

# FOS Data Structures and Data Assessment

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This chapter assumes that you have selected and retrieved some FOS data from the HST Data Archive or that you have your own data. We describe the contents of the delivered data, the structure of the various data files, and how to assess them with particular emphasis on the utility of the FOS paper products. We also provide a few examples of how Phase II proposals were turned into observations and data products.

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## 30.1 Contents of Delivered Data

Unless you have read your FOS data from very old data tapes, the data you have on your machine will be in FITS format. These files need to be converted to GEIS format with the STSDAS routine **strfits**, as is described in Chapter 2 (Volume 1). The resulting GEIS format files will have default suffixes, as described in Table 30.1.

You will be most interested in the contents of the **.c1\***, **.c0\***, and **.c2\*** files as these contain the flux-calibrated data, wavelengths and errors for an exposure. The easiest way to get a quick glance at your spectra is by using the routine **splot** or **fwplot** if you want to plot wavelength vs. flux (see “FOS and GHRS Spectra” on page 3-17). We recommend that you generate the FOS paper products for your data with the STSDAS routine **pp\_dads** and obtain a variety of displays and

tables which, as we shall see in “FOS Paper Products” on page 30-15, can facilitate the assessment of your data quality.

**Table 30.1:** FOS File Name Suffixes

Suffix	File Contents	Suffix	File Contents
<i>Raw Data Files (input for calfos)</i>		<i>Calibrated Data Files (output from calfos)</i>	
.d0h/.d0d	Science data image	.c0h/.c0d	Calibrated wavelengths
.q0h/.q0d	Science data quality	.c1h/.c1d	Calibrated fluxes
.shh/.shd	Standard header packet	.c2h/.c2d	Propagated statistical error
.d1h/.d1d	Science trailer line	.c3h/.c3d	Special statistics
.ulh/.uld	Unique data log	.c4h/.c4d	Count rate
.x0h/.x0d	Science header line	.c5h/.c5d	Flat-fielded object spectra
.xqh/.xqd	Science header line data quality	.c6h/.c6d	Flat-fielded sky spectra
.q1h/.q1d	Science trailer line data quality	.c7h/.c7d	Background spectra
		.c8h/.c8d	Flat-fielded object minus smoothed sky spectra
		.cqh/.cqd	Calibrated science data quality
<i>Additional Files</i>			
.jih/.jit	Jitter files (.cmh, .cmj, .cmi)	.trl	Trailer file
.pdq/.ocx	PODPS/OPUS data quality files		

### 30.1.1 Uncalibrated (Raw) Data Files

Table 30.1 lists the science files that are used as required input to **calfos**. These files are described briefly below.

#### Science Data Files (.d0h/.d0d)

Science data files contain single-precision floating point values that represent the number of detected counts accumulated in each pixel. The number of data elements in the one-dimensional science data array depends on the observation mode; specifically, the number of diodes, the number of substeps, the number of Y steps, and the number of repeats (sometimes called *slices* or *bins*) used in the observation. The maximum number of data elements is 12288. The associated header file also provides information on the different steps to be performed during pipeline calibration processing, and the reference files and tables to be used in the calibration.

#### Science Header Line (.x0h/.x0d)

The science header line (SHL) file is a one dimensional array with a length equal to a line of the science data. It contains a partial copy of the unique data log.

### Science Trailer Line (.d1h/.d1d)

The science trailer line (STL) file is also a one dimensional array containing the number of measurements rejected from the various combinations of  $x$  substeps,  $y$  steps, repeats, etc. The information in these files is used to compute the total effective exposure time per pixel which is later used to convert the counts into count rates.

### Data Quality Files (.q1h/.q1d)

The science data files, science header line files, and the science trailer files have corresponding data quality files that contain the flags for bad or suspect data. These raw data quality files have quality flags as follows:

- *Good* data has the data quality flag =1.
- *Raw data dropouts* and *filled raw data* have the data quality flag =16.
- *Data failing a Reed-Solomon error check* has the data quality flag =100.
- *Fill data* have the data quality flag =800.

The data quality files are identified by the suffixes .q0h, .q0d, .xqh, .xqd, .q1h, and .q1d corresponding to the science data, science header, and science trailer files. Table 30.2 lists FOS data quality flags.

### Standard Header Packet (.shh/.shd)

The standard header packet (SHP) contains the telemetry values for engineering data and some FOS-unique data. The engineering data include temperatures, currents, and voltages at various points in the instrument. The FOS-unique data varies depending on the onboard processing used for a given observation. The header packet also contains information used in the operation of the spacecraft, such as target name, position and velocity of the telescope, the right ascension and declination of the target, the sun, and the moon, and other proposal information used in the observation which was provided in Phase II of the proposal process.

### Unique Data Log (.ulh/.uld)

The unique data log (UDL) contains the mechanism control blocks used to control the entrance aperture, entrance port, polarizer, and filter grating wheel assembly. This file also contains the discriminator level, disabled diode table, serial engineering data, instrument configuration, and exposure parameters.

### Trailer File (.trl)

The trailer file contains many messages generated by the so-called “generic conversion” of the data from what was onboard the spacecraft into STSDAS images. These messages may contain information on missing or filled data packets. Informational messages produced by **calfos** during calibration are also stored in the trailer file. The trailer file is identified by the suffix .trl.

## 30.1.2 Calibrated Data Files

Several types of calibrated output files are produced by **calfos**. These are listed in Table 30.1. More extensive descriptions of each type of file are provided below.

### Calibrated Wavelength Files (.c0h/.c0d)

These files contain single-precision floating point calibrated vacuum wavelengths corresponding to the center of each pixel of the science data. All FOS wavelength solutions assume the first pixel is pixel 0.

### Calibrated Flux Files (.c1h/.c1d)

These files contain single-precision floating point calibrated fluxes (in  $\text{ergs sec}^{-1} \text{cm}^{-2} \text{\AA}^{-1}$ ) corresponding to each pixel of the science data.

### Calibrated Statistical Error Files (.c2h/.c2d)

These files contain the statistical errors of the original data. These files are calibrated in lock-step with the science data files. *Errors caused by sky and background subtraction, flatfields, and sensitivity are not included in the error estimates.*

### Calibrated Special Mode Data Files (.c3h/.c3d)

Data acquired in the rapid-readout, time-resolved, or spectropolarimetry modes require processing steps in addition to (or complementing) those used for standard ACCUM data. The calibrated data are then stored in special mode data files. For RAPID mode, the files contain the total flux, integrated over all pixels, and the associated statistical error for each readout. For TIME RESOLVED mode, the files contain the pixel-by-pixel average of all slices or bins, the difference between each slice or bin and the average, and the average propagated statistical errors. For POLARIMETRY mode, the file contains the Stokes I, Q, U, and V parameters, the linear and circular polarization, and the polarization position angle. The polarimetric quantities and the propagated errors are calculated for each of the separate pass directions, the combined pass direction data, and the combined pass direction corrected for interference and instrumental orientation.

### Calibrated Data Quality Files (.cqh/.cqd)

The quality flags in these files flag the bad pixel values in the calibrated files. The quality flags from the raw data are updated and additional flags are added for problems detected in the calibration process. The data quality flags are defined in Table 30.2.

### Intermediate Calibrated Output Data Files (.c4\* - c8\*)

At most, six sets of intermediate calibrated output files are produced depending on the observation mode.

- **Count Rate Object (and Sky) Spectra:** The files containing the count rate spectra are corrected for overscanning, noise rejection, and lost signal caused by disabled diodes. These files are identified by the suffixes .c4h and .c4d.

**Table 30.2:** FOS Data Quality Flag Values

Flag Value	Description
<i>Category 1: Data not useful. Data values set to zero.</i>	
800	Data filled
700	Data filled due to GIM correction
400	Disabled channel
300	Severe saturation (uncertainty greater than 50%)
200	Inverse sensitivity invalid ( $\lambda < 1100 \text{ \AA}$ or $\lambda > 7000 \text{ \AA}$ )
<i>Category 2: Data Uncertain. Uncertainty not Indicated in Error Calc.</i>	
190	Large saturation correction (uncertainty greater than 20%)
170	Intermittent noisy channel
160	Intermittent dead channel
130	Moderate saturation correction (uncertainty greater than 5%)
120	Sky or background fixed or extrapolated
100	Reed-Solomon decoding error
<i>Category 3: Data uncertain. Uncertainty in propagated error file</i>	
50	Sampling less than 50% of nominal

- **Flatfielded Object Count Rate Spectrum:** These files contain .c4 object-only data further corrected for paired pulses, detector background, flatfield structure and, if applicable, pipeline corrected for GIM effects. The flatfielded object spectrum files are identified by the suffixes .c5h and .c5d.
- **Flatfielded Sky Count Rate Spectrum:** These files contain .c4 sky-only data further corrected for flatfield structure and, if applicable, also pipeline corrected for GIM effects. The flatfielded sky spectrum files are produced only if a sky observation was obtained. These files are identified by the suffixes .c6h and .c6d.
- **Background Count Rate Spectrum:** The scaled background spectrum that has been subtracted from the .c4 product is identified by the suffixes .c7h and .c7d.
- **Flatfielded and sky-subtracted Object Count Rate Spectrum:** If the sky is observed, then a smoothed sky-subtracted object spectrum prior to flux calibration is produced. The files containing the smoothed sky-subtracted object spectrum are identified by the suffixes .c8h and .c8d.

### Trailer File (.trl)

We list the trailer file again as any log comments written by the pipeline **calfos** procedures are appended to spacecraft and generic conversion information already in the file. The trailer file is identified by the suffix `.trl`.

### 30.1.3 Paired-Aperture File Structures

The FOS paired apertures were sampled in two different ways which lead to very different internal file structures and data products:

- **Case 1:** RPS2 (RPSS) specification of STEP-PATT=SINGLE which leads to group parameter APER\_POS=SINGLE and header keyword YSTEP1=OBJ.
- **Case 2:** RPS2 (RPSS) specification of STEP-PATT=OBJ-OBJ or OBJ-SKY (in early cycles referred to as STAR-SKY) which leads to group parameter APER\_POS=UPPER or LOWER and header keywords YSTEP1 and YSTEP2 being populated with either OBJ (STAR) or SKY as appropriate. Anomalies exist in some archived datasets that will result in incorrect **calfos** processing of paired aperture data (see “Paired Aperture Calibration Anomaly” on page 31-25).

For case 1, the files are identical to those for single aperture data and as described in the foregoing data product sections.

For case 2, measures were taken from the upper and lower sections of the aperture (always starting in the lower aperture section which has the more negative Y-base value) in approximate 10-second alternating segments, readout to memory at the interval appropriate to the data-taking mode (either ACCUM or RAPID). In the `.d0*` files the data are stored in groups that are twice as long as single aperture groups, e.g., the default paired aperture ACCUM group size is 4128 pixels. The first 2064 pixels correspond to data readout at the Y-base for data taken in YSTEP1 and the second 2064 pixels are from YSTEP2. YSTEP1, which can be either OBJ (STAR) or SKY, always corresponds to the lower aperture. (The mapping of OBJ (STAR) and SKY to upper and lower halves of the aperture was dependent upon user-specification.) Case 2 `.c4*` files contain twice as many groups as in case 1 with the odd-numbered group containing to the count rate spectrum groups for YSTEP1 and the even-numbered groups containing the count rate spectrum groups for YSTEP2.

### 30.1.4 Other Important Observation-related Files

#### Observation Log Files (.jih/.jit)

As of February 1995, the observation log (or jitter) files (`.jih`, `.jit`, etc), which are provided by the Observatory Monitoring System (OMS), became routinely available (some files from the October 1994 through February 1995 time period are also available). These can give useful information, such as telescope performance during the observation and the position of the target within the aperture. A so-called *jitter ball* is a routine part of all FOS paper products for

which jitter files exist (see Figure 30.8). This plot shows (V2,V3) motions of the FGSs needed to keep the guide stars centered, recorded every six seconds throughout the exposure. See Appendix C for a description of the observation logs and jitter files.

### **PODPS Data Quality File (.pdq)**

STScI staff performed a quick Data Quality Assessment (DQA) of the target acquisitions and the science observations. This assessment identified any target acquisition failures, guide star acquisition failures, other spacecraft anomalies, or instrumental problems; the assessment was recorded in the data quality keywords of the PDQ (Procedural Data Quality) file. PDQ files are archived to data class PDQ and can be retrieved from the HST Archive using StarView. The FOS paper products list each relevant PDQ file comment for every exposure.

OCX files (Observatory Support System (OSS) Observer Comment files) contain information about the success or failure of target acquisitions and science observations. Before April 17, 1992, OCX files were not always archived separately, and, in some cases, were prepended to the RSDP pipeline history file, the `.trl` trailer file. After February 1995, OCX files were produced only to document real-time activity (e.g., interactive target acquisition) in support of an observation. After October 1996, OCX files may contain information about observation execution problems.

The PDQ files and the comments they contain should not be over-interpreted. The remarks were based upon a visual examination of the data and the experience of the OPUS staff. Technical remarks are usually sound, but some comments about the “quality” of the observations can arise from an incomplete knowledge of the science goals of the original proposer. Unless the object was significantly miscentered, for example, the achieved signal-to-noise is probably close to what was expected, even if it may appear low in a single exposure. To assess whether or not a low or varying flux is meaningful, you should examine the jitter file or other records of spacecraft performance. The lack of a comment is also not a guarantee that there were not some problems with the data.

## **30.1.5 Reference Files and Tables**

The calibration pipeline used reference files and tables to flux calibrate FOS data. Data in the archive and the data that were sent to GOs were calibrated with the reference files that were available at the time of the observation. These are generally not the “best” files to use to calibrate these data today. StarView allows you to retrieve either the “used” or the “best” reference files. The “best” reference files reflect our accumulated experience of FOS calibrations and derive from the late 1997 FOS closeout calibration analyses.

### **Naming and Structure of FOS Reference Files and Tables**

The reference files and tables are typically referred to by the name of the Calibration Data Base System (CDBS) reference relation that holds their names. The suffixes of the reference tables and files are of the form `.cyn`, `.rnh` and `.rnd` where  $n$  represents a value from 0 to 9 and A to D (see Table 30.3). These files are

maintained in the CDBS. The STScI web site also includes a catalog of these tables and files.

A thorough description of the internal header and data formats of FOS reference files and tables is beyond the scope of this document, but all this information can be found in rigorous detail in STScI document ICD-47 which is available from the FOS WWW page and in paper format from [help@stsci.edu](mailto:help@stsci.edu). A description of what each FOS reference file and table is used for is found in “Details of the FOS Pipeline Process” on page 31-13.

