mode. Optional steps which can improve may results include: bias image subtraction, dark image subtraction, correction for detector non-linearities, flat fielding and background subtraction.

2) Locate the positions of spectral lines with known laboratory wavelengths (the lines' approximate positions can be found using the wavelengths generated in step 1. If a previous dispersion solution for the mode is not available, a wavelength scale can not be produced in step 1 and a spectral lines will need to be identified interactively (typically only a few are needed to obtain a crude dispersion relation which can be used to repeat the process to obtain an accurate solution). The "exact" line positions can be determined by searching a region (with a user specified width) around the approximate position determined from the wavelength scale from step 1. The center of the line (pixel position) can then be found by fitting a Gaussian or cross correlation of the line with a template. If cross correlation is used, the position of the line to sub-pixel accuracy, can be obtained by fitting a quadratic to the correlation value at the position of maximum correlation and its two neighboring correlation values. This gives a table of pixel positions of the spectral lines versus spectral order and laboratory wavelength. Lines should be excluded from further analysis (in the subsequent steps) if one of the following conditions occur:

- The peak counts in the line is less than a user specified threshold.
- The found position of the line is greater than a user selectable distance from the approximate position.
- The position of maximum correlation is at the edge of the search region.
- The user interactively flags the line for removal.

3) The positions of the lines found in step two are adjusted by the offsets found in a detector distortion reference file. If the residuals of the fit in the next step are to be used to help calibrate the detector distortions (section 6.10), this step should be skipped.

4) The dispersion coefficients are determined by a least squares fit to values in the table of detector position versus spectral order and wavelength. The fit should be iterated with rejection of lines deviating by more than a user selectable number of sigma from the average deviation. In the echelle modes, a fit to the entire format may not sufficiently model the optical distortions. If this is the case, an option should be available to fit portions of the echelle format separately by dividing the data in regions of a user specified number of spectral orders. Dispersion coefficients are then fit for each set of spectral orders.

For extended source spectra, dispersion solutions will vary with position along the slit. The long slit data should be summed in the cross-dispersion direction into in bins of a user selectable number of cross-dispersion pixels. For example, a 1024 by 1024 image could be summed into bins of 16 rows giving spectra at 64 positions along the slit each separated by 16 rows. A separate set of dispersion coefficients is computed for each row. For extended source wavelength calibration another step should be available between steps 3 and 4. In this step the pixel positions of each spectral line is fit by a polynomial of position along the slit with iterative rejection of deviant points. The positions computed by evaluating the polynomials can then be used for step 4. This gives another method of removal of deviant points, allows accurate calibration of slit positions blocked by an occulting bar, and allows some extrapolation of the dispersion relation beyond the two ends of the slit.

The dispersion coefficients should be tabulated along with the following information:

- Observation rootname
- Observation time
- Detector
- Dispersion mode
- Central commanded order
- Central commanded wavelength
- Range of spectral orders included
- Mode Select Mechanism Encoder Positions
- Cross-dispersion pixel position (position within the slit)
- Aperture number
- Aperture name
- Aperture wheel encoder position
- Statistics of the dispersion fit (number of lines in the region, number of lines found, number of lines rejected during the fitting process)

The table header should give the processing log including values of all adjustable parameters used by the calibration process.

An alternate method of computing the dispersion relation is to use cross correlation of the observed spectrum with a template spectrum that has a known dispersion solution. The template spectrum will typically be an calibrated spectrum taken at the same Mode Select Mechanism position. It may or may not be taken in the same slit. This method is particularly

useful for the wider slits where it is more difficult to accurately determine the position of the spectral lines because of line blending.

The process to compute the dispersion relation for the new observation by cross correlation is then given by:

1) Process the observation with the routine reduction routine (section 5) using the dispersion coefficients of the template spectrum.

2) Optionally smooth the template spectrum to match the resolution of the observed using a mean filter or user specified line spread function.

3) Divide the spectrum into a user specified number of wavelength bins. Cross correlate each wavelength bin with the same wavelength bin in the template spectrum and tabulate the cross-correlation offsets versus central wavelength of the bins. Ignore bins with fewer than a user specified number of counts. Also, optionally allow the user to interactively delete bins from the analysis.

4) Compute an average offset in pixels (either the median or a mean offset) and adjust the A_0 dispersion coefficient by this amount. For the grating modes, compute an average offset (median or mean) and adjust the A_0 coefficient or fit a first or second order polynomial to the offsets as a function of $m\lambda$. The coefficients of the polynomial can then be used to adjust the A_0, A_1, and A_2 dispersion coefficients. For the prism only a constant offset will be supported.

6.8 Wavelength Offsets between Slits

To avoid having to calibrate and store dispersion coefficients for every dispersion mode and slit, the wavelength offsets can be modeled as a function of the spatial offsets between the slits (as measured in section 6.5). The offsets will be modeled by using the following adjustments to the wavelength dispersion coefficients.

$$\acute{A}_0 = A_0 + a_1\delta + a_2\delta^2$$
$$\acute{A}_1 = A_1 + b_1\delta$$

where δ is offset between the slits in arcsec. The coefficients a_1, a_2, and b_1 are computed by least squares fit to observed offsets. The offsets to A_0 and A_1 can be computed by cross-correlation of spectra taken in the different slits as described in section 5.12. IMPORTANT NOTE: Data for calibrating the entrance aperture offsets should be taken with motion of the slit wheel only between observations. The Mode Select Mechanism must not be moved. Once the offset has been calibrated for a few slits, it can be used for computing offsets to the remaining slits using the δ measured in a camera mode. There is no need to take wavelength calibration data through every slit.

6.9 Flux Calibration

The flux calibration relates observed count rates per pixel to absolute incidence flux units and includes the efficiency of the detectors, the efficiency of the optical components, and the throughput of the slit or filter. It would be unrealistic to calibrate every combination of dispersion mode, central wavelength and order, and slit position separately. We therefore break the flux calibration into components which can be calibrated separately and shared between different observing configurations. The separation allows much of the calibration to be done using internal calibration lamps as opposed to external astronomical sources. The components are:

1. Pixel to pixel non-uniformities (flat field)
2. Low frequency variations in sensitivity across the detector.
3. Echelle ripple function
4. Aperture throughput function
5. Absolute sensitivity function

The pixel to pixel non-uniformities or detector flat field function gives the high frequency variations of the detector pixels. A separate value which is dependent only on pixel position and wavelength must be determined for each detector pixel. It is expected that this function will be a slowly varying function of wavelength. It can be calibrated using internal continuum lamps and does not require any prior knowledge of the spectral distribution or the lamp except for locations of sharp spectral features.

The low frequency variations in the sensitivity across the detector is a function of dispersion mode, detector position and central order and wavelength. It will also include any vignetting. This calibration requires knowledge of the relative shape of the spectral flux versus wavelength but does not require an absolute photometrically calibrated source.

The echelle ripple or blaze function is required only for the echelle modes. It is a function that depends on the angles of incidence and reflection of the light on the echelle grating. It does not depend on the entrance slit or the position within the slit. It can be calibrated using internal continuum lamps.

The aperture throughput function gives the relative throughput of each slit relative to a reference slit. The throughput is a function of wavelength only. The throughput calibrated in one dispersion mode can be applied to other modes. This function is used to make all of the other flux calibration components independent of slit. Separate throughput functions are required for extended and point sources. The throughput function for extended sources can be computed using internal lamps. Point source throughput calibrations require observations of external point source targets.

6.9.1 Flat Field Calibration

In the spectral modes, the pixel to pixel non-uniformities will be normally calibrated with internal continuum lamp observations in the long slit mode. Echelle modes will be calibrated using the cross-dispersion calibration modes (modes 1.7 and 2.7) where the light is dispersed only in the cross-dispersion direction. In the camera modes, the flat field calibrations will be done using a camera aperture or filter illuminated by an internal calibration lamp.

In addition to the input flat field observation, the calibration software should accept the following optional inputs:

- A table of wavelength regions containing spectral features which should not be used in the calibration
- A table containing the input lamp spectrum (flux versus wavelength.)

The input lamp flux versus wavelength does not need to be in absolute flux units. It will be used to remove any spectral features that may be present and can be created by coadding data from different slit positions, binning data from a higher resolution, or combining data taken in an FP-SPLIT mode where the multiple observations are taken with small wavelengths shifts between them.

The flat field observations are first preprocessed using the standard reduction routine (section 5). The following steps should be performed: overscan and bias image subtraction, conversion to count rates, dark rate subtraction, correction for detector non-linearities and wavelength assignment. For CCD observations, cosmic rays should be removed by combining multiple exposures. If multiple exposures are not available, suspected cosmic rays should be flagged. No flat field response will be computed for the cosmic ray pixels.

After preprocessing, spectral features can be removed by dividing by the optional input lamp flux spectrum. Any wavelength regions in the other optional input table should be flagged. No flat field response will be computed for these regions.

The next step is to remove low frequency variations in the flat field. In addition to low frequency variations in the detector response, these variations may include variations in the input spectrum or lamp illumination. The low frequency variations can be computed by a median filter of the image, or fitting polynomials or spline curves to the image. The image is then divided by the low frequency image to give the high frequency pixel-to-pixel non-uniformities.

The outputs of the flat field routine should include:

1. An image file containing the flat field non-uniformities.
2. A data quality table indicating positions where no flat field could be computed.
3. The propagated statistical errors

A utility should be available for averaging flat fields using the data quality table and propagated statistical errors to properly weight the data.

An alternate method for computing flats is to use FP-SPLIT observations to separate the flux distribution from the flat field response. In this method, multiple observations are taken with small wavelength shifts. Wavelength shifts can be obtained by repositioning the mode select mechanism or small movements of the slit wheel. This data results in an over-determined system of equations which can be solved with Fourier or iterative techniques to separate the flat field non-uniformities from the input spectrum.

In the spectral modes, the flat field files do not depend on the slit. They depend only on the wavelength of the light illuminating the pixel. Flat fields from one grating mode can be used to calibrate data from another, provided that the wavelengths are approximately the same. In fact, it should be possible to take multiple observations taken from a medium resolution first order scanned grating mode and construct flat field files for the echelle modes or to use them to calibrate the the objective prism mode where a single flat field file can not be used.

6.9.2 Low Frequency Response Variations Across the Detector

In addition to pixel to pixel variations in the detector response, there will be some low frequency variations in the detector response as you move from one side of the detector to the other. To calibrate this variation using internal lamps in the camera modes, the illumination function of the lamp as a function of position is required. After launch, this function can be calibrated by observing the same external target at various locations within the aperture.

The low frequency detector variations can be calibrated in the spectral modes by observing a star at various locations along a long slit. The calibration can be done using internal lamps provided that the shape of the spectrum (flux versus wavelength), the aperture illumination function, and the aperture throughput versus position along the long slits are known. Both the aperture illumination function and aperture throughput function determined in one dispersion mode can be applied to the other modes.

The routine to compute the low frequency response variations should have the following inputs:

- The STIS observation.
- The aperture illumination function (for non-point source observations)
- A table of flux versus wavelength for the target. The overall shape of the spectrum is important and absolute flux levels are not required. An initial flux distribution can be obtained using a scanned grating and measuring the flux at approximately the same detector position using observations with different central wavelengths.

The raw STIS data should be preprocessed with the all reduction steps (as appropriate for the observing mode) except for the correction of low frequency detector variations and vignetting. Conversion to absolute flux units is optional and is only required if the input flux table is in absolute flux units.

The following steps are then used to compute the calibration function:

1. Divide the processed observation by the spectral flux distribution resampled to the same wavelength scale. For the long slit modes, this should be repeated for each row of the 2-D extended source extraction.
2. For internal calibration lamp observations divide the spectra by the appropriate aperture illumination value which varies with slit position.
3. Optionally bin the data from the long slit observation to a coarser scale in the cross-dispersion direction.
4. Fit a smooth curve (response versus pixel position) through each spectra (a polynomial or spline curve).
5. Normalize the results to 1.0 at a user selectable detector position (normally at the center of the detector). In the echelle modes optionally normalize each spectral order to 1.0 at a center of the detector in the dispersion direction.
6. Evaluate the curves on a user specified pixel grid and tabulate the curves versus spectral order or position along the slit.

6.9.3 Echelle Ripple Function

A theoretical echelle efficiency (ripple) function is given by:

$$efficiency = \frac{\cos(a)}{\cos(b)}\left(\frac{\sin(t)}{t}\right)^2$$

where:

$$t = m\pi\cos(a)\frac{\sin((\alpha+\beta)/2-\theta)}{\sin((\alpha+\beta)/2)}$$

$a = \alpha$, $b = \beta$ when $\alpha \geq \beta$
$a = \beta$, $b = \alpha$ when $\alpha < \beta$
m is the spectral order number
θ is the echelle blaze angle
$\alpha = \theta + \delta + \Delta\theta$ (angle of incidence)
$\beta = \theta - \delta + \Delta\theta + \varepsilon$ (angle of reflection)
d is 1/2 the angle between the angle of incidence and angle of reflection (at the detector center) in the plane of dispersion
$\varepsilon = \arctan(y/F)$
$\Delta\theta$ is grating angle with respect to the blaze angle computed from the encoder positions or the central wavelength and order
y is the distance from the center of the detector in the dispersion direction
F is the focal length

It may be necessary to modify the theoretical formulation to match the observed data. One such modification is to replace t with t' where:

$$t' = f_0 + f_1 t$$

f_0 varies the center of the sinc function and f_1 varies the width. f_0 and f_1 may need to be order dependent. A non-linear least squares fit is required to fit f_0 and f_1 by the following method. The echelle blaze angle is not included in the fit. However the user should have the option to manually adjust the blaze angle.

1) Preprocess the echelle data using the routine reduction process with the echelle ripple correction step turned off.

2) Divide each spectral order by a table of source flux versus wavelength rebinned to the same wavelength scale. If the source flux is not known, it will be estimated and removed in step 4 using the blaze maximum flux values to estimate its shape.

3) Divide all data by cos(a)/cos(b) computed for each data point.

4) Normalize all spectral orders to have a peak at unity by dividing by a curve created by fitting a smooth function through the data values at the peak of the echelle blaze function (Fig. 6-4). This results in all spectral orders having approximately unity height.

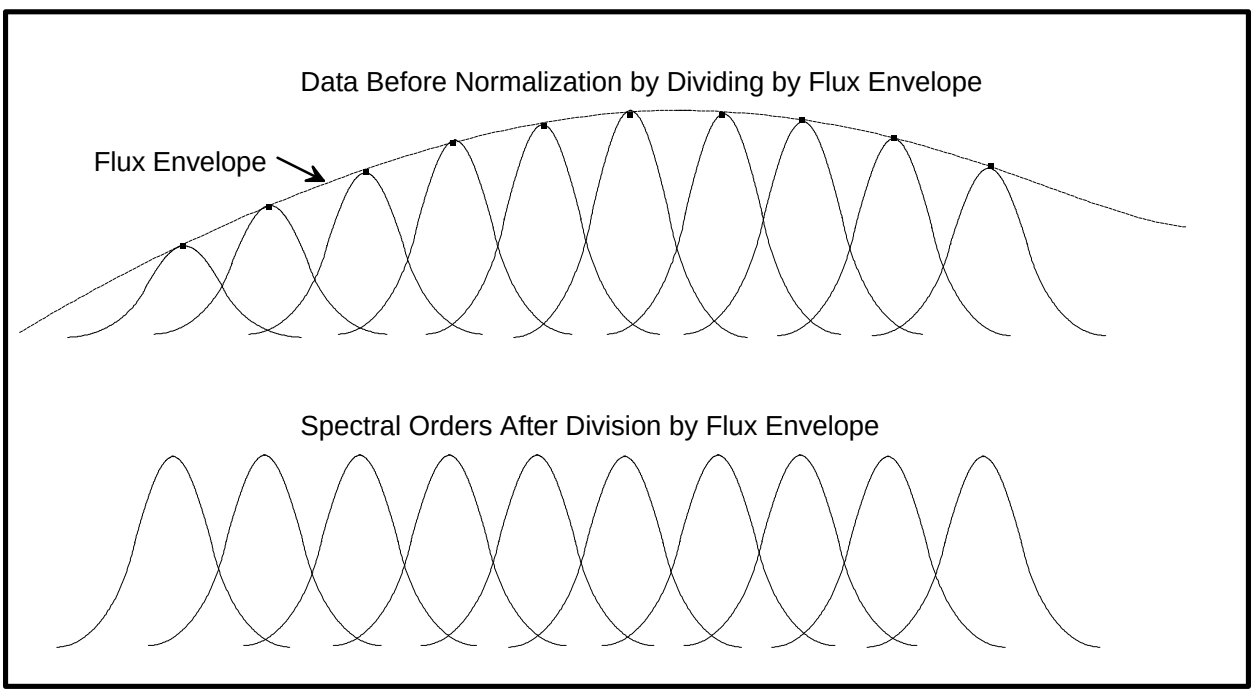


Fig. 6-4 Normalization of spectral orders by dividing by a curve fit through the data at blaze maximum

5) Perform a least squares fit to compute the values of f_0 and f_1. The user should have the option to fit all orders simultaneously, separately, or in groups of N orders, where N is user selectable.

The resulting f_0 and f_1 values should be tabulated as a function of echelle mode and spectral order. The values of the other echelle parameters (e.g. echelle blaze angle) should be included in the table header. The computed values of f_0 and f_1 will vary if any of the other echelle parameters are varied.

A second output table should contain the raw data and least squares fits for each spectral order. This table will allow the results or residuals of the fits to be plotted.

A utility should be available to optionally allow the user to fit polynomials to f_0 and f_1 as a function of order number to make the coefficients smooth functions of order number. This routine should allow the user to combine the results of multiple images taken with the same or different central order numbers.

6.9.4 Aperture Throughput Function

To avoid having to flux calibrate every slit/disperser mode combination the sensitivity function is divided into a aperture throughput function and an absolute sensitivity function. The calibration of the aperture throughput function in a low resolution mode can be applied to the higher resolution mode. The aperture throughput function gives the throughput of each slit or position along a slit as a function of wavelength. Separate functions are needed for point source and extended source targets. The throughput for point source targets depend on the point spread function at the slit wheel and can only be estimated using PSF models prior to launch. For extended sources, the relative throughput can be calibrated using internal calibration lamps which illuminates the entire aperture. The relative throughput of a slit (or position within a slit) to a reference slit can be computed by reducing both observations with the routine pipeline processing routine (without executing the aperture throughput step). A ratio or the two spectra (which can be fit by a low order polynomial) can be used to model the relative throughput. If internal lamps are used, the ratio must be adjusted for variations in the illumination function of the lamp which varies with aperture position.

6.9.5 Absolute Sensitivity Function

The absolute sensitivity function (sensitivity versus wavelength) is used to convert count rates (corrected for the other flux calibration steps) to absolute flux units. A standard photometric calibration source of known flux versus wavelength is required to compute this calibration function. Observations of the standard photometric source are first processed through the standard reduction pipeline (section 5) with all steps except for the conversion to absolute flux units. The corrected count rates and a table of the known flux versus wavelength of the source are then rebinned to the same wavelength scale. The following rebinning methods

should be available depending on the resolution of the STIS observation as compared to the standard star flux table:

1. Integrate (Trapezoidal) the STIS observation to match the flux table.
2. Integrate the flux table to match the STIS observation (this method should be used for the prism where the dispersion if very low and changes significantly with wavelength).
3. Integrate both the STIS observation and the flux table to uniform user selectable wavelength bins.
4. Linear interpolation of the STIS observation to match the flux table.
5. Linear interpolation of the flux table to match the STIS observation.

Before rebinning, the user should have the option to convolve either or both the observation and flux table by a smoothing function to match their resolution.

The ratio of the corrected count rates and the known flux gives the sensitivity function versus wavelength. The sensitivity function should be inherently smooth (any high frequency variations should have been removed in the flat fielding). Therefore a smooth curve (least squares cubic spline) is fit to the computed sensitivity function. This smooth curve is then tabulated for use by the pipeline processing.

If the internal continuum lamps are stable, they can be used to cross-calibrate the sensitivity of the various modes. The cross-calibrations can then be applied to an absolute sensitivity calibration of one mode to generate the absolute sensitivity function for the other mode.

6.10 Spatial Distortion

If small scale detector distortion is present, it will not be adequately modeled by the dispersion relation or by the smooth spectral order tracings. If the distortion is significant, A distortion file which has an *x* and *y* distortion for each pixel may be necessary. Calibrations of these distortions can best be done before the detectors are integrated into STIS. Mask's can be used to illuminate the detector with vertical and horizontal lines. Measurement of the center of the line should be a smooth function of position along the line. Deviations from a smooth function indicate detector distortions. To obtain accurate measurements, high signal to noise observations and accurate flat fielding are required to separate actual position deviations from deviations due to noise. By moving a mask with horizontal and vertical lines across the detector, a map of distortions at all pixels can be constructed.

