PART 5:

Goddard High Resolution Spectrograph

This chapter describes the Goddard High Resolution Spectrograph (GHRS) instrument, the calibration process, reference files and tables used in calibrating GHRS data, and some common problems and their solutions. To help illustrate the process of data analysis we use some case studies, our primary example being a program that obtained both images and spectra of several stars in R136a in the Large Magellanic Cloud.

In addition to the information provided in this handbook, The *GHRS Instrument Handbook* provides information used to prepare GHRS observation proposals. It also includes details of the construction and operation of the instrument. This document generally does not repeat the instrument descriptions given in the *GHRS Instrument Handbook*, however, it does include much of the information that could be obtained from the *GHRS Instrument Science Reports*. Because the GHRS is expected to be removed from the HST as part of the 1997 servicing mission, version 6.0 will likely be the last *GHRS Instrument Handbook*, however, the information in this manual will continue to be maintained.

Because the GHRS changes with time and our knowledge of it does as well, updates to software, reference files, calibration files, etc. are made from time to time. We urge you to check the GHRS web page or to consult the STScI Help

Desk (help@stsci.edu) before proceeding if you are unsure of what files or software to use. The GHRS web page may be found at the following URL:

http://www.stsci.edu/ftp/instrument_news/GHRS/topghrs.html

With a little guidance, practice, and experience, the software for reducing GHRS observations (the STSDAS **calhrs** task) is fairly straightforward to use. Practical difficulties sometimes arise, but most questions have to do with estimating the uncertainties in the reduced quantities after the software has been run. Some of these uncertainties can be determined quantitatively, but others can only be estimated based on experience. We will speak of the dimensions of GHRS data in the form that you probably examine them: flux versus wavelength at various times. The dimensions are these:

- **Wavelength:** The wavelength scale is established from measurements of the spectrum of a calibration lamp, either from an observation obtained with the astrophysical observations, or by using the default wavelength calibration. The wavelength scale and its accuracy can depend on the temperature of the GHRS, the geomagnetic latitude, and time. Corrections must also be made for the differing locations of the apertures used for observing.
- **Flux:** The flux scale is determined by observing standard stars that have fluxes we believe we know and which are not thought to change with time. There are substantial uncertainties in establishing the absolute flux scale and in comparing other stars to it because of such things as the blaze function of the grating, continuum placement, “vignetting,” and so on. Relative fluxes can be determined much more precisely, making it possible to compare, say, two stars at the same wavelength or the same star at the same wavelength at different times. For extended objects, the absolute throughput of the aperture used is also important.

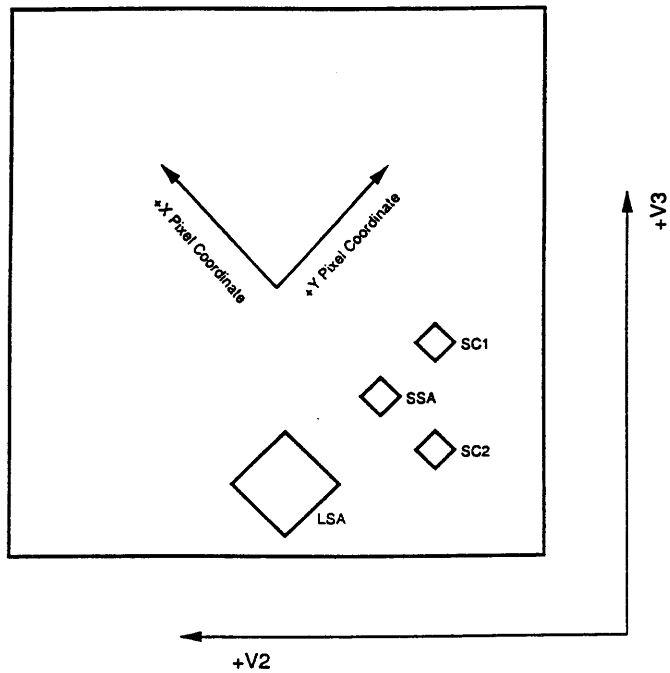
CHAPTER 21: GHRS Instrument Overview

In This Chapter...

The GHRS is one of the first generation science instruments aboard HST. The spectrometer was designed to achieve high spectral resolution, high photometric precision, and sensitivity throughput in the wavelength range 1100 to 3200 Å. The instrument is a modified Czerny-Turner spectrograph and has an assortment of components: two science apertures (large—LSA, and small—SSA), two detectors (D1 and D2), dispersers, and camera mirrors. There are also a wavelength calibration lamp, flatfield lamps, and mirrors to acquire and center objects in the observing apertures. A more in-depth description of the GHRS can be found in the *GHRS Instrument Handbook*.

Schematics of the mechanical and optical layout can be found in the *GHRS Instrument Handbook*. 6.0, Figures 6-1 to 6-9. The GHRS was installed as one of the axial scientific instruments with the entrance aperture adjacent to FGS 2 and FGS 3. With the installation of COSTAR, the entrance apertures are at the former position of the HSP. The GHRS has two science apertures, designated Large Science Aperture (LSA or 2.0) and Small Science Aperture (SSA or 0.25). The 2.0 and 0.25 designations are the pre-COSTAR size of the apertures in arcseconds. The LSA has a shutter to block light from entering the spectrograph, while the SSA is always open. Because of this, scattered light from a target in the SSA can contaminate a wavelength calibration exposure (*wavecal*). The locations of the GHRS apertures relative to the spacecraft axes are displayed in Figure 21.1.

Figure 21.1: Locations of GHRS Apertures Relative to Spacecraft Axes



Light from an astronomical target is collected by HST and focused on one of the two GHRS apertures. After passing through an aperture, the light strikes the collimating mirror and is directed toward the carrousel. The collimated beam illuminates one of the gratings or a flat mirror. Selection of a grating or mirror is performed by rotating the carrousel. Camera mirrors focus the dispersed light onto one of the Digicon photocathodes. Photoelectrons from the Digicons are focused onto a linear silicon diode array.

Dispersers

The dispersers are mounted on a rotating carrousel, together with several plane mirrors used for acquisition. The first-order gratings are designated as G140L, G140M, G160M, G200M, and G270M, where “G” indicates a grating, the number indicates the blaze wavelength (in nm), and the “L” or “M” suffix denotes a “low” or “medium” resolution grating, respectively. The GHRS medium resolution first-order gratings are holographic in order to achieve very high efficiency within a limited wavelength region. G140L is a ruled grating. The first two first-order gratings, G140L and G140M, have their spectra imaged by mirror Cam-A onto detector D1, which is optimized for the shortest wavelengths (about 1050 to 1700 Å.). The other three gratings have their spectra imaged by Cam-B onto detector D2, which works best at wavelengths from about 1700 to 3200 Å, but which is also useful down to 1200 Å.The useful spectral wavelength ranges of the first order gratings are listed in Table 21.1.

Table 21.1: Useful Wavelength Ranges for First-Order Gratings

Grating	Useful Range (Å)	Å per diode	Bandpass (Å)	Comment
G140L	1100 – 1900	0.572 – 0.573	286 – 287	
G140M	1100 – 1900	0.056 – 0.052	28 – 26	
G160M	1150 – 2300	0.072 – 0.066	36 – 33	2nd order overlap above 2300 Å
G200M	1600 – 2300	0.081 – 0.075	41 – 38	2nd order overlap above 2300 Å
G270M	2000 – 3300	0.096 – 0.087	48 – 44	2nd order overlap above 3300 Å

Table 21.1 summarizes the useful wavelength range for each of the first-order gratings of GHRS. Note that little or no flux below 1150 Å is reflected by the COSTAR mirrors because of their magnesium fluoride coatings.

The carrousel also has an echelle grating. The higher orders are designated as mode Ech-A, and they are imaged onto D1 by the cross-disperser CD1. The lower orders are designated as mode Ech-B, and they are directed to D2 by CD2. The spectral wavelength range bandpass and sensitivity of the echelle gratings can be found in the *GHRS Instrument Handbook*, version 6.0, Table 8-3.

Finally, mirrors N1 and A1 image the apertures onto detector D1, and mirrors N2 and A2 image onto D2. The “N” mirrors are “normal,” i.e., unattenuated, while the “A” mirrors (“attenuated”) reflect a smaller fraction of the light to the detectors, so as to enable the acquisition of bright stars. (The mode designated as N1 actually uses the zero-order image produced by grating G140L).

Bright targets are acquired with one of the attenuated mirrors, A1 or A2. These acquisitions will take substantially longer than if the N1 or N2 mirrors were used. SSA acquisitions (ACQ/PEAKUPs) with the A1 mirror are usually doubled up to center the target in the SSA. Acquiring a target in the SSA first requires a LSA acquisition (3x3 search) followed by a SSA acquisition (5x5 search).

The GHRS LSA is 74 arcseconds from the FOS Blue aperture. Starting with Cycle 5, it became possible to acquire a faint target with the FOS and slew the telescope to position the target into the GHRS LSA. It also became possible to acquire a bright target with the GHRS and slew the telescope to position the target into the FOS Blue aperture. Therefore, a GHRS dataset obtained during Cycles 5 and 6 may contain FOS observations.

Use of the various gratings or mirrors produces one of three kinds of GHRS data: 1) an image of the entrance aperture, which may be mapped to find and center the object of interest; 2) a single-order spectrum; or 3) a cross-dispersed, two-dimensional echelle spectrum.

Detectors

The flux in these images is measured by photon-counting Digicon detectors; the portion of the image plane that is mapped onto the Digicon is determined by magnetic deflection coils. The detectors are the heart of the GHRS and they involve subtleties that must be understood if data are to be reduced properly and competently.

First, there are two Digicons: D1 and D2. D1 has a cesium iodide photocathode on a lithium fluoride window that makes D1 effectively *solar-blind*, i.e., the enormous flux of visible-light photons that dominate the spectrum of most stars will produce no signal with this detector, and only far-ultraviolet photons (1060 to 1800 Å) produce electrons that are accelerated by the 23 kV field onto the diodes. D2 has a cesium telluride photocathode on a magnesium fluoride window. Each Digicon has 512 diodes that accumulate counts from accelerated electrons. 500 of those are *science diodes*, plus there are *corner diodes* and *focus diodes.*

The 500 science diodes are 40 x 400 microns on 50 micron centers. The focus diodes are 25 x 25 microns and there are three located on each end of the array. Two 1,000 x 100 micron diodes are used to measure background and two 1,000 x 100 micron diodes are used to monitor high energy protons. Eight diodes map the LSA and the SSA is 1 diode wide and 1/8 diode high.

Second, both photocathodes have granularity—irregularities in response—of about 0.5% (rms) that can limit the S/N achieved, and there are localized blemishes that produce irregularities of several percent. The Side 1 photocathode also exhibits "sleeking," which is slanted, scratch-like features that have an amplitude of 1 to 2% over regions as large as half the faceplate. The effects of these irregularities could in principle be removed by obtaining a flatfield measurement at every position on the photocathode, but that is, in general, impractical. Instead, the observing strategy is to rotate the carrousel slightly between separate exposures and so use different portions of the photocathode. This procedure is called an FP-SPLIT, and with it each exposure is divided into two or four separate-but-equal parts, with the carrousel moving the spectrum about 5.2 diode widths each time in the direction of dispersion. These individual spectra can be combined together during the reduction phase.

Third, the diodes in the Digicons also have response irregularities, but these are very slight. The biggest effect is a systematic offset of about 1% in response of the odd-numbered diodes relative to the even-numbered ones. This effect can be almost entirely defeated by use of the default `COMB` addition procedure. `COMB` addition deflects the spectrum by an integral number of diodes between subexposures and has the additional benefit of working around dead diodes in the instrument that would otherwise leave image defects.

Fourth, the Digicons' diodes are about the same width as the FWHM of the point spread function (PSF) for HST. Thus the true resolution of the spectrum cannot be realized unless it is adequately sampled. That is done by making the magnetic field move the spectrum by fractions of the width of a diode, by either half- or quarter-diode widths, and then storing those as separate spectra in the onboard memory. These are merged into a single spectrum in the data reduction phase. The manner in which this is done is specified by the STEP-PATT parameter, described in more detail later. The choice of STEP-PATT also determines how the background around the spectrum is measured.

Internal Calibration

The GHRS was built with two Pt-Ne hollow-cathode lamps to provide a rich spectrum of emission lines for accurate calibration of wavelengths. The locations of these lamps and the way in which they illuminate the spectrograph optics are illustrated in the *GHRS Instrument Handbook*. The apertures through which calibration exposures are made are the same size as the Small Size Aperture (SSA). Moreover, calibration aperture SC2, the one most frequently used, is offset from the SSA in the x direction (the direction of dispersion), but is aligned in the y direction (see Figure 21.1). This offset in x introduces a systematic shift in wavelength between the SSA and SC2 because light from them hits the gratings at different angles. By convention, the wavelength scale of the GHRS is calculated so as to be correct for the SSA.

These wavelength calibration lamps are also used for other internal instrumental calibrations, such as DEFCALs (deflection calibration) and SPYBALs (Spectrum-Y-Balance). Only one of these lamps has been available for use ever since the failure of Side 1 in 1991. A wavelength calibration exposure ("wavecal") is obtained by specifying an ACCUM in the Phase II Proposal with a target of WAVE and an aperture of SC2. (Prior to 1991 SC1 was a valid aperture designation and so older observations may show it.)

A wavecal is not the only way to assess the quality of the wavelength scale for observations. As will be noted in the example for R136a, a SPYBAL is obtained just before an ACCUM that uses a grating for the first time. A SPYBAL is just a wavecal that is obtained at a predetermined carrousel position for each grating, and SPYBALs are done to align the spectrum on the diodes in the y direction (perpendicular to dispersion). A SPYBAL contains wavelength information that can be used to check for zero-point offset.

Side 1

The installation of the GHRS Redundancy Kit during the first service mission (December 1993) eliminated the risk of a Side 1 power supply failure affecting Side 2. With this risk removed, Side 1 operations were resumed during Cycle 4. These operations have been nominal.

When the Side 1 carrousel is commanded through the Side 2 electronics during a Side 1 observation, the telemetry word containing the carrousel position will read the Side 2 commanded position during carrousel configuration, and the Side 1 encoder position after integration. The Side 1 GHRS data headers do contain the correct Side 1 position of the carrousel.

GHRS Side 1 observations cover the time spans April 1990 to June 1991 and February 1994 to the Second Servicing Mission.

COSTAR

The spherical aberration of the HST primary mirror was corrected by the first servicing mission (December 1993) with the installation of the Corrective Optics Space Telescope Axial Replacement (COSTAR) assembly. COSTAR deployed corrective reflecting optics in the optical path of the GHRS. The post-COSTAR GHRS has a different response with wavelength than the pre-COSTAR instrument. Interim sensitivity files were installed in CDBS on 16 April 1994, and updated during Cycle 4 and 5 when calibration observations became available. GHRS observations obtained early in Cycle 4 may require recalibration. See GHRS ISR 062, “First Measures of Sensitivity For the Post-COSTAR GHRS with Interim Values for Data Analysis”, and ISR 071, “Stability of the GHRS Sensitivity During Cycle 4”, for more details.

CHAPTER 22:

GHRS Planned vs. Executed Observations

In This Chapter...

In this chapter we will use several examples of actual GHRS programs to illustrate how Phase II Proposals get turned into observations and data products. We hope that these are useful to you in understanding your own data. Complete explanations are provided later for reference.

Case 1: R136a in the LMC

Program 5297 was executed in the spring of 1994 as an Early Release Observation (ERO), following the 1993 servicing mission. During that mission, COSTAR mirrors were deployed so that the full optical quality of HST could be realized by the GHRS. Also, a repair kit was installed that allowed Side 1 of the GHRS to be used once again (Side 1 capabilities were lost in 1991 due to the failure of a low-voltage power supply).

Program 5297 was designed to take advantage of and demonstrate these capabilities by obtaining low-resolution spectra of closely-spaced hot stars in a young cluster (R136a) in the Large Magellanic Cloud (LMC). Two of the stars to be observed were only about 0.12 arcsec apart, less than the size of the GHRS Small Science Aperture (SSA), which is 0.22 arcsec square. Thus, precise positioning was needed. To achieve this, the telescope was first to acquire and center on the brightest object in the R136a field. That object was itself the convolution of two stars, so that some allowance had to be made for the apparent centroid of what was acquired. This was done using information from a WF/PC-1 image of R136a obtained before the servicing mission. Once centered on R136a1, the SSA could then be moved with high relative precision, but to ensure understanding of what was observed, IMAGEs were taken at each position.