Except for some spectropolarimetric reference files, which are twice this length (for two pass directions), all reference files contain a vector of length:

$$(N_{chan} + N_{over} - 1) \times N_x$$

Where

- $N_{chan}$  – is the number of channels observed (keyword NCHNLS).
- $N_{over}$  – is the number of channels multiplexed (keyword OVERSCAN).
- $N_x$  – is the number of substeps (keyword NXSTEPS).

Although the reference files can be generated for any combination of NXSTEPS, FCHNL (first channel), NCHNLS, and OVERSCAN, the routine calibration reference files have a length of 2064 pixels, corresponding to the standard keyword values:

- NXSTEPS = 4
- FCHNL = 0
- NCHNLS = 512
- OVERSCAN = 5

For other values of FCHNL, NCHNLS, and NXSTEPS **calfos** interpolates from or resamples the standard reference files. *Only* OVERSCAN = 5 is supported by FOS calibration.

**Table 30.3:** FOS Reference Files and Tables

Header Keyword	Filename Suffix	File Contents
CCS0	.cy0	Aperture areas
CCS1	.cy1	Aperture positions
CCS2	.cy2	Sky emission line positions
CCS3	.cy3	Sky and background filter widths
CCS4	.cy4	Polarimetry parameters
CCS5	.cy5	Sky shift parameters
CCS6	.cy6	Wavelength dispersion coefficients
CCS7	.cy7	GIM correction scale factors
CCS8	.cy8	Predicted background (count rate)
CCS9	.cy9	Un-illuminated diodes for scattered light correction
CCSA	.cya	OTA focus positions for aperture throughputs
CCSB	.cyb	Aperture throughput coefficients
CCSC	.cyc	Throughput corrections versus focus
CCSD	.cyd	Instrument sensitivity throughput correction factors
CCG2	.cmg	Paired-pulse coefficients
BACHFILE	.r0h & .r0d	Default background file (count rate)
FL $n$ HFILE	.r1h & .r1d	Flatfield file
IV $n$ HFILE	.r2h & .r2d	Inverse sensitivity file (ergs cm <sup>-2</sup> Å <sup>-1</sup> count <sup>-1</sup> diode <sup>-1</sup> )
RETHFILE	.r3h & .r3d	Retardation file for polarimetry data
DDTHFILE	.r4h & .r4d	Disabled diode file
DQ $n$ HFILE	.r5h & .r5d	Data quality initialization file
AISHFILE	.r8h & .r8d	Average inverse sensitivity file

## 30.2 Headers, Keywords, and Group Parameters

Header files provide much of the information needed to reduce FOS data. A description of each keyword is generally provided in the header itself. Some important header parameters, such as exposure timing information, background correction, or scattered light correction, have different values for each group of data within the file. Such parameters are termed *group parameters*. Table 30.4 is a description of the different topics covered in the various header files. The header files used most often are the standard header packet (.shh), the science data

header file (.d0h), and the calibrated science data header file (.c1h). Most of the information needed to understand the data is found among the header keyword types that describe general information (Table 30.4a) and among the processing and calibration information (Table 30.4c) sections of the headers. Table 30.5 lists many important header keywords used to interpret FOS data.

IRAF tasks such as **imhead** or **hselect** can be used to list the various header keywords. Values of group parameters, on the other hand, can be obtained only with **imhead**. Table 30.6 provides a listing of all FOS group parameters, with typical values and explanatory comments for each.

**Table 30.4:** Information in FOS Header Keywords

Keyword Type	Information in Keywords	Source
<i>a.) General Information</i>		
General data	General structure information for data file in standard FITS style	All headers
Group Parameters: OSS	Acquisition data description, including time of acquisition (modified Julian date), maximum and minimum data values, and axes information	All headers
Group Parameters: PODPS	Observation type and ground-based GIM correction values from GIMP_CORR	Calibrated header files
Generic Conversion Keywords	Existence of science trailer line and reject array	.d0h
FOS Descriptor Keywords	Description of FOS file and GIM correction	All headers
COSTAR Keywords	Positions of the COSTAR FOS M1 mirror	.shh
<i>b.) Engineering Information</i>		
Time Conversion Keywords	Spacecraft and Universal time at start of observation	.shh
CDBS Keywords in SHP	Engineering data regarding temperatures, currents, and voltages at various points in the instrument	.shh
CDBS Keywords in UDL	Data acquisition details, such as number of channels used, value of magnetic field deflections used	.ulh

**Table 30.4:** Information in FOS Header Keywords (Continued)

Keyword Type	Information in Keywords	Source
<i>c.) Processing and Calibration Information</i>		
Statistical Keywords	Processing information	.shh, .d0h, and calibrated data headers
Calibration Flags and Indicators	Type of observation and configuration of aperture, grating, and detector	.d0h and calibrated data headers
Calibration Reference Files & Tables	Reference files and tables for calfos processing (either used or to be used)	.d0h and calibrated data headers
Calibration Switches	Calibration steps for calfos processing (either used or to be used)	.d0h and calibrated data headers
Pattern Keywords	Magnetic field deflection pattern used in acquiring the data	.d0h and all calibrated data header files
Calibration Keywords	Observing time, user-supplied GIM offset table name, LIVETIME, DEADTIME, position angle of aperture, burst noise rejection limit	.d0h and calibrated data headers
Aperture Position	Aperture position in RA and Dec	.d0h and calibrated data headers
Exposure Information	Exposure information and commanded FGS lock	.d0h and calibrated data headers
<i>d.) Observer-Supplied Observing Information from Phase II Proposal</i>		
Support Schedule: Program Info	Information on cover page of proposal and type of output data requested by GO	.shh
Support Schedule: Flags and Indicators	Type of observation requested by GO, for example, the aperture, the detector, the number of channels, etc.	.shh
Proposal Info	Observing strategy, e.g., instrument configuration, target description, and information on flux, exposure, moving target, spatial scan etc.	.shh
Target and Proposal ID	Target and PEP information	.shh
<i>e.) Observing Information Produced in TRANS Stage</i>		
Support Schedule: Data Group II	Telescope pointing and instrument configuration on the sky, i.e., target RA and Dec and offset objects, position angle of diode array, OFFSET information, spacecraft velocity, guide stars, etc.	.shh
Onboard Ephemeris Model	Spacecraft ephemeris	.shh

**Table 30.5:** FOS Header Keywords

<b>Keyword</b>	<b>Description and Comments</b>
<i>General Information from Header File—usually in .d0h or .c1h</i>	
GCOUNT	Number of groups in data file
YTYPE	Nature of observation, important for paired aperture observations. (Not real values in d0h file). Values are OBJ, BKG, or SKY
YPOS <sub>n</sub>	Location of diode center in Y-base units, of the <i>n</i> th group, useful for interpreting ACQ/BIN data. If there is only one group then YPOS is the Y-base of that one group. Not populated with real values in the .d0h file
YBASE	YPOS of group #1
XBASE	XDAC units needed to center aperture on the diode array for group #1
DEFDDTBL	UDL disabled diode table to be used (value: T) or DDTHFILE table to be used (value: F)
BUNIT	Flux units of the data. Values: COUNTS, COUNTS/SEC, ERGS/SEC/ CM <sup>2</sup> /A, or ANGSTROM
FILLCNT	Number of sequences of filled data
ERRCNT	Number of sequences with bad data
INSTRUME	Instrument used for the observation. This will be FOS.
ROOTNAME	Rootname of the observation set. Will start with letter “y”
FILETYPE	Type of data in the file: SHP is science header packet, UDL is unique data log, SDQ is raw science data quality, WAV is wavelength, FLX is calibrated flux, ERR is calibrated flux error, MOD is CALFOS special mode processed data, SCI is object, sky, or background science data, OBJ is object data, BKG is background data, CDQ is calibration data quality, SKY is sky data, NET is sky-subtracted object data
GRNDMODE	Ground software mode of FOS. Can be SPECTROSCOPY, TARGET ACQUISITION, IMAGE, RAPID-READOUT, SPECTRO-POLARIMETRY, or TIME-RESOLVED
DETECTOR	Detector in use for the observation. AMBER or BLUE
APER_ID	Aperture used for the observation; A-1 corresponds to the 4.3”, A-2 to the 0.5” pair (square), A-3 to the 0.25 pair (square), A-4 to the 0.1 pair (square), B-1 to the 0.5” (round), B-2 to the 0.3” (round), B-3 to the 1.0” (round), B-4 is blank, C-1 to the 1.0” pair (square), C-2 to the 0.25”x2.0” slit, C-3 to the 0.7”x2.0” bar, and C-4 to the 2.0” bar apertures respectively
POLAR_ID	Polarization waveplate used for the observation. A is the waveplate A, B is the waveplate B and C is no polarizer used (clear)
FGWA_ID	Filter and grating used for the observation. Hxx means Gxx0H filter, L15 means G160L, L65 means G650L, PRI means PRISM, and CAM means camera (mirror).
POLANG	Initial angular position of the polarizer in degrees
FCHNL	First diode used in observation (first diode in array is designated as zero)
NCHNLS	Number of diodes used in the observation, useful for interpreting ACQ/BIN data and exposure time. Usually 512 (except target acquisition and other specific modes, see below)
OVERSCAN	Number of overscans used in the observation, useful for interpreting ACQ/BIN data and exposure time. Usually 5. FOS reference files and calibration support <i>only</i> OVERSCAN=5.
NXSTEPS	Number of X substeps used in the observation, useful for interpreting ACQ/BIN data and exposure time. Usually 4

**Table 30.5: FOS Header Keywords (Continued)**

<b>Keyword</b>	<b>Description and Comments</b>
MINWAVE	Minimum wavelength in Å. (Not populated in .c0h file)
MAXWAVE	Maximum wavelength in angstroms. (Not populated in .c0h file)
YFGIMPEN	Onboard GIM correction enabled. T or F
KYDEPLOY	COSTAR mirror deployment for the FOS. T or F
<i>Exposure Time Information—usually in .d0h or .c1h</i>	
FPKTTIME	Time of first data packet sent to the SDF, i.e., approximate time of the <i>end</i> of the group exposure. The units are modified Julian date. Each group has its own unique FPKTIME, accurate to about 1/8 second.
LPKTTIME	Approximate time of the last data packet sent to the SDF. The units are modified Julian date.
DATE-OBS	FPKTTIME of group 1 converted to standard notation for date
TIME-OBS	FPKTTIME of group 1 converted to standard notation for time, truncated to integer value; thus these are only accurate to 1/8 of a second
EXPSTART	Exposure start time in modified Julian date
EXPOSURE	Exact exposure time per pixel in seconds for each group. Note that this keyword is not populated with real values in the d0h file
<i>Pattern Keywords for Exposure Times—usually in .c0h or .c1h</i>	
LIVETIME	Time, in units of 7.8125 microseconds, during which accumulator is open
DEADTIME	Time, in units of 7.8125 microseconds, in which accumulator is closed
INTS	Number of repetitions of the live time/dead time cycle
YSTEPS	Number of Y substeps used in the observation. Usually 1
NPAT	Number of patterns used per readout
SLICES	Number of repeats of the magnetic field deflection sequence. Usually 1
NREAD	Number of readouts per memory clear. For the ACCUM mode this is usually the number of groups. For RAPID mode this is 1
NMCLEARs	Number of memory clears per obs. 1 for ACCUM, number of groups for RAPID mode when NMCLEARs > 1
<i>Aperture Orientation Information—usually .shh and .d0h of acquisition image</i>	
OPMODE	Operation mode of the FOS for the observation. Can be: ACQ, ACQ/BIN, ACQ/PEAK, ACQ/FIRMWARE, IMAGE, ACCUM, RAPID or PERIOD
PA_APER	Position angle of the aperture in degrees
RA_APER1	RA of aperture center in degrees
DECAPER1	Dec of aperture center in degrees

**Table 30.6:** FOS Group Parameter Keywords

<b>Keyword</b>	<b>Typical Value</b>	<b>Alternate Name in Header</b>	<b>Description</b>
CRVAL1	1.	PTYPE1	Reference pixel value
CRPIX1	1.	PTYPE2	Pixel number of reference pixel
CD1_1	1.	PTYPE3	Pixel increment
DATAMIN	1.946443E-14	PTYPE4	Minimum value in the data
DATAMAX	1.118037E-13	PTYPE5	Maximum value in the data
RA_APER	297.4443291667	PTYPE6	Right ascension of aperture (deg)
DEC_APER	48.961	PTYPE7	Declination of aperture (deg)
FILLCNT	0	PTYPE8	Number of segments containing fill
ERRCNT	0	PTYPE9	Error count of the data
FPKTTIME	50441.0428552372	PTYPE10	Time of the first packet (Modified Julian Date)
LPKTTIME	50441.0428653645	PTYPE11	Time of the last packet (Modified Julian Date)
CTYPE1	PIXEL	PTYPE12	First coordinate type
APER_POS	SINGLE	PTYPE13	Aperture used
PASS_DIR	0	PTYPE14	Polarization pass direction
YPOS	-1597.	PTYPE15	y-position on photocathode (Y-bases)
YTYPE	OBJ	PTYPE16	Observation type: OBJ, SKY, BCK
EXPOSURE	62.5	PTYPE17	Exposure time per pixel (seconds)
X_OFFSET	0.	PTYPE18	x_offset for GIMP correction (diodes)
Y_OFFSET	0.	PTYPE19	y_offset for GIMP correction (defl.units)
SCT_VAL	0.1351963	PTYPE20	Scattered light correction value (cts/sec/pixel)
SCT_ERR	0.01424327	PTYPE21	Scattered light correction error (cts/sec/pixel)

## 30.3 FOS Paper Products

The FOS *paper products* are a package of summary text and diagnostic graphics that can be generated for any set of FOS observations. The FOS products were redesigned in 1996 to enhance their clarity and usefulness. Paper products can be generated for any FOS data by using **pp\_dads** which is in the STSDAS **hst\_calib.paper\_prod** package. In order to generate a full set of FOS paper products you will need the following six types of files: `.d0h/.d0d`, `.c0h/.c0d`, `.c1h/.c1d`, `.shh/.shd`, `.jih/.jit`, and `.pdq` (the first four sets are required to obtain a minimal set of products). Please refer to the task help file for information on how to run this package.

The FOS paper products produce title pages for an observation series and several pages of summary and diagnostics for each rootname in the series. At the exposure level three generic types of output are produced:

- Plots for each exposure, designed to provide diagnostic information for rapid data quality assessment.
- A spacecraft and exposure summary page which provides any Routine Science Data Pipeline (RSDP) post-observation assessments concerning data quality, guiding and jitter information including, if possible, a jitter ball plot, and extracts of important quantitative information from the data headers.
- A calibration status listing giving the status of all pipeline calibration flags as well as listing the reference files and tables used in the **calfos** calibration of the data.