After installation of the detectors into STIS, distortions can be measured in the cross-dispersion direction by examination of the deviations of spectral order tracings from a smooth curve. A single echelle observation can have as many as 60 "horizontal lines" (i.e. spectral orders). In the dispersion direction positions of lines from the spectral calibration lamp should be a smooth curve as a function of position along a long slit. Deviations from a smooth curve will give distortions in the dispersion direction provided the data has sufficient signal to noise and is adequately flat fielded.

The distortion measurement software should be able to both track vertical or horizontal lines and determine the center of the line as a function of position along the line. It should then fit a smooth curve (spline or polynomial) to the positions and tabulate the residuals (in the direction perpendicular to the line) as a function of detector position. The results for a large number of line measurements can then be combined to construct a distortion map.

Section 7
Performance and Trend Analysis

Performance and Trend Analysis software is important for:

- Evaluating errors in the routine reduction process and analyzing the quality of the reduced data including signal-to-noise, wavelength accuracy, and resolution.
- Determining how calibrations functions change with time and how often calibrations must be repeated.
- Evaluating how calibration functions and instrument performance vary with environmental conditions to allow: optimization of observing techniques, determination of selection criteria for calibration reference functions, and creation of models for variations in the calibration functions.

The most important job in performance and trend analysis is record keeping. The analyses may require examination many data sets taken over a long period of time. Since much of the analysis is matching changes in performance with time and environmental conditions (e.g. detector temperature), it is important that each calibration or performance value can be quickly associated with time and environmental parameter values. This record keeping will be done using the IDL data base software described in section 3.3. Each observation will be cataloged into a merged observing log which will describe the instrument configuration as well as the environmental information contained in the engineering snapshots. Any performance characteristic measured from a series of observations can be quickly correlated with time or any environmental parameter stored in the catalog. Additional IDL data base files can be used to maintain records of calibration functions or parameters. For example, an IDL data base containing a catalog of all flat field files can be used to quickly locate files needed to analyze flat field variations with time or wavelength.

7.1 Engineering Data

Most of the parameters describing the environment (temperatures, voltages, etc.) during a STIS observation that are needed for trend analysis will be found in the engineering snapshots available with every observation. The snapshots will normally contain values of the engineering parameters at the beginning and at the end of an exposure. There are however, two additional sources of engineering data that may be useful for performance and trend analysis.

The first are engineering diagnostic data collected by the flight software. When operating in the diagnostic mode, the flight software can simultaneously collect up to 32 engineering parameters with very high time resolution. This mode has limited usefulness for trending science data since it can not be done while collecting science data.

The second source of engineering data is the engineering telemetry stream. During a long exposure, the engineering snapshots do not give any indication of how an environmental parameter is changing during the exposure. However, this information can be extracted from the engineering stream with 6 second time resolution. During the prelaunch calibration of STIS, the method for accessing the engineering telemetry is still TBD.

7.2 Mechanism Repeatability

The repeatability of the mode select mechanism (MSM) and the slit wheel is important in determining: the wavelength accuracy when a WAVECAL is not taken with a science observation, the maximum distance the reduction software should search when determining wavelength and order tracing shifts, and optimal parameters and techniques for on-board target acquisition. It is currently expected that the slit wheel will be very repeatable. However, the non-repeatability of the MSM may require a WAVECAL to be taken before or after every science observation when a MSM motion occurs.

Because of the non-repeatiblity of the MSM, measurement of the slit wheel repeatability will require a series of observations to be taken that exercise the slit wheel without movement of the MSM. For observations in the camera mode, the software described in section 6.5 can be used to measure image positions and slit wheel repeatability. Changes in the measured aperture position after the slit wheel has moved and then returned to the same position can be used to characterize the slit wheel repeatability. In the dispersed light modes, the wavelength calibration software and order tracing software can be used to measure motion of spectral features or spectral orders.

MSM repeatability can be measured using the same software by comparing results taken at the same MSM positions after moving the MSM and then returning to the same location.

7.3 Detector Stability

Trending software is required to monitor the performance of the detectors with time and environmental conditions (e.g. detector temperature). The software should allow measurement of the following quantities and correlate them with temperatures, orbital position, CCD amplifier, or time.

average bias image level
number of hot pixels
average dark rate
cosmic rays

Most of the requirements of detector stability can be done by proper cataloging of the calibration results from sections 6.1 (CCD Bias Images) and 6.2 (Detector Dark Rate). IDL data bases should be constructed to record these results after each calibration along with the observation rootnames used for the calibration. The rootnames will allow extraction of all required engineering parameters from the merged observing log.

Analysis of variations in flat field and detector sensitivity can be accomplished by catalogs of all flat field and sensitivity files. Flat fields taken in the same mode or approximately the same wavelength can be quickly located and compared.

Histograms are very important in locating detector problems and studying the characteristics of cosmic rays and hot pixels. Software should allow generation of histograms of any image. In particular, a library of histograms should be maintained for dark images and CCD bias images. Analysis of cosmic rays in CCD dark images should include: computation of the number of cosmic rays per unit time, computation total counts in the cosmic rays per unit time, generation of histograms of counts per cosmic ray and number of neighboring pixels affected by each cosmic ray.

7.4 Spectra and Image Resolution

The following methods should be available for measuring spectral or spatial resolution:

Camera Modes:

Resolution will be estimated by measuring the width and/or height of a illuminated slit by fitting a Gaussian to its profile or by measuring the distance between the half-max flux points on each side of the peak. For the long slit mode, the software should make measurements as a function of position along the slit (after optionally binning the data in the direction parallel to the slit). After launch, stellar sources can be used to measure resolution in the camera modes and create accurate point spread functions.

Prism/Grating Modes (Wavelength Resolution):

Resolution will be estimated by measuring the width (by Gaussian fits) of spectral lines from the internal Pt-Ne-Cr lamps. For the long slit modes, the software should make measurements as a function of position along the slit. For the low dispersion modes where significant line blending may occur, simultaneous fitting of multiple Gaussians may be needed.

Prism/Grating Modes (Spatial Resolution):

Spatial resolution can be measured by computing the width of the spectral orders observed in a small point source slit after an optional binning of the data in the direction parallel to the orders.
Results should be tabulated versus spectral order, wavelength, and position on the detector. These results may also be useful for optimal weighted slit extractions and for flat fielding parallel shift and dwell data sets where the cross dispersion profile is required.

Section 8
Post-Reduction Display and Analysis

After STIS data has been processed by the routine data processing system the following types of software are required to analyze, interpret, and display the data.

1) Post Reduction Data Enhancement and Manipulation: In a sense, this is a continuation of the routine data calibration and reduction task which can not easily be automated in a routine fashion. These reduction tasks usually require some interactive, judgmental, heuristic input from the user which does not allow for completely automated processing.

2) Data Analysis and Interpretation: This includes feature identification and measurements, photometry, astrometry, comparison of observed data with models.

3) Display of Data and Results: This includes display of the information to allow visual analysis and assessment. It also includes the preparation of publication quality graphics.

Most of the software tools needed to analyze reduced data from STIS are already available in numerous astronomical software packages. Software development requirements for analysis and display software will be primarily limited to:

- installing existing software package into the STIS science data management and analysis system
- modifying existing routines to allow them to be used on STIS data
- re-formatting STIS data products to a form usable to other packages or routines
- development of special IDL drivers to simplify the use of non-IDL software routines (e.g. standalone FORTRAN routines)
- creating new routines on an as needed basis

Sources of significant IDL software available for data analysis and interpretation include:

- IDL software libraries available from the developer of IDL, Research Systems, Inc.
- IUE Regional Data Analysis Facility at GSFC
- GHRS science data management and analysis facility at GSFC
- FOS instrument team's analysis system at the ST ScI
- UIT (Ultraviolet Image Telescope) analysis facility at GSFC
- IDL Astronomy users library at GSFC

Details of the software available from these systems are described in sections 8.1 through 8.3.

Significant Non-IDL astronomical analysis software packages include:

- MIDAS - Munich Astronomical Data Analysis System

- IRAF - Image Reduction and Analysis Facility
- SDAS - ST ScI Science Data and Analysis System
- AIPS - Astronomical Image Processing System

IRAF and SDAS will be installed in the STIS science data management system and are described in section 8.4.

8.1 Software Supplied with IDL

In addition to being a powerful programming language, IDL's intrinsic functions, routines, and application libraries makes it into a powerful data analysis and display package. The following summarizes the routines that are available with IDL.

General Input/Output: Routines to read from tape or disk files that may have an arbitrary format.
Special routines for supporting:

- Common Data Format (CDF)
- Network Common Data Format (netCDF)
- Hierarchical Data Format, (HDF)
- Microsoft Windows Bitmap format (BMP)
- Graphics Interchange Format (GIF)
- JPEG files
- Macintosh PICT files
- Sun raster format files
- Wavefront Advanced Visualizer files
- X11 bitmap files
- X Windows Dump files(XWD)
- 8-bit TIFF files
- NCAR Raster Interchange files (NRIF)

Plotting, Two-Dimensional and General: General plotting package including simple vector plots, contour plots, two-dimensional fields and vector flow plots, and an interactive plotting tool. Routines allow complete plot annotation and interactive cursor input. Support is included for the major graphic output formats including: Tektronix, Regis, X-Windows, PCL, Postscript, CMG, and HP.

Plotting, Multi-Dimensional: Surface plots, shaded surface plots, 3-dimensional flow/velocity fields, visualization of iso-surfaces and slices through volumes.

Mathematical functions: trigonometric, logarithms, exponentials, Bessel, Error, Gamma, Gaussian, Voight, Fourier transforms, and square root.

Interpolation: Linear, bi-linear, splines, and image warping.

Image Processing: Convolution, fourier analysis, filtering, histograms, histogram equalization, warping, edge enhancement, rotation, and color table manipulation

Statistics: Analysis of variance, correlation coefficients, histograms, population comparison, regression analysis, support for chi-square, F, binomial, Gaussian, and T-distributions.

Numerical Recipes™ Functions: Matrix manipulation, decomposition, and inversion, integration, differentiation, solutions to linear and non-linear equations, spline interpolation, wavelet transforms, and roots of complex polynomials.

Animation: flicker display between two images, create and display animated sequences of images.

8.2 IDL Astronomy User's Library

The IDL Astronomy User's Library is a central repository for general purpose astronomy routines written in IDL. The library is located at GSFC and is funded under the NASA Astrophysical Data Program. The library contains routines in the following areas (a complete listing of the routines can be found in appendix C).

Astronomical Utilities: astrometric coordinate conversions, date and time conversion, position of Sun and Moon, proper motion and precession computation, flux unit conversions, etc.

DAOPHOT-type Photometry Procedures: a set of routines for point spread function fitting photometry.

Database Procedures: a set of IDL data base procedures developed the GHRS instrument team.

Disk I/O: routines to support file input/export from AIPS, MIDAS, and IRAF

Astrometry: Astrometric plate solutions, update of FITS header astrometry information during image manipulation, and support of ST ScI guide star survey images.

SDAS I/O support - complete set of routines for reading/writing SDAS image and table files. SDAS images and tables will be the primary format for internal storage of STIS data and calibration files.

FITS I/O - routines for reading FITS images, ASCII tables, and 3D binary tables from disk and tape.

Math and Statistics - integration, linear regression, interpolation, function minimization, least square fitting, and principal component analysis.

8.3 GHRS, FOS and IUE analysis software

Numerous IDL software analysis tools exist in the GHRS Instrument team's system, the FOS Instrument Team's system and in the IUE Regional Data Analysis Facility. Many of these will be usable with STIS data with no modifications. A listing of the ones most relevant to STIS are:

AIRTOVAC, VACTOAIR - air/vacuum wavelength corrections

BASEREM - interactive baseline removal

BBCMP - compute RMS and average deviations of an observed spectrum from Plank curves

BBDRAW - blackbody spectrum overplotting

BINS, BIN_SPEC - spectral binning

BLEMISH, FLAG_BLEM, PATCH - spectral blemish flagging and removal

CALHRS_HEL, VELSUN - heliocentric wavelength computation

COADD - coaddition of spectra

CRUD_ITERATE - iterative fixed pattern noise computation from FP-SPLIT type data.

FEATURE, FMEAS - spectral feature analysis including computation of central wavelength, radial velocity, continuum flux, integrated flux, and equivalent width

GASSFITS, SPECFIT - multiple Gaussian profile fitting

HRS_MERGE - coaddition and merging spectral data from multiple observations containing overlapping wavelength regions or spectral orders.

HRS_OFFSET - spectral registration using cross-correlation

HST_ORBIT - computes HST's orbital positions and velocity

KURUCZ - retrieves a Kurucz model atmosphere

LINTERP, QUADTERP - interpolation

LYMANA - Correct flux for a Lorentzian absorption profile at Lyman alpha

NORM - continuum fitting and normalization

OPT_FILTER - Brault and White (1971, A & A, **13**, 169.) optimal filtering

POINT - interactive measurement of wavelength/flux points

RV - radial velocity measurements

UNRED - corrects for interstellar reddening

8.4 IRAF/STSDAS Analysis Tools

IRAF (Image Reduction and Analysis Facility) is one of the more popular astronomical data analysis systems. IRAF analysis packages continue to be added and improved. STSDAS (Space Telescope Science Data Analysis System) runs under IRAF. Some of the major packages under IRAF that can be used for interpretation and analysis of STIS data include:

noao.onedspec.splot - spectral plot and analysis routine including capabilities for Gaussian fitting, continuum fitting and normalization, spectra arithmetic, equivalent widths, filtering, and statistics.

noao.digiphot.apphot - aperture photometry package including automated star finding, magnitude computation in polygonal regions, and model PSF determination.

noao.digiphot.daophot - crowded-field photometry package using model PSF determination and fitting.

noao.rv - radial velocity analysis including Fourier cross-correlation

stsdas.analysis.fitting - 1 and 2 dimensional linear and non-linear curve fitting routines.

stsdas.analysis.fourier - Fourier analysis including autocorrelation, cross-correlation, convolution, and power spectrum computation.

stsdas.analysis.gasp - astrometry and access to the HST guide star catalog on CD-ROM.

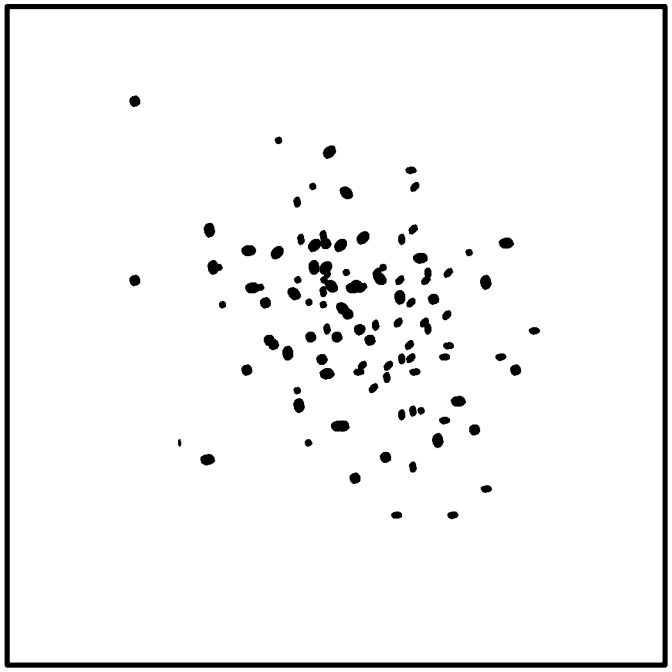
stsdas.analysis.restore - 1 and 2 dimensional deconvolution and restoration.

stsdas.analysis.statistics - linear regression and other statistical analyses.

stsdas.analysis.timeseries - time series photometry and analysis.

APPENDIX A
STIS Observing Mode Picture Book

External Targets



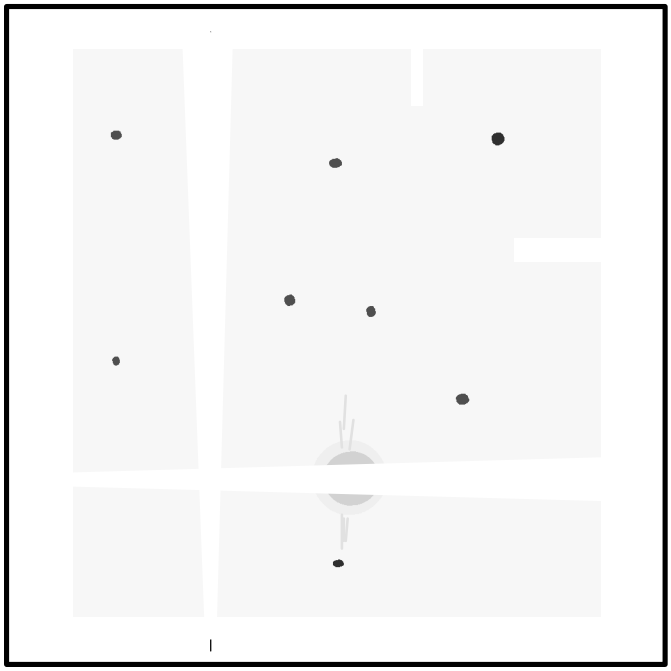
Camera Modes

Modes 1.6, 2.6, 3.6, 4.6

Imaging modes have a 50 x 50 arcsec field of view for band 3, 28 x 50 for band 4 and 24.7 x 24.7 for bands 1 and 2.

Various neutral density, bandpass, and wavelength cutoff filters are available.

This mode is used with an internal calibration lamp to obtain flat fields for STIS camera-mode images and used for target acquisition. Band 4.6 is the nominal target acqusition mode.

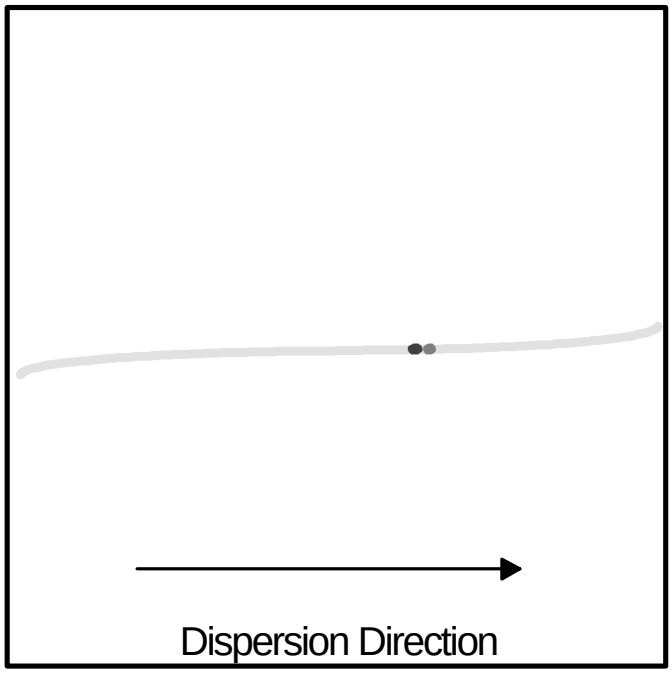


Camera Mode
(with Occulting Bar Aperture)

Modes 1.6, 2.6, 3.6

In addition to the occulting bars on the long spectral slits, STIS has a camera aperture with fingers and occulting bars. Shown is a bright object placed behind one of the occulting bars which has a variable width of 0.2 to 3 arcsec.

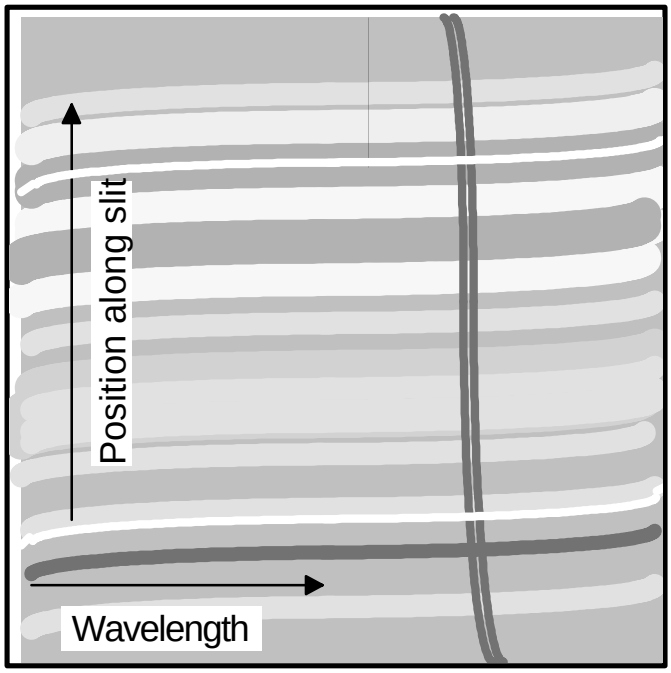
This aperture could also be used for slit-less spectroscopy



First Order Grating Modes (Point Source)

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2.