The Exposure Logsheet

An abridged version of the Phase II Proposal for 5297 is shown in Figure 22.1. The first portion of the figure is the Target List and the bottom half is the Exposure Logsheet. Here are some notes to go with individual lines of the Exposure Logsheet:

- **Line 1:** R136a1 is acquired with the Large Science Aperture (LSA). The LSA is denoted as "2.0" but has a true size of 1.74 arcsec square with the COSTAR mirrors in place. SEARCH-SIZE=5 is specified to ensure a good acquisition by providing a wider search area. (The default SEARCH-SIZE=3 is adequate in nearly all cases, but the crowding of this field lead to using a more liberal value.) The specified exposure time of 25 seconds implies a STEP-TIME of 1.0 second; STEP-TIME is the dwell per point in the spiral search pattern. MIRROR-N2 is used because these stars are faint. Using MIRROR-N1 would be preferable for brighter objects because then it would be unnecessary to switch from using detector D2 on Side 2 (implied by MIRROR-N2) to detector D1 on Side 1 (implied by using Spectral Element G140L on line 20). Switching from one Side of the GHRS to the other takes about 40 minutes because of the need to let the electronics stabilize. However, MIRROR-N1 reflects light only from about 1200 to 1700 Å, and the STEP-TIME needed to acquire these stars would exceed the maximum permitted value of 12.75 seconds. Note the comment explaining how the exposure time was estimated and the Special Requirements that tie this acquisition to the subsequent exposures. Acquisitions are explained in detail in the *GHRS Instrument Handbook*. The comment about BRIGHT=RETURN means that the onboard acquisition algorithm will determine which dwell point had the most counts and will center the LSA at that point.
- **Line 2:** Here the object R136a1 is centered in the LSA. The exposure time of 102 seconds implies a STEP-TIME of 1.0 seconds, as for the initial acquisition. As we noted, what is called "R136a1" is not a single object but is a convolution of R136a1 with R136a2 because of the finite resolution of HST and the size of the LSA. An estimate of the centroid of a1+a2 was made from a pre-COSTAR WF/PC-1 image.
- **Line 3:** Here R136a1 is centered in the SSA, with SEARCH-SIZE=5 and an implied STEP-TIME of 1.0 second. The true post-COSTAR size of the SSA is 0.22 arcsec square. As for line 1, the acquisition algorithm will automatically determine which dwell point had the most counts and will move the SSA to that point. (The SSA ACQ/PEAKUP algorithm is the same as the LSA BRIGHT=RETURN acquisition algorithm.)

- **Line 4:** An IMAGE of R136a1 in the SSA is obtained. The values of NX, NY, DELTA-X, and DELTA-Y were chosen to fully cover the SSA with the minimum spacing between points. The time spent at each point is 1.0 seconds, as implied by the 169 second total exposure time.
- **Line 5:** This is the same as line 4 except that the object is R136a2. This implies that the telescope has been moved 0.052 arcsec north and 0.105 arcsec east, for a net motion of 0.117 arcsec, about half the size of the SSA. An IMAGE is taken to confirm the positioning.
- **Line 20:** This line obtains a ten-minute exposure on R136a2 with grating G140L centered at 1300 Å. The STEP-PATT value chosen (3) is not the default value of 5, but was selected to maximize the time on target at the cost of some uncertainty in the background. Because the object is faint and low signal-to-noise is anticipated, FP-SPLIT=NO has been chosen. Using a Side 1 spectral element (G140L) implies a wait of about 40 minutes between lines 5 and 20 to allow one detector to be turned off and the other to be turned on and brought to a stable configuration.
- **Line 21:** Here a second spectrum centered at 1610 Å is obtained. Lines 20 and 21 will provide as much spectrum as G140L is capable of delivering.
- **Line 50:** Now the target is R136a5, implying a small motion of the telescope. The central wavelength is the same as for line 21 to eliminate a grating movement. A longer exposure of 30 minutes is needed for this fainter target. In this case the FP-SPLIT feature has been used.
- **Line 51:** Same as line 20, but for R136a5. Again, FP-SPLIT is used.
- **Line 52:** A wavelength calibration exposure obtained at the previous position for G140L.
- **Line 99:** An IMAGE of R136a5, analogous to line 5. As before, the use of MIRROR-N2 implies waiting about 40 minutes to switch Sides.
- **Line 100:** An IMAGE of R136a5 in the LSA with MIRROR-N2.
- **Line 101:** This “acquisition” at the end of the sequence of operations may seem odd, but what it achieves is a coarse image over a broader area (SEARCH-SIZE=3) than an IMAGE itself is capable of.

Each of these lines is an operation specified by the observer, and they correspond closely to the operations performed by the instrument and the data files that are generated, as shown in Table 22.1. For example, each of the ACQuisitions, ACQ/PEAKUPs, and IMAGEs results in a data file, but each is also preceded by a DEFCAL. This is a DEFlection CALibration, in which an internal lamp illuminates an aperture (SC2) which the acquisition mirror then images on the photocathode. Software on the spacecraft then determines where the actual image of the aperture is falling on the diodes so that the image can be properly centered. The image moves slightly due to thermal effects and the earth’s magnetic field. These DEFCALs are essential for proper operation of the GHRS, but the information they contain is rarely of use to the observer.

You will note that many, but not all, of the ACCUMs are preceded by a SPYBAL exposure. SPYBAL stands for SPectrum Y BALance, and it, like a

DEFCAL, is performed to ensure proper alignment of the spectrum on the science diodes. However, a SPYBAL is an actual spectrum recorded at a selected wavelength for each grating (chosen to provide a uniform distribution of comparison lines) and it is performed each time a different grating is used for the first time. In longer programs SPYBALs will appear about every 90-minutes of alignment time as well, in order to compensate for thermal drifts and the like. An exposure will not be interrupted to insert a SPYBAL.

In general, SPYBALs will be obtained at some wavelength that is different from the one at which you obtained your observations. However, the primary changes in wavelength occur in the zero point, not to the dispersion. As a result, a SPYBAL may be used to derive a correction to the default wavelengths that ends up being nearly as good as if a full wavelength calibration had been obtained.

Figure 22.1: Exposure Logsheet for Program 5297

PROPOSAL FOR HUBBLE SPACE TELESCOPE OBSERVATIONS ID 5297
1.Proposal Title: FIRST SPECTRA OF O STARS IN R136A

TARGET LIST a) Fixed Targets ID = 5297 [3]

1	2	3	4	5	6	7	8	
Tar No	Target Name	Target Description	Target Position	Coord Eqnx	Radial Vel.	Acqui Prblm	FLX REF	Flux data
1	R136a1	B,103,D,203	RA = 05H 38M 42.438S +/- 0.1S, DEC = -69D 06’ 02.294” +/- 0.5”	2000			1 2	V=12.77 B-V=+0.43
	Comments: V,B-V from Malumuth & Heap (1993)							
2	R136a2	B,103,D,203	RA = 05H 38M 42.4576S +/- 0.1S, DEC = -69D 06’ 02.242” +/- 0.5”	2000			1 2	V=13.38 B-V=+0.43
	Comments: WN star in R136a; coordinates and V,B-V from Malumuth & Heap (1993)							
5	R136a5	B,105,D,203	RA = 05H 38M 42.4785S +/- 0.1S, DEC = -69D 06’ 02.096” +/- 0.5”	2000			1 2	V=13.73 B-V=+0.12
	Comments: O star in R136a; coordinates and V,B-V from Malumuth & Heap (1993)							

EXPOSURE LOGSHEET ID = 5297 [4]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Line Number	Seq Name	Target Name	Instr Config	Oper. Mode	Aper or FOV	Spectral Element	Central Waveln.	Optional Parameters	Num Exp	Time	S/N Rel. Time	Flx Ref	Pr	Special Requirements
1		R136a1	HRS	ACQ	2.0	MIRROR-N2		SEARCH-SIZE=5	1	25S		1	1	CYCLE 4/1-101 ONBOARD ACQ FOR 2-3 SEQ 1-101 NO GAP
	Comments: Time=(128*Nmap +SS2)*StepT =(0 +5x5)*1.0S = 25S GHRS HDBK/Fig 7.3 gives N1 c/s=2500 for V=13.0, (B-V)o=-.3, E(B-V)=.4													
2		R136a1	HRS	ACQ/ PEAKUP	2.0	MIRROR-N2			1	102S		1	1	CYCLE 4
	Comments: Time=Fapt*StepT =102 * 1S													
3		R136a1	HRS	ACQ/ PEAKUP	0.25	MIRROR-N2		SEARCH-SIZE=5	1	25S		1	1	ONBOARD ACQ FOR 4-52
	Comments: Time=SSIZE^2 * StepT =25 * 1S BRIGHT=RETURN assumed													
4		R136a1	HRS	IMAGE	0.25	MIRROR-N2		NX=13 NY=13 DELTA-X=1 DELTA-Y=1	1	169S		1	1	
	Comments: Time=13*13*1S=169S													
5		R136a2	HRS	IMAGE	0.25	MIRROR-N2		NX=13 NY=13 DELTA-X=1 DELTA-Y=1	1	169S		1	1	
	Comments: Time=13*13*1S=169S													
20		R136a2	HRS	ACCUM	0.25	G140L	1300	STEP-PATT=3 FP-SPLIT=NO	1	10M			1	

Figure 22.1 (continued): Exposure Logsheet for Program 5297

```
-------------------------------------------------------------------------------------------------------------------------------------
21                R136a2      HRS    ACCUM   0.25    G140L    1610    STEP-PATT=3     4   10M                     1
                                                                      FP-SPLIT=NO
-------------------------------------------------------------------------------------------------------------------------------------
50                R136a5      HRS    ACCUM   0.25    G140L    1610    STEP-PATT=3     4   30M                     1
                                                                      FP-SPLIT=FOUR
     Comments: total texp=120M
-------------------------------------------------------------------------------------------------------------------------------------
51                R136a5      HRS    ACCUM   0.25    G140L    1300    STEP-PATT=3     1   30M                     1
                                                                      FP-SPLIT=FOUR
     Comments: total texp=30M
-------------------------------------------------------------------------------------------------------------------------------------
52                WAVE        HRS    ACCUM   SC2     G140L    1300    STEP-PATT=3     1   25.6S                   1
                                                                      FP-SPLIT=NO
     Comments: WAVECAL FOR SPECTRA
-------------------------------------------------------------------------------------------------------------------------------------
99                R136a5      HRS    IMAGE   0.25    MIRROR-N2        NX=13           1   169S                1   1
                                                                      NY=13
                                                                      DELTA-X=1
                                                                      DELTA-Y=1
     Comments: Time=13*13*1S=169S
-------------------------------------------------------------------------------------------------------------------------------------
100               R136a5      HRS    IMAGE   2.0     MIRROR-N2        NX=22           1   968S                1   1
                                                                      NY=22
                                                                      DELTA-X=2
                                                                      DELTA-Y=2
     Comments: Time=22*22*2S=968S
-------------------------------------------------------------------------------------------------------------------------------------
101               R136a5      HRS    ACQ     2.0     MIRROR-N2        SEARCH-SIZE=3   1   1161S               1   1
                                                                      LOCATE=NO
                                                                      MAP=ALL-POINTS
     Comments: Time=(128*Nmap +SS2)*StepT
               =(128*9 +3X3)*1.0S=1161S
-------------------------------------------------------------------------------------------------------------------------------------
```

Table 22.1: Relationship Between Proposal Lines and Files for Program 5297

Exposure Logsheet Line #	OBSMODE	APERTURE	MIRROR or GRATING	TARGNAME	FP_SPLIT	Central Wavelength (Å)	ROOTNAME for output file
1	DEFCAL						z2bd0101t
	ACQ	LSA		R136a1			z2bd0102t
2	DEFCAL						z2bd0103t
	ACQ/PEAKUP	LSA		R136a1			z2bd0104t
3	DEFCAL						z2bd0105t
	ACQ/PEAKUP	SSA		R136a1			z2bd0106t
4	DEFCAL						z2bd0107t
	IMAGE	SSA	N2	R136a1			z2bd0108t
5	DEFCAL						z2bd0109t
	IMAGE	SSA	N2	R136a2			z2bd010at
20	SPYBAL	SC2	G140L	WAVE	NO	1414.899	z2bd010bt
	ACCUM	SSA	G140L	R136a2	NO	1304.579	z2bd010ct
21	ACCUM	SSA	G140L	R136a2	NO	1608.027	z2bd010dt
50	SPYBAL	SC2	G140L	WAVE	NO	1414.903	z2bd010et
	ACCUM	SSA	G140L	R136a5	FOUR	1598.548	z2bd010ft
51	SPYBAL	SC2	G140L	WAVE	NO	1414.728	z2bd010gt
	ACCUM	SSA	G140L	R136a5	FOUR	1294.922	z2bd010ht
52	ACCUM	SC2	G140L	WAVE	NO	1313.492	z2bd010it
99	DEFCAL						z2bd010jt
	IMAGE	SSA	N2	R136a5			z2bd010kt
100	DEFCAL						z2bd010lt
	IMAGE	SSA	N2	R136a5			z2bd010mt
101	DEFCAL						z2bd010nt
	ACQ	LSA	N2	R136a5			z2bd010ot

Table 22.2 shows some of the different kinds of files generated in this program for the different operations that resulted from the Exposure Logsheet. The entries are Exposure Logsheet line numbers. The lines at the bottom of the table show what kinds of files are generated for the different kinds of operations. For example, all observations generate log files with extensions `.shh`, `.ulh`, and `.trl`. The * next to the acquisition files for lines 1 and 3 indicate that these observations also generate `.d1h` files and the corresponding `.q1h` data quality files. `.d1h` files are generated for Return-to-Brightest (RTB) acquisitions and SSA

peakups (which use the RTB algorithm). Notice that LSA peakups do not generate `.d1h` files; nor would an LSA acquisition that does not use the RTB algorithm.

Table 22.2: Breakdown of Files by Proposal Line Number for Program 5297

TARGET	DEFCAL	ACQ	ACQ/PEAKUP	IMAGE	(MAP)	SPYBAL	WAVECAL	ACCUM	FP-SPLIT
	1	1*							
R136a1	2		2						
	3		3*						
	4			4					
	5			5					
R136a2						20		20	
								21	
						50			50
						51			51
R136a5							52		
	99			99					
	100			100					
	101				101				
Header File Extensions	Log files: `.shh`, `.ulh`, `.trl`.			All log files, plus *raw data files*: `.d0h`, `.q0h`, `.x0h`, `.xqh`		All log files, all raw data files, plus *calibrated files*: `.c0h`,`.c1h`,`.c2h`, `.c3h`, `.c4h`, `.c5h`, `.cqh`			

Examining the ACCUMs

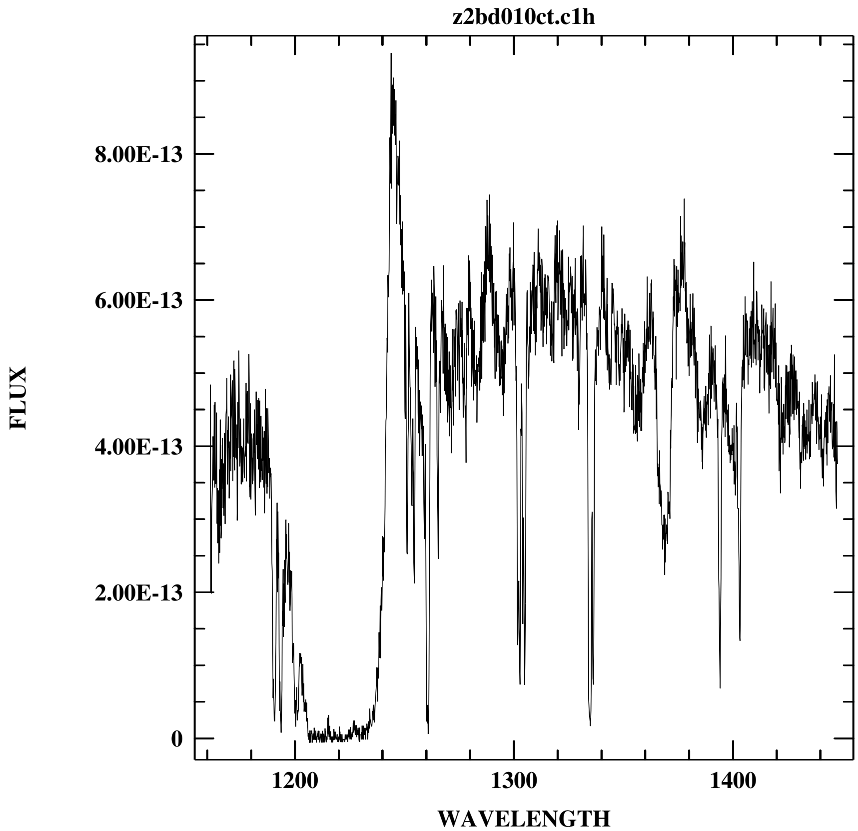
There are many, many data files for this program, but to start you would probably like to look at the reduced spectra, and then go back to understand how they got the way they are and how the calibrations might be improved.

The reduced wavelength and flux files have extensions of `.c0h` and `.c1h` (for a complete explanation of file extensions, see Table 23.2 on page 348). GHRS observations have separate files for wavelengths because they are on a non-linear scale; i.e., there is a distinct wavelength associated with each output data point, and those wavelengths are not necessarily evenly spaced. For a quick look, we need to use **fwplot**, a task in **stsdas**. The **fwplot** task will display flux versus wavelength and it can find the right wavelength file automatically (unless you have changed its name!), so we use the following to examine the first group of a repeat observation containing R136a2:

```
>fwplot z2bd010ct.c1h
```

to get what is shown in Figure 22.2. Plots of the other spectra can be obtained by changing the rootname. **fwplot** can also plot error bars and the like, which we'll get to in a moment.

Figure 22.2: Flux vs. Wavelength for R136a2



Now that we have seen the spectrum, let's understand better why it looks the way it does. First let's look at counts versus pixel to get a sense of the quality of the observations. Since there are three repeats in this observation, let's look at all four of the corresponding groups of data. We must create a listing of the file names with the group numbers attached, so we use **grlist** and redirect the output to a file. Then we stack the spectra using **sgraph**:

```
>grlist z2bd010ct.d0h - > lis
>sgraph @lis st+
```

Note how few counts we have at the short-wavelength (left) end (Figure 22.4). We can see the effect of this in the reduced spectrum. If we use **fwplot** to plot the a small part of the reduced spectrum with its errors (Figure 22.3) we get essentially the same information in a more compact form, and we can see that the errors are the statistical ones calculated from raw counts.