Table 30.7 lists the types of FOS exposure-related paper products produced for each observing mode. Additionally, the order of the pages in the output products for a particular mode is given by reading from top to bottom along a column in this table.

Examples of FOS paper products are shown below for reference in this chapter. We have not included the title or closing pages in order to save space, but these examples do show representative cases of each type of mode-specific plot.

### 30.3.1 Title Pages

The first (cover) page produced by **pp\_dads** lists the proposal number and the name of the Principal Investigator. A closing page is produced that is virtually identical to the cover page.

Following the first page is a list of targets for the observations and a list of the individual exposures (see Figure 30.1). On this listing each exposure has a data quality flag that will be set if any `.pdq` file comment of sufficient severity exists. These comments are printed on the HST Performance Summary section of the Observation Summary paper product page for the relevant exposure. Many `.pdq` file comments are benign, so a raised data quality flag should simply serve as an indication that you need to check further. The presence of a telemetry gap in the

**Table 30.7:** FOS Paper Products by Observing Mode

Paper Product	ACCUM	RAPID	IMAGE grating	Polar- imetry	PER- IOD	IMAGE MIRROR	ACQ/ BIN	ACQ/ PEAK	ACQ/ FIRM
Flux vs Wavelength	<i>Last group</i>	<i>First group</i>	-	-	-	-	-	-	-
Counts vs Wavelength	<i>Last group</i>	<i>First group</i>	<i>All steps</i>	-	-	-	-	-	-
Group Counts	<i>If &gt; 1 group</i>	<i>If &gt; 1 group</i>	-	-	-	-	-	-	-
ACQ/BINARY diagram	-	-	-	-	-	-	✓	-	-
ACQ/PEAK scan plot	-	-	-	-	-	-	-	✓	-
Grayscale	-	-	-	-	-	✓	-	-	-
Observation Summary	✓	✓	✓	✓	✓	✓	✓	✓	✓
Calibration Summary	✓	✓	✓	✓	✓	✓	✓	✓	✓

data is not sufficient to cause the data quality flag to be set, but all telemetry gap messages from the .pdq file will also be printed on the HST Performance Summary section of the Observation Summary paper product page.

### 30.3.2 Observation Summary Page

This one-page summary sheet (see Figure 30.8) is divided into sections that describe basic exposure characteristics, telescope performance characteristics (OMS summary), calibration pipeline performance, and OPUS data quality evaluation comments.

#### Exposure Summary

The right-hand section of the page presents information from keywords that characterize the exposure, including target name, proposal-specified coordinates (not actual telescope pointing), disperser, aperture, observing mode, total exposure time, observation date, aperture position angle on sky, substepping and overscanning values, mean total dark per pixel for the exposure, mean scattered light correction per pixel (if applicable), and average readout time (for RAPID mode only).

#### OMS Summary

The OMS (Observatory Monitoring System) Summary presents, if the jitter file information is available, the jitter plot (*jitter ball*) which shows samplings made every six seconds of the spacecraft motion about nominal pointing in the (V2,V3) plane. The plot is always scaled based upon the extrema of the data being

plotted. Also included is a summary of the rms jitter in V2 and V3 in units of milliarcseconds, as well as the number of recenterings and losses-of-lock during the exposure. More information about OMS engineering data is available in Appendix C.

### Comments

Any comments found in the .pdq file are printed following the OMS statistics in the HST Telescope Performance Summary section. These comments include those made by OPUS personnel in their routine post-observation review of the observational data quality and automatic comments included by OPUS observation-evaluation software. Although such comments are often benign, the presence of most is sufficient to cause the Observation List observational quality flag to be set to “not OK.”

### Pipeline Performance

A listing of pipeline calibration anomalies, if any, is presented in the lower-left corner of the page.

## 30.3.3 Exposure Diagnostic Plots

For the purpose of data quality assessment, this is the most important section of the FOS paper products. Depending upon the observing mode, 0–3 pages of diagnostic plots and diagrams are produced for each individual exposure. Table 30.7 lists the types of plots that are generated for each observing mode. Following is a description of each type of plot:

### Flux vs. Wavelength

Two plots are provided (see Figure 30.5). The upper plot is a standard calibrated flux (.c1 file) vs. wavelength (.c0 file) with the display auto-scaled to the data extrema. The lower plot presents  $\log(\text{flux})$  vs. wavelength. Points with zero or negative values prior to the log operation are not plotted. This plot is made only for ACCUM and RAPID mode. For ACCUM mode, the last data group is plotted; for RAPID the first group is plotted.

### Corrected Counts vs. Wavelength

*Corrected counts* are the count-rates in each pixel of the .c5 file (raw observational data that have been corrected for all instrumental effects except the instrumental sensitivity correction to calibrated fluxes) *multiplied by* the effective exposure of each pixel. In this manner we plot a quantity that is easily manipulated (take the square root) to give a good approximation of the formal statistical S/N as a function of wavelength (see Figure 30.6).

The wavelength scale (from the .c0 file) is magnified by plotting the first half of the observed wavelength range in the upper half of the diagram and the balance of the spectrum in the lower half of the display.

This plot is made only for ACCUM, RAPID, and dispersed-light IMAGE mode. For ACCUM mode, the last data group is plotted and for RAPID the first group is plotted. For IMAGE mode all y-steps are plotted vs *pixel number* as IMAGE mode spectra are not wavelength calibrated.

## Group Counts

Again the ordinate is “corrected counts.” Here we plot the sum of the corrected counts over all pixels for each readout of the diode array vs. readout (group) number for all readouts in the exposure (see Figure 30.7). Note that the left-hand vertical axis is labeled in counts, but the right-hand vertical axis is labeled in percent of the maximum ordinate value. This provides an easy way of assessing the consistency of the counts between groups.

This plot provides a light curve of the target during the observations. This is an interesting display for variable objects, and it is also an easy way to assess the photometric repeatability of the measures and the stability of the telescope and the instrument during an entire observation.




---

We strongly recommend that the group counts plot be inspected for every ACCUM and RAPID mode observation in your data since it is a quick way to identify many of the more common problems that can affect FOS data.

---

This plot is made only for ACCUM and RAPID modes. For ACCUM mode, the individual groups are decomposed to produce the counts actually accumulated during each readout.

## ACQ/BINARY Deflection Diagram

There are several portions of this diagram (see Figure 30.3). Up to a maximum of eleven individual accumulated counts vs. pixel number (detector  $x$ -axis) plots are given. The first three correspond to mappings of the middle, lower, and upper thirds of the 4.3 aperture respectively. The remainder are for each of the magnetic deflections used to place the target on a  $y$ -edge of the diode array (and thereby produce a signal roughly half of the maximum detected in the first three images). The group number and  $Y$ -base for the deflection is printed on each plot.

To the left of these count-level plots is a diagram showing the relative  $y$ -position of diode center (in  $Y$ -base units) of each individual step in the binary search sequence. The final derived target  $Y$ -base position is also marked. Recall that one diode height is 256  $Y$ -base units.

The calculated  $(x,y)$  and equivalent  $(V2,V3)$  offsets are given in arcseconds. The  $x$ -offset is also given in pixels and the  $y$ -offset in  $Y$ -bases.

A compass rose showing the orientation of the detector  $+x$  and  $+y$  axes with respect to north and east on the sky is also given. The sense of the  $x$ -axis in the count-level plots and the  $y$ -direction in the deflection graphic are identical to the sense of the same directions illustrated in the compass rose.

## ACQ/PEAK Scan Diagram

This diagram shows the relative position of each dwell point in an ACQ/PEAK scan pattern plotted in the FOS detector  $(x,y)$  plane (see Figure 30.4). Note that  $x$  and  $y$  are displayed as if we are viewing the sky by looking through the detector from its back side. A compass rose shows the correct orientation of north and east

on the sky. Ordinal numbers are printed next to each scan position as are the total counts detected during each dwell.

ACQ/PEAK is a “return-to-brightest” (for pickup) algorithm. No attempt to centroid the contours or interpolate a position intermediate between dwell points is made. The dwell point with the highest number of counts is marked as the location to which the telescope moved after the pickup sequence. Check the OMS jitter ball, if available, to insure that no significant positioning errors occurred in the slew to the brightest location.

The calculated  $(x,y)$  and equivalent  $(V2,V3)$  offsets are given in arcseconds. The  $x$ - and  $y$ -step sizes for the scan pattern are also given.

The distribution of counts in each ACQ/PEAK pattern can be used to estimate the degree of centering error after movement to the brightest dwell point.

### Grayscale Image

A grayscale plot is made of the two-dimensional image in the FOS instrument coordinate  $(x,y)$  plane (see Figure 30.2). The units on both axes are FOS pixels. For a standard post-COSTAR ACQ image 1 pixel corresponds to approximately 0.075". A rule depicting the scale of 1" is also given.

A grayscale vs. counts key is provided. The orientation of the detector coordinates relative to north and east is provided via a compass rose.

This plot is provided only for IMAGE mode observations that use the MIRROR and for standard ACQ images.

## 30.3.4 Calibration Summary Page

This page (see Figure 30.9) presents in successive columns all **calfos** switch settings for each step in the calibration process, their status, the reference file or table used, the pedigree (if available) of the reference file, and a description of the action of each calibration switch or step. The shaded banner again gives logsheet line number, observation rootname, and proposal ID.

**Figure 30.1:** Visit Summary Listing

Visit: 04		Proposal: 06750				FOS			
<i>Target List</i>									
Target Name	R.A. (J2000)	Dec. (J2000)	Description						
TT-HYA	11:13:12.51	-26:27:54.4	STAR;B6-B9.5 V-IV;K III-I;INTERACTI						
<i>Observation List</i>									
Logsheet Line#	Rootname	Target Name	Operating Mode	Detector	Aperture	Spectral Element	Obs Date	Exposure (sec)	Quality Flags
4.004	Y38J0404T	TT-HYA	ACQ/PEAK	BLUE	0.26 SINGLE CIRC	H19	7/05/96	27.0	○
4.030	Y38JA402T	TT-HYA	ACCUM	BLUE	0.86 SINGLE CIRC	H19	7/05/96	1960.0	○
Quality flags: ○ = OK    ● = Not OK    Blank = Unknown or file missing									

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**Figure 30.2:** ACQ Image Plot

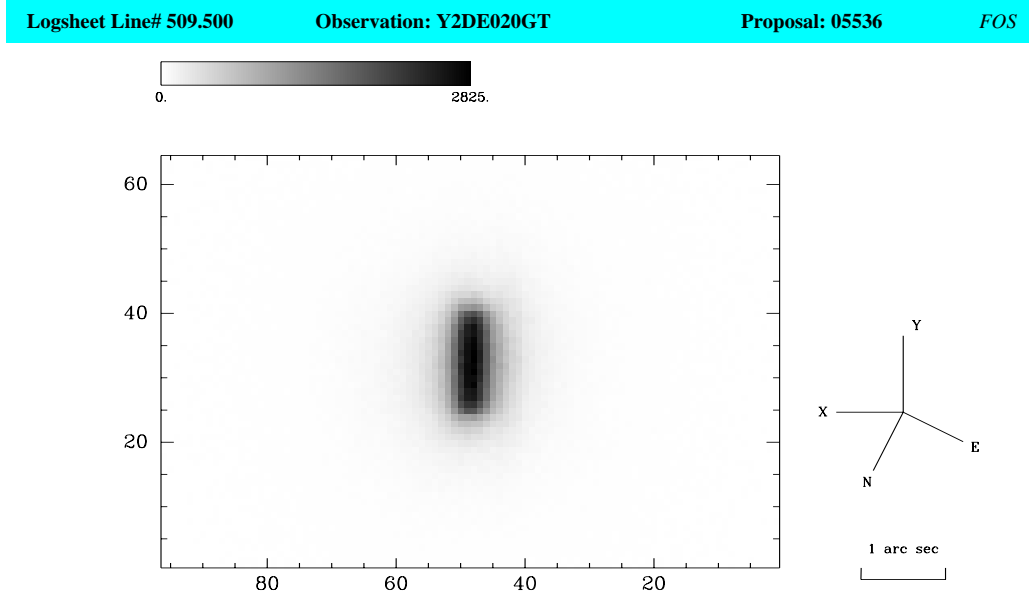
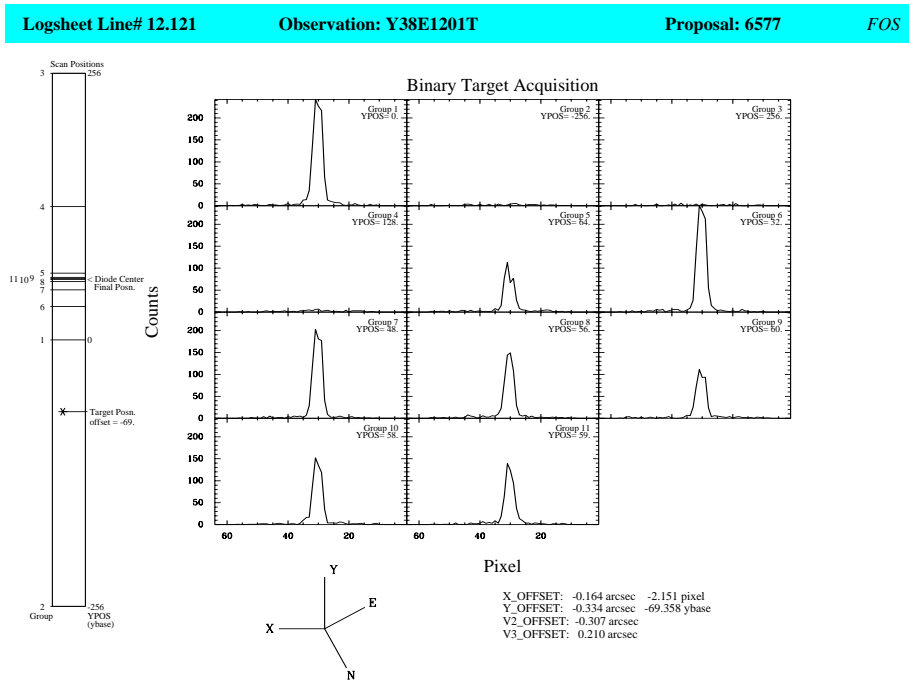