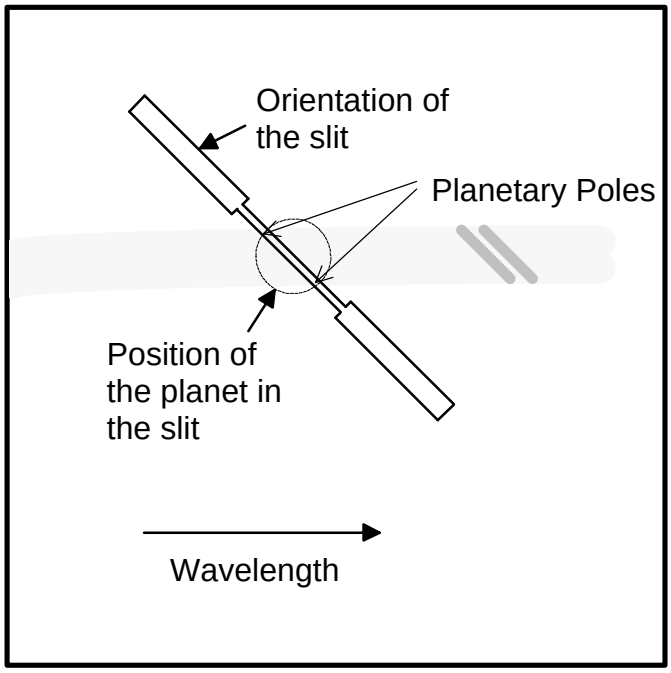
In modes x.2, only a portion of the spectrum falls on the detector. Multiple observations with different mode select mechanism positions are required to cover the full spectral range. In modes x.1 the full spectral format falls on the detector.



First Order Grating Modes (Extended Source)

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2

Two horizontal white lines are the occulting bars. Double vertical lines are emission lines at constant wavelength.



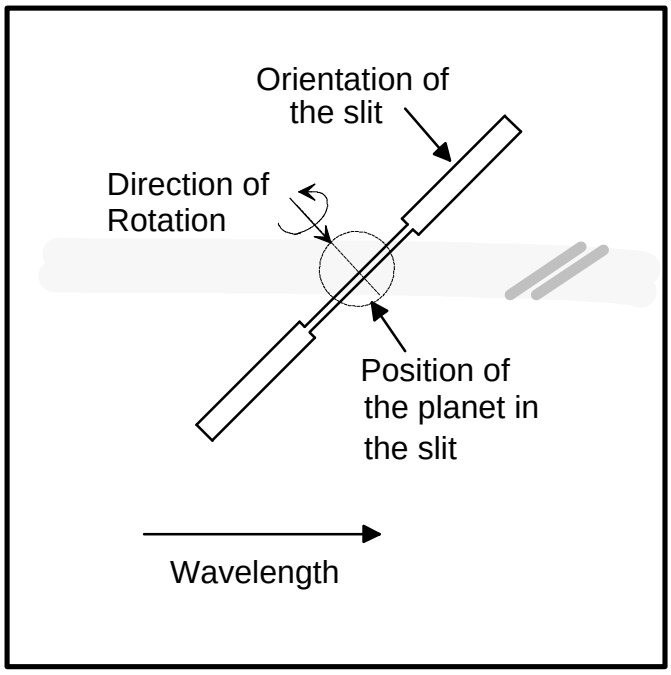
First Order Grating Modes (Planetary)

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2

Slits are available at either +45 or -45 degrees to correctly orient the planet subject to the roll constraints of the telescope.

Shown is the slit oriented along the rotation axis of the planet.

A line of constant wavelength is sloped at approximately 45 degrees.



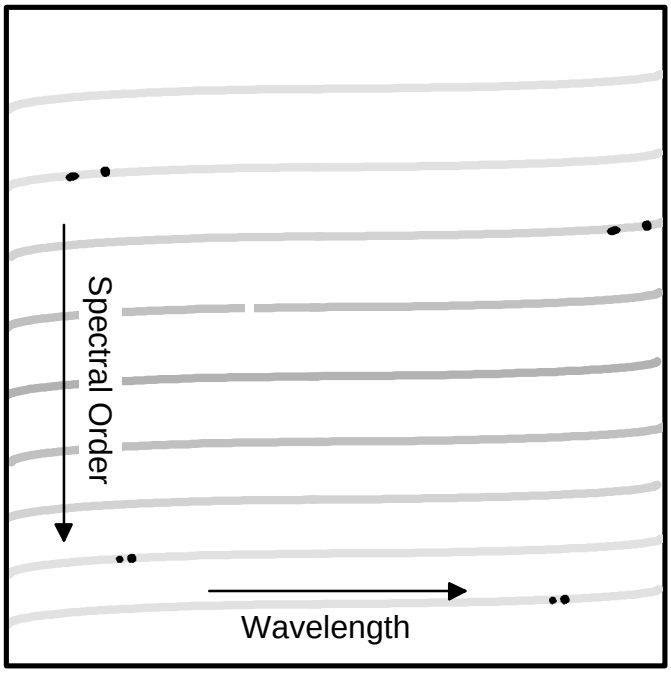
First Order Grating Modes (Planetary)

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2

Slits are rotated at either +45 or -45 degrees.

In this image, the slit is oriented along a line of constant latitude..

Although a line of constant wavelength is sloped at approximately 45 degrees, the spectral features are more inclined due to the rotation of the planet.

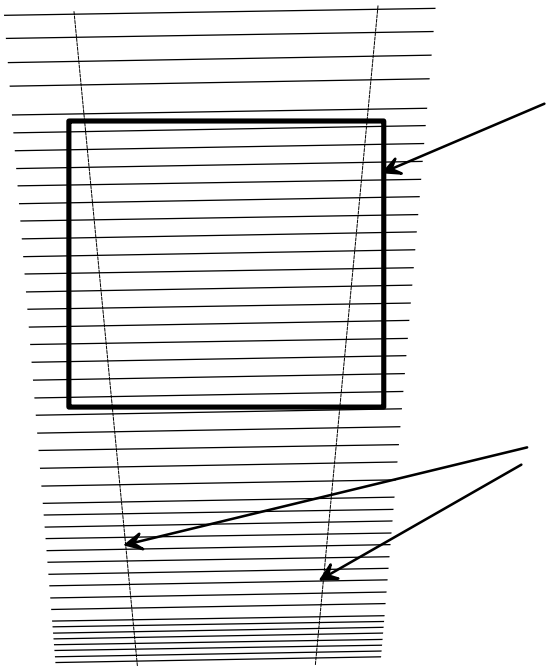


Echelle Modes
(Point source)

Modes 1.3,1.4, 2.3, 2.4

In modes 1.4, 2.3, and 2.4, all orders can not be observed simultaneously. Multiple mode select mechanism positions are required.

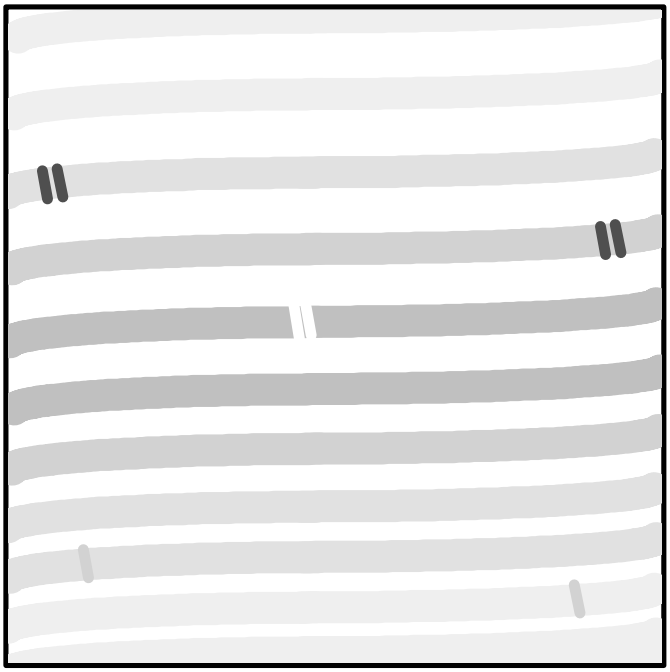
Echelle Format



Box shows portion of format visible at one mode select position

The mode select mechanism can move the format in both directions.

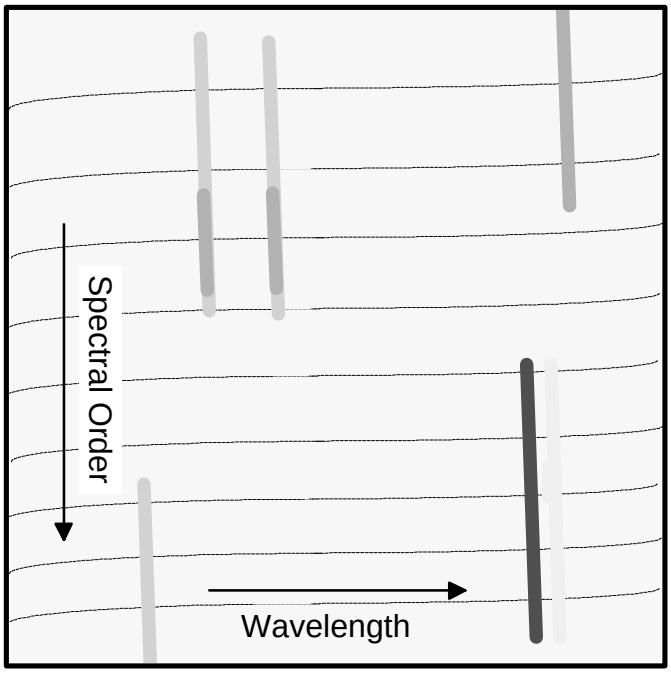
Dashed lines show the free spectral range



Echelle Modes
(Extended source, Short Slit)

Modes 1.3, 1.4, 2.3, 2.4

Short slit used to avoid order overlap.

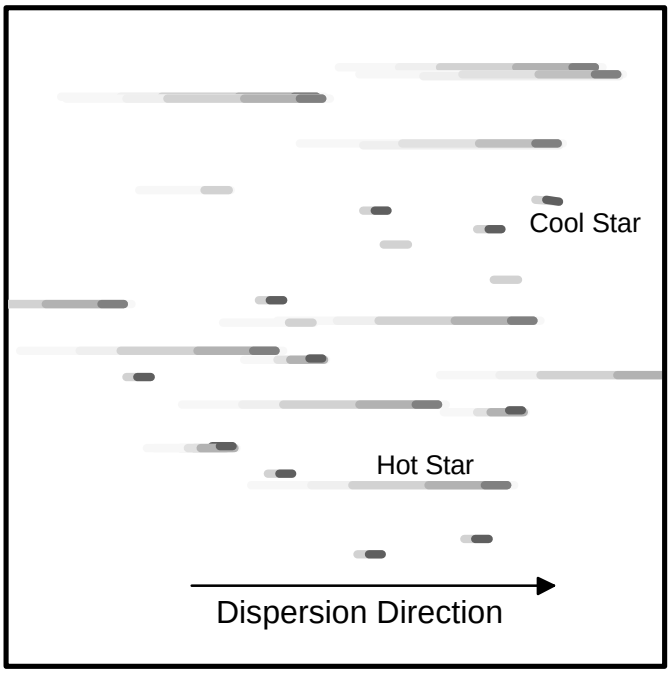


Echelle Modes
(Extended source, Long Slit)

Modes 1.3, 1.4, 2.3, 2.4

Longer slits can be used with the spectral orders overlapping. This allows simultaneous exposure of multiple emission lines.

Dotted Lines show the centers of the spectral orders.

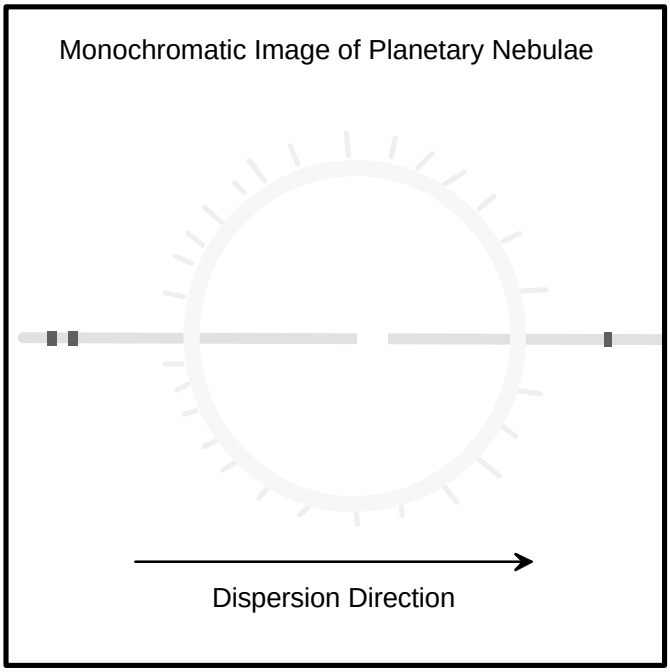


Objective Prism Mode

Mode 2.5

Uses a camera aperture with the light dispersed by a prism.

Most stars are cool, so they have low UV flux. They will appear as very short smears or even dots.



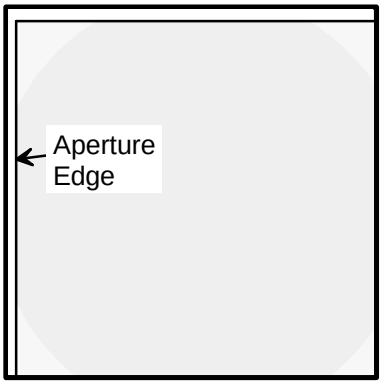
Slit-less Grating Mode

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2

Uses a camera aperture with light dispersed by a first order grating. Unlike the objective prism mode, it can be used with the CCDs.

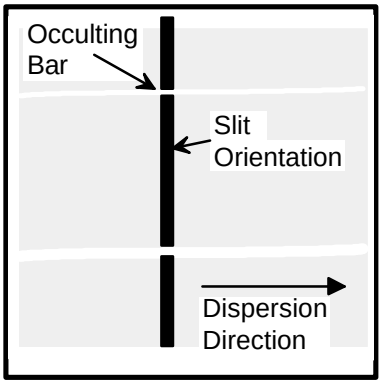
With the medium resolution gratings, the mode can be used to isolate the light from an isolated emission line to generate monochromatic images.

Flat Field Calibration



Camera Modes

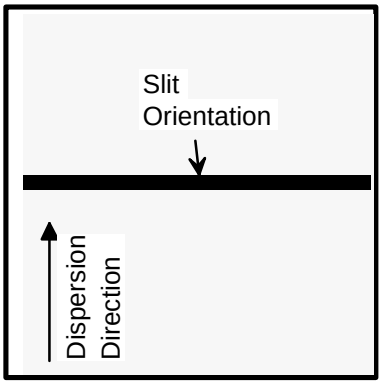
Modes 1.6, 2.6, 3.6, 4.6
Light is not dispersed.
Filtered apertures can be used for flats with different wavelength coverage.
This mode can also be used for calibrating the relative locations of the camera apertures and slits.



First Order Grating (Long Slit Mode)

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2
Can also be used with shorter length slits.

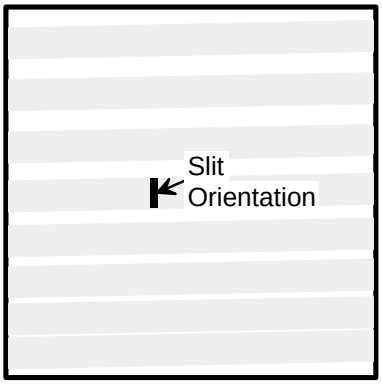
Mode 2.2 flats at different central wavelengths can be used to reduce data taken in the objective prism mode (2.5).



Cross-Dispersed Modes

Modes 2.7(x3), 2.7(x4), 3.7(x3), 3.7(x4)

Used to create flats for the echelle modes.

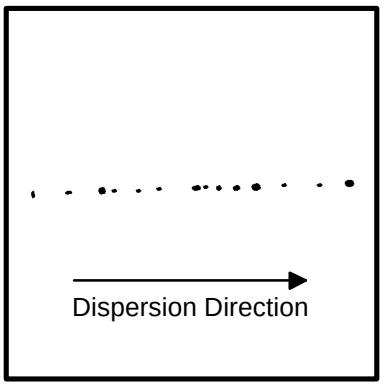


Echelle Modes

Modes 1.3, 1.4, 2.3, 2.4

This is an alternate method of creating flats for the echelle modes. The light follows same optical path as is used external targets. For the longer slits and smaller order separation, the orders will overlap. For shorter slits, a larger portion of the interorder region is left uncalibrated.

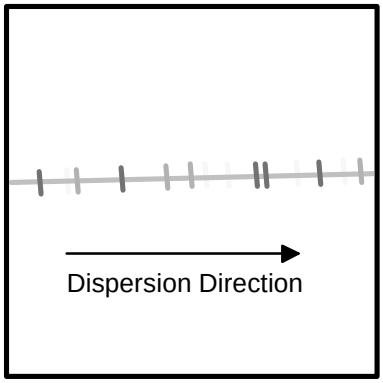
Spectral Calibration Lamp



First Order Gratings: Point Source Slit, CIM Calibration Sub-system, Pt/Cr-Ne Lamp

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2
Also applicable to the Objective Prism Mode (2.5)

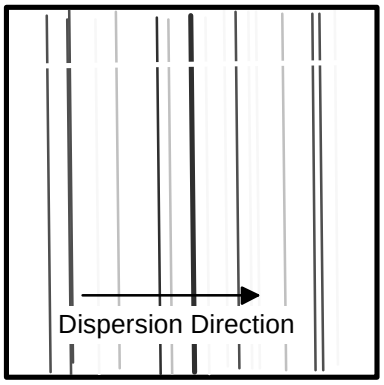
Calibration insert mirror blocks light from external sources.



First Order Gratings: Medium Length Slit, HITM Calibration Sub-system, Pt/Cr-Ne Lamp, Point Source Target

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2

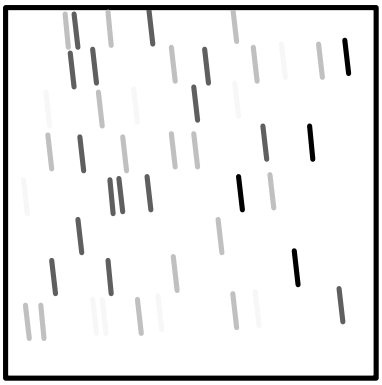
Spectral calibration lamp spectrum (which completely fills the slit) is overlayed on the external source spectrum. The HITM calibration sub-system is the standard system for first order grating wavelength calibration.



First Order Grating: Long Slit Mode

Modes 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2
Also applicable to the Objective Prism Mode (2.5)

With HITM Calibration Subsystem, the spectrum of the external source is overlayed with the Pt/Cr-Ne lamp spectrum. Occulting bars will cause discontinuities in the spectral lines.



Echelle Modes

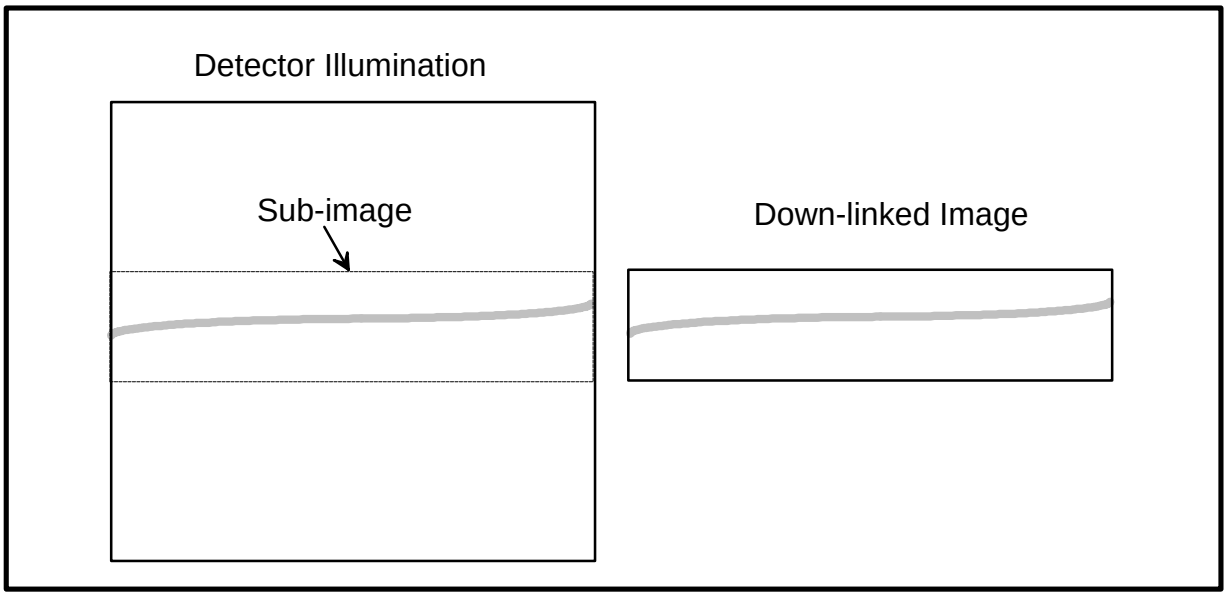
Modes 1.3, 1.4, 2.3, 2.4.
CIM calibration sub-system will be normally used with the external target blocked. Shown is a echelle extended source slit. The height of the calibration lines will vary with slit length.