Figure 22.3: Reduced Spectrum of R136a2 with Error Bars

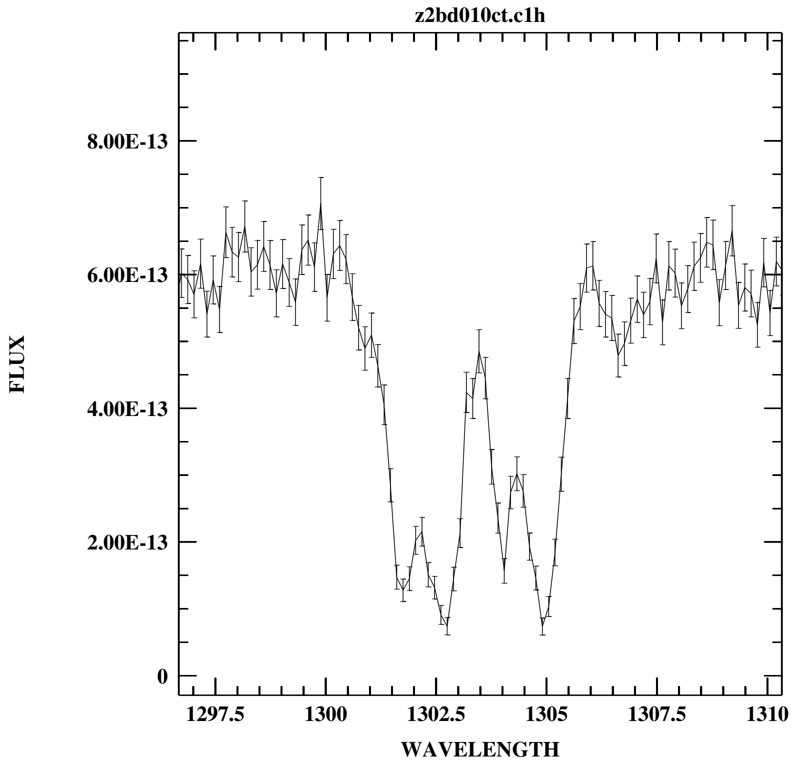
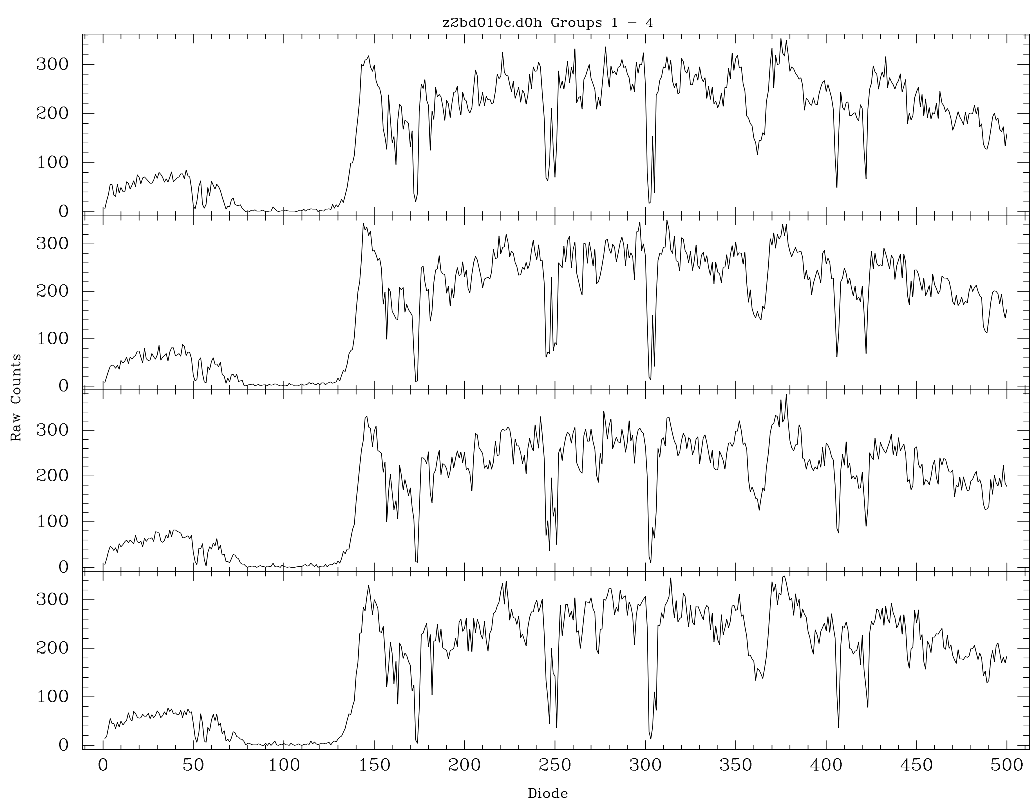
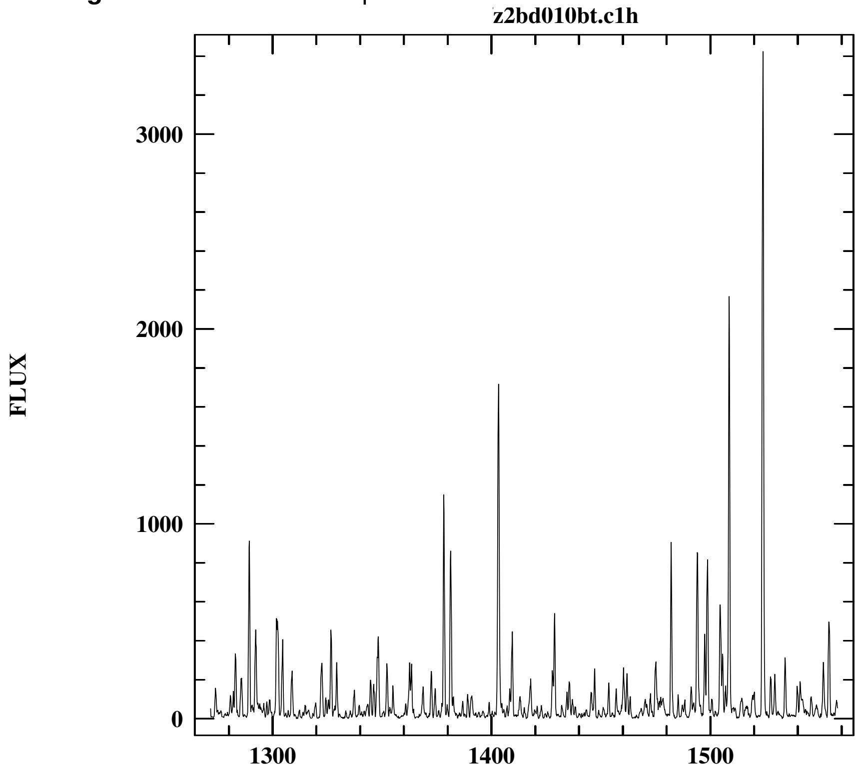


Figure 22.4: Raw Counts vs. Diode Number for Four Spectra in z2bd010c.



The reduced spectrum in Figure 22.3 has a wavelength scale that is the default from the pipeline reduction system. There are two ways to improve on this, either by using a wavelength calibration exposure or by using a SPYBAL. We can take the SPYBAL `z2bd010bt` and process it with **waveoff**. The wavecal exposure is shown in Figure 22.5, and the net result is that we compute a wavelength offset of 0.708Å . See the help file for **waveoff** for examples of how to use it.

Figure 22.5: SPYBAL Exposure z2bd010bt



Putting FP-SPLITs Back Together

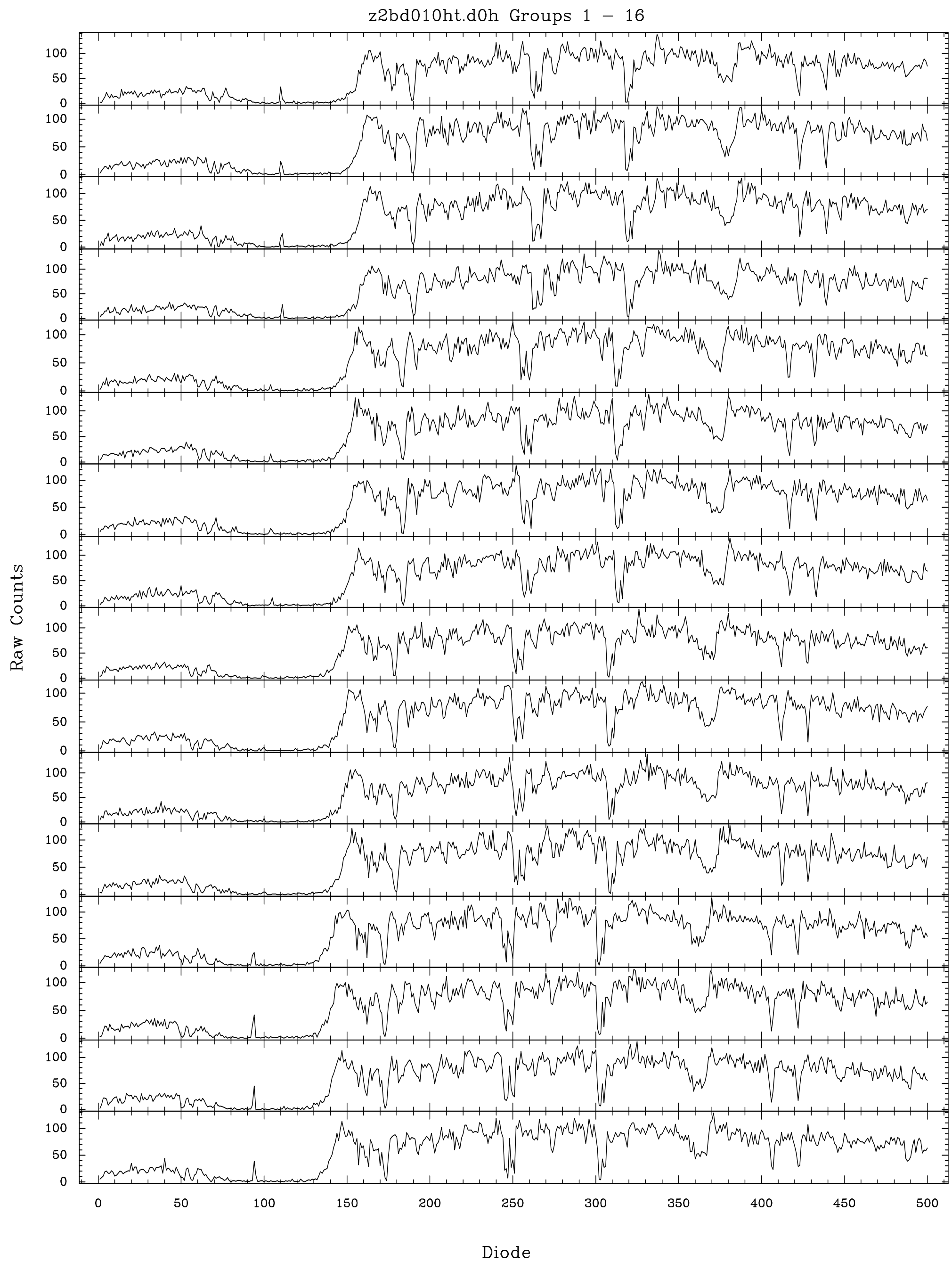
Specifying FP-SPLIT=FOUR (or any value except “NO”) on the exposure logsheet results in small motions of the grating carrousel between individual subexposures. This moves the source spectrum slightly on the diode array, making it possible to distinguish fixed-pattern noise from true spectrum features and to correct for that pattern.

The most sophisticated use of FP-SPLITs involves iteration to determine a function representing the fixed-pattern noise. This may be augmented by obtaining spectra obtained with larger discrete motions of the grating as well; see the discussion by Cardelli et al. 1993, Ap.J., 402, L17; Cardelli and Ebbets 1994, Calibrating Hubble Space Telescope, HST Calibration Workshop, ed. J.C. Blades and A.J. Osmer (Baltimore:STScI), 322. Here we describe the simplest use of FP-SPLITs for achieving more modest gains in signal-to-noise. This involves simply realigning the individual subexposures so that spectrum features line up, and then adding up the spectra.

The best way to align the subexposures is by cross-correlating them against the first exposure obtained. When there is not enough signal-to-noise for that it is possible to determine the shift to apply from knowledge of instrument parameters, but the factors that limit the quality of the wavelength scale (see "Recalibrating GHRS Data" on page 369) make that method inferior to cross-correlation.

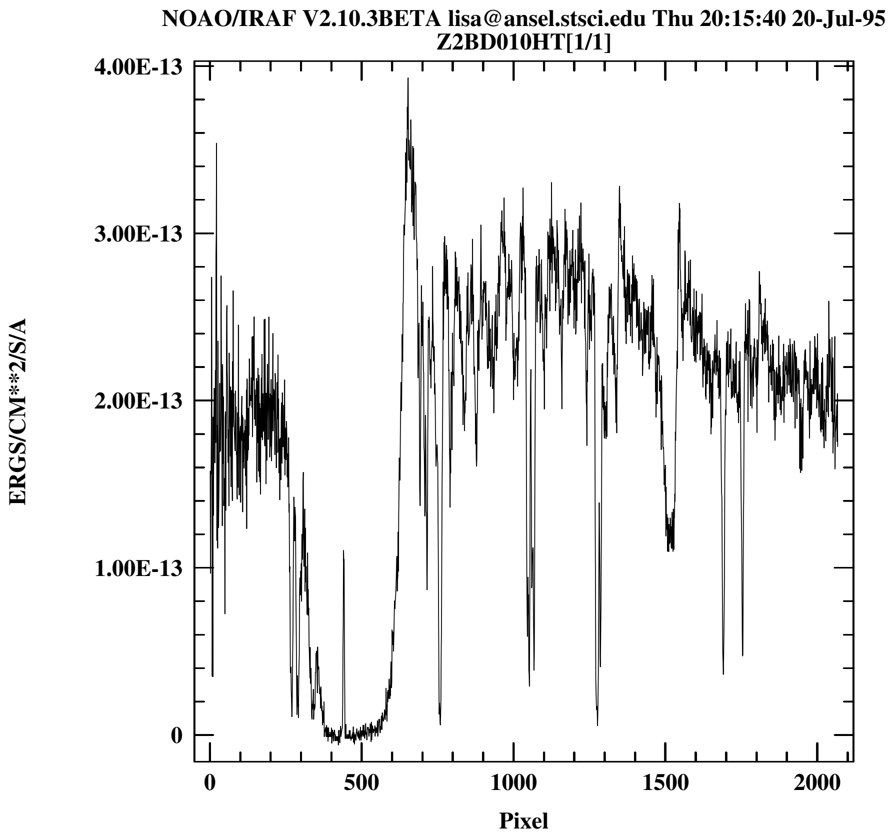
The cross-correlations to restore FP-SPLITs are done in **stsdas** with the **specalign** task. An example of raw data produced by an FP-SPLIT is shown in Figure 22.6.

Figure 22.6: Raw FP-SPLIT Observations for R136a5



Note that there are four groups of four, with a shift in wavelength after every fourth spectrum. The result of shifting and adding all the subexposures for R136a5 is shown in Figure 22.7using **sgraph** to show that there are more pixels in the combined spectrum than in the output of the pipeline software.

Figure 22.7: Summed Spectrum for R136a5



Case 2: RAPID Mode (and a little about Spatial Scans)

RAPID mode is used relatively rarely, but it has some unique capabilities. There are also some unique problems that arise in treating the resultant data.

Proposal 5745 was a calibration test designed to map out the central portion of the PSF as presented to the GHRS apertures by COSTAR. This particular test made use of a spatial scan to map out the PSF while collecting data in RAPID mode.

The Exposure Logsheet

An abridged version of the Phase II Proposal for 5745 is shown in Figure 22.8. Here are some notes to go with individual lines of the Exposure Logsheet:

- **Line 10:** Sk–65°21 is acquired with an ONBOARD ACQ using MIRROR-N1.
- **Line 15:** A confirmation IMAGE is taken as a sanity check for this program. In general, an IMAGE is unnecessary.
- The geometry of the spatial scan is shown in Figure 22.9. The **splot** display shows the relative orientations of the GHRS x,y and HST V2-V3 coordinate systems. Data points are delta distances in units of arcseconds.
- **Line 20:** Sk–65°21 is moved to the SSA using an ACQ/PEAKUP. The STEP-TIME was increased to compensate for the reduced throughput of the SSA relative to the LSA and to increase the signal-to-noise for the PEAKUP algorithm.
- **Line 25:** Another ACQ/PEAKUP. Again this is an exception rather than the rule for SSA ACQ/PEAKUPs (except when using MIRROR-A1).
- **Line 40:** This is the line where we get the spectra. We have specified a RAPID of 112.5 minute duration with a SAMPLE-TIME of 1.0 seconds. We expect to get about 6750 individual spectra from this observation.
- **Spatial Scan:** The spatial scan specifies a dwell scan that is 15 dwell points by 15 dwell points in extent. The spacing between dwell points is 0.053 arc seconds (about 2 deflection steps). The time spent at each dwell point will be 30 seconds. Note that the total number of spectra is 30 one-second exposures, times 15 dwell points, times another 15 dwell points in the other direction, for a total of 6750.