Figure 30.3: ACQ/BINARY Plot



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Figure 30.4: ACQ/PEAK Plot

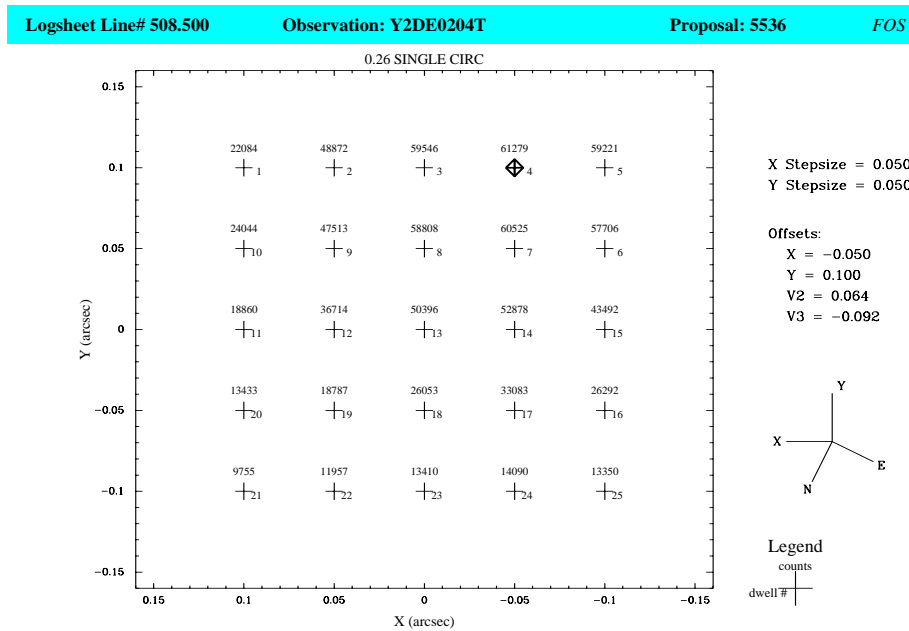


Figure 30.5:  $F_\lambda$  vs  $\lambda$  and  $\log F_\lambda$  vs  $\lambda$  Plot

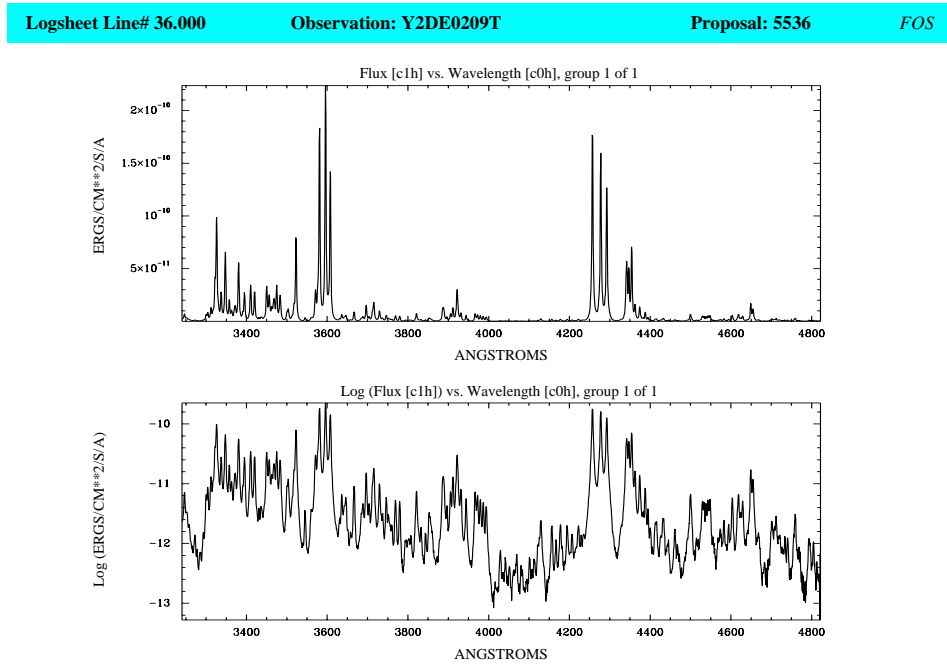
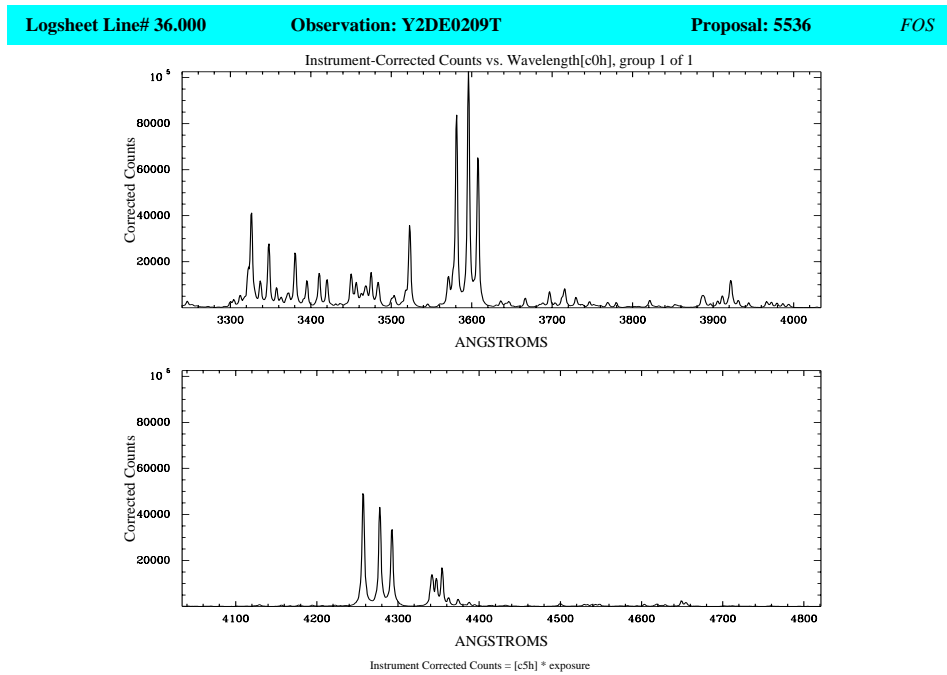


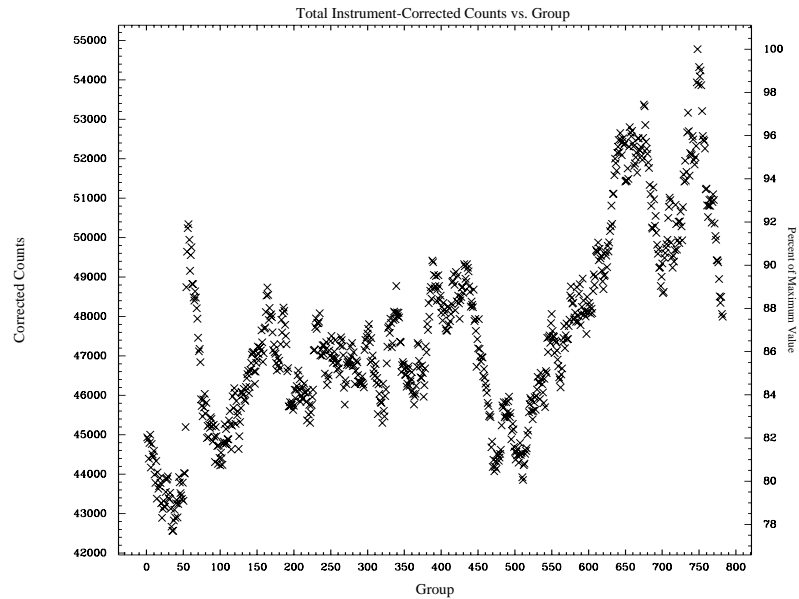
Figure 30.6: Corrected Counts vs  $\lambda$  Plot



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Figure 30.7: Group Count Plot

Logsheet Line# 2.500      Observation: Y2GN0205T      Proposal: 5498      FOS



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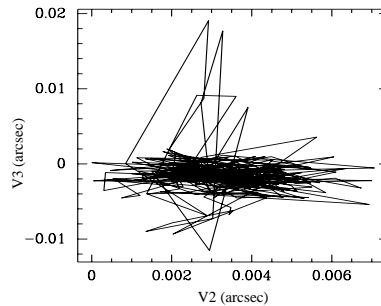
Figure 30.8: Observation Summary Page with Jitter Ball

Logsheet Line# 1.008      Observation: Y2XS0108T      Proposal: 06042      FOS

*HST Spacecraft Performance Summary*

# Recenterings:                      # Losses of Locks:  
 V2 Jitter (RMS):                    V2 Jitter (PP):  
 V3 Jitter (RMS):                    V3 Jitter (PP):

No apparent problems



*Pipeline Processing Summary*

*Exposure Summary*

Target Name: J1  
 RA (J2000): 10:45:04.38  
 Dec (J2000): -59:40:52.5  
 X POSTARG:  
 Y POSTARG:

Detector: AMBER  
 Grating: H19  
 Aperture: 0.86 PAIR SQUARE  
 Exp Time (sec): 900.0

Rootname: Y2XS0108T  
 Date: 5 Jul 96  
 Time: 15:14:17  
 Proposal: 06042  
 PI: DUF0UR

Ground Mode: SPECTROSCOPY  
 Position Angle: 26.33  
 First Channel: 0  
 # of Channels: 512  
 NXSTEPS: 4  
 Overscan: 5  
 YSTEPS: 2  
 Mean Dark Rate: 0.0131 cts/s/pix  
 Mean Dark Counts: 0.2105 cts/pix  
 Mean Scat. Light: -0.02071 cts/pix

Figure 30.9: Calibration Summary Page

Logsheet Line# 42.300		Observation: Y2ET0F0RT		Proposal: 05539	FOS
Calibration Status					
Flag	State	Reference File	Pedigree	Description	
ERR_CORR	OMIT			Propogated Error Computation	
CNT_CORR	COMPLETE	yref\$d9h1244ay.r4h		Disabled Diode Correction	
		yref\$b2f1308hy.r5h			
		N/A			
OFF_CORR	OMIT	ytab\$ba910502y.cy7		GIMP Correction	
PPC_CORR	COMPLETE	mtab\$sa3d1145ly.cmg		Paired Pulse Correction	
BAC_CORR	OMIT	N/A		Background Subtraction	
		ytab\$sa3d1145gy.cy3			
		ytab\$e3i09491y.cy9			
GMF_CORR	OMIT	ytab\$ba31407ly.cy8		Scale Reference Background	
SCT_CORR	OMIT	ytab\$e3i09491y.cy9		Scattered Light Correction	
FLT_CORR	OMIT	N/A		Flat-field Removal	
		N/A			
SKY_CORR	OMIT	ytab\$sa3d1145dy.cy0		Sky Subtraction	
		ytab\$sa3d1145fy.cy2			
		ytab\$sa3d1145gy.cy3			
		ytab\$sa3d1145jy.cy5			
WAV_CORR	OMIT	ytab\$e5v11576y.cy6		Wavelength Scale Determination	
FLX_CORR	OMIT	N/A		Flux Scale Generation	
		N/A			
APR_CORR	OMIT	n/a		Aperture Throughput Correction	
		n/a			
		n/a			
AIS_CORR	OMIT	N/A		AIS Flux Scale Generation	
TIM_CORR	OMIT	n/a		Time Changes in Sensitivity	
MOD_CORR	OMIT	N/A		Mode Dependent Corrections	
		ytab\$e5v13262y.cy4			

## 30.4 Evaluating Planned Observations

### 30.4.1 Planned Observations (Exposure Logsheet)

An examination of the RPS2 (RPSS for pre-COSTAR) input file or, more commonly, the concise proposal summary logsheet can be helpful in understanding the structure and content of an observation sequence. As will be emphasized in Chapter 32, the observational strategies employed, such as target acquisition or limitation of wavelength readout, can have a very profound effect on the quality of FOS data. An understanding of what was planned can be beneficial in comprehending what was actually obtained.

The exposure logsheets and RPS2 input files for post-COSTAR programs are available from the PRESTO web page:

<http://presto.stsci.edu/public/propinfo.html>

FOS program logsheets and RPS2 (RPSS) input files are available via the FOS WWW page **propfind** query:

[http://www.stsci.edu/ftp/instrument\\_news/FOS/propfind.html](http://www.stsci.edu/ftp/instrument_news/FOS/propfind.html)

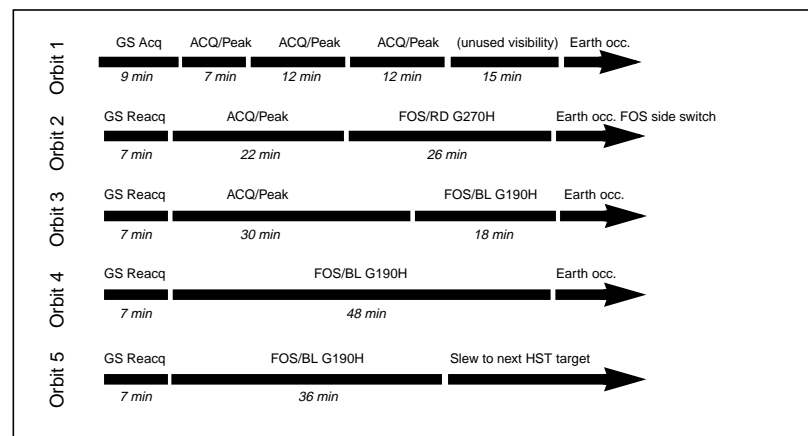
In Figure 30.11 we show one exposure logsheet as an example. This will be used occasionally in the following to outline a few checks you can run on your

data in order to assess whether what you see is what you expected. In our example the FOS observations started with a four-stage ACQ/PEAK target acquisition at the beginning of the visibility period, followed by science observations using the FOS/RD detector with the G270H grating and the circular 1.0" aperture. The investigators used the occultation time after the second visibility period to execute a side switch from FOS/RD to FOS/BL, which takes about 50 minutes. Then, in exposure 5, they re-acquired the target with a single-stage peak-up in order to insure good pointing accuracy and then continued their science observations, now using the G190H grating for a total of 100 minutes. By looking at the data files, but not the exposure logsheet or the RPS2, one can find out that this long integration was split into three separate exposures: the first filling the remainder of the re-acquisition orbit and then one each in the subsequent two orbits. Naturally, each such exposure will receive its own rootname and complete set of data files, and each will produce its own set of diagnostic paper product pages.

In summary, since FOS exposures are not interruptible, a single exposure logsheet line or RPS2 exposure line may produce several distinct FOS exposures and hence several sets of data files. Each set of data files will be identified by unique, usually consecutively ordered, rootnames.