Sub-image readouts of regions containing bright spectral lines

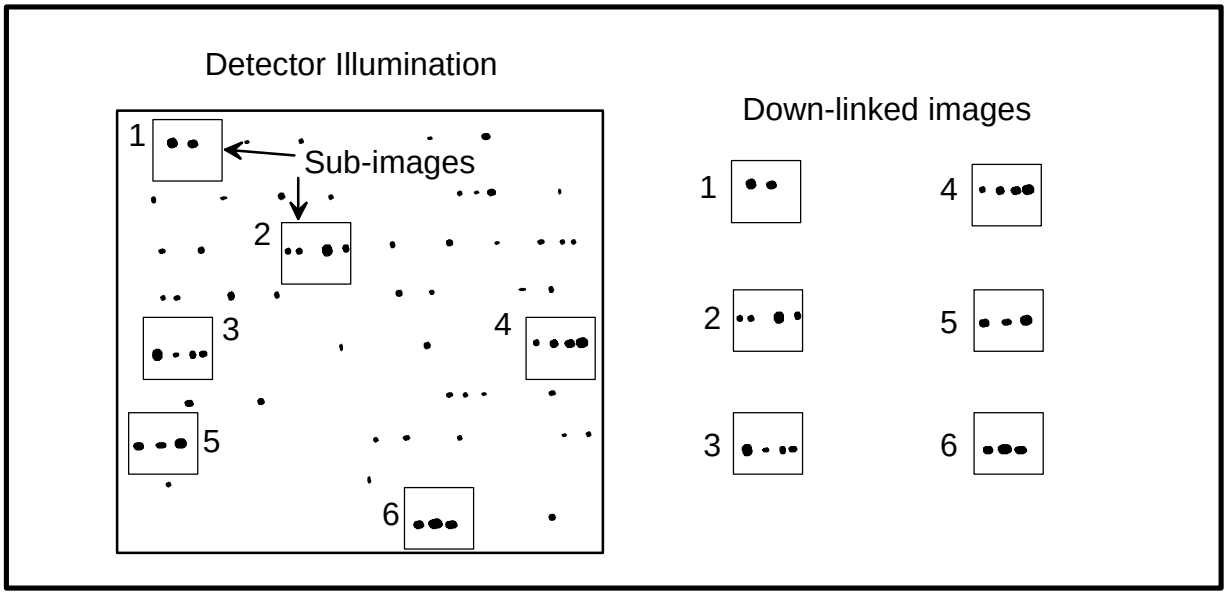
Sub-image Readout

Sub-image readout can be used with any MAMA or CCD internal or external source. Up to 8 equal size sub-images can be defined.

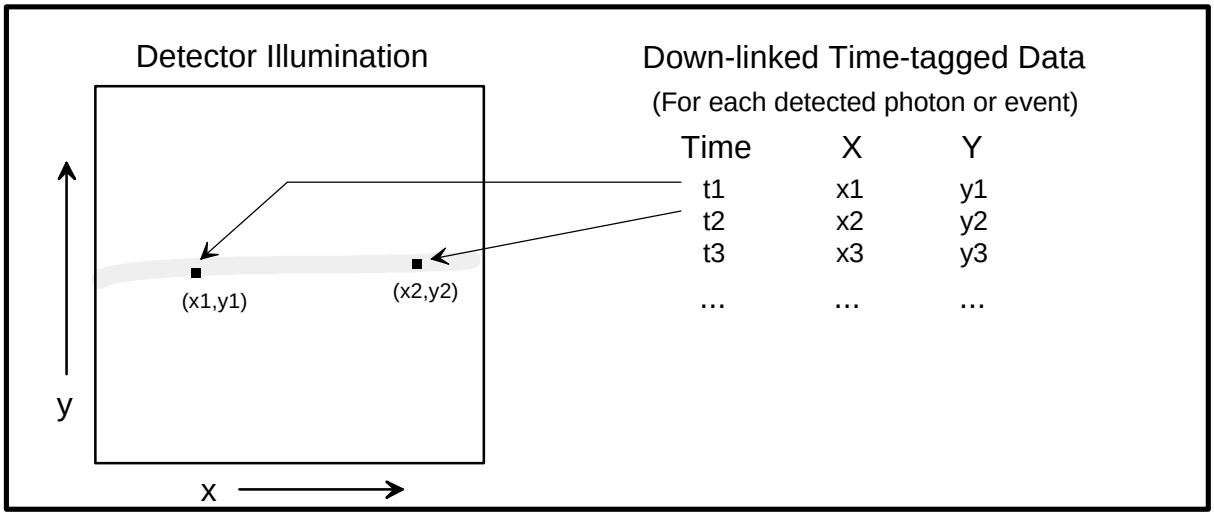
Example 1: First order grating external point source



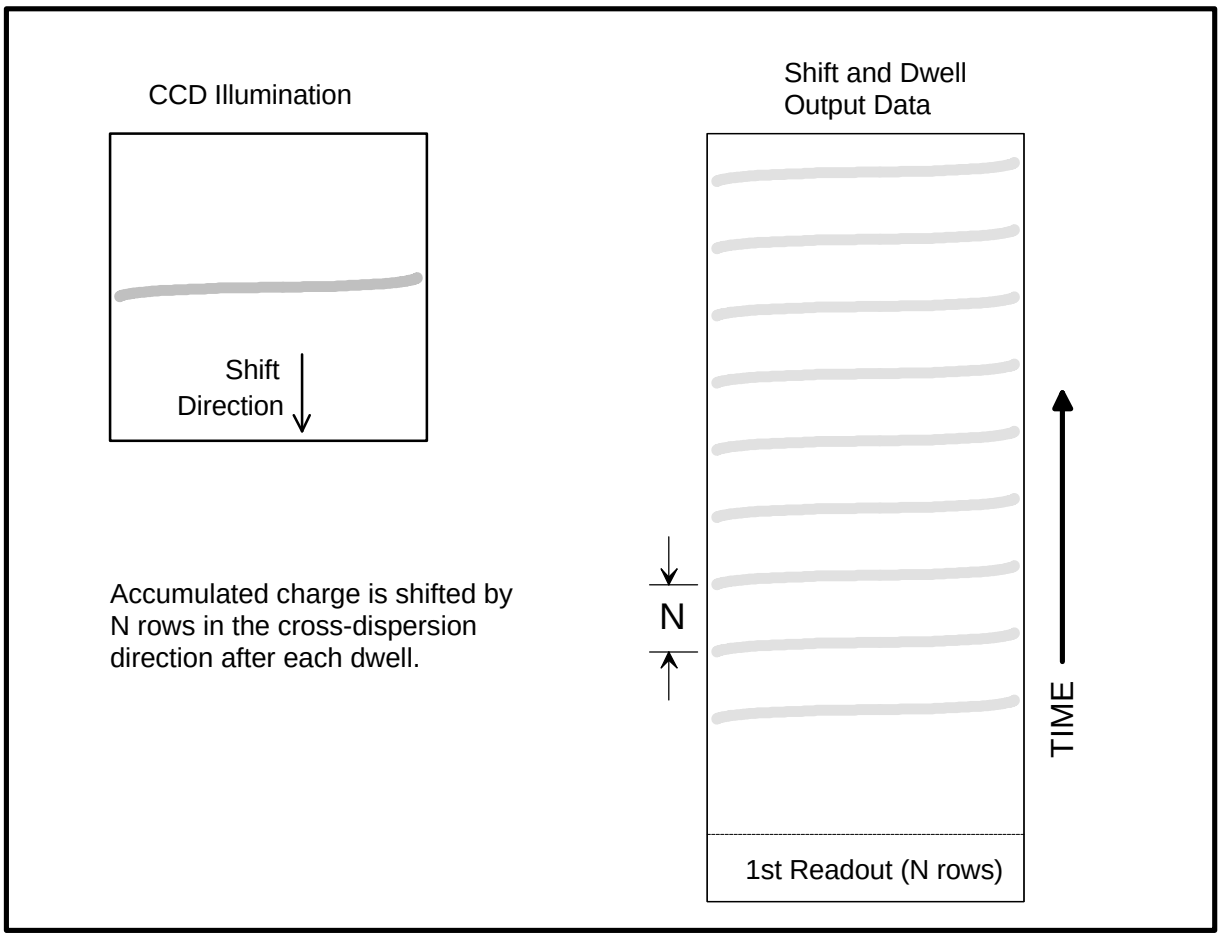
Example 2: Echelle Wavelength Calibration



Time Tagged Mode



CCD Parallel Shift and Dwell



Appendix B
STIS Grating Format Plots

The plots which follow show the spectral format projected onto the STIS detectors for each of the dispersion modes. The parameters included with the plots are:

blaze	θ	grating blaze angle
gr/mm	$10^7/d_g$	grating grooves per millimeter
delta	δ	1/2 angle between the angle of incidence and the angle of reflection (at the detector center) in the plane of dispersion
sigma	σ	out of plane angle
angle	$\Delta\theta$	Grating angle with respect to the blaze angle
F	F	the focal length in millimeters
alpha	α	the angle of incidence $\alpha = \theta + \delta + \Delta\theta$
beta	β	the angle of reflection at the detector center $\beta = \theta - \delta + \Delta\theta + \varepsilon$ where: $\varepsilon = \tan^{-1}(y/F)$ y - is the distance from the center of the detector in the dispersion direction.
x_* -	same values for the cross-disperser	
rotate -	optional detector rotation angle	
max_eff	maximum theoritical grating efficiency. Contour lines are normalized with respect to the max_eff	

Wavelengths (in Angstroms) are computed by:

$$\lambda = \frac{d_g \cos(\sigma)(\sin(\alpha) + \sin(\beta))}{m}$$

where:

$$d_g = \frac{10^7}{gr/mm}$$

m is the spectral order (1 for first order spectra)

Grating efficiencies are computed by:

$$efficiency = \frac{\cos(a)}{\cos(b)}\left(\frac{\sin(t)}{t}\right)^2$$

where:

$$t = m\pi\cos(a)\frac{\sin((\alpha+\beta)/2 - \theta)}{\sin((\alpha+\beta)/2)}$$

$$a = \alpha,\ b = \beta \quad \text{when } \alpha \geq \beta$$
$$a = \beta,\ b = \alpha \quad \text{when } \alpha < \beta$$

Appendix C
Contents of the STIS Science Data Packets

Each word is 2 bytes.

0. 8 words of Initial Fill Pattern

Each word contains the value 43690 (or equivalently hexidecimal number AAAA)

I. Internal Header Packet (Programmatic Numbers) 4 words

A. PROG ID (2 words)
B. OBSET ID (1 word)
C. GROUND OBSERVATION NUMBER (1 word)

II. Internal Unique Data Log (Internal UDL with 842 words)

A. Data Unpacking Information (4 words)

1. Flight (Software Generated) Observation Number (1 word)
2. Number of Words in this Image, including Internal Header Packet and UDL (2 words)

   This is 965 (the initial fill pattern, the internal header packet, the internal unique data log, and the final fill patter) plus the amount of actual image data. The number of words in this image does not include the final fill words at the end of the image data.

3. Number of SDF lines in this image (1 word)

B. Image Definition

1. HST Time at start of Image (5 words including; 4 bytes base time from time-code-update + 3*16 bits elapsed time). STIS maintains elapsed time in the MIE coarse-time-word of 32 bits.
2. Image Type: (1 word)
   detector pixel science data, or memory dump data, or diagnostics data
3. Memory Dump Definition (5 words)
   a. Memory Dump Source: (1 word) CS, MIE, State-Machine
   b. Memory Dump Starting Address (2 words)
   c. Number of Words (2 words)
4. ED Diagnostic Definition (34 words)
   a. Items to Collect (32 words); tem designators (0 indicates an invalid item)
   b. Collection Time (1 word)
   a. Collection Rate (1 word) 0 for FAST mode, Otherwise, SLOW mode.

5. Science Data Definition (19 words)
   a. Detector Number: (1 byte) CCD, or MAMA1, or MAMA2
   b. Detector Science Data Type: (1 byte)
      Accumulate-over-time, Time-Tag, or Parallel Shift and Dwell
   c. Subarray Definition (18 words)
      i.. Common Subarry Size (2 words), number of rows and number or columns
         a. Number of rows (1 word)
         b. Number of columns (1 word)
      ii. 8 Subarray Indicators (2 words each)
         a. Starting Row Number (1 word)
         b. Starting Column Number (1 word)

C. Calibration Information (174 words)

1. OPTICAL_MODE (1 word) Mode Select dispersion element or mirror ID

   The OPTICAL_MODE will be the value of the parameter *Optical Mode* in the macro *Move MSM to Observe Position*. The OPTICAL_MODE will be set to 0 if the macro Move MSM to Absolute Position is used

2. WCENTER (1 word) Central wavelength of the spectral format

   The WCENTER will be the value of the parameter *Center Wavelength* in the macro *Move MSM to Observe Position*.

3. ECHELLE_ORDER (1 word) Center echelle order

   The ECHELLE_ORDER will be the value of the parameter *Center Echelle Order* in the macro *Move MSM to Observe Position*.

4. SLIT_NUMBER (1 word) Slit, Aperture or Filter ID

   The SLIT will be the value of the parameter *Slit Number* in the macro *Move SW to Slit Position*. The SLIT will be set to 0 if the macro *Move SW to Absolute Position* is used.

5. CCDGAIN1 (1 byte) gain for CCD amplifier 1 (0 if amp not used)
6. CCDGAIN2 (1 byte) gain for CCD amplifier 2 (0 if amp not used)
7. CCDGAIN3 (1 byte) gain for CCD amplifier 3 (0 if amp not used)
8. CCDGAIN4 (1 byte) gain for CCD amplifier 4 (0 if amp not used)

These values will be the parameters *Gain* (Four Gain Values) in the macro *Load Default CCD Configuration*. Alternately, these values will be individually determined from the parameters *Which Gain* and *Gain Value* in the macro *Select CCD Gain*.

9. SERIAL_BIN (1 word) Data bin size in sample (serial) direction
10. PARALLEL_BIN (1 word) Data bin size in line (parallel) direction

These values will be the values of the parameters *Parallel Binning Ratio* and *Serial Binning Ratio* in the macro *Setup CCD Binning Exposure*.

Alternately, these values can be derived from the parameters *Binning Ratio* and *Binning Selection* in the macro *Setup CCD Binning PSD Exposure*. (Binning Selection can be none, parallel, or serial. If parallel, then PARALLEL_BIN will be the value of Binning Ratio and SERIAL_BIN will be set to 0. If serial, then SERIAL_BIN will be the value of Binning Ratio and PARALLEL_BIN will be set to 0. If none, then both PARALLEL_BIN and SERIAL_BIN will be set to 0).

11. PSHIFT (1 word) Parallel shift and dwell, shift value

PSHIFT will be the value of the parameter *PSD Window Size* (in rows) in the macro *Setup CCD PSD Exposure* or in the macro *Setup CCD Binning PSD Exposure*.

12. PDWELL (1 word) Parallel shift and dwell, number of dwells

PDWELL will be the value of the parameter *Number of Dwells* in the macro *Setup CCD PSD Exposure* or in the macro *Setup CCD Binning PSD Exposure*. (The dwell-time can be computed as the integration time INTEGTIME divided by the number of dwells PDWELL.)

13. DOPCOR (1 word) on-board Doppler correction enables (Y/N)

DOPCOR will be set to the value 1 (Y) or 0 (N) by the CS FSW depending on whether or not the macro *Setup Doppler* is activated prior to starting a MAMA exposure.

14. DOPZERO (2 words) Doppler shift zero phase time

DOPZERO will be the value of the parameter *Time of Zero Doppler Shift* in the

macro *Setup Doppler*.

15. DOPMAG (1 word) Doppler shift magnitude (Hi-Res pixels)

DOPMAG will be the value of the parameter *Doppler Magnitude* in the macro *Setup Doppler*.

16. K_LAMP (0.125 words) Krypton lamp status (1 - on, 0 - off)

KR_LAMP will be set to 0 or 1 by the CS FSW depending on the value of the parameter *On or Off Select* in the macro *Turn KL On/Off*

17. D_LAMP (0.125 words) Deuterium lamp status

DE_LAMP will be set to 0 or 1 by the CS FSW depending on the value of the parameter *On or Off Select* in the macro *Turn DL On/Off*

SPARE (0.25 words)

18. T1_BULB (0.125 words) Tungsten Bulb 1 status
19. T2_BULB (0.125 words) Tungsten Bulb 2 status
20. T3_BULB (0.125 words) Tungsten Bulb 3 status
21. T4_BULB (0.125 words) Tungsten Bulb 4 status

The values of the above parameters will be individually set to 0 or 1 depending on the value of the parameter *Bulb Select* and the parameter *On or Off Select* in the macro *Turn TL Bulb On/Off*

22. PCN1_LAMP (0.25 words) Pt-Cr-Ne lamp 1 status
23. PCN2_LAMP (0.25 words) Pt-Cr-Ne lamp 2 status
24. PCN3_LAMP (0.25 words) Pt-Cr-Ne lamp 3 status

The values of the above parameters will be individually set to 0,1,2, or 3 depending on the value of the parameter *Lamp Number* and the parameter 0, 1, 2, or 3 Select in the macro *Turn PCNL On/Off*

SPARE (0.25 words)

25. DFIELD_METH (1 word) Diffuse field position determination method

DFIELD_METH will be the value of the parameter *Centering Method* in the macro *Target Locate of Diffuse Source*

26. SCAN_TYPE (0.125 words) Target Search type during centering scan: LINEAR or SPIRAL

SCAN_TYPE will be set to the value 0 (LINEAR) or 1 (SPIRAL) by the CS FSW depending on which target centering macro is activated: *Center Target using Linear Scan* or *Center Target using Spiral Scan*

SPARE (0.875 words)

27. CENTROID_TYPE (0.5 words) centroid type selection: peak-up or peak-down or flux-weighted centroid

CENTRIOD_TYPE will be the value of the parameter *Centroid Type Selection* in the macro *Center Target Using Linear Scan*. (This parameter will distinguish between use of flux-weighted centroid or return-to-brightest or return-to-dimmest)

28. SPIRAL_SIZE (0.5 words) spiral size

SPIRAL_SIZE will be the value of the parameter *Spiral Size* in the macro *Center Target Using Spiral Scan* (This will be the order of the spiral.)

29. SPIRAL_STEPSIZE (1 word) size of each step in a spiral scan

SPIRAL_STEPSIZE will be the value of the parameter *Step Size* in the macro *Center Target Using Spiral Scan*

30. LINSCAN_DIR (0.5 words) direction of linear scan (x or y)

LINSCAN_DIR will be the value of the parameter *X or Y Direction* in the macro *Center Target Using Linear Scan*

31. LINSCAN_NSTEPS (0.5 words) number of steps in a linear scan

LINSCAN_NSTEPS will be the value of the parameter *Number of Steps* in the macro *Center Target Using Linear Scan*

32. LINSCAN_STEPSIZE (1 word) size of each step in a linear scan

LINSCAN_STEPSIZE will be the value of the parameter *Step Size* in the macro *Center Target Using Linear Scan*

33. CR_REJ (0.5 word) cosmic ray rejection (YES/NO)

CR_REJ will be the value of the parameter *Cosmic Ray Rejection* in the macro *Target Locate of Isolated Point Source*, *Target Locate of Point in Crowded Field,* or *Target Locate of Diffuse Source*

SPARE (0.5 words)

34. CHECK_BOX_SIZE (1 word) checkbox size

CHECK_BOX will be the value of the parameter *Check Box Size* in the macro *Target Locate of Isolated Point Source* , *Target Locate of Point in Crowded Field,* or *Target Locate of Diffuse Source*

35. CROWDED_FLUX_THRESHOLD (1 word) flux threshold for target locate in crowded field

CROWDED_FLUX_THRESHOLD will be the value of the parameter *Flux Threshold* in the macro *Target Locate of Point in Crowded* Field

36. CENTROID_AREA (2 words) centroid area for threshold centroid

CENTROID_AREA will be the value of the parameter *Area of Centroid* in the macro *Target Locate of Diffuse Source* (This area for a threshold centroid will also be needed in the execution of the macro *Position Slit using Centroid of Illumination*, where the area will be obtained from an on-board table indexed by the parameter *Slit Number*, but no downlinkable image is generated for this macro, so no science data header will be populated for this macro.)