Figure 22.8: Exposure Logsheet for Program 5745

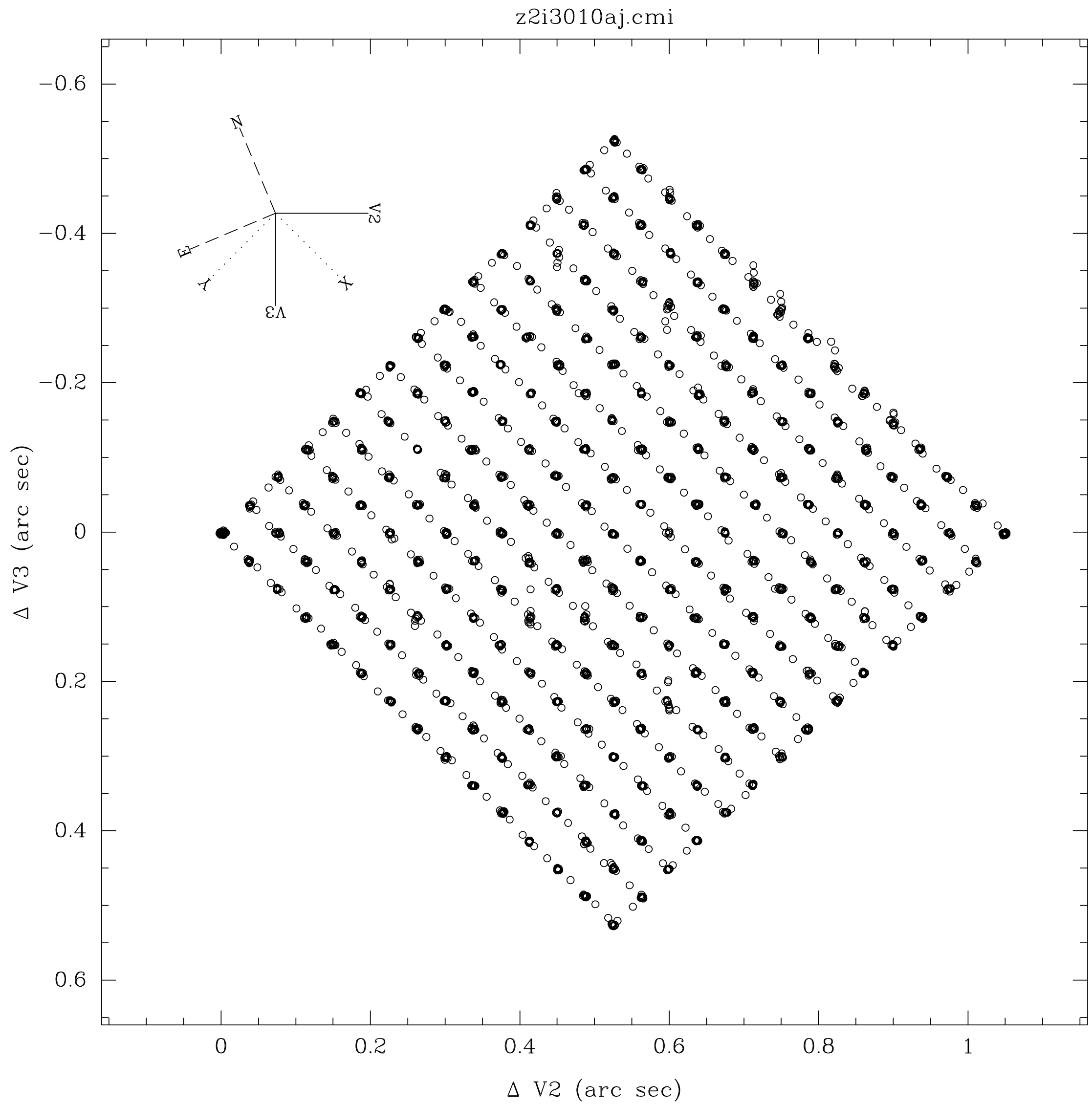
```
---------------------------------------------------------------------------------------------
-----------------------------------------
EXPOSURE                                                                             LOGSHEET
ID = 5745             [  4]
---------------------------------------------------------------------------------------------
-----------------------------------------
 1      |  2   |     3     |  4   |   5   |   6   |    7   |   8   |       9       |10 |   11
|   12   |13 |14|        15
---------------------------------------------------------------------------------------------
-----------------------------------------
  Line  |  Seq  |   Target   |Instr | Oper. | Aper  |Spectral|Central|   Optional    |Num|
Time |   S/N   |Flx|Pr|     Special
 Number | Name   |      Name     |Config| Mode    |or FOV |Element |Waveln.|   Parameters
|Exp|       |Rel. Time|Ref|  |   Requirements
---------------------------------------------------------------------------------------------
-----------------------------------------
10               SK-65D21    HRS    ACQ     2.0     MIRROR-N1        SEARCH-SIZE=5   1   25S
1  ONBOARD ACQ FOR 15

BRIGHT=RETURN                                  -20

                       CYCLE 4 / 10-40
     Comments: STEPTIME=1.0S EXPECT APPROX.
               2800 COUNTS/S TARGET IS IN CVZ
---------------------------------------------------------------------------------------------
-----------------------------------------
15               SK-65D21    HRS    IMAGE   2.0     MIRROR-N1        NX=16           1   256S
1
                                                                     NY=16
                                                                     DELTA-X=4
                                                                     DELTA-Y=4
     Comments: STEPTIME=1.0S
---------------------------------------------------------------------------------------------
-----------------------------------------
20               SK-65D21    HRS    ACQ/    0.25    MIRROR-N1        SEARCH-SIZE=5   1   25S
1  ONBOARD ACQ FOR 25
                                    PEAKUP
     Comments: STEPTIME=1.0S
---------------------------------------------------------------------------------------------
-----------------------------------------
25               SK-65D21    HRS    ACQ/    0.25    MIRROR-N1        SEARCH-SIZE=5   1   25S
1  ONBOARD ACQ FOR 40
                                    PEAKUP
     Comments: STEPTIME=1.0S
---------------------------------------------------------------------------------------------
-----------------------------------------
40              SK-65D21    HRS    RAPID   0.25    G140L    1400    SAMPLE-TIME=1.0 1   112.5M
1  SPATIAL SCAN

                       SINGLE-EXP
     Comments: 15X15 GRID WITH 0.053 ARC SEC
               SPACING EXPTIME AT EACH DWELL
               POINT=30S
---------------------------------------------------------------------------------------------
-----------------------------------------
Scan      Paramters      Form                                        Proposal       ID:
5745                                                                          [  5]
---------------------------------------------------------------------------------------------
-----------------------------------------
Data ID: 1
Exposure Logsheet lines: 40
FGS Scan:                     DWELL      Dwell Only: dwell points/line:        15   Seconds
per dwell:                   30.00
Scan width (arc-secs):       0.7420      Scan length (arc-secs):          0.7420    Angle
between sides (degrees)       270.00
Number of lines:               15      Scan rate (arc-sec/sec):         0.0000   PA of first
scan line (degrees)     90.000
Scan frame (CEL or S/C):      S/C      Length Offset (arc-sec):         0.3710   Width Offset
(arc-sec):            0.3710
---------------------------------------------------------------------------------------------
-----------------------------------------
```

Figure 22.9: Geometry of Spatial Scan



Examining the RAPID Data

First let's look to see how many individual spectra we got:

```
cl> imhead ../data/z2i3010at.d0h,../data/z2i3010at.c1h l-
../data/z2i3010at.d0h[1/9024][500][real]: Z2I3010AT[1/9024]
../data/z2i3010at.c1h[1/9021][500][real]: Z2I3010AT[1/9021]
```

The **imheader** task shows that we got many more spectra than expected. Further investigation turned up the fact that ten seconds is allocated for the slew from dwell point to dwell point. So we ended up having an extra ten seconds for each slew. Not all of these extra spectra are useful since the telescope was actually moving but we ended up getting about 35 seconds per dwell point instead of the anticipated 30 seconds. The **imheader** output also shows that there are three less spectra in the calibrated output than in the raw data. Keep in mind that since there is no substepping or FP-SPLITs possible when using RAPID mode, that a single raw spectrum maps to a single calibrated spectrum. Contrast this with a standard ACCUM with the default STEP-PATT — the raw data will contain six individual spectra (four substeps and two background spectra), which are merged into a single calibrated spectrum. In the case of RAPID mode, the first two readouts are generated during a hysteresis sequence that precedes every observation, and the last readout is produced by a final pass deflection made at the end of every observation. These readouts contain no useful science data and are not included in the calibrated data.

Manipulating a very large image can be difficult. For demonstration purposes, let's examine an arbitrary subsection of the original raw image in Figure 22.10. The **gcopy** task is used to extract a subset of groups from the original multi-group image. **gstat** computes the statistics for the new image.

Figure 22.10: Manipulating a Large Image

```
cl> gcopy ../data/z2i3010at.d0h subset.hhh groups=4604-4644
../data/z2i3010at.d0h -> subset.hhh
cl> gstat subset.hhh groups=*
# Image Statistics for subset.hhh
# GROUP       NPIX      MEAN     MIDPT    STDDEV       MIN       MAX
      1        500    10.048   9.00849    5.7949        0.       28.
      2        500      9.68   9.87606   5.31584        0.       24.
      3        500       10.   9.12097   5.48161        0.       27.
      4        500    10.334   9.88548   5.68217        0.       27.
      5        500    10.174   9.94917   5.75412        0.       28.
      6        500    10.166   9.00516   5.83254        0.       28.
      7        500    10.014   9.06106   5.56919        0.       25.
      8        500     10.04    9.8603   5.64465        0.       29.
      9        500     9.792   9.00807   5.29384        0.       28.
     10        500     9.886   9.92473   5.40587        0.       26.
     11        500     9.818   8.99274   5.39881        0.       28.
     12        500    10.072   9.82091   5.79603        0.       27.
     13        500    10.092   9.89125   5.59913        0.       25.
     14        500     9.856   9.10092   5.50562        0.       29.
     15        500    10.004   9.05718   5.64195        0.       29.
     16        500     9.822   9.01055   5.71381        0.       35.
     17        500     9.952   9.88586   5.57313        0.       24.
     18        500    10.054   9.94277   5.68822        0.       30.
     19        500     9.856   9.01978   5.35805        0.       25.
     20        500     9.958   8.97168   5.75312        0.       28.
     21        500     9.916   8.98258   5.69824        0.       26.
     22        500     10.07   9.86902   5.49741        0.       23.
     23        500     9.834   9.90083   5.55231        0.       25.
     24        500    10.206   9.83871   5.75446        0.       32.
     25        500    10.122   9.00645   5.72859        0.       28.
     26        500    10.148    10.128   5.65137        0.       31.
     27        500    10.286   10.0233    5.7052        0.       28.
     28        500      9.76   9.03122   5.41859        0.       25.
     29        500    10.068   9.04799   5.69493        0.       25.
     30        500     10.12   10.0108   5.52473        0.       28.
     31        500     9.908   8.98854   5.53071        0.       26.
     32        500     9.856   9.09568   5.40905        0.       29.
     33        500    10.076   9.90533   5.61045        0.       25.
     34        500     9.942   9.84996   5.42379        0.       27.
     35        500     9.822   9.88937   5.39598        0.       25.
     36        500     9.832   9.87903   5.58553        0.       25.
     37        500    10.206    9.8606   5.54952        0.       27.
     38        500     10.05    9.8626   5.61128        0.       26.
```

```
 39        500    10.102   9.97581   5.49509       0.       25.
 40        500    10.304   9.91161   5.80646       0.       27.
 41        500     9.926   8.99917   5.49809       0.       32.
```

Examining RAPID data as a two-dimensional image can be instructive. A simple way to convert the multi-group subset.hhh into a 2-d image is to use the **gftoxdim** task.

```
cl> gftoxdim subset.hhh subset_d2.hhh
```

The new image is now two-dimensional: the first dimension runs from diode 1 to 500 while the second dimension marks time.

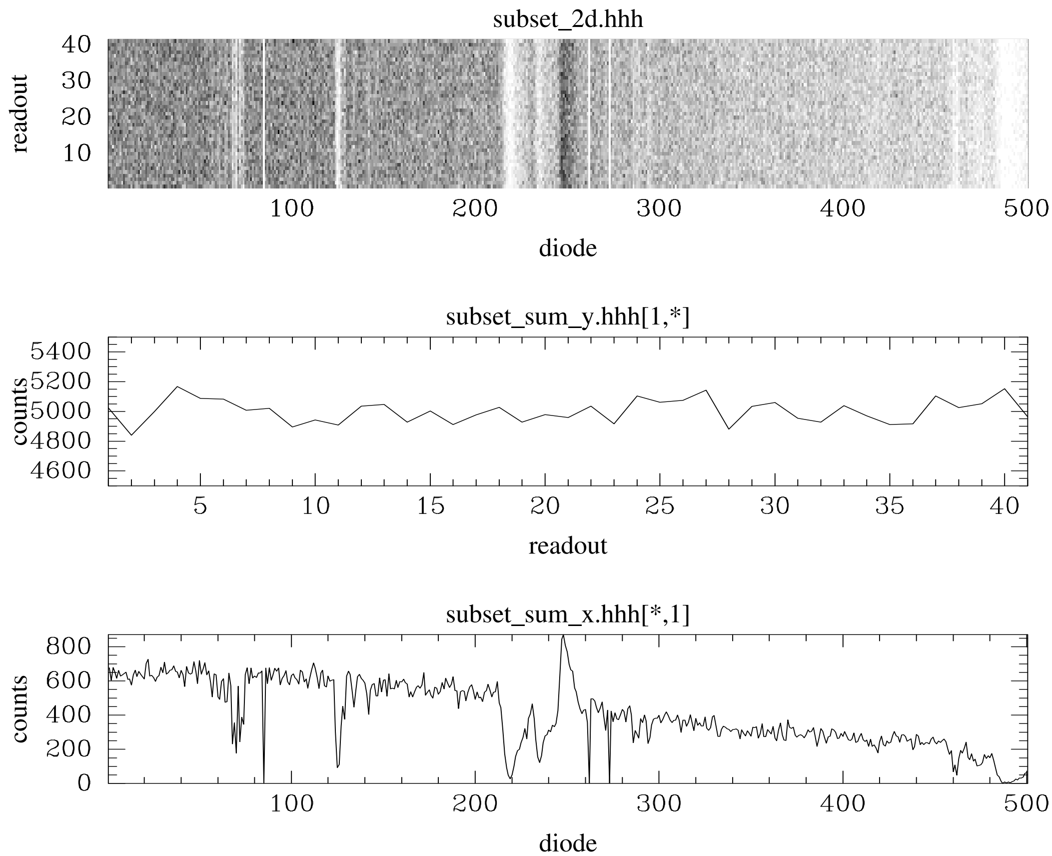
```
cl> imhead subset_d2.hhh l-
subset_2d.hhh[500,41][real]: SUBSET_2D[1/1]
cl> display subset_d2.hhh 1 z1=0 z2=40 zr- zs-
```

We can sum the 2-d image in each dimension for further inspection:

```
cl> blkavg subset_2d.hhh subset_sum_y.hhh b1=1 b2=41 option=sum
cl> blkavg subset_2d.hhh subset_sum_x.hhh b1=500 b2=1 option=sum
imhead subset_sum_?.hhh l-
subset_sum_x.hhh[500,1][real]: SUBSET_SUM_X[1/1]
subset_sum_y.hhh[1,41][real]: SUBSET_SUM_Y[1/1]
```

Figure 22.11 shows plots of three images. At the top is a greyscale plot of the extracted two-dimensional image, in the middle is a plot of the sum of the 500 diodes as a function of time, and at the bottom is a summed plot of the spectra over time.

Figure 22.11: RAPID Data



CHAPTER 23: Calibrating GHRS Data

In This Chapter...

The GHRS calibration task **calhrs** was developed and is maintained at STScI. **calhrs** is part of STSDAS. The calibration process has two basic goals: to assign flux and wavelength values to each raw data point. In addition, **calhrs** corrects for non-uniformity in diode response and for diodes that have been turned off (dead diodes). **calhrs** produces, as output, the calibrated spectra, wavelength solution, error estimates, and data quality images. The calibration software used in the RSDP pipeline to calibrate GHRS observations is the same software used within the **calhrs** task. The **calhrs** task can be found within the STSDAS **hst_calib** package.

Raw Science Data

The raw science data images are the output of the RSDP pipeline generic conversion process: `.d0h`, `.q0h`, `.d1h`, `.x0h`, `.xqh`, `.shh`, `.ulh`, `.trl`.

Science Data

The science data (`.d0h` image) contains the single-precision floating point values representing the number of detected counts accumulated for each diode. Depending on the pattern used for the observation, there may be only one, or up to six groups of science data per pattern (STEP-PATT). The science data includes the 500 science diodes. The data quality image (`.q0h`) associated with the science data records whether there is fill data due to technical problems with the observation or due to problems in transmitting the data from the telescope.

Return-To-Brightest and Small Science Aperture ACQ/PEAKUP

The return-to-brightest (RTB) target acquisition record will be placed in the `.d1h` image. This image will contain the total counts at each dwell point in the spiral search performed by the RTB acquisition algorithm. Small Science Aperture ACQ/PEAKUPs use the same algorithm as RTB target acquisitions. Therefore, they will also have a `.d1h` file whose header file contains information on which dwell point (MAPFND) contained the largest flux (FLUXFND). Also, the RTB record is extracted and placed in the trailer file (`.trl`).

Extracted Data

For ACCUM and RAPID mode observations, the extracted data image (`.x0h`) contains the values of the twelve special diodes in the detector (see Table 23.3) and 12 pixels of engineering data relevant to each pattern execution are appended to this image. The 12 special diodes are the focus, background monitor, and radiation monitor diodes. The data quality file (`.xqh`) records whether any of the data represent fill due to technical problems with the observation or telescope during the observation.

Standard Header Packet (SHP)

The standard header packet (image extension `.shh`) contains the telemetry values from the engineering data and some GHRS-unique data. The engineering data includes temperatures, currents, and voltages at various points in the instrument. 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, sun, and moon, and other proposal information used in the observation which was provided in the Phase II part of the proposal. There is one group of `.shp` data per pattern used in the observation.