Figure 30.10 shows in graphical form the time sequence of events and exposures during the execution of lines 1 through 6 of the sample exposure logsheet. For the example orbits shown the target visibility is 55 minutes and Earth occultation lasts 41 minutes. Note that the exposure for logsheet line 4 was shortened from 33 to 26 minutes in order to fit it into the available target visibility. The HST scheduling system routinely shortened or lengthened exposures by up to 20% in such cases

**Figure 30.10:** Timeline for FOS Activities in Sample Program



**Figure 30.11:** Sample FOS Exposure Logsheet

Exposure Number	Target Name	Instr  Config	Oper.  Mode	Aper  or FOV	Spectral  Element	Central  WaveIn.	Optional  Parameters	Num  Exp	Time	Special  Requirements
1	ARP102B	FOS/RD	ACQ/ PEAK	4.3	MIRROR		SCAN-STEP- Y=1.204 SEARCH-SIZE-X=1 SEARCH-SIZE-Y=3	1	1.4S	ONBOARD ACQ FOR 2 GROUP 1-7 WITHIN 3D GROUP 1-6 NO GAP
2	ARP102B	FOS/RD	ACQ/ PEAK	1.0	MIRROR		SCAN-STEP- X=.602 SCAN-STEP- Y=.602 SEARCH-SIZE-X=6 SEARCH-SIZE-Y=2	1	2.0S	ONBOARD ACQ FOR 3
3	ARP102B	FOS/RD	ACQ/ PEAK	0.5	MIRROR		SCAN-STEP- X=0.30 SCAN-STEP- Y=0.30 SEARCH-SIZE-X=3 SEARCH-SIZE-Y=3	1	10S	ONBOARD ACQ FOR 3.5
3.5	ARP102B	FOS/RD	ACQ/ PEAK	0.3	MIRROR		SCAN-STEP- X=0.06 SCAN-STEP- Y=0.06 SEARCH-SIZE-X=5 SEARCH-SIZE-Y=5	1	10S	ONBOARD ACQ FOR 4
4	ARP102B	FOS/RD	ACCUM	1.0	G270H	2760		1	33M	
5	ARP102B	FOS/BL	ACQ/ PEAK	0.3	MIRROR		SCAN-STEP- X=0.06 SCAN-STEP- Y=0.06 SEARCH-SIZE-X=5 SEARCH-SIZE-Y=5	1	30S	ONBOARD ACQ FOR 6
6	ARP102B	FOS/BL	ACCUM	1.0	G190H	1950		1	100M	

## 30.5 Assessing FOS Acquisitions

Nearly all FOS observations included an onboard target acquisition that used instrument observing modes to locate the science target in the desired aperture. Under normal circumstances, prior to any FOS acquisition or science observation sequence the FGS performed a guide star acquisition and commenced FINE lock guiding. A guide star re-acquisition was also performed at the start of all subsequent visibilities in the same visit. Occasionally, some aspect of the acquisition or re-acquisition failed. Appendix C provides for more information about guide star acquisition failure. Chapter 35 (for the GHRS) also contains useful discussions of a variety of guide star acquisition and guiding anomalies.

Before June 1993, the FOS aperture door was closed for the remainder of any exposure during which a guiding anomaly occurred. As a safety measure, commencing in June 1993 the FOS shutter door was always closed for the duration of the obset (typically remainder of the visit) if guide star lock was not

established at the start of any exposure. After October 1995, a significant number of FOS acquisitions failed in this manner due to anomalous losses-of-lock caused by FGS1.

This section describes each type of FOS acquisition by giving a detailed discussion of the acquisition method (in the “Understanding” subsection), a discussion of pointing accuracy limitations with the method, a description of and references to examples of the mode-specific paper products, tips for understanding and using the paper products to assess the observational data quality, a description of the structure and content of the output data products, analysis information, and, in some cases, very detailed background information for the most inquisitive users.




---

No FOS acquisition exposure (e.g., an ACQ/BINARY exposure or a single scan-pattern of an ACQ/PEAK) could be interrupted by Earth occultation.

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Some additional practical information on target acquisition is given in Chapter 2 of the *FOS Instrument Handbook* version 6.

### 30.5.1 Binary Acquisition—ACQ/BIN

*Binary search acquisition mode* is indicated by a raw data header file (.d0h) OPMODE value of ACQ/BIN. This method was used for targets that are point sources with well known energy distributions. Although ACQ/BIN was designed to select the *n*th brightest object in a crowded field, this option was never correctly used except in calibration programs. The following discussion will describe how the brightest target was acquired.

#### Understanding ACQ/BINARY

The binary search algorithm used MIRROR and began by mapping the 4.3 aperture (only the 12 central diodes which cover the 4.3 aperture provide the data) with 3 *y*-scans which are stored in the raw data file as 3 groups. The first raster (i.e., group 1) was of the central region of the 4.3 aperture, the second (group 2) was of the lower region of the 4.3 aperture, and the third (group 3) was of the upper region of the 4.3 aperture. The binary search algorithm summed in each group the counts from all pixels that are bounded by the user-specified FAINT and BRIGHT limits. The program then compared the count levels in the three scans, and located the target in one of the three scans by finding the total number of peaks in the scan and the number of counts in each individual peak. The brightest peak, representing the target, was then selected. If more than five peaks per raster were found by the binary search algorithm, the target acquisition failed. If there were two peaks (within a diode width) in two adjacent scans, the algorithm summed up the number of counts in the two peaks to determine the brightness of the target. The search program then continued (up to eight more tries) to electronically deflect the image of the target in the *y*-direction (note the telescope was never moved in this search process) until the target image was on

the edge of the diode array, i.e., until the number of counts in the peak was half the maximum number of counts observed in the initial three scans. For each deflection the data were stored as a group.

The offset required to position the target on the edge of the diode array was stored in the .shh file. This quantity was then used to determine the slew that was necessary to place the object in the nominal center of the 4 . 3 aperture. Note that no further refinement of position was made in the binary search algorithm.




---

If ACQ/BINARY failed for any reason (*except* 8-steps-to-success described below), the telescope *did not slew* to place the target at the nominal center of the 4 . 3 aperture, and subsequent exposures in the visit were executed at the initial blind pointing position of the telescope.

---

### Pointing Accuracy: ACQ/BINARY

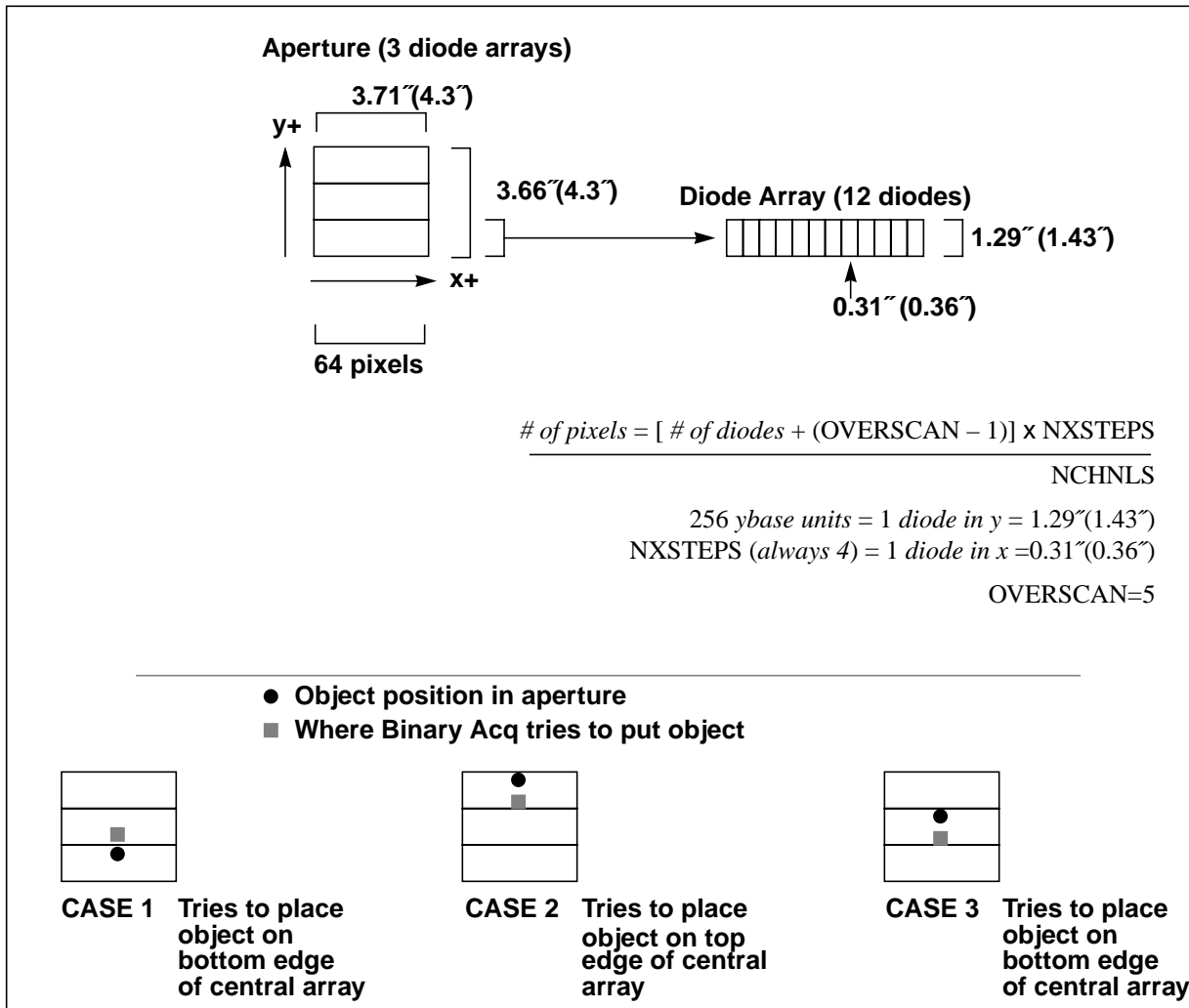
If a binary search was successful, we can only determine the amount of telescope slew that occurred to place the target at the STScI-determined nominal aperture center on the diode array. We cannot locate the exact position of the target in the aperture unless a confirming image was acquired after the acquisition.

Since binary search determined the offset to place the target on the edge of the diode array and used that offset to calculate the offset slew required to place the target at the expected center of the 4 . 3 acquisition aperture, the accuracy of centering was dependent on both the accuracy of the half-power point algorithm and the 0.1" accuracy with which the location of the center of the 4 . 3 aperture was known (see *FOS ISR 139*).

The statistical 1-sigma uncertainty for ACQ/BIN is 0.08" for post-COSTAR FOS/BL and 0.12" for post-COSTAR FOS/RD. Pre-COSTAR uncertainties are estimated to be of similar order, but an additional worst-case uncertainty of up to 0.15" due to uncorrected GIM motion must be added in quadrature for all ACQ/BIN acquisitions prior to April 5, 1993.

If an ACQ/BIN spectrum has 11 groups, it may have been considered to have failed. Before June 1, 1993, all such acquisitions were returned to the blind pointing. Commanding was changed on that date to recognize the fact that any additional correction to be applied after the algorithm reached the eleventh step was typically of order 0.02" and of no significance. After this date, these so-called 8-steps-to-success "failures" resulted in the position implied by the last ACQ/BIN iteration being chosen as the pointing. Figure 30.12 illustrates some of the characteristics of ACQ/BINARY.

Figure 30.12: Binary Target Acquisition (pre-COSTAR sizes in parentheses)



### Paper Products: ACQ/BINARY

Figure 30.3 provides an illustration of the FOS paper products ACQ/BINARY diagnostic plots. The one-dimensional images (counts vs pixel) for each group are plotted as well as a separate map of Y-bases chosen for each deflection step. The final x- and y-offsets, and their equivalent V2 and V3 offsets required to center the target are given. A compass rose, oriented identically to the spatial coordinates of the individual plots, is also provided. Conversion of offsets to right ascension and declination is described in "Converting X,Y to RA, Dec" on page 33-9.

### Output Data Products: ACQ/BINARY

The binary search target acquisition mode is identified by the OPMODE value of ACQ/BIN. The ACQ/BIN data (.d0h file) contains up to 11 groups (depending at which stage the algorithm stopped the search) and each group has images of 64 pixels (12 diodes scanned with NXSTEPS=4 and OVERSCAN=5). The central

pixel is defined to be number 32 of the numeric range 1–64. The **calfos** calibration only corrects the data for paired-pulse effects and converts the raw counts into a count rate. No further calibration procedures are applied.

### **Analysis: ACQ/BINARY**

If there are fewer than four groups in the ACQ/BINARY data files, the binary search target acquisition has failed.

A binary search may have failed due to one of the following reasons:

- The FAINT limit provided by the observer was too low, i.e., the algorithm was confused due to the dominance of the wings of the PSF (particularly applicable to pre-COSTAR observations). This commonly yielded field-too-crowded failures.
- The algorithm was not completed in 11 steps because the target was extended or the GIM moved the target (for observations generally before April 5, 1993, when onboard GIM was not yet activated).
- The field was too crowded, i.e., the algorithm found more than five peaks in a scan.
- The source was much fainter than determined by the observer, i.e., there were very few counts in the observations.
- The FAINT limit provided by the observer was too high, i.e., the algorithm encountered fewer counts than the faint limit.
- The BRIGHT limit provided by the observer was too low, i.e., the algorithm encountered too many counts.

## **30.5.2 Pickup or Peakdown Acquisition (ACQ/PEAK)**

This acquisition mode was used for bright targets, variable targets, targets whose energy distributions were not well known, and especially for those cases in which very accurate pointing was required. This acquisition mode was used extensively throughout the FOS operational lifetime. The highest pointing accuracies achieved with FOS used ACQ/PEAK and after July 1, 1992, all FOS flatfield, photometric calibration, and external wavelength calibration observations used high-precision multiple-stage ACQ/PEAK acquisitions.

### **Understanding ACQ/PEAK**

An ACQ/PEAK stage consisted of a series of NXSTEPS=1, OVERSCAN=1 exposures made at each point in a user-specified scan pattern. All successful ACQ/PEAK stages ended with a telescope slew to the pointing corresponding to the brightest (for pickup) or faintest (for peakdown) exposure in the scan pattern. No attempts were made to interpolate positions between individual pointings in the scan pattern. Evaluation of the brightness of the signal at each dwell point was performed onboard by simple addition of the counts accumulated in all pixels with no correction for background, dead or noisy diodes, paired pulse, or even *edge-pixel exposure* effects.