37. XOFF1 (1 word) x-offset1 for crowded field acquisition
38. YOFF1 (1 word) y-offset1 for crowded field acquisition
39. XOFF2 (1 word) x-offset2 for crowded field acquisition
40. YOFF2 (1 word) y-offset2 for crowded field acquisition
41. XOFF3 (1 word) x-offset3 for crowded field acquisition
42. YOFF3 (1 word) y-offset3 for crowded field acquisition

The above offsets will be the values of the parameters *Target X/Y Offsets to 3 Stars* in the macro *Target Locate of Point in Crowded Field*

43. FLUXES (98 words) Fluxes for each of 49 dwell points in target acq scan

These FLUXES will be computed by the CS FSW during the execution of the macros *Center Target Using Linear Scan* or *Center Target Using Spiral Scan*. Each flux will be the total counts within the selected subarray at each dwell point.

There may be fewer than 49 dwell points; the actual number of dwell points can be determined from the values LINSCAN_NSTEPS and SPIRAL_STEPSIZE above.

44. INTEGTIME (2 words) integration time (units of 100 milliseconds)

INTEGTIME will be the value of the parameter *Integration Time* in the macro *Start CCD Exposure, Start MAMA Exposure, Target Locate of Isolated Point Source, Target Locate of Point in Crowded Field, Target Locate of Diffuse Source, Position Slit Using Centroid of Illumination, Position Slit Using Aperture Edge, Center Target Using Linear Scan,* or Center Target Using Spiral Scan.

Note: The CCD electronics is commanded in units of 1.024 milliseconds; INTEGTIME will thus not exactly specify the actual CCD integration time

45. NINTERRUPT (1 word) number of exposure interrupts

NINTERRUPT will be computed by the CS FSW and will reflect the number of exposure interrupts either for ground-generated idles or for TDF (Tale Data Flag) transitions. Idles begin by the occurrence of the macro *Idle Current Exposure* and end by the occurrence of the macro *Resume Current Exposure*. TDF transitions begin by the occurrence of the macro *TDF Went Down* and end by the occurrence of the macro *TDF Went UP*. TDF transitions are noted only if the macro *Enable/Disable TDF Response* has been executed with the parameter *Enable*.

46. START1 (5 words) exposure start time (1st interrupt)
47. STOP1 (5 words) exposure stop time (1st interrupt)
48. START2 (5 words) exposure start time (2nd interrupt)
49. STOP2 (5 words) exposure stop time (2nd interrupt)
50. START3 (5 words) exposure start time (3rd interrupt)
51. STOP3 (5 words) exposure stop time (3rd interrupt)
52. START4 (5 words) exposure start time (4th interrupt)

53. STOP4 (5 words) exposure stop time (4th interrupt)

The above start and stop times will be noted by CS FSW at the start and stop of ground-generated idles and TDF transitions, as described above. Each start time and each stop time will be given as the value of the last time-code-update received from the NSSC-1, together with the value of the coarse time retrieved from the MIE at the moment the start or stop occurred. Idles and TDF transitions may be freely intermixed but no indication will be given here as to which occurred. Overlapping idles and TDF transitions will not be reported separately.

D. 2 ED Snapshots (300 words each)

Selected TBD temperatures, remaining mechanism positions, currents, and voltages, i.e. a full set of A/D values gathered by CS. The exact content and format of an ED Snapshot will be defined by Ops and Electronics as the detailed design continues. An ED Snapshot will include, but not be limited to,

3 MSM Encoder Values
Slit Wheel Encoder Value,
4 CCD offsets, 6 CCD biases

E. Final Fill Pattern (111 words)

Each word contains 21865. This fill is used to pad the header to exactly one SDF line.

III. Image Data

IV. Final Fill Pattern to end of final line

Appendix D
Prototype STIS Science Data Headers

Prototype STIS science data headers follow which give both the keyword information extracted from the STIS telemetry and the keywords that are expected to by populated by the ground system after launch. Keywords that will be used during the pre-launch calibration and reduction package are in bold.

An attempt has been made to standardize the headers so that the pre-launch science team software will be compatible with the post launch data received from the Space Telescope Science Institute (ST ScI). The keyword names used in these headers are the science teams initial proposed names and may change with future coordination meetings with the ST ScI.

The following prototype headers are provided:

- **Unique Data Logs** - STIS does not produce Unique Data Log telemetry packets, instead internal Unique Data Logs are inserted in the Science Data packets. The header for this file contains extracted information from the internal unique data logs and most of the keywords from other ground sources. The unique data log file is the only one that will be produced for every STIS observation.
- **Grating Mode Science Data** - the science data file contains the raw accumulated, time-tagged, or parallel shift and dwell data. It will not be generated for target acquisition observations when the images are not down-linked.
- **Camera and Objective Prism Mode Science Data** - Science data file contains camera mode images and images taken in the objective prism mode.
- **Time-Tag MAMA data** - This table contains three columns giving the time, and x and y location of each event.
- **Bad Pixel Table** - This table contains a list of regions of the science data containing a telemetry error. Columns contain the group, starting sample, starting line, number of samples, number of lines, and quality value for regions of the science data containing telemetry errors (dropouts or Reed-Solomon encoding errors)
- **Standard Header Packets** - Since all STIS observations will not have a standard header packet associated with it, this header only contains minimal information.
- **Engineering Data Diagnostics** - This will contain the values of the engineering parameters sampled during a engineering data diagnostics observation.
- **Memory Dump** - This file contains a portion of the on-board flight software memory down-linked during a memory dump.

Keywords shown in bold will be populated and used by both the pre-launch and post-launch data reduction systems.

STIS PROTOTYPE UNIQUE DATA LOG HEADER

SIMPLE = F	**image conforms to the fits standard**
BITPIX = 16	**bits per data value**
DATATYPE = UNSIGNED*2	**datatype of the array**
NAXIS	**number of data axes**
NAXIS1	**length of first data axis**
GROUPS = T	**image is in group format**
GCOUNT	**number of groups**
PCOUNT	**number of group parameters**
PSIZE	**bits in the group parameter block**

/ GROUP PARAMETERS

PTYPE1 = FILLCNT	**number of segments containing fill**
PDTYPE = INTEGER*4	
PSIZE1 = 32	
PTYPE2 = ERRCNT	**Number of segments containing errors**
PDTYPE2 = INTEGER*4	
PSIZE2 = 32	
PTYPE3 = FPKTTIME	**time of the first packet (MJD)**
PDTYPE3 = REAL*8	
PSIZE3 = 64	
PTYPE4 = LPKTTIME	**time of the last packet (MJD)**
PDTYPE4 = REAL*8	
PSIZE4 = 64	

/ STIS DATA DESCRIPTOR KEYWORDS

INSTRUME	**instrument in use**
ROOTNAME	**rootname of the observation set**
FILETYPE	**shp, udl, sci, dmp, edd, ttg, psd**
SCIDATA	**Observation contains science data file(s) logical T/F**

/ INSTRUMENT CONFIGURATION

OBSMODE	**char*8**	**ACCUM, TIME-TAG, PSD, ACQ, ACQ/PEAK**
DETECTOR	**char*8**	**MA1, MA2, or CCD**
DISPERSER	**char*8**	**Mode Select dispersion or mirror element ID**
MSM_ENC1	**integer**	**Mode Select Mechanism encoder value 1**
MSM_ENC2	**integer**	**Mode Select Mechanism encoder value 2**
MSM_ENC3	**integer**	**Mode Select Mechanism encoder value 3**
SLIT_NUM	**integer**	**Slit number**
SLIT	**char*8**	**Slit or filter identification**
SLIT_ENC	**integer**	**Slit wheel encoder position**
CCDGAIN1	**integer**	**Gain for CCD amplifier 1 (0 if amp. not used)**
CCDGAIN2	**integer**	**Gain for CCD amplifier 2 (0 if amp. not used)**
CCDGAIN3	**integer**	**Gain for CCD amplifier 3 (0 if amp. not used)**
CCDGAIN4	**integer**	**Gain for CCD amplifier 4 (0 if amp. not used)**
CCDOFF1	**integer**	**CCD bias offset number 1**
CCDOFF2	**integer**	**CCD bias offset number 2**

CCDOFF3	**integer**	**CCD bias offset number 3**
CCDOFF4	**integer**	**CCD bias offset number 4**
VDDAB	**real*4**	**CCD Bias voltage VddAB**
VODAB	**real*4**	**CCD Bias voltage VodAB**
VLGAB	**real*4**	**CCD Bias voltage VlgAB**
VDDCD	**real*4**	**CCD Bias voltage VddCD**
VODCD	**real*4**	**CCD Bias voltage VodCD**
VLGCD	**real*4**	**CCD Bias voltage VlgCD**
KR_LAMP	**integer**	**Krypton lamp status (1 - on, 0 - off)**
DE_LAMP	**integer**	**Deuterium lamp status**
T1_LAMP	**integer**	**Tungsten lamp bulb 1 status**
T2_LAMP	**integer**	**Tungsten lamp bulb 2 status**
T3_LAMP	**integer**	**Tungsten lamp bulb 3 status**
T4_LAMP	**integer**	**Tungsten lamp bulb 4 status**
PT1_LAMP	**integer**	**Pt-Ne-Cr lamp 1 status**
PT2_LAMP	**integer**	**Pt-Ne-Cr lamp 2 status**
PT3_LAMP	**integer**	**Pt-Ne-Cr lamp 3 status**
SLITPOS	**real*4**	**Target position within slit (if set by flight software)**

/TARGET ACQUISITION PARAMETERS

DFIELD	**char*16**	**Diffuse field position determination method**
SEARCH	**char*8**	**Target search type: SPIRAL, SCAN**
CENTROID	**char*8**	**centroid peak-up or peak-down spiral or scan**
NSPIRAL	**integer**	**spiral size**
NXSCAN	**integer**	**x-scan size**
NYSCAN	**integer**	**y-scan size**
XS_STEP	**real*4**	**x-scan step size**
YS_STEP	**real*4**	**y-scan step size**
CR_ELIM	**char*8**	**Cosmic ray elimination during ACQ/PEAK (YES/NO)**
CHECK_BOX	**integer**	**ACQ check-box size**
ACTHRESH	**integer**	**ACQ threshold**
ACQ_AREA	**integer**	**ACQ area**
XOFF1	**real*4**	**x-offset1 for crowded field acquisition**
YOFF1	**real*4**	**y-offset1 for crowded field acquisition**
XOFF2	**real*4**	**x-offset2 for crowded field acquisition**
YOFF2	**real*4**	**y-offset2 for crowded field acquisition**
XOFF3	**real*4**	**x-offset3 for crowded field acquisition**
YOFF3	**real*4**	**y-offset3 for crowded field acquisition**
ACQMIN	**integer**	**minimum value in target acquisition peak-up/down scan or spiral**
ACQMAX	**integer**	**minimum value in target acquisition peak-up/down scan or spiral**

/ INSTRUMENT STATUS

<selected TBD temperatures, remaining mechanism positions, currents, and voltages>

/ STATISTICAL KEYWORDS

DATE	**date this file was written (dd/mm/yy)**
PODPSFF	0=(no podps fill), 1=(podps fill present)
STDCFFF	0=(no st dcf fill), 1=(st dcf fill present)

STDCFFP		st dcf fill pattern (hex)

/ TIME CONVERSION KEYWORDS

CLKDRFTR		**spacecraft clock drift rate**
CLKRATE		**spacecraft clock rate**
SPCLINCN		**spacecraft clock at UTC0**
UTCO1		**bytes 5-8 of UTC0**
UTCO2		**bytes 1-4 of UTC0**
UTC0		**Coordinated Universal Time (Mod Julian Date)**

/SUPPORT SCHEDULE: FLAGS AND INDICATORS

SS_MODE	char*8	Observation mode (ACCUM, TIME-TAGGED, ...)
SS_DET	char*8	Detector (MA1, MA2, CCD)
SS_DISP	char*8	Disperser
SS_APER	char*8	Aperture Identification
RTAMATCH		above f&i match RTA (TRUE, FALSE, NO TRA F&I AVL)

/ SUPPORT SCHEDULE: PROGRAMMATIC DATA

PROGRMID	program id (base 36)
PR_INV_L	last name of principal investigator
PR_INV_F	first name of principal investigator
PR_INV_M	middle initial of principal investigator
AFFILIAT	proposal class (eg: GO, IDT, OS)
ACCPDATE	proposal acceptance date (yyyyddd)
OBSET_ID	observation set id
CALIBRAT	calibrate data flag
OBSERVTN	observation number (base 36)
EXPACKET	expected number of source packets
PRODTYPE	output product medium type
OPFORMAT	output product format specification
CALIBTYP	calibration type : E, I or Blank
CDBSDATA	cdbs notification flag: 'CAL' or 'FALSE'

/ SUPPORT SCHEDULE: DATA GROUP II DATA

WRD11_14	word 11/14 (0-255)
PSTRTIME	predicted obs. start time (yyyy.ddd:hh:mm:ss)
PSTPTIME	predicted obs. stop time (yyyy.ddd:hh:mm:ss)
APEROBJ	si object aperture id
APERSKY	si sky aperture id
TARG_ID	SPSS target ID from proposal+target no.
APERTYPE	aperture type (SICS, SIAS, SIDS)
RA_V1	right ascension of v1 axis of st (deg)
DEC_V1	declination of v1 axis of st (deg)
PA_V3	position angle of v3 axis of st (deg)
APEROFFX	x comp of object offset in aperture (arcsec)
APEROFFY	y comp of object offset in aperture (arcsec)

ANGLESEP	ang separation of target from ref obj (arcsec)
DGESTAR	FGS ID(F1,F2,F3) concat. w/ dom. gd. star id
SGESTAR	FGS ID(F1,F2,F3) concat. w/ subdom. gd. star id
PA_APER	position ang of aperture used with target (deg)
PA_REF	position ang of target from ref. object (deg)
SAAAVOID	SAA model for SAA Avoidance (range 02-99)
TARAQMOD	target acquisition mode (values 00, 01, 02, 03)
POSTNSTX	position of space telescope x axis (km)
POSTNSTY	position of space telescope y axis (km)
POSTNSTZ	position of space telescope z axis (km)
VELOCSTX	vel of space telescope along x axis (km/sec)
VELOCSTY	vel of space telescope along y axis (km/sec)
VELOCSTZ	vel of space telescope along z axis (km/sec)
RA_SUN	right ascension of the sun (deg)
DEC_SUN	declination of the sun (deg)
RA_MOON	right ascension of the moon (deg)
DEC_MOON	declination of the moon (deg)
VELABBRA	aberration in position of the target
ANNPARRA	par. shift in position, non-solar sys target
V2APERCE	V2 offset of target from aper. center (arcsec)
V3APERCE	V3 offset of target from aper. center (arcsec)
EQRADTRG	equatorial radius of target (km)
FLATNTRG	flattening of target
NPDECTRG	north pole declination of target (deg)
NPRATRG	north pole right ascension of target (deg)
ROTRTTRG	rotation rate of target
LONGPMER	longitude of prime meridian (deg)
EPLONGPM	epoch of longitude of prime meridian (sec)
SURFLATD	surface feature latitude (deg)
SURFLONG	surface feature longitude (deg)
SURFALTD	surface feature altitude (km)
MTFLAG	moving target flag; T if it is a moving target
S0INVMAG	S0 inverse magnitude
S0XDIR	S0 X direction
S0YDIR	S0 Y direction
S0ZDIR	S0 Z direction
TRK_TYPE	track 48 or track 51 commanding used (T48, T51,
T51_RATE	rate of motion commanded (arcsecs/sec)
T51_ANGL	position angle of motion of aperture (deg)
TARGDIST	distance to target from Earth's center (km)
PAR_CORR	parallax correction used (T or F)
RA_REF	right ascension of reference object (deg)
DEC_REF	declination of reference object (deg)

/ ONBOARD EPHEMERIS MODEL PARAMETERS

EPCHTIME	epoch time of parameters (secs since 1/1/85)
SDMEANAN	2nd deriv coef for mean anomaly (revs/sec/sec)
SDMA3SQ	3 * (SDMEANAN**2) radians/second**2.
HSTHORB	half the duration of the ST orbit (seconds)
CIRVELOC	circular orbit linear velocity (meters/second)
COSINCLI	cosine of inclination
ECCENTRY	eccentricity

FDMEANAN		1st derivative coef for mean anomly (revs/sec)
RCASCNRD		rt chge right ascension ascend node (rads/sec)
RCASCNRV		rt chge right ascension ascend node (revs/sec)
ARGPERIG		argument of perigee (revolutions)
MEANANOM		mean anomaly (radians)
RCARGPER		rate change of argument of perigee (revs/sec)
RASCASCN		right ascension of ascending node (revolutions)
SINEINCL		sine of inclination
SEMILREC		semi-latus rectum (meters)
TIMEFFEC		time parameters took effect (secs since 1/1/85)
OBSSTRTT		predicted obs. start time (secs since 1/1/85)

/ PROPOSAL INFO: Instrument Configuration

CONFIG	char*8	proposed instrument configuration
OPMODE	char*8	proposed operation mode
TARGTYPE	char*8	target type POINT, CFIELD, DFIELD, UNKOWN
LAMBDA1	real*4	Proposal wavelength sub-array 1
LAMBDA2	real*4	Proposal wavelength sub-array 2
LAMBDA3	real*4	Proposal wavelength sub-array 3
LAMBDA4	real*4	Proposal wavelength sub-array 4
LAMBDA5	real*4	Proposal wavelength sub-array 5
LAMBDA6	real*4	Proposal wavelength sub-array 6
LAMBDA7	real*4	Proposal wavelength sub-array 7
LAMBDA8	real*4	Proposal wavelength sub-array 8

/ PROPOSAL INFO: Target Description

TAR_TYPE		target type
TARDESCR		target description
TARGESC2		target description (cont.)
TARGCAT		first target category
TARKEY1		target key description for targcat
TARKEY2		target key description for targcat
TARKEY3		target key description for targcat
TARKEY4		target key description for targcat
TARKEY5		target key description for targcat
TARGCAT2		second target category
TARKEY6		target key description for targcat
TARKEY7		target key description for targcat
TARKEY8		target key description for targcat
TARKEY9		target key description for targcat
TARKEY10		target key description for targcat
ALIAS1		synonym for target name
ALIAS2		synonym for target name

/ PROPOSAL INFO: Flux Information

MAG_V		expected V Magnitude
SURF_V		expected V surface brightness
MAG_B		expected B Magnitude
SURF_B		expected B surface brightness
MAG_U		expected U Magnitude

SURF_U	expected U surface brightness
MAG_R	expected R Magnitude
SURF_R	expected R surface brightness
COL_B_V	expected B-V color
COL_U_B	expected U-B color
COL_V_R	expected V-R color
E_B_V	E(B-V)
EXTNCT_V	extinction in V

/ PROPOSAL INFO: Exposure Information

CMD_EXP	commanded time per exposure (from TRANS)

/ PROPOSAL INFO: Moving Target Information

MT_LV1_1	moving target information
MT_LV1_2	moving target information
MT_LV1_3	moving target information
MT_LV1_4	moving target information
MT_LV1_5	moving target information
MT_LV2_1	moving target information
MT_LV2_2	moving target information
MT_LV2_3	moving target information
MT_LV2_4	moving target information
MT_LV2_5	moving target information
MT_LV3_1	moving target information
MT_LV3_2	moving target information
MT_LV3_3	moving target information
MT_LV3_4	moving target information
MT_LV3_5	moving target information

/ PROPOSAL INFO: Target Properties

REDSHIFT	target redshift from proposal
PARALLAX	target parallax from proposal
RA_PROP	target right ascension from proposal (degrees)
DEC_PROP	target declination from proposal (degrees)
PEQUINOX	equinox of coordinate system from proposal
MU_RA	target proper motion from proposal (degrees RA)
MU_DEC	target proper motion from proposal (degrees DEC)
MU_EPOCH	epoch of proper motion from proposal
SP_TYPE	target spectral type from proposal
RAD_VEL	target radial velocity from proposal (km/sec)

/ PROPOSAL INFO: Spatial Scan Info

SCAN_TYP	C:bostrophidon; D:'C'with dwell; N:not applicab
SCAN_WID	scan width (arcsec)
ANG_SIDE	angle between sides of parallelogram (deg)
DWELL_LN	dwell pts/line for scan pointing (1-99,0 if NA)