Unique Data Log (UDL)

The unique data log (image extension `.ulh`) contains the Observation Control Table used to control the aperture, detector, carrousel, Digicon deflections, observing modes, and flux measurements. There are two groups of `.udl` data per pattern per observation. For images and standard ACCUM mode, a leading and following `.udl` is readout that brackets the observation. For RAPID mode, only one `.udl` is read out before the science observation begins. Therefore, the PKTTIMEs of the UDL observations can be used to estimate the start and stop times of the observation.

Trailer File

The trailer file (extension .trl) contains many messages generated by the conversion of the data from what is on-board the spacecraft into STSDAS images. These messages include RTB information for some acquisitions or the informational messages produced by **calhrs** as it is used to calibrate the data.

Header Keywords

The header files provide all the information needed to calibrate GHRS data. The headers are divided into groups of keywords that deal with specific types of information (i.e., observing information, engineering information, and processing and calibration information). Table 23.1 lists a few of the important GHRS header keywords.

Table 23.1: Important GHRS Header Keywords

Keyword	Description/value
GCOUNT	Number of data groups
FILETYPE	shp, udl, ext, sci, img, wav, flx
NBINS	Number of substep bins in this pattern
RPTOBS	Expected number of observation repeats
STEPPATT	Step pattern sequence
FP_SPLIT	FP-SPLIT (NO, TWO, FOUR, DSTWO, DSFOUR)
COMB_ADD	Comb-addition (NO, TWO, FOUR, DSTWO, DSFOUR)
FINCODE	Observation termination code
OBSMODE	Observation mode (ACCUM,RAPID,SPYBAL,DEFCAL,ACQ,)
DETECTOR	Detector in use (1 or 2)
GRATING	Grating, echelle, or mirror in use
APERTURE	Aperture name
DATE	Date this file was written (dd/mm/yy)
PKTFMT	Packet format code
KZDEPLOY	COSTAR deployed for the HRS (T or F)
APER_FOV	Aperture field of view (arcsec), N/A for cal
FGSLOCK	Commanded FGS lock (FINE,COARSE,GYROS,UNKNO
DATE-OBS	UT date of start of observation (dd/mm/yy)
TIME-OBS	UT time of start of observation (hh:mm:ss)
EXPTIME	Exposure duration (seconds)—calculated

An HST observation is composed of packets of information sent down to the ground and each observation packet has an embedded packet format code to identify the packet as an .shp, .udl, or .sci. Each science packet has a packet format code (PKTFMT) that identifies the type of science. The default GHRS calibration switches are set by the PKTFMT keyword value, specified by the type of observation (Target Acquisition, IMAGE, ACCUM, or RAPID mode). The default calibration switches have been selected to achieve the best possible calibration. The PKTFMT values are set when the observations are scheduled. They are used to determine the values of the science header keywords. This information is stated here for completeness.

The eighteen GHRS calibration steps are listed and described at the end of this chapter.

Pipeline Calibration Process

The RSDP pipeline will only perform those calibration steps specified by the calibration switches in the raw science header (.d0h). If there are problems with the observation, it will be set aside for repair. If there are missing packets, and no further packets are forthcoming from the spacecraft, the RSDP pipeline will place fill packets into the position of the missing packets. Information about missing packets and fill data can be found in the trailer file (.trl). Calibration output files are produced, archived into the HST Data Archive, and a laser printer plot is generated for the first group in the uncalibrated and calibrated image. These laser printer plots are solely for the purpose of first look by the observer and are not intended to be publication quality or available to the public.

calhrs will produce several types of calibrated output files, depending on the calibration steps performed. The calibrated output images are listed in Table 23.2.

Table 23.2: Calibrated Images

Data	File Contents
.c0h	Calibrated wavelength solution
.c1h	Calibrated science data (fluxes)
.c2h	Propagated statistical error
.c3h	Calibrated special diodes
.c4h	Special diodes data quality
.c5h	Background
.cqh	Calibrated science data quality

- Calibrated Wavelength Solution (.c0h): This image contains the wavelengths in Angstroms of the corresponding pixels in the .c1h file. The dimensionality and number of groups is the same as the .c1h file. This file is produced when ADC_CORR is set to PERFORM.

- Calibrated Science Data (`.c1h`): This image contains the calibrated science data and is always produced by **calhrs**. The number of groups and dimensions of the spectra depends on the pattern used (STEP-PATT) in the observation and which calibration steps are performed. The contents can range from being an exact copy of the raw science data (found in the `.d0h` image) to a fully flux-calibrated spectrum.
- Propagated Statistical Error (`.c2h`): This image contains the propagated statistical error associated with the `.c1h` science data. The number of groups and dimensions of this file will be the same as the `.c1h` image. The units of the error will also be the same as the final units of the science data.
- Calibrated Special Diodes (`.c3h`): This image contains the calibration of the special diodes whose raw values correspond to the first 12 pixels in the `.x0h` file. See Table 23.3.

Table 23.3: Special Diodes

Diode Array Index	.c3h or .x0h Pixel #	Description
1	1	Upper Left Background (corner) Diode
2	2	Lower Left Background (corner) Diode
3	3	Left High-Energy Diode
4	4	Middle Focus (disabled) Diode
5	5	Upper Left Focus Diode
6	6	Lower Left Focus Diode
507	7	Upper Right Focus Diode
508	8	Lower Right Focus Diode
509	9	Middle Focus Diode
510	10	Right High-Energy Diode
511	11	Upper Right Background (corner) Diode
512	12	Lower Right Background (corner) Diode

- Special Diode Data Quality (`.c4h`): This image contains the data quality flags for the special diodes. See Table 24.2 on page 367 for data quality flags.
- Background (`.c5h`): This image contains the subtracted background. The units of the background will be either in counts or count rate, depending on the setting of the EXP_CORR switch. This file is produced when BCK_CORR is set to PERFORM.

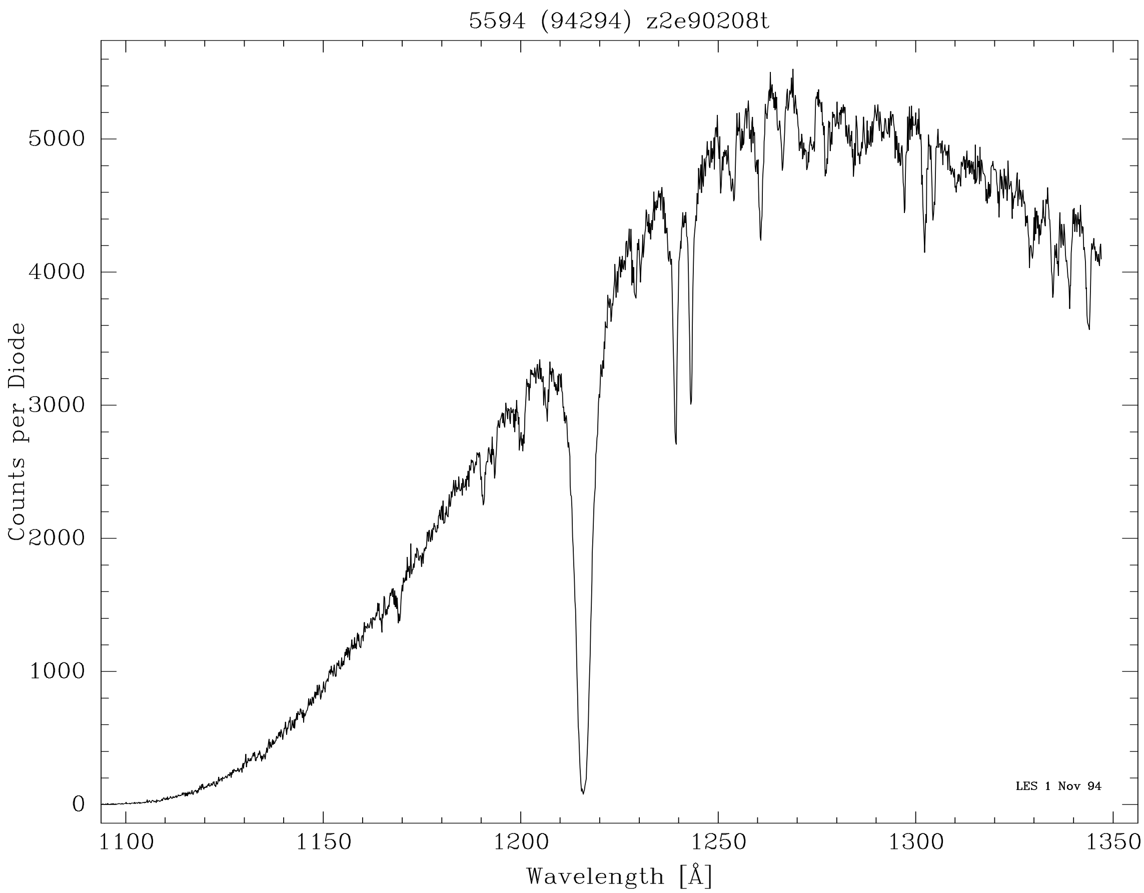
- Calibrated Science Data Quality (.cqh): This image contains the data quality flags associated with each pixel in the calibrated science data image. The flags are numbers; the higher the value, the worse the data in the corresponding pixel. See Table 24.2 on page 367 for data quality flags.

Standard Stars

The stars used as flux references are members of the set of standards established by STScI. Targets for specific observations are selected primarily on the basis of UV brightness, since we want to obtain count rates high enough to achieve adequate S/N (>50) in short exposure times.

During Cycle 4, we used the ultraviolet standard stars BD+28D4211 and μ Columbae as flux references. Both stars are not known to show significant variability in the ultraviolet. BD+28D4211 is a hot white dwarf that was used for the sensitivity calibrations for the low and medium dispersion gratings. The corresponding observations for the echelle were done with the bright late-O supergiant μ Columbae. An example of such an observation is in Figure 23.1.

Figure 23.1: Spectrum of BD+28D4211 Obtained with Grating G140L in Fall 1994



Observational Procedures and Data Reduction

Sensitivity monitoring is done for Side 1 and Side 2 separately. The Side-1 monitor contains a series of visits of the ultraviolet standard BD+28D4211 with identical instrumental configuration (except for exposure times) for all observations. The target was acquired into the Large Science Aperture with a 5 x 5 spiral search using mirror N1, followed by a peak-up. The science observations were done with grating G140L in the ACCUM mode at two central wavelengths: 1200 Å and 1500 Å. For the Side 2 observations, BD+28D4211 was acquired into the LSA with a 3 x 3 spiral search using mirror N2, followed by a peak-up. Centering was confirmed by taking an image with the LSA. A series of spectra in the ACCUM mode were taken with gratings G160M, G200M, and G270M. Central wavelengths were 1200 Å, 1500 Å, 2000 Å, 2500 Å, 3000 Å. This sequence was repeated approximately every three months.

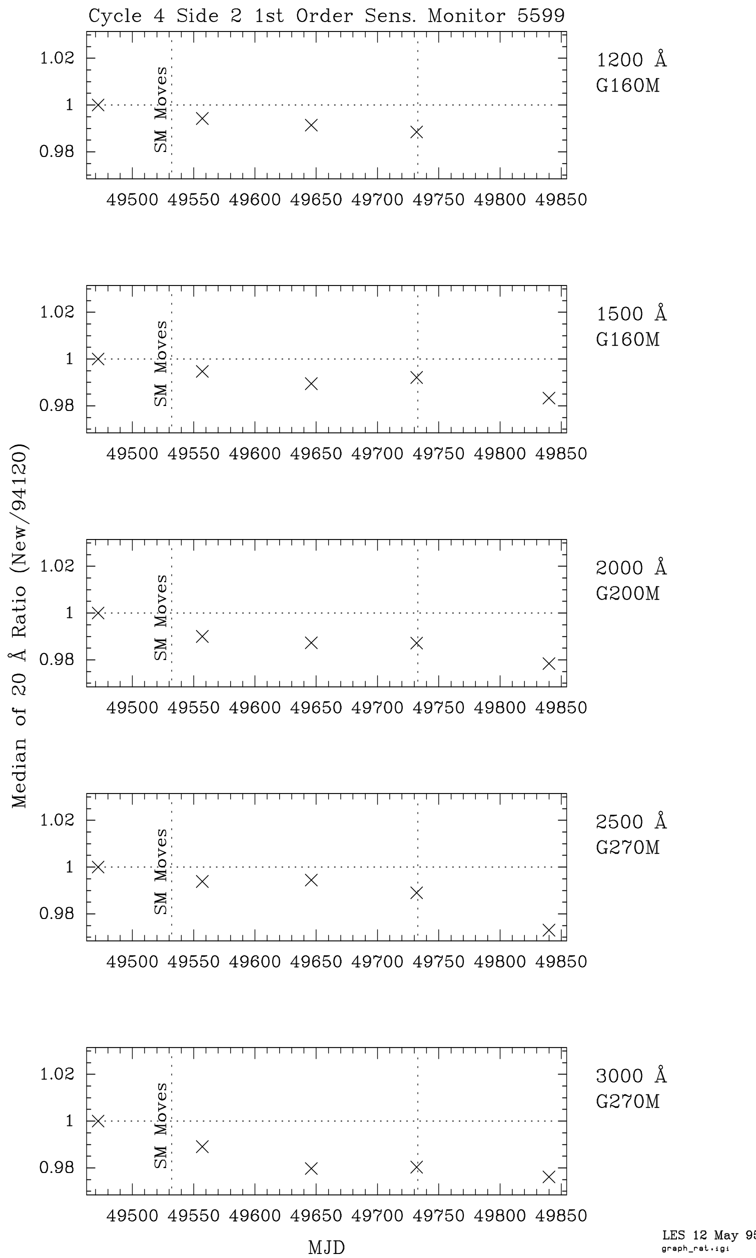
Relative Fluxes

The results of the GHRS sensitivity monitor suggest that during Cycle 4 the GHRS sensitivity changes between 1200 Å and 3000 Å do not exceed about 2%. We find marginal evidence for a time-dependence of the sensitivity with a decline rate of about 2% per year. As an example we show in Figure. 23.2 flux ratios of BD+28D4211 obtained during Cycle 4 and referenced to the beginning of the cycle. (Details are in *GHRS Instrument Science Report* 071). The current sensitivity files used by calhrs reflect the state at the beginning of Cycle 4. We will continue to monitor both Side 1 and Side 2 for further decreases of the sensitivity. If the sensitivity decrease becomes larger than 5% between 1200 Å and 3000 Å with respect to the value at the beginning of Cycle 4, updated sensitivity files will be installed.

In Figure 23.2, the five panels are for central wavelengths of 1200 Å, 1500 Å, 2000 Å, 2500 Å, and 3000 Å. Each point represents ratio of the median counts measured over 20 Å relative to the counts measured on SMS 94120 over the same 20 Å (the first data point).

Below 1200 Å the sensitivity is clearly decreasing with time. This trend was marginally present in data obtained early in the Cycle and has been confirmed later in Cycle 4. The loss of sensitivity from the beginning to the end of Cycle 4 at 1140 Å is about 10%. Observers wishing to calibrate their Cycle 4 observations at the shortest wavelengths of the G140L grating should contact the STScI GHRS team via the Help Desk (`help@stsci.edu`).

Figure 23.2: Side 2 Sensitivity During Cycle 4



Absolute Fluxes

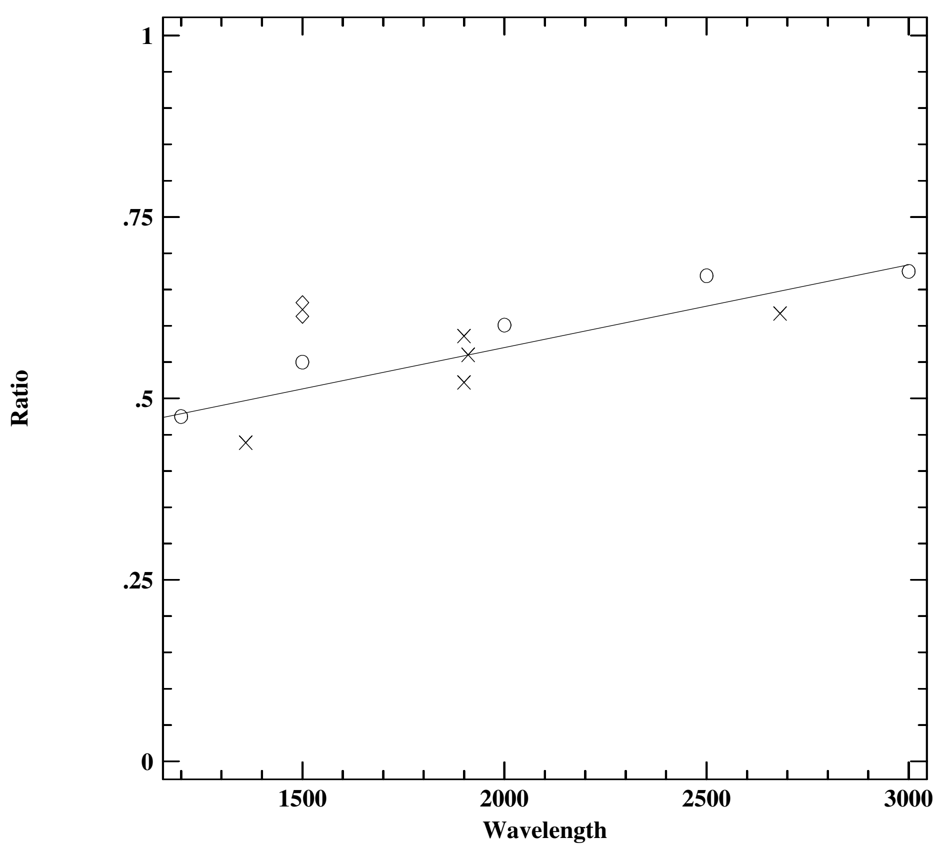
Fluxes on an absolute scale are known to within approximately 10%. The absolute flux scale used by the GHRS is tied to the system of STScI observatory standards. In May 1994, we switched over to the new, revised absolute flux scale established from observations of the white dwarf G191B2B (see *GHRS Instrument Science Report* 062). The new scale differs from the old one by up to 10%, depending on wavelength. Archived data obtained prior to May 1994 have not been recalibrated with the new flux scale. Therefore spectra of the same star taken before and after May 1994 are on a different flux scale.