As for ACQ/BIN, the first stage of a peak-up target acquisition was normally done in three integration steps with the 4.3" aperture and either the camera MIRROR or a disperser. As with all FOS acquisitions, the original target coordinates for the first stage were required to be accurate to about 1", so that the object fell within the 4.3" aperture. After this first stage the measured signals from the dwell points were stored in the raw data file as three groups. The dwell point with the maximum number of counts was determined and the telescope was positioned with the center of the aperture corresponding to this dwell point. The second stage, a 2 x 6 step pattern, using the 1.0" aperture, traced the location of the source within the 1.3" x 3.7" (1.4" x 4.3" pre-COSTAR) area where it was found in the first stage and these measures were recorded as groups in a separate data file. This narrowed the area in which the target was located to the surface area of the 1.0" aperture (to the one of the 12 integrations that had the most counts). The third stage of a peak-up sequence was normally a 3 x 3 point scan of the area of the 1.0" aperture, with the 0.5" aperture and a step size of about 0.3". This led to a pointing accuracy of about 0.2". If higher accuracy was needed, the surface area of the 0.5" aperture had to be scanned with the 0.3" aperture, possibly in two steps with decreasing step sizes. A variety of patterns and pattern-sequences were used by observers. Please refer to Table 32.3 for a listing of the FOS team-recommended patterns and nominal worst-case pointing accuracies.

No individual peakup or peakdown stage could be interrupted by Earth occultation. For much of the HST lifetime, telescope commanding imposed a maximum duration, including overheads, for any peakup/peakdown stage (or scan sequence) of 3000 seconds.

### Pointing Accuracy: ACQ/PEAK

In the limit of perfect photon statistics, a positional accuracy upper limit for a particular coordinate in any ACQ/PEAK stage is one-half the step-size in that coordinate. This remains a good approximation for most commonly used apertures and scan patterns as the FOS team routinely recommended obtaining 10,000 counts in the peak dwell for so-called *critical peakups* (those that used the 0.3 or smaller aperture with step-sizes of 0.06" or smaller) and 50,000 counts in the most strongly exposed dwell of *critical peakdowns*. As Table 32.3 indicates, the most precise nominal worst-case pointing accuracy routinely recommended by the FOS team was 0.025" in each coordinate.

### Paper Products: ACQ/PEAK

Figure 30.4 presents a typical FOS paper product ACQ/PEAK diagnostic plot for a 5 x 5 scan pattern. Apart from a period between July and November 1994 when anomalous scan parameter values were written in the ACQ/PEAK headers (see below), the pattern is plotted in the correct orientation and in the correct sense of telescope motion in detector coordinates. The offset to move the telescope to the brightest (or faintest in the case of peakdown) tile of the scan pattern is provided in both the detector ( $x,y$ ) and telescope ( $V2,V3$ ) frames. A compass rose is given. PA\_APER is also given for easy conversion of ( $x,y$ ) offsets to the (RA, Dec) frame, although we do not calculate the offset in (RA,Dec). See "Converting X,Y to RA, Dec" on page 33-9 for a description of how to convert to the (RA,Dec) frame. No contour plot is provided. No spectra or images from the individual tiles are plotted, but in some cases you may wish to inspect the individual groups that

contain these quantities. The standard jitter ball is provided which typically shows the scan pattern in (V2,V3) and indicates how closely the telescope moved to the desired dwell point.

### Output Data Products: ACQ/PEAK

The *peakup* or *peakdown* mode is identified by the .d0h OPMODE value of ACQ/PEAK. Each stage of an ACQ/PEAK sequence produced its own set of output data files. An ACQ/PEAK scan-pattern with  $x$  rows and  $y$  columns produced output data files with  $(x \times y)$  individual groups.

ACQ/PEAK measures with the MIRROR produced a one-line raster of 96 pixels (NXSTEPS=4, OVERSCAN=5 pattern with 20 diodes readout). Note that even the 4.3 aperture, the largest FOS aperture, illuminated only 12 diodes. ACQ/PEAK measures with a disperser produced 512 pixels (NXSTEPS=1, OVERSCAN=1 pattern with all 512 diodes read out by default). The number of diodes sampled in a dispersed light ACQ/PEAK could be altered by the specification of a limited wavelength range to be read out. These images and spectra are not calibrated by the pipeline, but may contain scientifically useful information. We recommend inspection of these data files (see below).

### Analysis: ACQ/PEAK

You can determine the centering accuracy of most ACQ/PEAK stages by inspecting the distribution of counts in the tiles of the scan pattern. Notice that for many acquisitions, especially in the pre-COSTAR era, the centering accuracy is not the same in both FOS  $x$  and  $y$ . This led in some of these cases to compromised flat field and flux calibration.

The individual spectra in an ACQ/PEAK with either a disperser or MIRROR can yield valuable information about the distribution of light or excitation in extended sources, or provide additional spectroscopic information for point sources if the acquisition disperser was not used for any science observations. Care must be exercised, however, in analysis of these off-center observations as many such spectra will not be fully sampled by the diode array (see “Location of Image on Diode Array” on page 32-7).

In order to convert FOS  $x,y$  coordinates into sky coordinates, you need to know the position angle of the aperture, which is documented in the header keyword PA\_APER (see “Converting X,Y to RA, Dec” on page 33-9) and which is routinely provided in the paper products.

The FOS paper products algorithm calculates observed counts per dwell tile from the .c5 files, which have had several corrections applied that were not performed by the onboard ACQ/PEAK algorithm (most notably paired-pulse and edge-pixel exposure correction). In extremely rare cases involving very low count levels, the paper product algorithm may predict a different maximum tile than that actually chosen by the onboard processor. This discrepancy has been documented only in situations in which the FOS aperture door was closed due to guide star acquisition failure.

In mid-1994 the scan direction for some ACQ/PEAK exposures was changed at the same time that commanding overheads were made up to 20% more efficient. Between July and November 1994, ACQ/PEAK scan information was not written

to the header files. Analysis of ACQ/PEAK patterns in this period must be done manually with the information contained in the logsheet. The simplest approach to determine scan-pattern directions for your manual analysis is to run the FOS paper products for an equivalent ACQ/PEAK performed after November, 1994.

### 30.5.3 IMAGE Mode Target Acquisitions

#### Understanding FOS ACQ Imaging

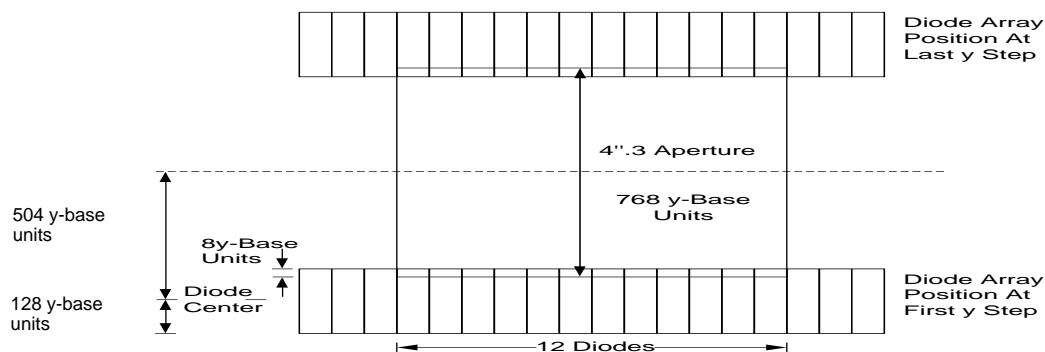
FOS IMAGE mode observations mapped more than one position in the aperture with the diode array.

#### ***Spectral Element: MIRROR***

FOS imaging mode with spectral element MIRROR was typically used for EARLY acquisition, INTERactive ACQuisition, or to obtain a verification image of the FOS large aperture to check the target position in the aperture.

Camera MIRROR images for interactive acquisition (logsheet entry INT ACQ) were designated by OPMODE=ACQ. Standard camera MIRROR images of the 4.3 aperture which did not require real-time interaction (logsheet entry ACQ) were designated, somewhat confusingly, by OPMODE=IMAGE. Both types of images have GRNDMODE=ACQUISITION and use the same set of pre-defined instrumental setups. The far less commonly used user-defined IMAGE command (logsheet entry IMAGE, spectral element MIRROR) allowed the user to specify image line and raster parameters for spectral element MIRROR and was designated by GRNDMODE=IMAGE, OPMODE=IMAGE. In the following we use the term FOS ACQ Imaging to refer to all of these imaging modes.

In a standard INT ACQ or confirming ACQ image the FOS Digicon was commanded through a pre-defined sequence of  $x$ -steps and  $y$ -steps which mapped the aperture. The 4.3" aperture was scanned with 64 strips, each of which was the height of the diode array, beginning at the bottom,  $-y$ , edge of the aperture. The post-COSTAR distance between the strips was 16 Y-base units or 0.0786" for FOS/BL and 0.0812" for FOS/RD. The pre-COSTAR distance was 0.08958" for both detectors. Each scan read out 20 diodes with the central 12 diodes spanning the 4.3" aperture. In the standard mode (NXSTEPS=4 and OVERSCAN=5) the number of pixels in each strip was 96. Thus the image has 96 x 64 pixels where each pixel were equally spaced on the sky (see Figure 30.13).

**Figure 30.13:** Digicon Faceplate Sampling Pattern in a Target Acquisition Image

### ***Spectral Element: Any Disperser***

The rarely used user-defined dispersed-light IMAGE command (logsheet entry IMAGE with any disperser as spectral element) allowed the user to specify image raster parameters with a spectral element. Spectra with user-specified values for NXSTEPS and OVERSCAN at YSTEPS y-positions, symmetrically spaced about the default aperture center Y-base were obtained. So-called dispersed-light interactive target acquisitions were occasionally employed for solar system moving targets, usually comets, with a dispersed-light IMAGE mode observation at several y-positions in the 4.3 aperture. The maximum integrated count level in the entire spectrum determined the y-position offset of the initial blind pointing from nominal and the deviation of a well-known spectrum line from its anticipated x-position allowed determination of the blind pointing mis-centering in the x-direction.

### **Pointing Accuracy: FOS ACQ Imaging**

***Mirror Mode Images:*** Image centroiding accuracies varied, but for well-exposed images centering accuracies were about 0.1" in both x and y.

***Dispersed-Light Mode Images:*** Uncertainties of <0.5" in both coordinates were achieved. This was typically sufficient for centering of comets in the 4.3 aperture.

### **Paper Products: FOS ACQ Imaging**

Paper products for FOS images with spectral element MIRROR present grayscale renderings of the raw aperture image (see Figure 30.2). No image rectification or deconvolution is attempted. A compass rose provides orientation information and plate-scale fiducials are plotted. An exposure level key is also provided. See "Image Mode Spectra (IMAGE)" on page 30-47 for a discussion of dispersed-light image mode paper products.

### **Output Data Products: FOS ACQ Imaging**

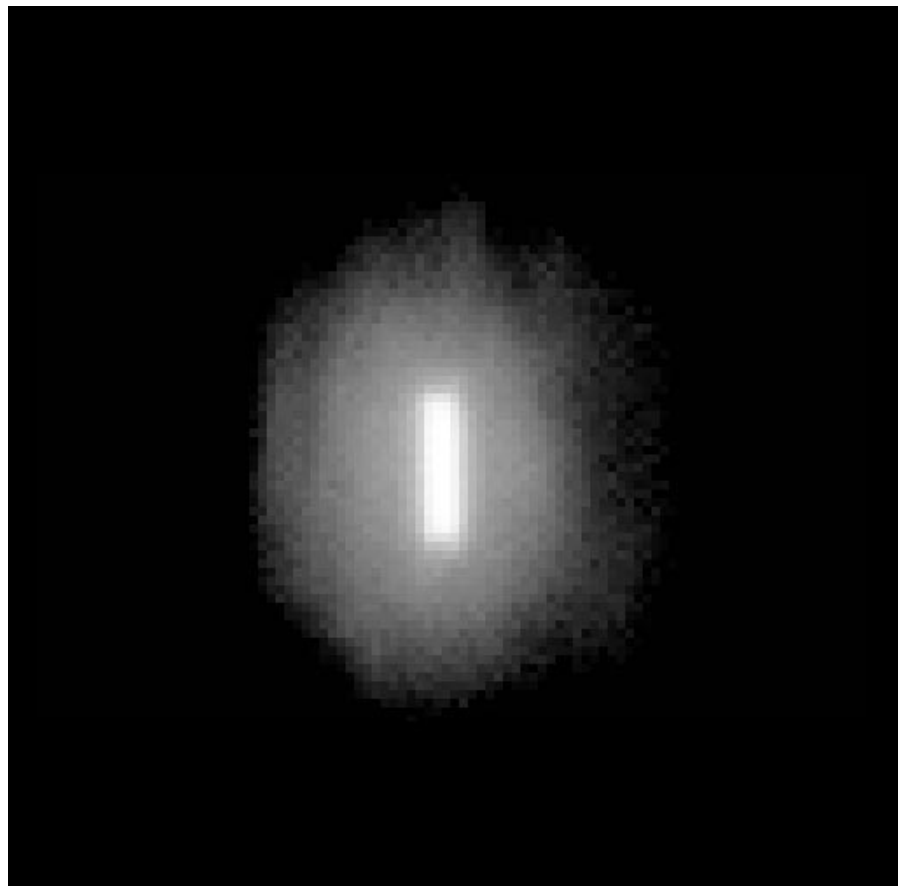
The calibrated INT ACQ and ACQ data files have 64 groups with each group having 96 pixels. The raw data file (.d0h) is an actual 96 x 64 image (1 group)

file. Output files for user-defined images contain header keyword YSTEPS groups of keyword  $(NCHNLS+(OVERSCAN-1))*NXSTEP$  pixels. Routine calibration processing produces .c4 files which are no longer two-dimensional images, rather are multi-group files with one group for each raster of the image. The IRAF/STSDAS task **rapidlook** converts these processed files back to a two-dimensional representation suitable for examination with standard image processing tasks. A discussion of dispersed-light image mode data products is presented in “Image Mode Spectra (IMAGE)” on page 30-47.

### Analysis: FOS ACQ Imaging

The substepping in both the  $x$  and  $y$  directions, and the elongated shape of the diodes, blurred and stretched the image (see Figure 30.14). A point source (which has the size of a PSF) on the photocathode was recorded by the same diode for four consecutive pixels in the  $x$  direction and 16 consecutive pixels in the  $y$  direction. The **tarestore** task in STSDAS can be used to deconvolve the image. In this task the image is trimmed and the flux resampled in the pixels. The **modeone** task also uses the **tarestore** task and displays the deconvolved image with the correct orientation on the sky (north and east are indicated).