DWELL_TM	wait time (duration) at each dwell point (sec)
SCAN_ANG	position angle of scan line (deg)
SCAN_RAT	commanded rate of the line scan (arcsec/sec)
NO_LINES	number of lines per scan (1-99,0 if NA)
SCAN_LEN	scan length (arcsec)
SCAN_COR	scan coordinate frame of ref: celestial,vehicle

/ PROPOSAL INFO: Auxiliary

PARENTID	PEP proposal identifier of the parent proposal

/ TARGET & PROPOSAL ID

TARGNAME	proposer's target name
RA_TARG	right ascension of the target (deg) (J2000)
DEC_TARG	declination of the target (deg) (J2000)
PROPOSID	PEP proposal identifier
PEP_EXPO	PEP exposure identifier including sequence
LINENUM	proposal line number
SEQLINE	PEP line number of defined sequence
SEQNAME	PEP define/use sequence name

END

STIS PROTOTYPE GRATING MODE SCIENCE DATA HEADER

SIMPLE = F	**image conforms to the fits standard**
BITPIX	**bits per data value**
DATATYPE	**datatype of the array**
NAXIS	**number of data axes**
NAXIS1	**length of first data axis**
NAXIS2	**length of second data axis**
GROUPS = T	**image is in group format**
GCOUNT	**number of groups**
PCOUNT	**number of group parameters**
PSIZE	**bits in the group parameter block**

/ GROUP PARAMETERS

PTYPE1 = RA_APER	right ascension of aperture (deg)
PDTYPE1 = REAL*8	
PSIZE1 = 64	
PTYPE2 = DEC_APER	declination of aperture (deg)
PDTYPE2 = REAL*8	
PSIZE2 = 64	
PTYPE3 = FILLCNT	**number of segments containing fill**
PDTYPE3 = INTEGER*4	
PSIZE3 = 32	
PTYPE4 = ERRCNT	**Number of segments containing errors**
PDTYPE4 = INTEGER*4	
PSIZE4 = 32	
PTYPE5 = FPKTTIME	**time of the first packet (MJD)**
PDTYPE5 = REAL*8	
PSIZE5 = 64	
PTYPE6 = LPKTTIME	**time of the last packet (MJD)**
PDTYPE6 = REAL*8	
PSIZE6 = 64	
PTYPE7 = SSTART	**starting sample of the image or sub-image**
PDTYPE7 = INTEGER*4	
PSIZE7 = 32	
PTYPE8 = LSTART	**starting line of the image or sub-image**
PDTYPE8 = INTEGER*4	
PSIZE8 = 32	
PTYPE9 = EXPOSURE	**Exposure time (Seconds)**
PDTYPE9 = REAL*4	**(Modified Julian Date)**
PSIZE9 = 32	
PTYPE10 = NITERUPT	**Number of exposure interupts**
PDTYPE10= INTEGER*4	
PSIZE10 = 32	
PTYPE11 = START1	**exposure start time**
PDTYPE11= REAL*8	**(Modified Julian Date)**
PSIZE11 = 64	
PTYPE12 = STOP1	**exposure stop time (for first interupt)**
PDTYPE12= REAL*8	**(Modified Julian Date)**

PSIZE12 = 64		
PTYPE13 = START2		**exposure start time**
PDTYPE13= REAL*8		**(Modified Julian Date)**
PSIZE13 = 64		
PTYPE14 = STOP2		**exposure stop time (for second interupt)**
PDTYPE14= REAL*8		**(Modified Julian Date)**
PSIZE14 = 64		
PTYPE15 = START3		**exposure start time**
PDTYPE15= REAL*8		**(Modified Julian Date)**
PSIZE15 = 64		
PTYPE16 = STOP3		**exposure stop time (for third interupt)**
PDTYPE16= REAL*8		**(Modified Julian Date)**
PSIZE16 = 64		
PTYPE17 = START4		**exposure start time**
PDTYPE17= REAL*8		**(Modified Julian Date)**
PSIZE17 = 64		
PTYPE18 = STOP4		**exposure stop time (for forth interupt)**
PDTYPE18= REAL*8		**(Modified Julian Date)**
PSIZE18 = 64		

/ STIS DATA DESCRIPTOR KEYWORDS

INSTRUME		**instrument in use**
ROOTNAME		**rootname of the observation set**
FILETYPE		**shp, udl, sci, dmp, edd, ttg, psd**

/ INSTRUMENT CONFIGURATION

OBSMODE	**char*8**	**ACCUM, TIME-TAG, PSD**
DETECTOR	**char*8**	**MA1, MA2, or CCD**
DISPERSER	**char*8**	**Mode Select dispersion or mirror element ID**
WCENTER	**real*4**	**Central wavelength of the spectral format**
MCENTER	**integer**	**Central order number (1 for first order gratings)**
MSM_ENC1	**integer**	**Mode Select Mechanism encoder value 1**
MSM_ENC2	**integer**	**Mode Select Mechanism encoder value 2**
MSM_ENC3	**integer**	**Mode Select Mechanism encoder value 3**
SLIT_NUM	**integer**	**Slit number**
SLIT	**char*8**	**Slit or filter identification**
SLIT_ENC	**integer**	**Slit wheel encoder position**
CCDGAIN1	**integer**	**Gain for CCD amplifier 1 (0 if amp. not used)**
CCDGAIN2	**integer**	**Gain for CCD amplifier 2 (0 if amp. not used)**
CCDGAIN3	**integer**	**Gain for CCD amplifier 3 (0 if amp. not used)**
CCDGAIN4	**integer**	**Gain for CCD amplifier 4 (0 if amp. not used)**
CCDOFF1	**integer**	**CCD bias offset number 1**
CCDOFF2	**integer**	**CCD bias offset number 2**
CCDOFF3	**integer**	**CCD bias offset number 3**
CCDOFF4	**integer**	**CCD bias offset number 4**
VDDAB	**real*4**	**CCD Bias voltage VddAB**
VODAB	**real*4**	**CCD Bias voltage VodAB**
VLGAB	**real*4**	**CCD Bias voltage VlgAB**
VDDCD	**real*4**	**CCD Bias voltage VddCD**
VODCD	**real*4**	**CCD Bias voltage VodCD**
VLGCD	**real*4**	**CCD Bias voltage VlgCD**

SUBIMAGE	**integer**	**Number of subimages**
NXSUM	**integer**	**Data bin size in sample direction**
NYSUM	**integer**	**Data bin size in line direction**
DOPCOR	**char*8**	**On-board doppler correction enabled (YES, NO)**
DOPZERO	**real*8**	**Doppler shift zero phase time (MJD)**
DOPMAG	**real*4**	**Doppler shift magnitude (Hi-Res Pixels)**
KR_LAMP	**integer**	**Krypton lamp status (1 - on, 0 - off)**
DE_LAMP	**integer**	**Deuterium lamp status**
T1_LAMP	**integer**	**Tungsten lamp bulb 1 status**
T2_LAMP	**integer**	**Tungsten lamp bulb 2 status**
T3_LAMP	**integer**	**Tungsten lamp bulb 3 status**
T4_LAMP	**integer**	**Tungsten lamp bulb 4 status**
PT1_LAMP	**integer**	**Pt-Ne-Cr lamp 1 status**
PT2_LAMP	**integer**	**Pt-Ne-Cr lamp 2 status**
PT3_LAMP	**integer**	**Pt-Ne-Cr lamp 3 status**
PSHIFT	**integer**	**Parallel shift and dwell, Shift value**
PDWELL	**real*4**	**Parallel shift and dwell, Dwell value**
SLITPOS	**real*4**	**Target position within slit (if set by flight software)**
TOT_EXPO	**real*4**	**Total Exposure time (all readouts)**
WAVECAL1	**char*18**	**Rootname of wavecal taken prior to obs.**
WAVECAL2	**char*18**	**Rootname of wavecal taken after the obs.**

/ CALIBRATION SWITCHES

DQICORR	char*8	Do data quality initialization (PERFORM, OMIT, COMPLETE
ERRCORR	char*8	propagate statistical errors or SKIPPED)
BLEVCORR	char*8	subtract bias level computed from overscan image
BIASCORR	char*8	Subtract bias image
EXPCORR	char*8	Convert to count rates
NLINCORR	char*8	Correct for detector non-linearities
DARKCORR	char*8	Subtract dark image
FLATCORR	char*8	Do flat field correction
FINDCORR	char*8	Find spectral order positions
EXTCORR	char*8	Perform spectral extraction
BACKCORR	char*8	Compute and subtract background, sky, or interorder
WAVECORR	char*8	Use input wavecal to adjust dispersion coefficients
ADCCORR	char*8	Compute wavelengths from dispersion coefficients
OFFCORR	char*8	Apply internal/external wavelength offsets
HELCORR	char*8	Convert to heliocentric wavelengths
RIPCORR	char*8	Echelle ripple correction
ABSCORR	char*8	Convert to absolute flux units
EXTTYPE	char*8	point source or extended object extraction
LORESCNV	char*8	Convert MAMA data to Lo-Res mode before processing
DQIOUT	char*8	Type of data quality output (table, image, or none)
ERROUT	char*8	Type of statistical error image (image, model in header keywords, or none)
EMETHOD	char*8	Extract method (values TBD)

/ CALIBRATION REFERENCE FILES

BIASFILE	char*18	bias image file name (name of header file)
DARKFILE	char*18	dark image file name
FLTFILE1	char*18	flat field file name (1st wavelength)

FLTFILE2	char*18	flat field file name (2nd wavelength)
FLTFILE3	char*18	flat field file name (3rd wavelength)
FLTFILE4	char*18	flat field file name (4th wavelength)
FLTFILE5	char*18	flat field file name (5th wavelength)
FLTFILE6	char*18	flat field file name (6th wavelength)
FLTFILE7	char*18	flat field file name (7th wavelength)
FLTFILE8	char*18	flat field file name (8th wavelength)
FLTFILE9	char*18	flat field file name (9th wavelength)
BPIXTAB	char*18	bad pixel table
APERTAB	char*18	Aperture description table (aperture size, position of occulting bars, ect)
SLOCTAB	char*18	spectral order location table
DISTTAB	char*18	spatial distortion (table or image file is TBD)
DCTAB	char*18	dispersion coefficient table
IATAB	char*18	incidence angle correction table
OFFTAB	char*18	internal/external wavelength offset table
BACKTAB	char*18	background subtraction parameter table
INTERTAB	char*18	echelle interorder scattered light correction coefficients
RIPTAB	char*18	echelle ripple coefficients
TPUTTAB	char*18	relative aperture throughput table (including throughput for position within slit)
ABSTAB	char*18	absolute sensitivity table

/ EXPOSURE INFORMATION

EQUINOX	equinox of the celestial coordinate system
SUNANGLE	angle between sun and V1 axis (deg)
MOONANGL	angle between moon and V1 axis (deg)
SUN_ALT	altitude of the sun above Earth's limb (deg)
FGSLOCK	commanded FGS lock (FINE,COARSE, GYROS,UNKNOWN)
DATE-OBS	**UT date of start of observation (dd/mm/yy)**
TIME-OBS	**UT time of start of observation (hh:mm:ss)**
EXPSTART	**exposure start time (Modified Julian Date)**
EXPEND	**exposure end time (Modified Julian Date)**
EXPTIME	**exposure duration (seconds)--calculated**
EXPFLAG	Exposure interruption indicator

/ STATISTICAL KEYWORDS

DATE	**date this file was written (dd/mm/yy)**
PODPSFF	0=(no podps fill), 1=(podps fill present)
STDCFFF	0=(no st dcf fill), 1=(st dcf fill present)
STDCFFP	st dcf fill pattern (hex)

/ TARGET & PROPOSAL ID

TARGNAME	proposer's target name
RA_TARG	right ascension of the target (deg) (J2000)
DEC_TARG	declination of the target (deg) (J2000)
PROPOSID	PEP proposal identifier
PEP_EXPO	PEP exposure identifier including sequence
LINENUM	proposal line number
SEQLINE	PEP line number of defined sequence
SEQNAME	PEP define/use sequence name

END

STIS PROTOTYPE CAMERA AND OBJECTIVE PRISM MODE SCIENCE DATA HEADER

SIMPLE = F	**image conforms to the fits standard**
BITPIX	**bits per data value**
DATATYPE	**datatype of the array**
NAXIS	**number of data axes**
NAXIS1	**length of first data axis**
NAXIS2	**length of second data axis**
GROUPS = T	**image is in group format**
GCOUNT	**number of groups**
PCOUNT	**number of group parameters**
PSIZE	**bits in the group parameter block**

/ GROUP PARAMETERS

PTYPE1 = CRVAL1	R.A. of reference pixel (deg)
PDTYPE1 = REAL*8	
PSIZE1 = 64	
PTYPE2 = CRVAL2	DEC of reference pixel (deg)
PDTYPE2 = REAL*8	
PSIZE2 = 64	
PTYPE3 = CRPIX1	x-coordinate of reference pixel
PDTYPE3 = REAL*4	
PSIZE3 = 32	
PTYPE4 = CRPIX2	y-coordinate of reference pixel
PDTYPE4 = REAL*4	
PSIZE4 = 32	
PTYPE5 = CD1_1	partial of RA w.r.t. x
PDTYPE5 = REAL*4	
PSIZE5 = 32	
PTYPE6 = CD1_2	partial of RA w.r.t. y
PDTYPE6 = REAL*4	
PSIZE1 = 32	
PTYPE7 = CD2_1	partial of DEC w.r.t. x
PDTYPE7 = REAL*4	
PSIZE7 = 32	
PTYPE8 = CD2_2	parial of DEC w.r.t. y
PDTYPE8 = REAL*4	
PSIZE8 = 32	
PTYPE9 = FILLCNT	**number of segments containing fill**
PDTYPE9 = INTEGER*4	
PSIZE9 = 32	
PTYPE10 = ERRCNT	**Number of segments containing errors**
PDTYPE10= INTEGER*4	
PSIZE10 = 32	
PTYPE11 = FPKTTIME	**time of the first packet (MJD)**
PDTYPE11= REAL*8	
PSIZE11 = 64	
PTYPE12 = LPKTTIME	**time of the last packet (MJD)**
PDTYPE12= REAL*8	

PSIZE12 = 64
PTYPE13 = CTYPE1 first coordinate type
PDTYPE13= CHARACTER*8
PSIZE13 = 64
PTYPE14 = CTYPE2 second coordinate type
PDTYPE14= CHARACTER*8
PSIZE14 = 64
PTYPE15 = SSTART starting sample of the image or sub-image
PDTYPE15= INTEGER*4
PSIZE15 = 32
PTYPE16 = LSTART starting line of the image or sub-image
PDTYPE16= INTEGER*4
PSIZE16 = 32
PTYPE17 = EXPOSURE Exposure time (Seconds)
PDTYPE17= REAL*4 (Modified Julian Date)
PSIZE17 = 32
PTYPE18 = NITERUPT Number of exposure interupts
PDTYPE18= INTEGER*4
PSIZE18 = 32
PTYPE19 = START1 exposure start time
PDTYPE19= REAL*8 (Modified Julian Date)
PSIZE19 = 64
PTYPE20 = STOP1 exposure stop time (for first interupt)
PDTYPE20= REAL*8 (Modified Julian Date)
PSIZE20 = 64
PTYPE21 = START2 exposure start time
PDTYPE21= REAL*8 (Modified Julian Date)
PSIZE21 = 64
PTYPE22 = STOP2 exposure stop time (for second interupt)
PDTYPE22= REAL*8 (Modified Julian Date)
PSIZE22 = 64
PTYPE23 = START3 exposure start time
PDTYPE23= REAL*8 (Modified Julian Date)
PSIZE23 = 64
PTYPE24 = STOP3 exposure stop time (for third interupt)
PDTYPE24= REAL*8 (Modified Julian Date)
PSIZE24 = 64
PTYPE25 = START4 exposure start time
PDTYPE25= REAL*8 (Modified Julian Date)
PSIZE25 = 64
PTYPE26 = STOP4 exposure stop time (for forth interupt)
PDTYPE26= REAL*8 (Modified Julian Date)
PSIZE26 = 64

/ STIS DATA DESCRIPTOR KEYWORDS

INSTRUME instrument in use
ROOTNAME rootname of the observation set
FILETYPE shp, udl, sci, dmp, edd, ttg, psd

/ INSTRUMENT CONFIGURATION

OBSMODE char*8 ACCUM, TIME-TAG, PSD

DETECTOR	**char*8**	**MA1, MA2, or CCD**
DISPERSER	**char*8**	**Mode Select dispersion or mirror element ID**
WCENTER	**real*4**	**Central wavelength of the spectral format**
MCENTER	**integer**	**Central order number (1 for first order gratings)**
MSM_ENC1	**integer**	**Mode Select Mechanism encoder value 1**
MSM_ENC2	**integer**	**Mode Select Mechanism encoder value 2**
MSM_ENC3	**integer**	**Mode Select Mechanism encoder value 3**
SLIT_NUM	**integer**	**Slit number**
SLIT	**char*8**	**Slit or filter identification**
SLIT_ENC	**integer**	**Slit wheel encoder position**
CCDGAIN1	**integer**	**Gain for CCD amplifier 1 (0 if amp. not used)**
CCDGAIN2	**integer**	**Gain for CCD amplifier 2 (0 if amp. not used)**
CCDGAIN3	**integer**	**Gain for CCD amplifier 3 (0 if amp. not used)**
CCDGAIN4	**integer**	**Gain for CCD amplifier 4 (0 if amp. not used)**
CCDOFF1	**integer**	**CCD bias offset number 1**
CCDOFF2	**integer**	**CCD bias offset number 2**
CCDOFF3	**integer**	**CCD bias offset number 3**
CCDOFF4	**integer**	**CCD bias offset number 4**
VDDAB	**real*4**	**CCD Bias voltage VddAB**
VODAB	**real*4**	**CCD Bias voltage VodAB**
VLGAB	**real*4**	**CCD Bias voltage VlgAB**
VDDCD	**real*4**	**CCD Bias voltage VddCD**
VODCD	**real*4**	**CCD Bias voltage VodCD**
VLGCD	**real*4**	**CCD Bias voltage VlgCD**
SUBIMAGE	**integer**	**Number of subimages**
NXSUM	**integer**	**Data bin size in sample direction**
NYSUM	**integer**	**Data bin size in line direction**
DOPCOR	**char*8**	**On-board doppler correction enabled (YES, NO)**
DOPZERO	**real*8**	**Doppler shift zero phase time (MJD)**
DOPMAG	**real*4**	**Doppler shift magnitude (Hi-Res Pixels)**
KR_LAMP	**integer**	**Krypton lamp status (1 - on, 0 - off)**
DE_LAMP	**integer**	**Deuterium lamp status**
T1_LAMP	**integer**	**Tungsten lamp bulb 1 status**
T2_LAMP	**integer**	**Tungsten lamp bulb 2 status**
T3_LAMP	**integer**	**Tungsten lamp bulb 3 status**
T4_LAMP	**integer**	**Tungsten lamp bulb 4 status**
PT1_LAMP	**integer**	**Pt-Ne-Cr lamp 1 status**
PT2_LAMP	**integer**	**Pt-Ne-Cr lamp 2 status**
PT3_LAMP	**integer**	**Pt-Ne-Cr lamp 3 status**
PSHIFT	**integer**	**Parallel shift and dwell, Shift value**
PDWELL	**real*4**	**Parallel shift and dwell, Dwell value**
SLITPOS	**real*4**	**Target position within slit (if set by flight software)**
TOT_EXPO	**real*4**	**Total Exposure time (all readouts)**
WAVECAL1	**char*18**	**Rootname of wavecal taken prior to obs.**
WAVECAL2	**char*18**	**Rootname of wavecal taken after the obs.**

/ CALIBRATION SWITCHES

DQICORR	char*8	Do data quality initialization (PERFORM, OMIT, COMPLETE
ERRCORR	char*8	propagate statistical errors or SKIPPED)
BLEVCORR	char*8	subtract bias level computed from overscan image
BIASCORR	char*8	Subtract bias image
EXPCORR	char*8	Convert to count rates
NLINCORR	char*8	Correct for detector non-linearities

DARKCORR	char*8	Subtract dark image
FLATCORR	char*8	Do flat field correction
FINDCORR	char*8	Find spectral order positions
EXTCORR	char*8	Perform spectral extraction
BACKCORR	char*8	Compute and subtract background, sky, or interorder
WAVECORR	char*8	Use input wavecal to adjust dispersion coefficients
ADCCORR	char*8	Compute wavelengths from dispersion coefficients
OFFCORR	char*8	Apply internal/external wavelength offsets
HELCORR	char*8	Convert to heliocentric wavelengths
RIPCORR	char*8	Echelle ripple correction
ABSCORR	char*8	Convert to absolute flux units
EXTTYPE	char*8	point source or extended object extraction
LORESCNV	char*8	Convert MAMA data to Lo-Res mode before processing
DQIOUT	char*8	Type of data quality output (table, image, or none)
ERROUT	char*8	Type of statistical error image (image, model in header keywords, or none)
EMETHOD	char*8	Extract method (values TBD)