The absolute throughput of the LSA is poorly known. We estimate that approximately 90-95% of the light emitted by a point source is encompassed by the LSA.

The relative throughput of the SSA with respect to the LSA was determined before and after the installation of COSTAR (see *GHRS Instrument Science Report* 062). Post-COSTAR values are shown in Figure 23.2. LSA throughput is assumed to be 100% in this figure. The relative throughput of the SSA is wavelength dependent, with higher values measured at longer wavelengths.

In Figure 23.3, the circles are observations of μ Col—all five data points are based on a single SSA ACQ/PEAKUP. The crosses are for χ Lup—the first and last points are from a single ACQ/PEAKUP and the cluster of three points near 1950 Å is from another. The diamonds are for AGK+81″266—each point is based on an individual ACQ/PEAKUP. The solid line is a straight line fit to μ Col and χ Lup data.

Figure 23.3: Ratio of Count Rates for the post-COSTAR SSA to the post-COSTAR LSA.

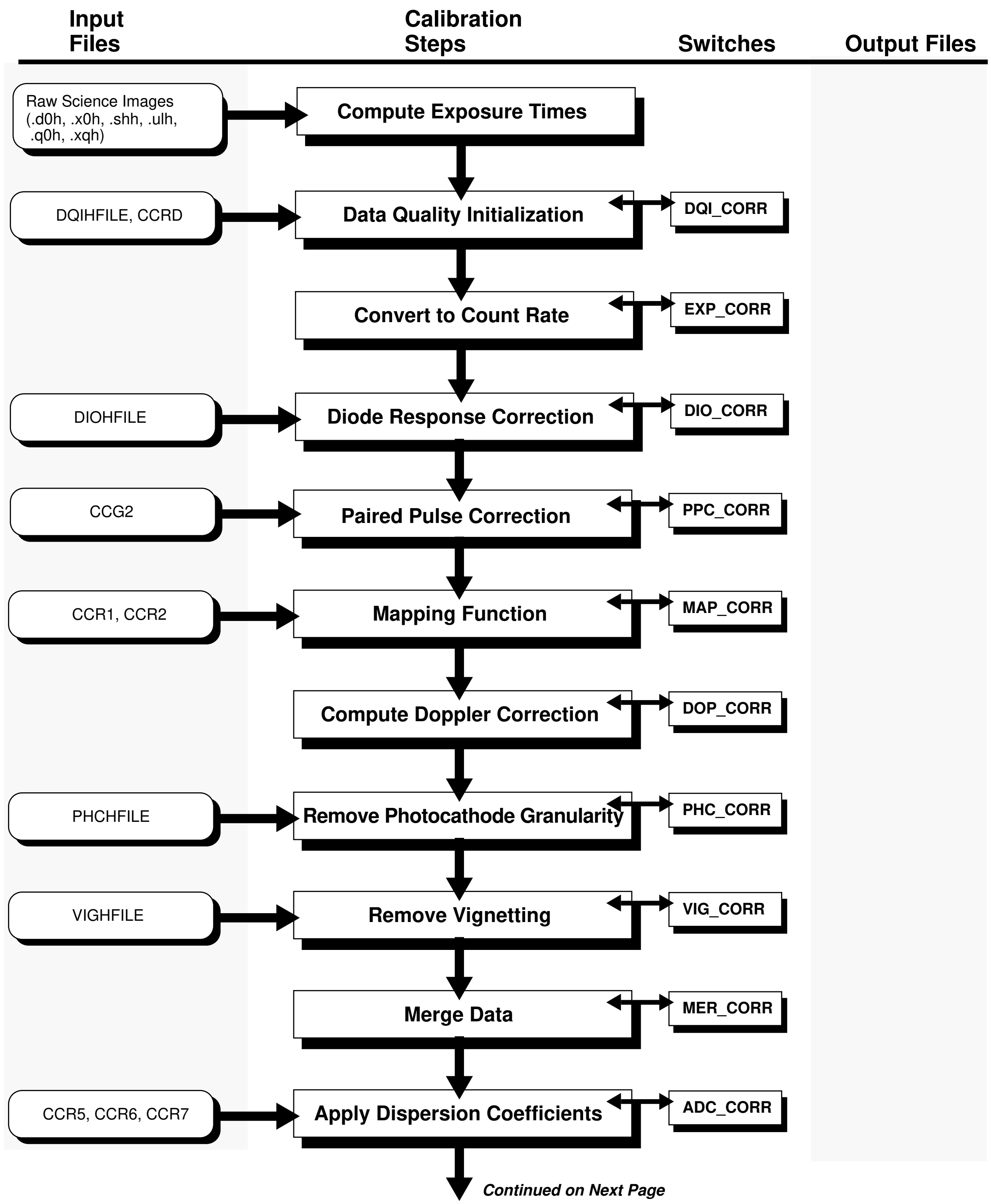


Note that the calibrated science data in the .c1h file take into account the different throughput for point sources of the LSA and SSA before and after the installation of COSTAR. Therefore a star observed before and after the installation of COSTAR will have the same flux although its count rate will be lower before COSTAR.

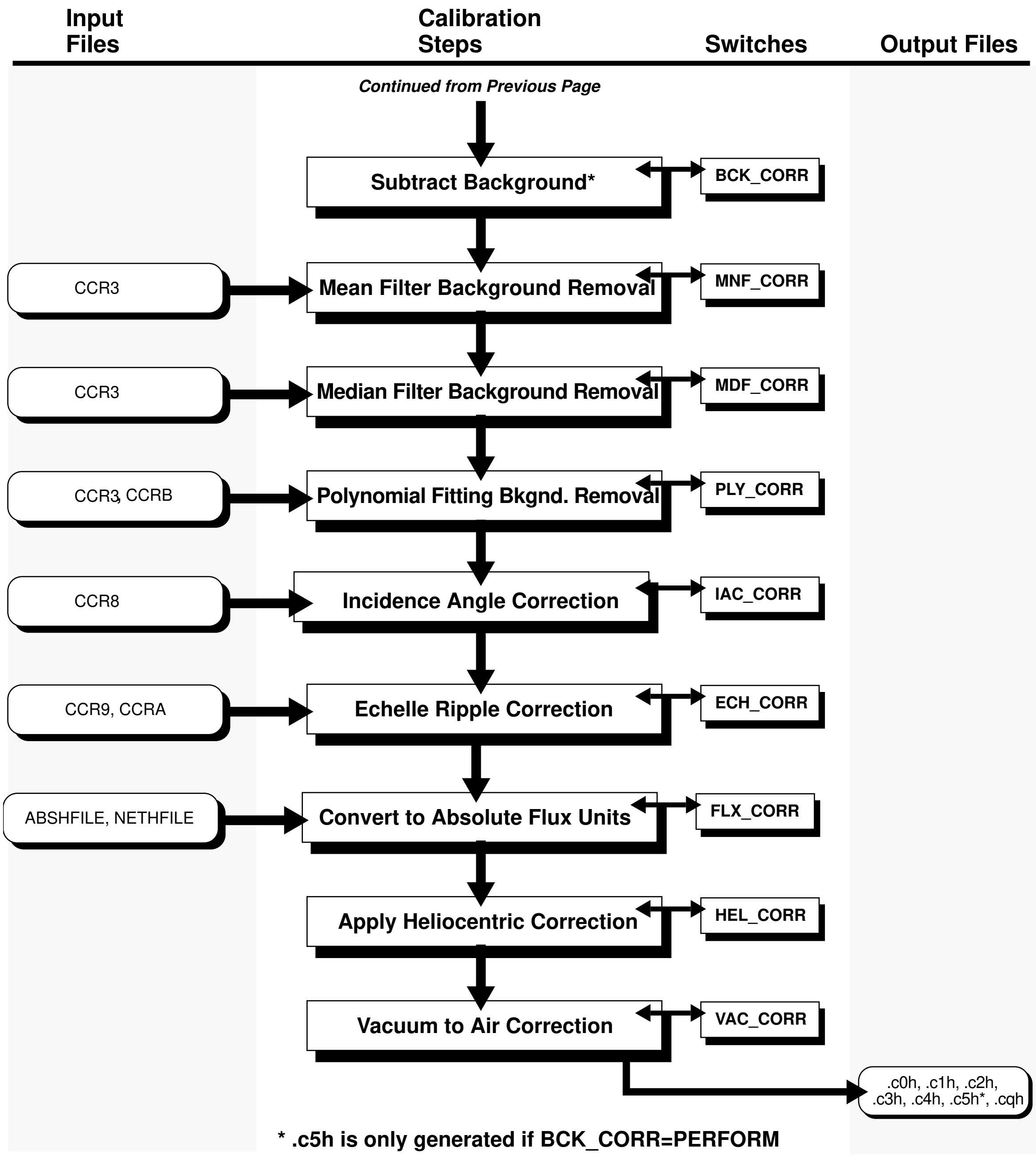
Calibration Steps

Each calibration step is detailed in this section along with the corresponding calibration switch and various reference files required by that step. A flowchart of the process is illustrated in Figure 23.4.

Figure 23.4: GHRS Calibration Process



Continued on Next Page



Data Quality Initialization (DQI_CORR)

Apply data quality initialization using the reference file, `dqihfile`, which contains a data quality flag for each diode. This step compares each data quality flag in the `.q0h` file with the corresponding flag in the data quality initialization file (`.r5h`). The most severe flag is kept. Quality flags are not additive and are never decreased. The most severe data quality flags are written to the output file (`.dqh`). Table 24.2 defines these flags (by order of decreasing severity).

Conversion to Count Rates (EXP_CORR)

This step converts the input data to count rates by dividing by the exposure times. The exposure time is computed for each bin as: $EXPOSURE = n_{coadd} \times (0.05 \times \mathrm{intper} - 0.002)$

where:

- *EXPOSURE* is the exposure time per bin as found in the keyword in the calibrated data headers,
- *intper* is the integration period in 0.05 second intervals,
- 0.002 is the overhead required to read out the data,
- n_{coadd} is the number of coadds to the bin.

If either value contains a fill value, no exposure time can be computed and the entire bin is flagged as unusable. The values for n_{coadd} and *intper* are read from the extracted engineering file.

Diode Response Correction (DIO_CORR)

The diodes within the Digicons of the GHRS do not have identical sensitivities. This step divides the count (or count rate) value by the diode's response (near unity) to correct for diode nonuniformity using the diode response file, `diohfile`. When comb-addition is used, a smooth diode response array is computed using a weighted average of diode responses. Data with a diode response value less than the minimum diode response value set in the `ccr3` table are set to 0.0.

Paired Pulse Correction (PPC_CORR)

Correct the raw count rates for saturation in the detector electronics using `ccg2`, the paired-pulse correction table. On the first pass, this routine reads the paired pulse parameters from table `ccg2`. If q_0 is not equal to zero, then the following equation is used:

$$X = \frac{y}{(1 - yt)}$$

where:

- X is the true count rate,
- y is the observed count rate,
- If $y \le F$, t is defined as:

$$t = q_0$$

  or if $y > F$, then:

$$t = q_0 + q_1 (y - F)$$

  q_0, q_1, and F are in `ccg2`.

- If $q_0 = 0$, then the following equation is used:

$$X = \frac{\ln(1 - ty)}{-t}$$

where:

- $t = tau1$ is from the `ccg2` reference table.

Photocathode Mapping (MAP_CORR)

This step computes where on the photocathode the spectrum was located. This mapping of the location is performed in LINE and SAMPLE space. LINE position is perpendicular to dispersion, and SAMPLE is parallel to the dispersion. This calculation is used by some of the following calibration steps. The position of the individual substep bins are mapped into photocathode space using the following:

$$\text{SAMPLE(bin)} = x_0 + b \times XD + c \times XD^2$$

$$\text{DELTAS(bin)} = e$$

$$\text{LINE(bin)} = L0 + A \times YD$$

where:

- *SAMPLE* is the sample position of the first diode,
- *DELTAS* is the spacing between sample positions,
- *LINE* is the line position of the diodes,
- *XD* is the X-deflection minus 2048,
- *YD* is the Y-deflection minus 2048,
- *s0*, *b*, *c*, and *e* are coefficients in `ccr2`, interpolated for the given Y-deflection, and
- *L0*, and *A* are coefficients in `ccr1`.

Doppler Compensation (DOP_CORR)

Correct for Doppler compensation when removing photocathode nonuniformities (PHC_CORR set to PERFORM) and vignetting (VIG_CORR set to PERFORM). Do not confuse this with the on-board Doppler compensation indicated in the science header by the value of the DOPPLER keyword. This step computes the percentage of time spent at each Doppler offset. These are computed by dividing the observation into time segments and computing the deflection offset for each segment. The SHP packet time is used as the start of the readout and the packet time of the first science packet is used as the ending time of the readout. Currently, this step is not applied in the Routine Science Data Processing.

Photocathode Nonuniformity Removal (PHC_CORR)

This step removes the photocathode granularity using a reference file that has a granularity map, `phchfile`. (Presently, however, the GHRS is not using this feature because obtaining the flat-field exposures for all possible grating positions is impractical. Therefore the `phchfile` is currently a DUMMY file that is populated with ones and zeroes. However, there are plans to obtain a G140L flatfield during Cycle 5.) This map is intended to have a granularity vector for multiple line positions. At each line position, the granularity is tabulated with a constant starting sample for all lines and a constant delta sample. To compute the response for a given line and sample, bilinear interpolation is used within the reference file. If Doppler compensation is specified (DOP_CORR = 'PERFORM'), the response is smoothed by a weighting function describing the motion of the data samples along the photocathode. (This calibration will only be known initially for a very few selected wavelength ranges. Using FP-SPLIT will generally be required for high S/N work.)

Vignetting Removal (VIG_CORR)

This routine removes the vignetting and low frequency photocathode response using a reference file that has a vignetting map, `vighfile`. This map has a vignetting vector for multiple line positions and possibly carrousel positions. At each line position the vignetting response is tabulated with a constant starting sample for all lines and a constant delta sample. To compute the response for a given line and sample, tri-linear interpolation is used within the reference file over carrousel position, line position and sample position. If Doppler compensation is specified (DOP_CORR = 'PERFORM'), the response is smoothed by a weighting function describing the motion of the data samples along the photocathode.

Merging Substep Bins (MER_CORR)

This routine merges the spectral data. Unmerged output data are just a copy of the input data. The specified STEPPATT keyword value is used by **calhrs** to determine whether or not the data are to be merged. Any STEPPATT that accumulates 2 or more bins of spectra as listed in Table 8.5 in the *GHRS Instrument Handbook* will require merging. To illustrate the merging, consider input data having values Dbin.diode for bin number bin and diode number diode. The data would look like the following:

```
bin 1   D1.1  D1.2  D1.3  D1.4 ...
bin 2   D2.1  D2.2  D2.3  D2.4 ...
...
...
bin 7   D7.1  D7.2  D7.3  D7.4 ...
```

The position of the data points in the 2-dimensional data array mapped into a 1-dimensional data array are $500 \times bin + diode - 1$. This routine maps the data into the output array for half-stepped data as:

```
D1.1  D2.1  D1.2  D2.2  D1.3  D2.3 ...
```

And for quarter-stepped data as:

```
D1.1  D2.1  D3.1  D4.1  D1.2  D2.2  D3.2  D4.2  D1.3 ...
```

Background Removal (MDF_CORR, MNF_CORR, PLY_CORR, BCK_CORR)

This step removes the background from the observed flux. The switch BCK_CORR determines whether or not background removal is done. The other switches, MDF_CORR, MNF_CORR, and PLY_CORR, determine how the background is smoothed before subtraction.

1. If the science data are composed of multiple substep bins, the sky background will be resampled by linearly interpolating adjacent smoothed background data values. The background will then be scaled by

$$B_{scale} = B_{res} \times N_{aper}$$

   where
   - B_{scale} is the background to subtract from the science,
   - B_{res} is the resampled sky background,
   - N_{aper} is the normalization factor to compensate for the different sizes of the apertures.

   The two other methods involve internal measures of the background. Both methods use the same formula for determining the background vector: :

$$B_i = 0.5\,(a \times U_i + b \times L_i) - c \times N_i + d \times N_{ave}$$

   where:
   - B_i is the background at diode i,
   - a, b, c, d, are scattered light coefficients from table `ccrb`,
   - U_i is the upper inter-order background at diode i,
   - L_i is the lower inter-order background at diode i,
   - N_i is the net on-order count rate,
   - N_{ave} is the average of N over all science diodes.

   N_i is determined by

$$N_i = D_i - 0.5(U_i + L_i),$$

   and

   D_i is the on-order count rate at diode i.

   The three methods differ in how the U_i and L_i data are determined.

2. Background measured from inter-order spectra. The background is measured by the science diodes by observing the photocathode above and

below the science data. U_i is set to the upper background spectrum and L_i is set to the lower background spectrum.

3. Background measured from the corner diodes. There can be up to six substep bins sampling both the upper and/or lower background diodes. The background for each corner diode is the average of all measurements for that particular corner diode:

$$B_{corner} = B_{ncorner}/n$$

where

- *corner* is the corner diode identifier: *UL* - upper left, *UR* -upper right, *LL* - lower left, *LR* - lower right,
- B_{corner} is the effective background measured by the corner diode,
- $B_{ncorner}$ is the individual background measurement by the corner diode,
- n is the number of measurements from the corner diode.