**Figure 30.14:** Sample FOS Target Acquisition Image



The position of the target in the image can be found by using the task **aperlocy** in STSDAS. This task computes the location of the image edges, the midpoint of each axis, the centroid of the image, and the total flux in the image. Note that **aperlocy** can not be used on restored images and that it will produce meaningful results only for images with a single source present. The output units of this task are diodes for the  $x$ -axis and Y-base units for the  $y$ -axis. This task also takes into account the elongated shape of the diodes in determining the target centroid in the aperture. The nominal center for the 4.3 aperture is at the pixel (48,32). To determine the nominal aperture center in diode and Y-base units, the following equations are used:

$$\text{aper\_center (X)} = \text{FCHNL} + \frac{(48 - 1)}{\text{NXSTEPS}}$$

$$\text{aper\_center (Y)} = \text{YBASE} + (32 - 1) \times 16$$

where:

- FCHNL is the first channel.
- NXSTEPS is the number of substeps.
- YBASE is the location of the diode array for the first group.

The centroid of the target can then be compared with the aperture center to determine the location of the target in the aperture. Note that the **aperlocy** task can also be used for images of the paired apertures. See the on-line help files in STSDAS for details.

## 30.5.4 Firmware Target Acquisition

### Understanding ACQ/FIRMWARE

Firmware mode was occasionally used for pre-COSTAR planetary satellite observations, although this was an engineering mode. This procedure mapped the camera MIRROR image of the 4.3 aperture in  $x$  and  $y$  with small, selectable  $y$  raster increments. The microprocessor filtered this aperture map in real time and found  $y$ -positions of the peaks by fitting triangles through the data.

ACQ/FIRMWARE was less efficient than ACQ/BINARY and failed if more than one object were found. In practice this mode sometimes failed because the brightness limits were not set accurately by the observer. ACQ/FIRMWARE was used several times in the pre-COSTAR period and was included in an SMOV target acquisition testing program, but no ACQ/FIRMWARE acquisitions were performed in post-COSTAR science programs.

### Pointing Accuracy: ACQ/FIRMWARE

Pre-COSTAR accuracies for ACQ/FIRMWARE were similar to those for ACQ/BINARY, approximately 0.15-0.20" one sigma. No post-COSTAR evaluation of ACQ/FIRMWARE pointing accuracy was made.

**Paper Products: ACQ/FIRMWARE**

There are *no* ACQ/FIRMWARE-specific paper product displays. The standard spacecraft performance, jitter ball, and calibration status pages are produced.

**Output Data Products: ACQ/FIRMWARE**

The firmware target acquisition mode is identified by the OPMODE value of ACQ/FIRMWARE. The ACQ/FIRMWARE mode mapped the 4.3 aperture with a certain number ( $m$ ) of Y-steps acquiring data from 20 diodes covering the aperture in the standard ACCUM mode. The target acquisition data therefore has  $m$  groups with 96 pixels (NXSTEPS=4 and OVERSCAN=5).

**Analysis: ACQ/FIRMWARE**

The microprocessor onboard the FOS searched for the peaks in the data array within a specific window and the target was centered at this location. The  $m$  groups could be plotted as a function of location and the position of the target in the aperture could be determined in a manner similar to the ACQ mode.

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## 30.6 Assessing FOS Science Observations

After checking the target acquisition you may want to know whether the requested science integration time requirements were actually fulfilled. The exposure logsheet (see exposure number 4 in Figure 30.11) gives only a first estimate as requested exposure times were often modified by up to 20% to facilitate efficient orbit-packing. The actual on-source integration times are stored in the headers of the science data (e.g., the .c1h and .c0h files), in the header keyword EXPTIME. The Exposure Summary section of the FOS paper products Observation Summary page also provides this information. For example, logsheet exposure 4 in Figure 30.11 requested an exposure time of 33 minutes, but reference to Figure 30.10 shows that the actual integration time with the G270H grating was shortened to 26 minutes in order to fill the orbit up to occultation.

Alternatively, if an exposure should be much shorter than was planned, check whether the observation was interrupted by an earth occultation. In this case, the integration will have been resumed as a separate exposure with a new rootname after re-acquisition of the guide stars following the occultation. In the example of logsheet exposure 6 in Figure 30.11 a 100 minute exposure with grating G190H was requested. As shown in Figure 30.10 the initial G190H exposure could last only 17 minutes prior to occultation. A new G190H 48 minute exposure complete with separate rootname and data products entirely filled the next orbit and yet a third separate exposure of 35 minute duration in the orbit following rounded out the complete 100 minute exposure time requested. (If the proposer had used the appropriate RPS2 command, the last orbit could have been completely filled, but it was not in this case.) Since the three exposures were obtained in different orbits on different guide star re-acquisitions, it is important to check that no pointing or guiding anomalies have occurred and that all have produced comparable photometric results.



FOS exposures were not interruptible. Once data-taking stopped for occultation or SAA passage, the exposure was terminated. Upon target re-acquisition a new exposure began with a new observation rootname and resulted in a completely new set of science data products. Prior to co-adding such exposure segments they should be carefully compared to look for photometric or other differences that could be associated with pointing or guiding.

In the following sections we describe the details of each spectroscopic mode of FOS scientific data taking, namely ACCUM, RAPID, POLARIMETRY, PERIOD, and dispersed-light IMAGE. We describe the characteristics and structure of the mode-specific paper products and the electronic science data products. We will also provide guidelines concerning the analysis of the scientific data quality based upon evaluation of both the paper and electronic products.

The FOS paper products are useful for judging the quality of the spectra, including the quality of the calibration, the existence of artifacts, and the validity of specific features. Nonetheless, you may need additional detailed information on the single steps of the data calibration and on the characteristics of the instrument. Chapter 31 describes the pipeline calibration steps and how to recalibrate the data, which is always necessary. Chapter 32 delves into more detailed data analysis considerations, specifically error sources and attendant limiting accuracies for each of the major types of instrumental calibration.

The mode in which a given dataset was taken is identified in the data headers by the keywords OPMODE and GRNDMODE. The OPMODE (.shh) and GRNDMODE (.d0h, .c1h) keyword values are listed at the beginning of the output data products section in the following discussions of each of the individual science data-taking modes.

## 30.6.1 Spectrophotometry Mode (ACCUM)

### Understanding ACCUM

ACCUM was the most commonly used FOS spectroscopic mode. ACCUM mode spectra with a total exposure time lasting more than a few minutes were read out at regular, *equally sized*, intervals to the ground or to the onboard tape recorders. The frequent readouts protected against catastrophic data loss. Since the data were read out at regular intervals, all observations longer than a few minutes (the time between readouts was usually about two minutes for FOS/RD and usually about four minutes for FOS/BL) were time resolved. The first readout was stored as group one, the next readout was added (accumulated) to the previous readout and the sum was stored as group two, and so on. The last group contains the spectrum from the full exposure time of the observation. The number of groups per observation depended on the length of the exposure and the detector used. Remember that for paired apertures and STEP-PATT not SINGLE, half of the specified exposure time was spent in each aperture with the data accumulated in alternating intervals of approximately 10 seconds.

### Paper Products: ACCUM

ACCUM mode paper products produce three pages of mode-specific diagnostic plots. These are the flux vs. wavelength and log flux vs. wavelength page for the last group which contains the full exposure (see Figure 30.5), the corrected counts vs wavelength page for the last group (see Figure 30.6); and the group-by-group total counts plot (Figure 30.7). The last plot is particularly useful for assessing photometric repeatability and in revealing potential problems related to guiding, breathing, background, and intermittent noisy diodes. Please see additional notes in analysis section below concerning assessment of background count levels.

### Output Data Products: ACCUM

Spectrophotometry mode is identified by an OPMODE keyword value of ACCUM and a GRNDMODE keyword value of SPECTROSCOPY. For the standard ACCUM mode, the default value of NXSTEPS was 4 and OVERSCAN was 5. ACCUM mode data files for SINGLE aperture exposures contain GCOUNT groups of 2064 pixels each. The .d0\* and .c4\* files of OBJ-OBJ or OBJ-SKY paired aperture observation data products may be longer as discussed in “Paired-Aperture File Structures” on page 30-6.

### Analysis: ACCUM

In standard FOS ACCUM mode spectra the last group contains the accumulated total integration on the target. The paper products calibrated spectrum can be evaluated to check whether the flux level is roughly like that expected. (Alternatively, the IRAF/STSDAS task **fwplot** can also be used to perform this check.) If more than one detector readout occurred (i.e., the exposure was longer than two minutes for FOS/RD or four minutes for FOS/BL), use the paper products group counts plot to evaluate the overall photometric quality and repeatability of the measures. This plot can reveal the influence of poor guiding, breathing, re-centering events, and intermittent noisy diodes on individual groups that would normally not be expected from inspection of the last data group alone.

The background count rate is given in the Exposure Summary section and will be displayed in the paper product corrected count rate plot if it is on-scale. Although a model prediction of the background (and, for several dispersers, an approximation to the scattered light) has been removed from the quantities plotted in the paper products, it is useful to note that a 120 second total duration (30 seconds per pixel) standard FOS/RD ACCUM with 2064 pixels had a typical background component of 600-1200 dark counts per group. Similarly, a typical 240 second FOS/BL ACCUM exposure produced 900-1800 dark counts per group. It is often useful to compare this signal with the background-corrected quantity provided in the group counts plot. Extraction of individual group spectra can be accomplished with task **deaccum** (see “deaccum” on page 33-9).

If the spectrum was split up into two or more parts, for example because it was observed in more than one orbit due to occultations, you can obtain the sum of all integrations by adding up, with appropriate weighting, the last groups of all .c1 spectra of your target taken with the same instrument configuration (combination of detector, aperture, and disperser).




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For all but edge-pixels, the exposure time per pixel is *not* EXPTIME, but rather EXPTIME/NXSTEPS. Pipeline **calfos** processing correctly manages the exposure time for all pixels and populates the statistical error arrays according to actual detected count levels for all pixels.

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## 30.6.2 Rapid Readout Mode (RAPID)

### Understanding RAPID

For many astronomical targets where rapid variability in flux was suspected, but the precise period was unknown, or the expected variation was aperiodic, PERIOD mode of data acquisition was unsuitable because the bin folding period must be specified. In such cases the RAPID readout mode was used. RAPID mode was also used in cases where very strong signal would overflow the 16-bit FOS accumulators in the default ACCUM readout times (e.g., bright emission line sources). In this mode, the data were acquired using the normal substepping and overscanning techniques. The spectra were read out at intervals (chosen by the observer according to the scientific goals) that were much shorter than the normal four minute (FOS/BL) or two minute (FOS/RD) segments. Each readout was stored in the raw data file as a group. The number of groups in a RAPID mode observation .d0h file was equal to the number of individual readouts. For paired apertures and STEP-PATT not SINGLE, half of the specified exposure time was spent in each aperture with the data accumulated in alternating intervals of approximately 10 seconds or (readout time divided by 2), whichever was smaller.

### Paper Products: RAPID

RAPID mode paper products produce three pages of mode-specific diagnostic plots. These are the flux vs. wavelength and log flux vs. wavelength page for the first group of the time-series (see Figure 30.5), the corrected counts vs wavelength page for the first group (see Figure 30.6); and the group-by-group total counts plot (Figure 30.7). As with ACCUM mode, the last plot is particularly useful for assessing photometric repeatability and in revealing potential problems related to guiding, breathing, background, and intermittent noisy diodes. Further, since the group counts plot is essentially a count rate light curve, it provides a quick look at a science objective of many RAPID readout programs. Please see additional notes in analysis section below concerning assessment of background count levels.

### Output Data Products: RAPID

Rapid readout mode is identified by the keyword values OPMODE=RAPID and GRNDMODE=RAPID READOUT. There are GCOUNT groups of individual readouts. As with ACCUM mode, the default value of NXSTEPS is 4 and OVERSCAN is 5 and default spectrum length is 2064 pixels, however NXSTEPS was often modified by the user. The .d0\* and .c4\* files of OBJ-OBJ or OBJ-SKY paired aperture observation data products may be longer as discussed in “Paired-Aperture File Structures” on page 30-6. Additionally, the user could restrict the measured wavelength range, which produced a smaller number

of pixels to be read out, and which could, in certain circumstances, preclude scattered light correction.

The .c3h (special mode processing output - see next chapter) file contains two data groups. The number of pixels in each group is equal to the number of readouts (groups) in the original data. Group 1 of the .c3h file contains the summed flux values where the value of each pixel is the sum of all pixels from an original readout (i.e., pixel 1 contains the sum of all pixel values from readout 1, pixel 2 is the sum of all pixels from readout 2, etc. This is similar to, effectively a flux-calibrated version of, the information plotted in the paper products group counts display). Group 2 contains the sum of the corresponding statistical error values (in quadrature). The .c3h files effectively provide the light curve of the target for the length of the observation. See “Details of the FOS Pipeline Process” on page 31-13 for more details on special mode processing.

### **Analysis: RAPID**

The IRAF/STSDAS task to combine groups in a RAPID mode dataset is **rcombine** (see Chapter 3).

Often RAPID mode observations were taken with NSXTEPS values other than four. The standard calibration software routinely handles these cases without special user intervention.

A few programs used OVERSCAN=1 to facilitate extremely fast readout. OVERSCAN=1 data are not calibrated by routine operation of **calfos** as all FOS reference files are based upon OVERSCAN=5 calibration observations. As an approximation in these cases, the first 2048 pixels of STScI reference files can be resampled for the appropriate NXSTEPS and, after editing the OVERSCAN value in the header, used with **calfos**. Archive researchers should keep in mind that these OVERSCAN=1 observations were not designed with the intention of producing accurate absolute photometry.

Many FOS/BL programs included RAPID mode time-series with the G160L grating. In addition to the ultraviolet spectrum, the zeroth order signal was also recorded. Therefore, white-light curves were often recorded in concert with the ultraviolet observations. Careful assessment of the count levels in the zeroth order spike should be made before attempting quantitative analysis as this very strong signal often produced accumulator wraparound (overflow) even in the relatively short readout times common in RAPID mode programs.

The background count rate is given on the Exposure Summary page and will be displayed in the paper product corrected count rate plot if it is on-scale. Although a model prediction of the background (and, for several dispersers, an approximation to the scattered light) has been removed from the quantities plotted in the paper products, it is useful to note and compare these quantities with the detected count rates as shown in the corrected count vs wavelength plot. A similar comparison with the group count plot levels can be made in which the average background count level can be estimated as (5 x readout time)

The RAPID mode readout time interval (logsheet entry READ-TIME) was not always constant in actual practice due to the internal operation of the FOS. Determination of the precise start and stop times of the individual readouts in

many RAPID mode exposures requires special processing of engineering telemetry not normally available to the end user. If you need absolute or relative timing more precise than 0.125 sec, then you should contact [help@stsci.edu](mailto:help@stsci.edu) for special support. Additional information on RAPID mode timing is found in “RAPID Mode Observation Timing Uncertainties” on page 33-5, as well as in the *FOS Instrument Handbook*, and in *FOS ISR 154*.