/ CALIBRATION REFERENCE FILES

BIASFILE	char*18	bias image file name (name of header file)
DARKFILE	char*18	dark image file name
FLTFILE1	char*18	flat field file name (1st wavelength)
FLTFILE2	char*18	flat field file name (2nd wavelength)
FLTFILE3	char*18	flat field file name (3rd wavelength)
FLTFILE4	char*18	flat field file name (4th wavelength)
FLTFILE5	char*18	flat field file name (5th wavelength)
FLTFILE6	char*18	flat field file name (6th wavelength)
FLTFILE7	char*18	flat field file name (7th wavelength)
FLTFILE8	char*18	flat field file name (8th wavelength)
FLTFILE9	char*18	flat field file name (9th wavelength)
BPIXTAB	char*18	bad pixel table
APERTAB	char*18	Aperture description table (aperture size, position of occulting bars, ect)
SLOCTAB	char*18	spectral order location table
DISTTAB	char*18	spatial distortion (table or image file is TBD)
DCTAB	char*18	dispersion coefficient table
IATAB	char*18	incidence angle correction table
OFFTAB	char*18	internal/external wavelength offset table
BACKTAB	char*18	background subtraction parameter table
INTERTAB	char*18	echelle interorder scattered light correction coefficients
RIPTAB	char*18	echelle ripple coefficients
TPUTTAB	char*18	relative aperture throughput table (including throughput for position within slit)
ABSTAB	char*18	absolute sensitivity table

/ EXPOSURE INFORMATION

EQUINOX	equinox of the celestial coordinate system
SUNANGLE	angle between sun and V1 axis (deg)
MOONANGL	angle between moon and V1 axis (deg)

SUN_ALT	altitude of the sun above Earth's limb (deg)
FGSLOCK	commanded FGS lock (FINE,COARSE, GYROS,UNKNOWN)
DATE-OBS	**UT date of start of observation (dd/mm/yy)**
TIME-OBS	**UT time of start of observation (hh:mm:ss)**
EXPSTART	**exposure start time (Modified Julian Date)**
EXPEND	**exposure end time (Modified Julian Date)**
EXPTIME	**exposure duration (seconds)--calculated**
EXPFLAG	Exposure interruption indicator

/ STATISTICAL KEYWORDS

DATE	**date this file was written (dd/mm/yy)**
PODPSFF	0=(no podps fill), 1=(podps fill present)
STDCFFF	0=(no st dcf fill), 1=(st dcf fill present)
STDCFFP	st dcf fill pattern (hex)

/ TARGET & PROPOSAL ID

TARGNAME	proposer's target name
RA_TARG	right ascension of the target (deg) (J2000)
DEC_TARG	declination of the target (deg) (J2000)
PROPOSID	PEP proposal identifier
PEP_EXPO	PEP exposure identifier including sequence
LINENUM	proposal line number
SEQLINE	PEP line number of defined sequence
SEQNAME	PEP define/use sequence name

END

STIS PROTOTYPE TIME-TAGGED TABLE HEADER

INSTRUME		**instrument in use**
ROOTNAME		**rootname of the observation set**
FILETYPE		**ttg (time-tagged data)**
FILLCNT		**number of segments containing fill**
ERRCNT		**Number of segments containing errors**
FPKTTIME		**time of the first packet (MJD)**
LPKTTIME		**time of the last packet (MJD)**
	/ INSTRUMENT CONFIGURATION	
OBSMODE	**char*8**	**TIME-TAG**
DETECTOR	**char*8**	**MA1, MA2**
DISPERSER	**char*8**	**Mode Select dispersion or mirror element ID**
WCENTER	**real*4**	**Central wavelength of the spectral format**
MCENTER	**integer**	**Central order number (1 for first order gratings)**
MSM_ENC1	**integer**	**Mode Select Mechanism encoder value 1**
MSM_ENC2	**integer**	**Mode Select Mechanism encoder value 2**
MSM_ENC3	**integer**	**Mode Select Mechanism encoder value 3**
SLIT_NUM	**integer**	**Slit number**
SLIT	**char*8**	**Slit or filter identification**
SLIT_ENC	**integer**	**Slit wheel encoder position**
SUBIMAGE	**integer**	**Number of subimages**
NXSUM	**integer**	**Data bin size in sample direction**
NYSUM	**integer**	**Data bin size in line direction**
	/ EXPOSURE INFORMATION	
DATE-OBS		**UT date of start of observation (dd/mm/yy)**
TIME-OBS		**UT time of start of observation (hh:mm:ss)**
EXPSTART		**exposure start time (Modified Julian Date)**
EXPEND		**exposure end time (Modified Julian Date)**
EXPTIME		**exposure duration (seconds)--calculated**
	/ STATISTICAL KEYWORDS	
DATE		**date this file was written (dd/mm/yy)**
PODPSFF		0=(no podps fill), 1=(podps fill present)
STDCFFF		0=(no st dcf fill), 1=(st dcf fill present)
STDCFFP		st dcf fill pattern (hex)
	/ TARGET & PROPOSAL ID	
TARGNAME		proposer's target name
RA_TARG		right ascension of the target (deg) (J2000)
DEC_TARG		declination of the target (deg) (J2000)
PROPOSID		PEP proposal identifier
PEP_EXPO		PEP exposure identifier including sequence
LINENUM		proposal line number
SEQLINE		PEP line number of defined sequence
SEQNAME		PEP define/use sequence name

END

STIS PROTOTYPE BAD PIXEL TABLE HEADER

	/ STIS DATA DESCRIPTOR KEYWORDS	
INSTRUME		**instrument in use**
ROOTNAME		**rootname of the observation set**
FILETYPE		**bpt (bad pixel table)**
NGROUPS		**number of groups in science data file**
	/ INSTRUMENT CONFIGURATION	
OBSMODE	**char*8**	**ACCUM, TIME-TAG, PSD**
DETECTOR	**char*8**	**MA1, MA2, or CCD**
DISPERSER	**char*8**	**Mode Select dispersion or mirror element ID**
	/ EXPOSURE INFORMATION	
DATE-OBS		**UT date of start of observation (dd/mm/yy)**
TIME-OBS		**UT time of start of observation (hh:mm:ss)**
EXPSTART		**exposure start time (Modified Julian Date)**
EXPEND		**exposure end time (Modified Julian Date)**
EXPTIME		**exposure duration (seconds)--calculated**
	/ STATISTICAL KEYWORDS	
DATE		**date this file was written (dd/mm/yy)**
PODPSFF		0=(no podps fill), 1=(podps fill present)
STDCFFF		0=(no st dcf fill), 1=(st dcf fill present)
STDCFFP		st dcf fill pattern (hex)
	/ TARGET & PROPOSAL ID	
TARGNAME		proposer's target name
RA_TARG		right ascension of the target (deg) (J2000)
DEC_TARG		declination of the target (deg) (J2000)
PROPOSID		PEP proposal identifier
PEP_EXPO		PEP exposure identifier including sequence
LINENUM		proposal line number
SEQLINE		PEP line number of defined sequence
SEQNAME		PEP define/use sequence name

END

STIS PROTOTYPE STANDARD HEADER PACKET HEADER

SIMPLE = F	**image conforms to the fits standard**
BITPIX = 16	**bits per data value**
DATATYPE = UNSIGNED*2	**datatype of the array**
NAXIS = 1	**number of data axes**
NAXIS1 = 965	**length of first data axis**
GROUPS = T	**image is in group format**
GCOUNT	**number of groups**
PCOUNT	**number of group parameters**
PSIZE	**bits in the group parameter block**

/ GROUP PARAMETERS:

PTYPE1 = FILLCNT	**number of segments containing fill**
PDTYPE1 = INTEGER*4	
PSIZE1 = 32	
PTYPE2 = ERRCNT	**Number of segments containing errors**
PDTYPE2 = INTEGER*4	
PSIZE2 = 32	
PTYPE3 = PKTTIME	**packet time (MJD)**
PDTYPE3 = REAL*8	
PSIZE3 = 64	

/ STIS DATA DESCRIPTOR KEYWORDS

INSTRUME	**instrument in use**
ROOTNAME	**rootname of the observation set**
FILETYPE	**shp, udl, sci, dmp, edd, ttg, psd, shp**

/ TIME CONVERSION KEYWORDS

CLKDRFTR	**spacecraft clock drift rate**
CLKRATE	**spacecraft clock rate**
SPCLINCN	**spacecraft clock at UTC0**
UTCO1	**bytes 5-8 of UTC0**
UTCO2	**bytes 1-4 of UTC0**
UTC0	**Coordinated Universal Time (Mod Julian Date)**

/ TARGET & PROPOSAL ID

TARGNAME	proposer's target name
RA_TARG	right ascension of the target (deg) (J2000)
DEC_TARG	declination of the target (deg) (J2000)
PROPOSID	PEP proposal identifier
PEP_EXPO	PEP exposure identifier including sequence
LINENUM	proposal line number
SEQLINE	PEP line number of defined sequence
SEQNAME	PEP define/use sequence name

END

STIS PROTOTYPE ED DIAGNOSTIC HEADER

SIMPLE = F	**image conforms to the fits standard**
BITPIX = 16	**bits per data value**
DATATYPE = UNSIGNED*2	**datatype of the array**
NAXIS =2	**number of data axes**
NAXIS1	**number of items sampled**
NAXIS2	**number of samples**
GROUPS = T	**image is in group format**
GCOUNT	**number of groups**
PCOUNT	**number of group parameters**
PSIZE	**bits in the group parameter block**

/ GROUP PARAMETERS

PTYPE1 = FILLCNT	**number of segments containing fill**
PDTYPE = INTEGER*4	
PSIZE1 = 32	
PTYPE2 = ERRCNT	**Number of segments containing errors**
PDTYPE2 = INTEGER*4	
PSIZE2 = 32	
PTYPE3 = FPKTTIME	**time of the first packet (MJD)**
PDTYPE3 = REAL*8	
PSIZE3 = 64	
PTYPE4 = LPKTTIME	**time of the last packet (MJD)**
PDTYPE4 = REAL*8	
PSIZE4 = 64	
PTYPE5 = ITEM	**item number**
PDTYPE5 = INTEGER*4	
PSIZE5 = 32	
PTYPE6 = NAME	**item name**
PDTYPE6 = CHARACTER*8	
PSIZE6 = 64	

/ STIS DATA DESCRIPTOR KEYWORDS

INSTRUME	**instrument in use**
ROOTNAME	**rootname of the observation set**
FILETYPE	**shp, udl, sci, dmp, edd, ttg, psd**
DATE-OBS	**UT date of start of observation (dd/mm/yy)**
TIME-OBS	**UT time of start of observation (hh:mm:ss)**

/ STATISTICAL KEYWORDS

DATE	**date this file was written (dd/mm/yy)**
PODPSFF	0=(no podps fill), 1=(podps fill present)
STDCFFF	0=(no st dcf fill), 1=(st dcf fill present)
STDCFFP	st dcf fill pattern (hex)

/ED DIAGNOSTIC DEFINITION

MODE	**char*8**	**diagnostic mode (FAST or SLOW)**
DELTAT	**real*4**	**sampling frequency in SLOW mode**

END

STIS PROTOTYPE MEMORY DUMP HEADER

SIMPLE = F	**image conforms to the fits standard**
BITPIX = 16	**bits per data value**
DATATYPE = UNSIGNED*2	**datatype of the array**
NAXIS =1	**number of data axes**
NAXIS1	**length of first data axis**
GROUPS = T	**image is in group format**
GCOUNT	**number of groups**
PCOUNT	**number of group parameters**
PSIZE	**bits in the group parameter block**

/ GROUP PARAMETERS

PTYPE1 = FILLCNT	**number of segments containing fill**
PDTYPE = INTEGER*4	
PSIZE1 = 32	
PTYPE2 = ERRCNT	**Number of segments containing errors**
PDTYPE2 = INTEGER*4	
PSIZE2 = 32	
PTYPE3 = FPKTTIME	**time of the first packet (MJD)**
PDTYPE3 = REAL*8	
PSIZE3 = 64	
PTYPE4 = LPKTTIME	**time of the last packet (MJD)**
PDTYPE4 = REAL*8	
PSIZE4 = 64	

/ STIS DATA DESCRIPTOR KEYWORDS

INSTRUME	**instrument in use**
ROOTNAME	**rootname of the observation set**
FILETYPE	**shp, udl, sci, dmp, edd, ttg, psd**
DATE-OBS	**UT date of start of observation (dd/mm/yy)**
TIME-OBS	**UT time of start of observation (hh:mm:ss)**

/MEMORY DUMP DEFINITION

SOURCE	**char*8**	**dump source (CS or MIE)**
ADDRESS	**integer**	**starting address**
NBYTES	**integer**	**number of bytes dumped**

END

Appendix E
Contents of IDL Astronomy User's Library

July, 1994

Astronomical Utilities

A_b - Compute interstellar extinction in the B band as a function of galactic position (as in RC2 catalog, deVaucoulers).
ADSTRING - Format RA and DEC as a character string
AIRTOVAC - Convert air wavelengths to vacuum wavelengths
AITOFF - Convert longitude,latitude to X,Y using Aitoff equal-area projection
AITOFF_GRID - Create an overlay grid using the AITOFF projection
ARCBAR - Draw an arcbar over an image showing the astronomical plate scale
ARROWS - given a FITS header, display a "weathervane" showing N-E orientation
ASTDISP - Display formatter for pixel + astronomical coordinates
ASTRO - Interactive driver to compute astronomical precession, or coordinate conversions (calls EULER and PRECESS).
BARYVEL - Compute components of barycentric Earth velocity, given Julian date
BPRECESS - Precess coordinates, proper motion from J2000 to B1950
CCM_UNRED - Deredden a spectrum using the Cardelli, Clayton and Mathis (1989) parameterization.
CT2LST- Convert from civil time to local sidereal time
DATE - Convert day of year to a DY-MON-YR string
DATE_CONV - Function to perform various date format conversions
DAYCNV- Convert from Julian Date to calender date.
DEREDD- Deredden Stromgren indices (called by UVBYBETA)
EQPOLE - Convert longitude,latitude to X,Y using polar equal-area projection
EQPOLE_GRID - Create overlay grid using polar equal-area projection
EULER - Astronomical coordinate system conversions
FLAT - Correct a galaxy image for inclination effects.
FLUX2MAG - Convert from flux units to magnitudes
GCIRC - Compute rigorous great circle distance
GET_COORDS - Read in angular input in decimal or sexigesimal format
GET_DATE - Get the current date in DD/MM/YY format (FITS standard)
GET_JULDATE - Get the current Julian date as a double precision scalar
GLACTC- Convert between galactic and equatorial coordinates at any equinox
HELIO - Give (low-precision) heliocentric coordinates of the planets (in/jhuapl)
HELIO_JD - Convert geocentric (reduced) julian date to heliocentric julian date
IMCONTOUR - Contour plots with astronomical labeling (either RA,Dec or arc distance from the image center
IMF - Return values for a multi-component power law initial mass function
JDCNV - Convert from calender date to Julian date.
JPRECESS - Precess positions & proper motions from B1950 to J2000
JULDATE-Convert from calender date to reduced Julian date.
MAG2FLUX - Convert from magnitudes to flux units
MOONPOS-Compute the RA and Dec of the moon at a given date
PLANCK - Returns a blackbody flux for a given effective temperature
PRECESS - Precess RA and Dec to a new equinox
PREMAT - Returns precession matrix from equinox 1 to equinox 2
QDCB - Convert RA, Dec to quad cube database coordinates
QDCB_GRID - Create overlay grid using quad cube database coordinates
RADEC - Format RA, Dec as Hours,Min,Sec,Deg,Min,Sec
REDSHIFT - Interactively convert between redshift, distance, and velocity (in /jhuapl)

SIXTY - Convert decimal number to sexigesimal
SPHDIST - Find angular distance on a sphere (in /jhuapl)
STRINGAD - Convert a RA,DEC string to decimal RA and Dec.
SUNPOS - Compute the RA and Dec of the Sun at a given date
TEN - Convert sexigesimal number to decimal
TENV - Like TEN but will work on a vector of sexigesimal numbers.
TICPOS,TICLABELS,TICS,TIC_ONE - procedures called by IMCONTOUR to determine tic positions for contour
plots with astronomical labeling.
UNRED - Deredden an (ultraviolet) flux vector using one of 9 different extinction curves.
UVBYBETA - Use Stromgren indices to derive dereddened colors, metallicity, and effective Temperature.
VACTOAIR - Convert vacuum wavelengths to air wavelengths.
WCSSPH2XY - Convert between longitude,latitude to X,Y angular coordinates for 25 different map projection types
WCSXY2SPH - Inverse of WCSSPH2XY
WCS_DEMO - Demo program for WCSSPH2XY and WCSXY2SPH
XYZ - Compute heliocentric rectangular coordinates at given julian date.
YMD2DN - Convert year,month,day to day number of the year (in /jhuapl)
YDN2MD - Convert day number of the year to year, month,day (in /jhuapl)
ZANG - Compute angular size as a function of redshift in a Friedman cosmology
ZENPOS - Compute the RA and Dec of the local zenith at a given date

DAOPHOT-Type Photometry Procedures

APER - Circular APERture photometry
CNTRD - Obtain the centroid a star in an image array
DAOERF - Calculate the intensity, (and optionally, the derivatives) of a bivariate Gaussian, integrated over pixels.
Called by VALUE
DAO_VALUE - Obtain the value (and optionally, the derivatives) of a PSF, parameterized as a bivariate Gaussian,
and a lookup table of residuals. Called by NSTAR and PKFIT
FIND - FIND point sources within an image
GETPSF - Obtain a PSF (gaussian + residuals) from isolated stars.
GROUP - Place stars with non-overlapping PSF's in distinct groups
MMM - (Mean, Median, Mode) sophisticated sky background computation
NSTAR - Simultaneous PSF fitting of a group of stars
PKFIT - Fit a gaussian + residuals to a isolated star (called by GETPSF)
RDPSF - Read a PSF file that was created by GETPSF into an IDL array.
RINTER - Cubic Interpolation at a set of reference points, optionally obtain derivatives.
SKY - Compute image sky level using MMM
SUBSTAR- Subtract a scaled PSF at specified star positions
T_APER - Like APER but with I/O to a FITS ASCII table
T_FIND - Like FIND but with I/O to a FITS ASCII table
T_GROUP- Like GROUP but with I/O to a FITS ASCII table
T_GETPSF - Like GETPSF but with I/O to a FITS ASCII table
T_NSTAR - Like NSTAR but with I/O to a FITS ASCII table

Database Procedures

DBBUILD - Load or append a database with new entry values.
DBCIRCLE - Find entries within a specified circular area.