The U_i and L_i vectors are then calculated by interpolating between the corner diodes as follows:

$$U_i = \frac{(C - C_1) \times (B_{UR} - B_{UL})}{(C_2 - C)} + B_{UL}$$

and

$$L_i = \frac{(C - C_1) \times (B_{LR} - B_{LL})}{(C_2 - C)} + B_{LL}$$

where

- U_i is the upper background at diode i,
- L_i is the lower background at diode i,
- B is explained above,
- C is the channel for diode i,
- C_1 is the effective channel or diode for the left corner diodes,
- C_2 is the effective channel or diode for the right corner diodes.

The observation can specify any combination of corner diodes using the substep bin identifications (BINID) found in Table 23.4. If no specific corner diodes are specified, then all four corner diodes are used for each science substep bin.

If MDF_CORR is set to PERFORM, then a median filter is applied to the background. This size of the filter box is found in table `ccr3` in columns SKY_MDFWIDTH and INT_MDFWIDTH. This switch is not normally applied in RSDP. It is provided as a recalibration option.

If MNF_CORR is set to PERFORM, then a mean filter is applied to the background. The size of the filter box is found in table `ccr3` in the columns SKY_MNFWIDTH and INT_MNFWIDTH. This switch is not normally applied in RSDP. It is provided as a recalibration option.

If PLY_CORR is set to PERFORM, then a polynomial is fit to the background and the function is subtracted. The order of the polynomial is found in table `ccr3` in columns SKY_ORDER and INT_ORDER. Currently the order is set to 0 but can be modified in your own copy of the `ccr3` table as a recalibration option.

It is possible to have all three filter options set, in which case, they are all performed in the order given above.

Table 23.4: Background Diodes Used by Substepping

BINID	Corner Diodes Determining Background	BINID	Corner Diodes Determining Background
8	Right and Left Upper	12	Right Upper
9	Right and Left Lower	13	Right Lower
10	Left Upper	14	Upper and Lower Left
11	Left Lower	15	Upper and Lower Right

Determine Wavelengths (ADC_CORR, GWC_CORR)

Convert the sample positions on the photocathode to wavelengths by applying the dispersion constants using tables `ccr5`, `ccr6`, `ccr7`, and `ccrc` containing spectral order, dispersion, and thermal constants. ADC_CORR computes spectral orders and wavelengths. For first order gratings, the spectral order is set to 1. For echelle gratings, the spectral order is computed by the following formula:

$$order = NINT\left(\frac{b \times A \times \sin((C - carpos)/B)}{ydef - a - d \times A \times \sin((C - carpos)/B)}\right)$$

where:

- NINT is the nearest integer,
- A,B,C are in table ccr5,
- a, b, and d are in Table ccr5,
- carpos is the carrousel position, and
- ydef is the Y-deflection adjusted for the proper aperture (LSA: 128 added to it, SC1: 128 subtracted from it).

The wavelengths are computed by solving the dispersion relation for wavelength using Newton's iterative method. The dispersion relation is described by the following equation:

$$s = a0 + a1m\lambda + a2(m\lambda)^2 + a3m + a4\lambda + a5m^2\lambda + a6m\lambda^2 + a7(m\lambda)^3$$

where:

- *m* is the spectral order,
- *l* is the wavelength,
- *a0,a1*,... are the dispersion coefficients,

- and s is the sample position.

The dispersion constants are calculated in one of two ways. If the switch GWC_CORR is set to PERFORM then the dispersion coefficients are calculated from the `ccrc` table's set of global coefficients which define a function based on carrousel position. If ADC_CORR is PERFORM but GWC_CORR is set to OMIT, then the dispersion coefficients are read from the `ccr6` table, which contains the dispersion coefficients for a few carrousel positions. Therefore, when GWC_CORR is OMIT, interpolation is performed between two sets of coefficients bracketing the required position, if that particular position is not in the `ccr6` table.

Apply the Incident Angle Correction (IAC_CORR)

Adjust the zero-point of the wavelength scale for the large science aperture and the two spectral lamp apertures using table `ccr8` containing incidence angle coefficients. This routine adjusts the wavelength array for the difference in incidence angle of apertures LSA, SC1, and SC2 from the SSA. Table `ccr8` is searched for the correct grating, spectral order, aperture, and carrousel position to obtain two coefficients, A and B. Interpolation of the coefficients (in carrousel position) is used if an exact match is not found. These coefficients are then used to compute an offset using the following formula:

$$\lambda = \lambda + (A + Bs) / m$$

where:

- l is the wavelength,
- A and B are coefficients from `ccr8`,
- s is the photocathode sample position, and
- m is the spectral order.

Echelle Ripple Correction (ECH_CORR)

If one of the echelle gratings is used, divide the flux value by the normalized grating efficiency to remove the echelle ripple using tables ccr9 and ccra, which contain echelle ripple constants. This step performs the echelle ripple removal by dividing the flux by the following echelle ripple function:

$$ripple = gnorm \times \operatorname{sinc}(ax + b)^2$$

where

$$gnorm = \frac{\cos(\theta + \beta + \delta)}{\cos(\theta + \beta - \delta + e)}$$

$$x = \pi m \left(\frac{\cos(\theta + \beta + \delta) \times \sin(\theta + e/2)}{\sin(\theta + \beta + e/2)} \right)$$

$$e = \operatorname{atan}((samp - 280.0)/f)$$

$$\theta = \frac{2\pi \times (r0 - carpos)}{65536.0}$$

and

- *m* is the spectral order,
- *samp* is the photocathode sample position,
- *r0, b, d*, and *f* are grating parameters in the `ccra` table, and
- *a* and *b* are coefficients from the `ccr9` table.

The ripple function is normalized to 1.0 as the center of the order. The center of the order is defined to be the center of the photocathode at the carrousel position 27492 for echelle A and 39144 for echelle B.

Absolute Flux Conversion (FLX_CORR)

This step converts the input flux to absolute flux units by dividing it by a sensitivity stored in the `abshfile` (sensitivities) and the `nethfile` (wavelengths for the sensitivities) files. Quadratic interpolation is used within the sensitivity file to compute sensitivities for the input wavelengths.

Heliocentric Correction (HEL_CORR)

Convert wavelengths to heliocentric coordinate system. This step corrects for the earth's motion around the sun and modifies the wavelengths appropriately. The wavelength correction is computed as follows:

$$\lambda = \frac{\lambda_{obs}}{1 - \left(\frac{V}{c}\right)}$$

where

- λ_{obs} - is calculated by the dispersion correction (ADC_CORR)
- *V* - is the velocity of HST in the direction of the target,
- $V = V_x \cos\alpha \cos\delta + V_y \sin\alpha \cos\delta + V_z \sin\delta$
- V_x,V_y, and V_z are computed from parameters in the SHP file,
- α and δ are right ascension and declination of the target, and
- *c* is the velocity of light.

Vacuum Correction (VAC_CORR)

This step converts vacuum wavelengths to air wavelengths above 2000 A. This correction is *not* applied in the Routine Science Data Processing. GHRS data are routinely calibrated to vacuum wavelengths. This step is provided as a recalibration option. The following formula is used:

$$\frac{\lambda_{vac}}{\lambda_{air}} = 1.0 + 2.735182\times10^{-4} + \frac{131.4182}{\lambda_{vac}^2} + \frac{2.76249\times10^8}{\lambda_{vac}^4}$$

CHAPTER 24: GHRS Error Sources

In This Chapter...

In this chapter, various error sources affecting data obtained with the GHRS are discussed.

Calibration Pipeline

All HST science observations are first received on the ground at White Sands, New Mexico, and are then relayed by satellite to the DCF (Data Capture Facility, after January 1996, PACCOR), Goddard Space Flight Center, Maryland. The DCF staff perform a check of the transmission using a Reed-Solomon error checking routine. When Reed-Solomon is used, the data are encrypted into a cyclic pattern. The down-linked data are then decrypted and the Reed-Solomon code will verify the pattern and corrects, if possible, those words that are not as expected. If any packets are missing, DCF will wait for the next STR (space tape recorder) dump to verify no more data packets are forthcoming. Missing data packets and the results of the Reed-Solomon check are written to the data quality accounting capsule (QAC). The data packets and QAC are transmitted to the pipeline.

Each GHRS observation set will be processed through the Routine Science Data Processing (RSDP) pipeline as far as generic conversion. The output of generic conversion is what users refers to as the *raw* uncalibrated dataset. Furthermore, the pipeline automatically runs the **calhrs** software to calibrate science files, such as ACCUMs, RAPIDs, and SPYBALs. Any ACQuisition files, IMAGEs, and DEFCALs are not calibrated. It is left up to the user to decide whether to recalibrate the science data at a later time. See Chapter 24,

"Recalibrating GHRS Data" on page 369, for information that will help you decide when to recalibrate.

Raw Data Quality Files

Each science data file (.d0h), extracted data file (.x0h), and target acquisition (.d1h) have a corresponding data quality file containing flags or fill values for bad data. These quality files (.q0h,.xqh,.q1h) are created during RSDP pipeline processing and contain information extracted from the QAC or are filled during the data evaluation process. For each data point in the .d0h, .x0h, or .d1h file, there is a corresponding data point in the quality file. For each good data value, the corresponding point in the quality file will be zero. If there are missing data (data-dropout), due to tape recorder flips, down link problems, or data loss due to unforeseen problems, the RSDP pipeline will pad the corresponding data file with fill data; the corresponding data point in the quality file will be set to 16. If the data failed the Reed-Solomon error check, the corresponding data point in the quality file will be set to one. Data that fails the Reed-Solomon check are classified as suspect, and may not be bad data.

Table 24.1: Pipeline Data Quality Values

Quality Value	Description
0	Good data point
1	Reed-Solomon error
16	Fill data

Calibration Quality Files

The **calhrs** task reads the raw data quality files, operates on the data using the quality flags as a discriminate, and flags the appropriate data values in the output quality files. Fill data are ignored. Reed-Solomon flagged data are calibrated, but is flagged as suspect in the output quality files.

The initial error in the data is assumed to be Poisson limited. The error is propagated mathematically through the calibration process. The propagated statistical error file (.c2h) contains a measure of the statistical errors of the original data values; this file is calibrated in lock-step with the science data files.

The flux data quality file (.cqh) flags bad pixel values in the calibrated flux and propagated statistical error files.

The special diodes data quality files (.c4h) flags bad pixel values in the calibrated special diodes file (.c3h). Good pixel values are identified by a zero value.

Table 24.2: Data Quality Flags

Flag Value	Description
Category 1: Data not useful —data values set to zero	
800	Data filled
400	Dead or disabled channel
300	Severe saturation (uncertainty >50%)
Category 2: Data uncertain—uncertainty not indicated in error computation	
190	Large saturation correction (uncertainty > 20%)
180	Photocathode blemish (deep)
150	Photocathode blemish (medium)
140	Photocathode blemish (small)
130	Moderate saturation correction (uncertainty >5%)
100	Reed-Solomon decoding error
Category 3: Data uncertain—uncertainty indicated in propagated error file	
30	Dead diode contributed to comb-added data point

The pipeline data reduction system (PODPS) automatically assigns a wavelength scale to your GHRS ACCUMs[1] and RAPIDs when they are reduced. Note that this default wavelength scale is the one appearing in the `.c0h` file that goes with the `.c1h` file containing fluxes, *even if there is a wavelength calibration exposure (wavecal) available for that program*. If you have a wavecal, you must analyze it and apply the results yourself; this is explained in the section "Recalibrating GHRS Data".

This default wavelength scale is calculated using terms that depend primarily on the carrousel position (i.e., the orientation of the grating that was used), but there are also terms for the temperature within the GHRS (recorded in the engineering data stream). There is also a weak time-dependent term.

The default wavelength scale is good to approximately one diode rms, with contributions from various effects as enumerated in Table 24.3 (which is taken from Heap et al. 1995, PASP, 107, 871). Not listed is the error in wavelength that occurs for observations made in the Large Science Aperture (LSA). Light from the LSA strikes the gratings at a different angle than light from the SSA. The difference in wavelength can result in an error as large as 1.5 diodes. This effect is now being calibrated and will be corrected for in the future.

1. Here and elsewhere in this chapter we will consider OSCANs and WSCANs as equivalent to ACCUMs. Both OSCANs and WSCANs are "macros" that generate a series of ACCUMs when the program is executed on the telescope.

Table 24.3: Error Sources

Source of Error	Maximum Error (diodes)
Quality of dispersion coefficients	0.1
Incident angle correction, SC2 to SSA	0.1
Uncertainty in thermal and time models	1.0
Short-term thermal motions	0.4 hour^{-1}
Carrousel repeatability	0.5 (0.17 typical)
Onboard Doppler compensation effects	0.15 typical
Geomagnetic image motion	0.25
Uncertainty in centering target in SSA	0.21

The largest sources of uncertainty in wavelength are obviously due to the geomagnetic image motion (GIMP) and the model used to correct for thermal and time effects. We have long cautioned observers to break down long exposures into units lasting no more than five to ten minutes, in order to reduce the effects of GIMP below significant levels. Thus you should only rarely find GIMP leading to loss of resolution in the final spectrum.

The thermal effects, however, include a large component that appears to be random and unable to be calibrated. It is these thermal effects that are best removed through use of a wavecal or SPYBAL. Thermal motions are just that: a motion of the overall image of the spectrum. The changes in image scale – dispersion – that occur are very small and can safely be ignored in most instances. For example, for grating G270M, we have found that the centers of our calibration spectra deviate from the default wavelength scale by no more than 100 mÅ (and typically about 70). The slope of a fit through the measured positions for the comparison lines relative to the default wavelength scale deviates in the center by no more than 100 mÅ (and typically about 70 mÅ), and has a slope of about 3×10^{-4} (in dimensionless units of Å per Å), so that the ends deviate from the center by, typically, about 3 mÅ across a 40 Å wide spectrum. The rms scatter of the fit is typically about 0.2 km s^{-1}. Not all the gratings are this good, and some other values for the quality of fit are provided in Table 24.4

Table 24.4: Quality of Default Wavelength Scale for Side 2 First-Order Gratings

Grating	Wavelength	rms deviation of fit (mÅ)	rms deviation of fit (km s^{-1})	Deviation at center (mÅ)	Slope of fit (times 10^4)
G160M	1240	15	3.7	60	3
	1400+	3 to 7	0.6 to 1.3	20 to 70	2 to 4
G200M	all	3 to 6	0.4 to 0.8	20 to 80	2 to 5
G270M	all	1 to 10	0.1 to 1.3	50 to 100	2 to 10

CHAPTER 25:
Recalibrating GHRS Data

In This Chapter...

Many users will find the standard calibration produced by the RSDP pipeline is adequate for their purposes. The RSDP pipeline uses the most up-to-date calibration reference files available at the time the observation was received.

Monitoring of the GHRS has shown that the GHRS has been stable over the life time of the instrument. However, some instrumental properties have changed slightly over time. The Archive user should be aware that some GHRS observations were obtained before on-orbit calibration reference files were released to OPUS (formerly PODPS). Some calibration reference files are time tagged, indicating that they should be used with data taken within specific range of dates.

The chapter on GHRS Error Sources provides guidance on the quality of default calibrations. Updated or more timely reference files sometimes become available after the data were processed. If there are unusual features in the data, or if analysis requires a high level of accuracy, or if wavecal observations were obtained with the science observation, then the user may want to determine whether or not a better calibration will be possible and recalibrate the data.

The user should perform a StarView search and check the list of reference files used during RSDP pipeline processing against the recommended calibration reference files. The decision to recalibrate depends upon which calibration image or table changed, and whether that kind of correction is likely to affect the analysis. Before deciding to recalibrate, it is recommended the user retrieve the recommended and used calibration files and compare them to see if the differences are important.

All the information necessary to calibrate your GHRS observations is contained in the science data header keywords. **calhrs** opens the header file and determines which set of calibration steps to PERFORM or OMIT and which calibration reference files and tables to use during the calibration process.

The user has the option to use the current set of calibration switches and specified reference files in the header file or to alter the values of certain keywords. The STSDAS task **chcalpar** can be used to modify the calibration parameters simply and reliably.

How to use calhrs

The calibration software takes as input the raw data images (`.d0h`, `.q0h`, `.shh`, `.ulh`, `.x0h`, `.xqh`) and the calibration reference images or tables. The calibration software determines which calibration steps to perform and which reference files to use by the calibration keyword values (switches and reference files) in the header of the raw data (`.d0h`) file. The values of the calibration switches and reference file keywords depend on the instrumental configuration used, the date when the observations were taken, and any special pre-specified constraints. The header keyword values were populated in the raw data file in the RSDP pipeline during Generic Conversion.

Reference files consist of images and tables. A calibration reference image is an STSDAS image (IRAF imtype = “hhh”). It consists of two files, an ASCII header and a binary data file. A reference table is an STSDAS format table. This table is a single binary file which may contain data of several types. By convention, the extension of a reference image begins with the letter “r” and that of a reference table begins with the letter “c”.

The user should determine the values of the calibration switches and reference file keywords in the raw data (or calibrated) header. Prior to calibration (`.d0h`), the calibration switches will have the value OMIT or PERFORM. After calibration (`.c1h`), the switches for completed steps will have been assigned the value COMPLETE in the header keywords of the calibrated dataset, unless the software knows the reference file is a DUMMY file, in which case the value of the switch keyword will be SKIPPED.

The IRAF task **imheader** can be used to examine the data header file.

```
to> imheader rootname.d0h l+ | page
```

An excerpt from a GHRS science data header file showing the calibration reference files and switches is presented in Figure 25.1.