### 30.6.3 Spectropolarimetry Mode

#### Understanding SPECTROPOLARIMETRY

The polarimetry data consist of a number of exposures (POLSCAN=16, 8, or 4) with the waveplate set at different angles and taken consecutively (within one orbit). The Wollaston prism split the light beam into two spectra corresponding to the orthogonal directions of polarization. Hence, each exposure consists of the two orthogonal spectra obtained with a single waveplate angle. These spectra were deflected alternately onto the diode array, recorded as two pass directions, and stored as a single group in the raw data file. The first spectrum in the data group corresponds to the first pass direction (ordinary ray), the second to the second pass direction (extraordinary ray).

#### Paper Products: SPECTROPOLARIMETRY

There are *no* SPECTROPOLARIMETRY-specific paper product displays. The standard exposure summary, spacecraft performance, jitter ball, and calibration status pages are produced.

#### Output Data Products: SPECTROPOLARIMETRY

Spectropolarimetry mode<sup>1</sup> is identified by an OPMODE value of ACCUM and a GRNDMODE value of SPECTROPOLARIMETRY.

The number of groups in the raw data file is equal to NREAD x POLSCAN. Thus, normally (for NREAD=1) there will be as many groups in the raw data file as the number of waveplate positions used in the observation. The number of POLSCAN positions (and therefore the total number of groups in the raw data file) may be 4, 8, or 16 depending on the number of polscans requested.

The group contents of the raw (.d0h) data file are shown in Table 30.8. Note that the number of pixels in each group is twice the number of pixels in a single spectrum as there are two spectra appended together, one for each pass direction. The number of pixels in the spectrum depends on the values of NXSTEPS and OVERSCAN used.

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1. Further details concerning polarimetry datasets and their calibration procedures can be obtained from within IRAF by typing “help spec\_polar opt=sys”.

**Table 30.8:** Group Contents of Raw Polarimetry Science Data Files

Group #	Contents
1	Polscan 1: pass direction 1 and pass direction 2
2	Polscan 2: pass direction 1 and pass direction 2
3	Polscan 3: pass direction 1 and pass direction 2
...	....
15	Polscan 15: pass direction 1 and pass direction 2
16	Polscan 16: pass direction 1 and pass direction 2

The organization of calibrated polarimetry data files differs from the raw data files and calibrated data taken in other observing modes in that the two pass direction spectra from each readout are stored in separate data groups instead of being concatenated within one group. The calibrated fluxes, the corresponding statistical errors, and the data quality are stored in 2 x POLSCAN number of groups, similar to the wavelengths. *Note that for polarimetry data the statistical errors cannot be combined simply.* The errors in the Stokes parameters are calculated separately by the data reduction pipeline. The polarimetry-specific data are stored once again as groups in a separate file.<sup>2</sup>

The .c0h file is a dataset with 2 x POLSCAN groups with wavelengths for both pass directions through the Wollaston prism and each POLSCAN position. Note that the wavelengths for the different POLSCAN positions should be identical, but the wavelengths are offset between the two pass directions by a constant amount.

The .c1h file is a dataset with 2 x POLSCAN groups containing calibrated flux for both pass directions and each POLSCAN position. The calibrated fluxes are stored in exactly the same way as the wavelengths. Note that unlike calibrated flux data for non-polarimetric observations, the first group will not represent the absolute flux for the source, but only half, since the light was split into two spectra by the polarizer. Representative fluxes are formed by averaging the fluxes from the complete set of POLSCAN positions for each pass direction separately, and then summing the two. Since there is a wavelength shift between the spectra from the two pass directions, to combine the two mean spectra from both pass directions one spectrum must be shifted in wavelength to match the other. *Pass direction 2 is shifted onto pass direction 1. In the summed spectrum, any pixel that has contributions from only one pass direction is set to zero.* The total flux (Stokes I) is computed by the special mode processing phase of **calfos** and is stored in the .c3h dataset (see below) and so is more conveniently obtained from there.

The .c2h file is a dataset with 2 x POLSCAN groups with the statistical error of the calibrated flux for both pass directions and each POLSCAN position. The flux errors are stored in exactly the same way as the wavelengths and fluxes. As

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2. See *FOS ISR 078*.

for the calibrated flux dataset, this dataset differs from the statistical errors for non-polarimetric data and the errors cannot be simply combined. We suggest that the error on the Stokes I parameter computed by the polarimetry processing be used as the total flux error.

The .cqh file is a dataset with 2 x POLSCAN groups with the data quality values for the calibrated fluxes. The organization is exactly the same as that of the calibrated fluxes dataset. The group organization of the .c0h, .c1h, .c2h, and .cqh files is shown in Table 30.9.

**Table 30.9:** Group Organization of the Calibrated .c0h, .c1h, .c2h, and .cqh Files

Group	Contents Depending on Calibration File
1	Polscan 1, Pass direction 1: wavelength, flux, error or data quality
2	Polscan 1, Pass direction 2: wavelength, flux, error or data quality
3	Polscan 2, Pass direction 1: wavelength, flux, error or data quality
4	Polscan 2, Pass direction 2: wavelength, flux, error or data quality
...	...
31	Polscan 16, Pass direction 1: wavelength, flux, error or data quality
32	Polscan 16, Pass direction 2: wavelength, flux, error or data quality

The .c3h file is a dataset with 56 groups containing the reduced polarimetry data. The dataset is organized into four sets of 14 groups, where groups 1 through 14 contain the Stokes parameter and polarimetry data for pass direction 1, groups 15 through 28 for pass direction 2, groups 29 through 42 contain the merged data from both pass directions 1 and 2, and groups 43 through 56 contain the merged data corrected for interference and instrument orientation. The organization of the .c3h file is shown in Table 30.10.

Note that the wavelengths corresponding to the first set of 14 groups are given by the wavelength array for the first pass direction (i.e., group 1 of the .c0h file), while for the second set of 14 groups (groups 15 through 28) the corresponding wavelengths are given by the wavelength array for the second pass direction (i.e., group 2 of the .c0h file). For the merged data in the third and fourth sets of 14 groups (groups 29 through 56), the corresponding wavelengths are given by the first pass direction.

### Analysis: SPECTROPOLARIMETRY

All polarimetric observations should be recalibrated. The polarimetric calibration portions of **calfos** will soon include special corrections to remove the influence of the COSTAR optics on polarimetric measures.

**Table 30.10:** Group Organization of the Calibrated .c3h File

Group # Pass Direction 1	Group # Pass Direction 2	Group # Pass Direction 1&2	Group # Pass Direction 1&2 corrected	Contents
1	15	29	43	Stokes I
2	16	30	44	Stokes Q
3	17	31	45	Stokes U
4	18	32	46	Stokes V
5	19	33	47	Stokes I error
6	20	34	48	Stokes Q error
7	21	35	49	Stokes U error
8	22	36	50	Stokes V error
9	23	37	51	Linear polarization
10	24	38	52	Circular polarization
11	25	39	53	Polarization position angle
12	26	40	54	Linear polarization error
13	27	41	55	Circular polarization error
14	28	42	56	Polarization position angle error

### 30.6.4 Time-Resolved Spectrophotometry Mode (PERIOD)

#### Understanding PERIOD

This mode was designed for objects with known periodicity in the 50 msec to 100 sec range. To maintain the phase information of these observations, the known period (CYCLE-TIME) of the object was divided into *bins* or *slices*, where each bin had a duration time = period/BINS. The spectra acquired in this mode were stored in the different bins which correspond to a given phase of the period. The information obtained in each period was added to the pattern so that the phase information was maintained (so long as the period was known accurately).



Relativistic aberration is important for short periods and long observations. However, there is no correction for light travel time across the orbit.

#### Paper Products: PERIOD

There are *no* PERIOD-specific paper product displays. The standard exposure summary, spacecraft performance, jitter ball, and calibration status pages are produced.

### Output Data Products: PERIOD

Time-resolved spectrophotometry mode is identified by the keyword values OPMODE=PERIOD and GRNDMODE=TIME RESOLVED.

The raw (.d0h) data file for time-resolved mode contains a single data group that is made up of all the individual spectral slices (or bins) stored sequentially. For example, if an observation used 374 detector channels, with NXSTEPS=1, OVERSCAN=5, and SLICES=32, the .d0h file would contain one data group having a total length of:

$$(374 + (5 - 1)) \times 1 \times 32 = 12096 \text{ pixels}$$

The calibrated flux, wavelength, error, and data quality files will have the data from the individual slices (bins) broken out into separate groups. For the example above, the .c0h, .c1h, .c2h, and .cqh files would have 32 groups of 378 pixels.

The .c3h file is organized as follows. Groups 1 and 2 contain the average flux and average errors, respectively, of all the individual calibrated spectra. Following these, there are pairs of groups where the first group in each pair contains the difference between an individual flux spectrum and the average, and the second group in each pair contains the sum of the errors for the individual spectrum and the average. See “Special Mode Processing (MOD\_CORR)” on page 31-23 for details on how the average and difference spectra are generated. For example, if the observation consisted of 32 slices, the structure of the .c3h file would be that shown in Table 30.11.

**Table 30.11:** Group Structure of PERIOD Mode .c3h File with 32 Slices

Group #	Contents
1	Average of all 32 flux spectra from the .c1h file
2	Average of all 32 error spectra from the .c2h file
3	Spectrum 1 minus average
4	Combined spectrum 1 and average errors
5	Spectrum 2 minus average
6	Combined spectrum 2 and average errors
...	...
65	Spectrum 32 minus average
66	Combined spectrum 32 and average errors

### Analysis: PERIOD

Only two scientific programs employed PERIOD mode. Due to implementation problems and errors, no PERIOD mode observations were completely successful. Successful tests were performed during Science Verification.

## 30.6.5 Image Mode Spectra (IMAGE)

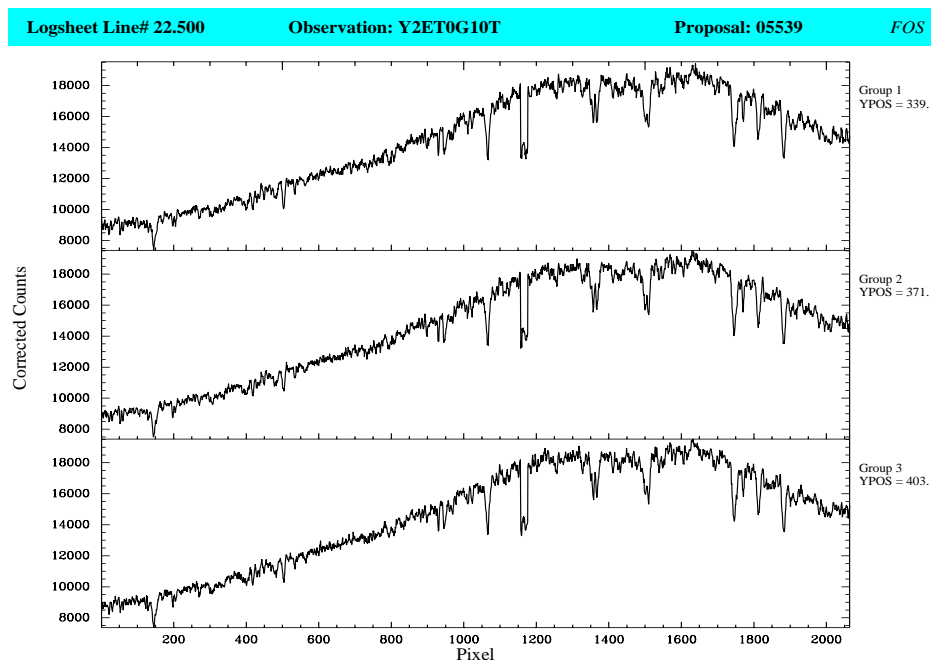
### Understanding IMAGE Spectra

FOS IMAGE mode observations imply mapping of more than one position in the aperture by the diode array. If a disperser was chosen as the spectral element, then spectra at YSTEPS *y*-positions, symmetrically spaced about the default aperture center *Y*-base were obtained. The specified exposure time was equally divided among the YSTEPS individual spectra, and was obtained in a continuing revolving series of approximately 10 second integrations at each individual *Y*-position until an exposure of EXPTIME was accumulated. Intermediate ACCUM-like readouts could occur. Although nearly all IMAGE mode FOS spectra were obtained for flux and flatfield calibration purposes, some measures of this type were used for the purpose of interactively acquiring moving targets with absorption lines at known wavelengths.

### Paper Products: IMAGE Spectra

Figure 30.15 below shows an example of the one page of mode-specific FOS paper products for IMAGE mode spectra. Flux and wavelength calibrations are not routinely applied to IMAGE mode spectra as these calibrations are normally for the central *y*-levels of an aperture whereas an IMAGE mode spectrum, by definition, might be sampled from any *y*-position in the aperture. As a result, only a plot of the corrected count spectra for each *y*-position (YPOS) of observation is made versus *pixel number*. No group counts plot is made to assess photometric repeatability.

Note the dead diode at approximately pixel 1150 in all three groups of Figure 30.15.

**Figure 30.15:** FOS Paper Products Corrected Counts Plot for IMAGE Spectra

### Output Data Products: IMAGE spectra

Image mode spectra are identified by an OPMODE value of IMAGE and a GRNDMODE value of IMAGE and a FGWA\_ID of any spectral element except MIRROR. Normally, NXSTEPS=4 and OVERSCAN=5 were used to produce groups of 2064 pixels, but the full range of commandable values was allowed.

Usually one output group exists in the output data products for each raster spectrum line (YPOS) in the image. If more than one readout occurred (rare, but it could happen), then YSTEPS x NREAD groups exist in the data files. Each set of YSTEPS groups were accumulated in the same fashion as ACCUM mode measures, so that the last set of YSTEPS groups contains the accumulated spectra.

IMAGE mode spectra are not routinely flux calibrated by the pipeline because the  $x$ -position mapping to wavelengths is calibrated only for the aperture center  $Y$ -base. Therefore, the .c1\* files are identical to the .c5\* files (i.e. count rates corrected for everything but sensitivity).

### Analysis: IMAGE spectra

The special FOS STSDAS routine **yfluxcal** can be used to flux calibrate IMAGE spectra on the assumption that the aperture-center wavelength calibration is applicable to the actual  $Y$ -base employed. This is a suitable assumption for virtually all calibration program IMAGE mode spectra.