DBCLOSE - Close a database
DBCREATE - Create a new database data, index and/or format file.
DBDELETE - Delete an entry from a database
DBEDIT - Interactively edit the entries in a database
DBEXT - Extract items from a database into IDL variables
DBFIND - Find entries meeting specified criteria
DBGET - Use instead of DBFIND when search values are in an IDL vector
DBHELP - List names of databases, or entries within a database
DBINDEX - Update the database index file.
DBMATCH - Match database entries one-to-one to specified item values
DBOPEN - Open a database
DBPRINT - Print specified fields about specified entries
DBSORT - Sort items from a database
DBUPDATE - Update a database with new item values.
DB_OR - Combine two catalog entry lists, removing duplicate values
IMDBASE - Find all catalog sources within the field of an image (given a FITS header with astrometry)
DB_ENT2EXT,DB_ENT2HOST,DBEXT_DBF,DBEXT_IND,DBWRT,DBXPUT,DBFPARSE,
DBFIND_ENTRY,DBFIND_SORT,DBPUT,DBRD,DBSEARCH,DBTITLE,DBXVAL,
DB_INFO, DB_ITEM,DB_ITEM_INFO,DB_TITLES - Lower level database procedures

Disk I/O (AIPS, MIDAS, IRAF files)

AIPSRD - Read an AIPS disk file into IDL image and header arrays (VMS only)
AIPSDIR - Give a listing of AIPS disk files on a directory (VMS only)
AIPSNAME - Create a VAX directory name from an AIPS user number, and image slot number. DST_INFO - Obtain header info from a .DST file. Called by READ_DST
IRAFDIR - Describe IRAF images on specified directory
IRAFRD - Read a disk IRAF image file into IDL variables.
IRAFWRT - Write IDL image and header to an IRAF (.pix & .imh) file
MID_RD_IMAGE - Read a MIDAS image (.BDF) file into IDL variables
MID_UP_IMAGE - Update the contents of a MIDAS image file
MID_RD_TABLE - Read a MIDAS table (.TBL) file into IDL variables
MID_UP_TABLE - Update the contents of a MIDAS table file.
MID_RD_DIRDSC - Lower level procedure to read MIDAS directory descriptor
READ_DST - Function to read a DAOPHOT (.DST) image file (CalTech data structure)

FITS Astrometry and Calibration

ABSCAL - Apply the BSCALE and BZERO FITS keywords values to a data array
AD2XY - Convert RA and DEC to pixel coordinates X,Y assuming a tangent projection, called by ADXY
ADXY - Interactive version of AD2XY
CONS_RA - Obtain the X and Y coordinates of a line of constant right ascension
CONS_DEC - Obtain the X and Y coordinates of a line of constant declination
EXTAST- EXTract ASTrometry parameters from a FITS header into an IDL structure
FITS_CD_FIX - Convert between different representations of the CD matrix
GET_EQUINOX - Return a numeric equinox value from a FITS header
GETROT- GET ROTation and plate scale from a FITS header. Also used to convert coordinate description (CD) parameterization to AIPS type parameterization.
GSSSEXTAST - Extract astrometry parameters from an STScI Survey Image
GSSSADXY - Convert RA, Dec to pixel coordinates for an STScI survey image
GSSSXYAD - Convert pixel coordinates to RA, Dec for an STScI survey image

GSSS_STDAST - Insert the best tangent projection astrometry into an an STScI Guidestar Survey Image
HASTROM-Rotate, Congrid, and/or shift an image until astrometry matches that in a reference FITS header. Used
to align images.
HBOXAVE - Boxaverage an image and update astrometry in a FITS header
HCONGRID - Congrid an image and update astrometry in a FITS header
HEXTRACT - Extract a subimage and update astrometry in a FITS header
HPRECESS - Precess the astrometry in a FITS header to a new equinox.
HREBIN - REBIN an image and update the astrometry in a FITS header
HREVERSE - Reverse an image about either dimension and update astrometry in a FITS header
HROT - Rotate an image and update astrometry in a FITS header.
MKHDR - Make a minimal FITS header for an image array.
PRECESS_CD - Precess coordinate description (CD) matrix in a FITS header to a new equinox.
PUTAST - Put astrometry parameters into a FITS header. If necessary, PUTAST will prompt for the plate scale,
rotation, and coordinates and position of a reference star.
STARAST - Obtain an exact astrometry solution given the coordinates and plate position of 2 or 3 stars. Results
given as a CD (coordinate description) matrix
XYAD - Interactive version of XY2AD
XY2AD - Convert pixel coordinates X,Y to RA,DEC assuming a tangent projection
XYXY - Convert X,Y values on one image to X,Y values in another image using astrometry in the FITS headers

STSDAS modified FITS Image manipulation

ASTRMFIX - Update an HST WF/PC or FOC header with rough astrometry
CONV_STSDAS - Convert internal format of .hhd file to that of the host machine architecture. Useful to copy
STSDAS files between machines
EXTGRP - Extract group parameter values and place them in a header
IMGREAD - Like STRD but supports group format and tailored to WF/PC, FOC files
STRD - Combine functions of SXOPEN and SXREAD to read STSDAS disk files into IDL data and header
variables
STWRT - Combine functions of SXOPEN and SXWRITE to write IDL data and header variables to STSDAS disk
files
SXADDHIST - Add a history record to a FITS or STSDAS header
SXADDPAR - Add or modify a parameter in a FITS or STSDAS header
SXDELPAR - Delete a keyword from a FITS or STSDAS header
SXGINFO - Return info on all group parameters in a FITS header
SXGPAR - Obtain group parameter values from a FITS header and parameter block
SXGREAD - Read group parameters from an STSDAS file
SXHCOPY - Copy a selected portion of one header into another
SXHEDIT - Interactively edit a STSDAS header using EDT or the default UNIX editor
SXHREAD - Read a STSDAS header from disk
SXHWRITE - Write a STSDAS header to disk
SXMAKE - Make a basic STSDAS header from an IDL array
SXOPEN - Open an STSDAS (modified FITS) disk header for subsequent I/O
SXPAR - Obtain the value of a keyword in a FITS or STSDAS header
SXREAD - Read an STSDAS (modified FITS) image from disk
SXWRITE - Write an image to STSDAS (modified FITS) format
WFPCREAD - Read an HST WFPC or FOC STSDAS group image

FITS ASCII Table I/O

FTADDCOL - Add a new column to a FITS ASCII table
FTCREATE - Create an empty FITS ASCII table (H and TAB)
FTDELCOL - Delete specified column from a FITS ASCII table
FTDELROW - Delete specified row(s) from a FITS ASCII table
FTDIR - Give a directory of modified FITS ASCII tables on disk
FTGET - Extract a specified field from a column in a FITS ASCII table
FTHELP - Display the fields in a FITS ASCII table header
FTHMOD - Modify the attributes of a field in a FITS ASCII table
FTINFO - Give information about a specified field in a FITS ASCII table
FTKEEPROW - Subscript (and reorder) a FITS ASCII table
FTPRINT - Print specified columns and rows in a FITS ASCII table
FTPUT - Update or add data to a field in a FITS ASCII table
FTREAD - Read a table in modified disk FITS ASCII table format.
FTSIZE - Return the size and number of fields in a FITS ASCII table
FTSORT - Sort a table according to the values in a specified field.
FTWRITE - Write a table in modified disk FITS ASCII format.

FITS 3D Binary Table I/O

TBDELCOL - Delete specified column from a FITS 3D Binary table
TBDELROW - Delete specified row(s) from a FITS 3D Binary table
TBGET - Extract a specified field from a column in a FITS 3D Binary table
TBHELP - Display the fields in a FITS 3D Binary table header
TBINFO - Give information about a specified field in a FITS 3D Binary table
TBPRINT - Print specified columns and rows in a FITS 3D Binary table
TBSIZE - Return the size and number of fields in a FITS 3D Binary table

FITS Binary Table Extensions I/O

FXADDPAR - Add or modify a parameter in a FITS header
FXBADDCOL - Create columns in the binary table extension header
FXPARPOS - Find position to insert record in a FITS header--called by FXADDPAR
FXBCLOSE - Close a FITS binary table extension that was opened for read
FXBCOLNUM - Returns the column number of a specified column
FXBCREATE - Open binary table file, and write header
FXBFIND - Find column keywords in a binary table header
FXBFINDLUN - Find LUN in FXBINTABLE--called by FXBCREATE,FXBOPEN
FXBFINISH - Close a binary table extension file that was open for write
FXBHELP - Show information about the binary table columns
FXBHMAKE - Create a basic FITS extension (BINTABLE) header
FXBISOPEN - Returns whether or not a FITS binary table is open
FXBOPEN - Open FITS binary table extension for reading
FXBPARSE - Parse binary table header--called by FXBCREATE, FXBOPEN
FXBTDIM - Parse keywords from binary tables with a TDIM-like format
FXBTFORM - Parse TFORM column descriptor--called by FXBPARSE
FXBREAD - Read data from a FITS binary table
FXBSTATE - Returns the state of a FITS binary table
FXBWRITE - Write data into binary table
FXFINDEND - Find the last FITS record--called by FXBCREATE

FXHCLEAN - Remove obsolete keywords--called by FXHMAKE, FXHBMAKE
FXHMAKE - Create a basic primary FITS header
FXHREAD - Read FITS header from an opened disk file--called by FXBOPEN
FXREAD - Read a primary array or subarray from a FITS file
FXWRITE - Write primary FITS file

FITS Input/Output

CHECK_FITS - Check that the NAXISi and BITPIX keywords of a FITS header (or SDAS header) agree with a supplied array
DFITSRD - Interactive driver to convert from disk FITS to STSDAS format
DFITSREAD - Convert from disk FITS to STSDAS format. Called by DFITSRD.
DFITSRD_LARGE - Like DFITSRD but works on large arrays, slower than DFITSRD but less demanding on virtual memory.
DFITSREAD_LARGE - Analogue of DFITSREAD, called by DFITSRD_LARGE.
DFITSWRT - Interactive driver to convert from STSDAS format to disk FITS.
DFITSWRITE - Convert from STSDAS format to disk FITS. Called by DFITSWRT.
FITSDIR - Display info about primary FITS header(s) on disk
FITS_INFO - Display info about disk FITS file(s) at a terminal or in Common
HEADFITS - Read a FITS header from a disk FITS file.
MKHDR - Make a minimal FITS header for an image array.
RDFITS_STRUCT - Read an entire disk FITS file into an IDL structure
READFITS - Read a disk FITS file into an IDL data and header array.
SXPAR - Obtain the value of a keyword in a FITS header
WRITEFITS - Write IDL data and header array to a disk FITS file.

Image Manipulation

BOXAVE - Boxave an image, always using at least REAL*4 arithmetic
CONVOLVE - Convolve an image with a PSF using the product of Fourier Transforms
CORREL_IMAGES - Correlation of two images. Called by CORREL_OPTIMIZE
CORREL_OPTIMIZE - Compute the optimal pixel offset of one image relative to another by maximizing the correlation function.
CORRMAT_ANALYZE - Analyze the correlation function made by CORREL_IMAGE
DIST_CIRCLE - Create an array where each pixel value is equal to its distance to a specified center. Useful for circular aperture photometry.
DIST_ELLIPSE - Create a mask array useful for elliptical aperture photmetry.
FILTER_IMAGE - Like MEDIAN or SMOOTH but handles edges & allows iteration
IMLIST - Display image pixel values around a specified center
MAX_ENTROPY - Deconvolution by Maximum Entropy, given a PSF
MAX_LIKELIHOOD - Deconvolution by maxmimum likelihood, given a PSF
PSF_GAUSSIAN - Create a 1-d, 2-d, or 3-d Gaussian with specified FWHM, center
SIGMA_FILTER - Replaces pixels deviant by more than a specified sigma from its neighbors. Useful for cosmic ray removal.

Math and Statistics

FITEXY - Best straight-line fit to data with errors in both coordinates
GAMMLN - Return the natural log of the gamma function (obsolete after V2.4.0)

GAUSSIAN - Evaluate a 1-d gaussian and optionally its derivative
KSONE - Compute the one-sided Kolmogoroff-Smirnov statistic
KSTWO - Compute the two-sided Kolmogoroff-Smirnov statistic
LINTERP - Linearly interpolate X,Y vectors onto a new X grid (e.g. interpolate wavelength-flux vectors onto a new wavelength grid.)
MINF_BRACKET - Find 3 points which bracket the minimum of a function
MINF_PARABOLIC - Minimize a function using Brent's method with parabolic interpolation
MINF_CONJ_GRAD - Find local minimum of a scalar valued function of several variables using conjugate gradient method
PCA - Perform a principal component analysis (karhunen-Loeve expansion)
POIDEV - Generate a Poisson random deviate
POLINT - Polynomial interpolation of an (X,Y) pair
PROB_KS - Return the significance of a Kolmogoroff-Smirnov statistic
POLY_SMOOTH - Apply a least-squares (Savitzky-Golay) polynomial smoothing filter
QSIMP - Integrate using Simpson's rule to specified accuracy
QTRAP - Integrate using trapezoidal rule to specified accuracy.
QUADTERP - Quadratic interpolation of X,Y vectors onto a new X grid
SIXLIN - Compute linear regression by 6 different methods.
SPLINE_SMOOTH - Compute cubic smoothing spline to (weighted) data
TABINV - Find the effective index of a function value.
TRAPZD - Compute Nth iteration of trapezoidal rule. Called by QSIMP, QTRAP
TSUM - Trapezoidal integration of the area under a curve
ZBRENT - Find the root of a function known to lie between specified limits

PLOTTING procedures

CLEANPLOT - Reset all plotting system variables to their default (X) values
CURFULL - Like intrinsic CURSOR procedure but with a full-screen cursor
LEGEND - Create an annotation legend for a plot
LEGENDTEST - Demo program demonstrating the capabilities of LEGEND
OPLOTERR - Overplot Y vs. X with optional X and Y error bars
PLOT_KEYWORDS - Get default values of plotting keywords
PLOTERR - Plot Y vs. X with optional X and Y error bars
PLOTHIST - Plot the histogram of an array
PLOTSYM - Define useful plotting symbols not in the standard PSYM definition

STRUCTURE procedures

COPY_STRUCT - Copy Fields with matching Tag names from one structure to another
COMPARE_STRUCT - Compare all matching Tag names and return differences
CREATE_STRUCT - Create an IDL structure from a list of tag types and dimensions
N_STRUCT - Return number of elements in a structure array and number of tags
PRINT_STRUCT - Print specified tags from structure (to LUN if given)
SIZE_STRUCT - Obtain the size in bytes of an IDL structure definition
WHERE_TAG - Like WHERE but works on a structure with a variable tag name

STSDAS (Binary) Table I/O

TABLE_APPEND - Append a list of STSDAS tables to create a single table.
TABLE_CALC - Add a new table column from an expression using existng columns.

TABLE_DELETE - Delete specified rows from an STSDAS table
TABLE_EXT - Extract column(s) of data from an STSDAS table to IDL variable(s)
TABLE_HELP - Describe an STSDAS table.
TABLE_LIST - List the contents of an STSDAS table
TABLE_PRINT - Print a disk STSDAS table in tabular form
TABLE_SORT - Order the contents of an STSDAS table by the specified column
TAB_ADDCOL - Add a new column to a STSDAS table
TAB_COL - Extract column info from a table control block. Called by TAB_READ
TAB_CREATE - Create an empty STSDAS table on disk
TAB_DEL - Delete specified row(s) from an STSDAS table
TAB_EXPAND - Expand the size of an STSDAS table. Called by TABLE_APPEND
TAB_FORTOSPP - Convert a FORTRAN print format to SPP. Called by TAB_MODCOL
TAB_MODCOL - Modify a column name, format or units in an STSDAS table.
TAB_NULL - Locate null values in a STSDAS table. Called by TAB_PUT
TAB_NULLROW - Place null values into a STSDAS table. Called by TAB_PUT
TAB_PRINT - Print the contents of an STSDAS table in tabular form
TAB_PUT - Put new values into a column of an STSDAS table
TAB_READ - Read table control block and data array from a disk STSDAS table.
TAB_SIZE - Return the size of a STSDAS table. Called by TABLE_LIST
TAB_SORT - Sort a STSDAS table according to the specified column
TAB_SPPTOFOR - Convert SPP print format to FORTRAN. Called by TAB_PRINT
TAB_TO_DB - Convert an STSDAS table to an IDL database
TAB_VAL - Extract values from a single column of an STSDAS table
TAB_WRITE - Write a STSDAS table to a disk file

Tape IO Procedures

FITSRD - Interactive driver to read a FITS tape into STSDAS (modified FITS) disk format.
FITSRD_LARGE - Like DFITSRD but works on large arrays, slower than DFITSRD but less demanding on virtual memory.
FITSREAD - Read a FITS tape to STSDAS format. Called by FITSRD
FITSREAD_LARGE - Analogue of FITSREAD, called by FITSRD_LARGE.
FITSLIST - List the headers on a FITS tape.
FITSTAPE - Function to perform FITS tape I/O. Called by FITSWRITE, FITSREAD, FITS2X, X2FITS.
FITSWRT - Interactive driver to write from STSDAS format to FITS tape
FITSWRITE- Write an STSDAS file to a FITS tape. Called by FITSWRT
FXTAPEWRITE - Copy a disk FITS file to tape
FXTAPEREAD - Copy a FITS file from tape to disk
REWIND, SKIPF, TAPRD, TAPWRT, WEOF - these are Unix tape handling procedures which emulate the intrinsic IDL VMS functions of the same names.
TINIT - Position a VMS tape between final double EOF for appending new files

TV Display Procedures

BLINK - Blink two windows in an X-windows display
CURS - Change the shape of the X windows cursor
CURVAL - Interactive display of image intensities and astronomical coordinates
PIXCOLOR - Set specified pixel values to a specified color
SIGRANGE - Find range of pixel values which contain 90% of the image values
TVBOX - Draw a box of specified size on the image display
TVCIRCLE - Draw a circle of specified radius on the image display

TVELLIPSE - Draw an ellipse of specified axes on the image display
TVLASER - Write an image to postscript file with annotation from a FITS header
TVLIST - Display intensity values surrounding the cursor position

Miscellaneous (Non-Astronomy) Procedures

ASTROLIB - Add the non-standard system variables in use in the IDL Astronomy User's Library
AVG - Return the average value of an array or 1 dimension of an array.
BOOST_ARRAY - Append one array onto another, adjusting dimensions if necessary
BSORT - Like the IDL SORT function but subscript order is maintained when value are equal -- like a bubble sort.
Called by DBINDEX.
CIRRANGE - Force an angle to be in the range 0 to 2*!PI (or 0 to 360).
CONV_UNIX_VAX - Convert IEEE datatype to VMS datatypes
CONV_VAX_UNIX - Convert Vax datatypes to Unix using proper byteswapping
CONV_VAX_BLOCK - Convert a VMS FORTRAN unformatted file to its Unix counterpart
DATATYPE - Return the datatype of an IDL variable as a string
DETABIFY - Replace tabs in a character string by equivalent number of spaces
DEFINE - Emulate the VMS DEFINE command within IDL (VMS)
DIR - Emulate the VMS DIR command within IDL
EDT - Use CALL_EXTERNAL to enter the EDT editor without spawning (VMS)
EVE - Use CALL_EXTERNAL to enter the EVE editor without spawning (VMS)
F_FORMAT - Find the "best" F format to display an array of REAL*4 numbers.
FDECOMP - Decompose a file name (Disk + Directory + Name + Extension + Version)
FORPRINT -Print a set of vectors by looping over each index value
GETFILES -Interactively specify a list of file numbers.
GETLOG - Format the input name as a logical directory in the host OS
GETOPT - Parse a user supplied string into numeric value(s).
GETPRO - Search !PATH directory for a procedure and copy into user's directory
GETTOK - Extract a string up to a specified character.
GETWRD - Get specified item (word) from a string (in /jhuapl)
HOST_TO_IEEE - Convert IDL variable from host machine bit order to IEEE
HPRINT - Pretty terminal display of a FITS header (or other string array)
IEEE_TO_HOST - Convert IDL variable from IEEE bit order to host machine
ISARRAY - Determine if an IDL variable is an array (in /jhuapl)
MAKE_2D - Change from 1-D indexing to 2-D indexing
MATCH - Find the subscripts where the values of two vectors match.
MINMAX - Return the min and max of an array in an 2 element vector
NINT - Nearest integer function
NULLTRIM -Delete all characters after, and including, the the first null byte(0). Called by TAB_PUT.
ONE_ARROW - Draw an arrow labeled with a single character
ONE_RAY - Draw a ray by specifying starting point, angle, and length
ORDINAL - Return the English equivalent of ordinal numbers, i.e. '1st','2nd'
OSFCNVRT- Format the input as a logical name in the host operating system
POLREC - Convert from polar to rectangular coordinates (in /jhuapl)
PRODUCT - Return the product of all the elements of an array.
QGET_STRING - Read a string (e.g. password) from the keyboad without echoing it
READCOL - Quickly read a file of free-format ASCII data into IDL vectors
READFMT - Quickly read a file of fixed-format ASCII data into IDL vectors
READ_KEY - Like GET_KBRD but returns a code for escape sequences.
READ_VAX_BLOCK - Read a single VMS FORTRAN unformatted record
RECPOL - Convert from rectangular to polar coordinates (in /jhuapl)

REMCHAR - Remove all appearances of a character from a string.
REM_DUP - Remove duplicate values from a vector.
REMOVE - Contract a vector or up to 8 vectors by removing specified elements.
REPCHR - Replace all occurrences of one character by another (in /jhuapl)
REPSTR - Replace all occurrences of one substring in a string by another.
SCREEN_SELECT - Allow user to interactively select from a list of strings. Used by the database software
SELECT_X - Vanilla X windows branch of SCREEN_SELECT
SELECT_O - VT100 terminal branch of SCREEN_SELECT
SELECT_W - IDL widget branch of SCREEN_SELECT.
SIGMA - Calculate standard deviation over an array or 1 dimension of array
SINCE_VERSION - Determine if the current version of IDL (in !VERSION.RELEASE) is later than a specified version
SPEC_DIR - Complete specification of a file name using default disk & directory
STORE_ARRAY - Insert one array into another, adjusting dimensions if necessary
STREBCASC - Convert an EBCDIC string scalar or vector to its ASCII equivalent
STRN - Convert a number to a string and remove padded blanks.
STRNUMBER- Determine whether a string is a valid numeric value.
TEXTOPEN - Open a file for text output as specified by !TEXTOUT. Controls the print output device for many procedures.
TEXTCLOSE - Close a file that had been opened by TEXTOPEN.
TO_HEX - Translate a decimal integer to a hex string. Called by AIPSNAME.
VECT - Display a set of numbers to a string with delimiters
WHERENAN - Find points equal to IEEE NaN (not a number) values
ZPARCHECK - Check the type and size of a parameter