Figure 25.1: Excerpt from Science Data Header File Showing Calibration Reference Files and Switches

```
/ CALIBRATION REFERENCE FILES
DIOHFILE= 'zref$cce1504az.r0h' / diode response header file
PHCHFILE= 'zref$bcc11275z.r1h' / photocathode response header file
VIGHFILE= 'zref$e751116dz.r2h' / vignetting response header file
ABSHFILE= 'zref$e5v0936rz.r3h' / absolute flux header file
NETHFILE= 'zref$e5v0936az.r4h' / absolute flux wavelength net header
file
DQIHFILE= 'zref$cce1505kz.r5h' / data quality initialization header
file
CCR1     = 'ztab$aau13518z.cz1' / photocathode line mapping parameters
table
CCR2     = 'ztab$ba412190z.cz2' / photocathode sample parameters table
CCR3     = 'ztab$c7f1130oz.cz3' / detector parameters table
CCR4     = 'ztab$a3d1045dz.cz4' / wavelength ranges table
CCR5     = 'ztab$e3u1417oz.cz5' / spectral order constants table
CCR6     = 'ztab$e3t1251bz.cz6' / dispersion constants table
CCR7     = 'ztab$e3t1250tz.cz7' / thermal constants table
CCR8     = 'ztab$e3t1250lz.cz8' / incidence angle coefficients table
CCR9     = 'ztab$e751042hz.cz9' / echelle interpolation constants table
CCRA     = 'ztab$e751041qz.cza' / echelle non-interpolation constants
table
CCRB     = 'ztab$d8b1457az.czb' / scattered light correction factors
CCRC     = 'ztab$e3u14301z.czc' / global wavelength coefficients table
CCRD     = 'ztab$e3t1028nz.czd' / photocathode blemish table
CCG2     = 'mtab$a3d1145ly.cmg' / paired-pulse correction table

/ CALIBRATION SWITCHES
DQI_CORR= 'PERFORM          ' / data quality initialization
EXP_CORR= 'PERFORM          ' / division by exposure time
DIO_CORR= 'PERFORM          ' / diode response correction
PPC_CORR= 'PERFORM          ' / paired-pulse correction
MAP_CORR= 'PERFORM          ' / mapping function
DOP_CORR= 'OMIT             ' / doppler compensation
PHC_CORR= 'PERFORM          ' / removal of photocathode nonuniformity
VIG_CORR= 'PERFORM          ' / removal of vignetting nonuniformity
MER_CORR= 'PERFORM          ' / merging of substep bins
GWC_CORR= 'PERFORM          ' / use global wavelength coefficients
ADC_CORR= 'PERFORM          ' / application of dispersion constants
MDF_CORR= 'OMIT             ' / median filter of background spectra
MNF_CORR= 'OMIT             ' / mean filter of background spectra
PLY_CORR= 'PERFORM          ' / polynomial smoothing of background
spectra
BCK_CORR= 'PERFORM          ' / background removal
IAC_CORR= 'PERFORM          ' / incidence angle correction
ECH_CORR= 'PERFORM          ' / correction for echelle ripple
FLX_CORR= 'PERFORM          ' / absolute flux calibration
HEL_CORR= 'PERFORM          ' / conversion to heliocentric wavelengths
VAC_CORR= 'OMIT             ' / vacuum to air correction
```

The HST data headers are self-documenting. The data processing steps performed are contained within the headers as is the state of the telescope and instrumentation at the time of the observation. The trailer file (`.trl`) contains the history of the RSDP pipeline processing, including the history of the calibration steps executed.

Selecting the “Best” Reference Images and Tables

Over the past four years a number of changes have been made to both the reference images and tables and the calibration software that employs them. In general, software changes are backwards-compatible with earlier versions of reference tables. However, this has not always been the case. Consequently, the current version of the software will not properly run with old data or old reference files. This is most likely to be a problem if one is using data from before November 11, 1991, in its original form. The simplest work-around to any problem of this sort is to obtain officially processed data and the latest (appropriate) reference images and tables from the HST Data Archive. There are two ways to identify the “best” reference images and tables to use when recalibrating GHRS data. 1) The **getreffile** task[1] in STSDAS is available for identifying appropriate reference images and tables for recalibration of GHRS data. These reference images and tables may be requested from STScI in the same fashion as any other non-proprietary data products. If you have any problems, send e-mail request to `help@stsci.edu`. 2) StarView can retrieve calibration images and tables from the HST Archive—the GHRS calibration form provides a simple interface for identifying the best files.

Finding Appropriate Reference Files

The calibration reference files used and recommended for a particular observation can be determined by performing a StarView search of the HST Archive. The user should select the option “Other Searches” upon entering StarView and select “Calibration” under the header GHRS. Input the observation rootname and perform the search to list the calibration reference files and tables used during RSDP pipeline processing and the recommended reference files for calibration.

These files can be obtained from the HST catalog and Archive through a StarView search and retrieval request. Requests for Archive accounts should be sent to `archive@stsci.edu.` (See Chapter 4 for a description of StarView.)

Information about CDBS (Calibration Data Base System) calibration reference images and tables can also be found on the STScI GHRS World Wide Web page or within the STScI anonymous FTP site.

Running the Software

The STSDAS software runs under IRAF and is free to the astronomical community; it can be retrieved through the “Software” web page on STEIS or from the STScI anonymous FTP area. See Chapter 2 for information about setting up and using IRAF and STSDAS.

1. This task works *only* at STScI because it accesses the Calibration Database (CDBS), which is *not* part of STSDAS.

In order to recalibrate your data, you need to have all the reference images and tables that are specified by the calibration switches in the science data header (`.d0h`). If you received your data by tape, these files are usually included. If you want to change any of the files used by the RSDP pipeline calibration software to calibrate the dataset originally, the files can be retrieved from the HST Archive. We strongly suggest copying the raw data files and calibration reference files to another directory for processing, thus preserving the original files.

If you want to change the calibration switches or update the reference files, we recommend that you use the **chcalpar** task (in the **ctools** package under **hst_calib**). This task provides a simple and consistent method to change calibration parameters in any of the HST instrument headers.

The calibration task **calhrs** has only two user-selectable parameters: the input and output file names. If only the input name is specified, the output filenames will have the same rootname.

```
hr> calhrs rootname output
```

calhrs will write out informational messages to the screen as it calibrates. These messages are saved in the trailer file (`.trl`) when RSDP calibrates the data. You can save them by redirecting the output into a file.

Each observation mode will have calibration switches set to default values. Because some steps require that other calibration steps be completed first, there can be cases where a switch is set to PERFORM yet the step is not executed in the pipeline. In this case, the calibration switch value will remain set to PERFORM in the output product (`.c*h`). The calibration process can logically be thought of in terms of two distinct steps: flux calibration and wavelength calibration. The extension of the file that contains the wavelength coefficients is `.c0h`, while the extension of the flux calibrated image is `.c1h`.

Each calibration step is detailed in the section “Calibration Steps” in the Chapter Calibrating GHRS Data along with the corresponding calibration switch and various reference files required by that step.

The flux calibration consists of the following steps:

1. Flag Dead Diodes: Identify known dead or problematic diodes to correct comb-added data values.
2. Convert to Count Rate: Divide by exposure time to convert from counts to counts/sec.
3. Correct for Diode Response: Correct for diode-to-diode variations.
4. Apply Paired-Pulse Correction: Correct deadtime in the detector electronics that results in nonlinear detector response at high count rates.
5. Correct for “Vignetting”: Correct for low-frequency variations due to optical obscuration and the quantum efficiency of the photocathode.
6. Subtract Background: Calculate background, smooth, and subtract from object spectrum. By default, the smoothing of the background is the mean of the background data obtained; i.e., a single value. This mean background is then subtracted from the object spectrum. The order of the polynomial used to fit the background is written to the standard output.

7. Remove Blaze Function: Correct for the low-frequency response along an order of the echelle grating.
8. Convert to Absolute Flux: Convert corrected count rates to absolute flux. This conversion is based on ratio of the empirical count rates to a set of established fluxes of a spectrophotometric standard star.

The wavelength calibration consists of the following steps:

1. Calculate Wavelengths: Calculate wavelengths based on carrousel position of the grating used. A zero-order correction is also made to account for thermal drifts.
2. Apply Incidence Angle Correction: Correct the wavelength scale to account for the geometric offset between apertures. Since the default wavelengths are determined for the SSA, observations in the LSA must be adjusted.
3. Convert to Heliocentric Wavelengths: Correct wavelength scale to account for the earth's motion around the sun.

Using Wavelength Calibration Exposures

The standard wavelength calibration can be improved by using a wavecal or SPYBAL observation taken close to the time of the science data to correct for zero-point offset. In addition, if a wavecal observation was deliberately obtained with the same carrousel position as the science data as part of the observations, and if the science observations were not obtained as an FP-SPLIT, you may choose to re-derive the wavelength dispersion constants and use them to create a new calibrated wavelength file (`.c0h` file) for the science observation. When re-deriving the dispersion, you should assure that the science data and the wavecal observation were obtained at the same carrousel setting by examining the value of the keyword parameter CARPOS in both files.

Correcting the Zero Point Offset

You can use the STSDAS **waveoff** task to derive a new zero point offset for the wavelength scale from either a wavecal or a SPYBAL.

Currently, **waveoff** will print the pixel, wavelength, and sample space offsets to the screen. You can then apply the wavelength offset to the science observations by using the **imcalc** task to add the calculated offset to each pixel (for all the groups) in the wavelength file. See the help file for **waveoff** for examples on how to do this.

Re-deriving the Dispersion Coefficients

You can use the task **zwavecal** to re-derive the wavelength dispersion coefficients from a wavecal observation and create a new calibration table with these values. You can then recalibrate your data with **calhrs**, using the newly derived dispersion coefficients to create the calibrated wavelength file (`.c0h` file) for your science observations. Note that you can only use this method if you have a wavecal observation at the same carrousel position as your science data, taken close in time to your science data, and your science data were *not* obtained as an FP-SPLIT. You can assure that the science data and the wavecal observation were obtained at the same carrousel setting by examining the value of the keyword parameter CARPOS in both files. Likewise, the value of the keyword FP_SPLIT should be set to 'NO'.

```
cl> hselect z29h0107t.c1h,z29h0108t.c1h $I,carpos,fp_split yes
z29h0107t.c1h   50680   NO
z29h0108t.c1h   50680   NO
```

Once you have run the **zwavecal** task, you can then use the **chcalpar** task (described in "Setting Parameters" on page 19) to change the value of the header keyword CCR6 (the dispersion constants reference table) in the science raw data header (`.d0h`) file to point to the newly created dispersion table. At the same time, change GWC_CORR to 'OMIT' and make sure that ADC_CORR is set to 'PERFORM'. Then re-run **calhrs** on the science observation. The **calhrs** task will produce a new set of calibrated files, including the new wavelength (`.c0h`) file reflecting the new dispersion solution. For example, if you had two observations, the first of which was a calibration lamp observation called `z29h0107t` that was requested at the same carrousel position as science observation `z29h0108t`, you could use the commands shown in Figure 25.2 to improve the wavelength solution.

Figure 25.2: Improving the Wavelength Solution

```
cl> zwavecal z29h0107t.c1h newdisp_0107
zwavecal: aperture SC2 carrousel position = 50680
wavefit: Iteration 1: 56 lines fit, chisq = 1.146993853700548

Removing 1 lines and fitting again...
wavefit: Iteration 2: 55 lines fit, chisq = 0.8818314073898266
Removing 1 lines and fitting again...
wavefit: Iteration 3: 54 lines fit, chisq = 0.7580552119929887
wavefit: maximum iterations reached.
cl> chcalpar z29h0108t.d0h
...
(ccr6   =     newdisp_0107.tab) dispersion coefficients table
...
(gwc_cor=                 omit) Use global wavelength coefficients
...
cl> calhrs z29h0108t new_z29h0108t
```

FP-SPLITs

If your data were taken in FP-SPLIT mode, then your calibrated data will have multiple groups which contain independent subintegrations taken at slightly offset carrousel positions. To obtain your final spectrum, with the full integration time, you need to combine the group spectra into a single spectrum. Recall that when taking data in FP-SPLIT mode, the grating carrousel is shifted slightly between subintegrations to assure that different portions of the photocathode are illuminated each time. Thus, each FP-SPLIT group in your calibrated spectrum is shifted in wavelength space with respect to the others (see "Putting FP-SPLITs Back Together" on page 335). When the individual FP-SPLIT spectra are combined into a single spectrum, the effects of the granularity of the photocathode response are reduced, since the flux measured in a single pixel in the final spectrum will have been collected over several (FP-SPLIT) different photocathode locations.

To combine the groups of an FP-SPLIT observation, you can use the two stsdas tasks **hrs.poffsets** and **hrs.specalign**. The **poffsets** task determines the shifts needed to align the spectra either by cross-correlating features in the individual spectra, or by using the information in the `.c0h` file which gives the wavelength at each pixel. The **specalign** task combines spectra after first shifting them to align in wavelength space. These tasks are not specific to GHRS data, but can be used on any spectra which you wish to co-align and co-add. They are, however, of particular use in combining the FP-SPLIT groups in an ACCUM mode GHRS observation since for high-signal-to-noise FP-SPLIT data, the tasks can also be used to derive the photocathode response function (i.e., the photocathode flatfield) for your observations. You can then use the photocathode response function to assess the reliability of the features in your final spectrum.

A detailed description of how to use **poffsets** and **specalign** to combine the groups of an FP-SPLIT observation can be found in the help files for the tasks.

Flux

How the Flux Scale is Calibrated

The sensitivity functions quantify the relationship between the observed flux from a target, and the count rate detected by the GHRS. For calibration purposes the fluxes of the reference stars are expressed in units of ergs/cm^2/sec/Å. The raw GHRS data have units of counts per diode per second. The sensitivity functions simply show the ratio of these quantities, with no other constants, scale factors or transformations included. The post-COSTAR sensitivity functions for all GHRS gratings are in Chapter 8 of the *GHRS Instrument Handbook*. (See GHRS ISR 060 for the pre-COSTAR sensitivity functions.) For planning purposes, a known or estimated flux can be multiplied by the sensitivity to estimate what the GHRS count rate will be for a particular grating. During data reduction an observed count rate can be divided by the sensitivity function to calibrate the data in flux units by setting the value of the FLX_CORR switch to PERFORM in the `.d0h` header.

The sensitivity functions are dependent on several factors. The telescope contributes its unobscured geometrical collecting area, the reflectivity of both mirrors, and the fraction of the light which manages to pass through the instrument's entrance apertures. The GHRS optics introduce a finite reflectivity at each surface and transmission at each filter and window, the blaze efficiency and linear dispersion of the gratings. The detectors have an overall quantum efficiency at each wavelength, spatial gradients related to vignetting or real QE variations, isolated scratches and blemishes, pixel scale irregularities, finite sampling by the diodes, and diode to diode gain variations. To simplify this problem, the calibration is broken into several components. The basic function relates flux and count rate measured at the center of the diode array, for a star centered in the LSA, at a range of wavelengths for each grating. The echelle ripple function is quantified separately for each order. Gradients of sensitivity across the diode array are described by vignetting functions which vary with wavelength for each grating or echelle order. The SSA throughput is measured relative to the LSA at several wavelengths, but should be independent of grating mode. Blemishes are tabulated as departures from the local sensitivity for each grating. Diode response functions are tabulated as detector properties, which depend on threshold settings, but not optical modes. Finally, the pixel to pixel granularity can be identified and suppressed as photometric noise.

Photometric Correction for Extended Sources

When **calhrs** photometrically calibrates your observations, it assumes you have observed a point source, and adjusts the flux in your spectrum to account for light loss due to the PSF outside of the aperture, i.e., it returns the flux you would have seen if all of the flux from your point source fell within the aperture. Therefore, the absolute fluxes (erg/cm^2/s/Å) of point sources measured through the LSA and SSA will be the same. Of course, the count rates will be lower for the SSA observation but **calhrs** will automatically apply a different sensitivity function to the SSA observation to account for the light loss. The properties of the GHRS apertures are presented in Table 25.1.

calhrs always assumes a point source is observed and it effectively applies a correction factor for the light lost outside the aperture. If you observed an extended source, then your source does not fill the aperture as does a point source and the flux calibration from calhrs will be inappropriate. To obtain a rough estimate of the specific intensity (in ergs sec^{-1} cm^{-2} Å^{-1} arcsec^{-2}) multiply the observed flux by 0.95 +/- 0.02 for observations taken through the LSA and divide by the area of the aperture in square arcseconds. This assumes that the extended source completely and evenly fills the aperture.[2] Questions about **calhrs** should be sent to the STScI Help Desk (`help@stsci.edu`).

The absolute fluxes for extended sources obtained with **calhrs** are incorrect.

---

2. See *GHRS Instrument Science Report* 061 for more details.

Table 25.1: Properties of GHRS Apertures

Name	Clear Aperture (mm)	pre-COSTAR	post-COSTAR	Shape
LSA	0.559	2.0”	1.74”	square
SSA	0.067	0.25”	0.22”	square

CHAPTER 26:
Specific GHRS Calibration Issues

In This Chapter...

Target Acquisition Problems

An onboard target ACQuisition will perform a spiral search (defaults are 3 x 3 for the LSA and 5 x 5 for the SSA) followed by returning to the dwell point with the most counts. The end phase of the onboard ACQ is the locate phase (coarse Y and X centering with a fine X balance at the end of the locate phase).

GHRS target acquisitions of very bright stellar targets may fail during the locate phase. This results from low contrast between the central four diodes of the eight diodes used for acquisitions. The high count rate in the central four diodes will flatten the Point Spread Function (PSF) leading to wrong centering in the aperture. Thus, lower count rate than expected in the LSA science observations, and possibly missing the target during the following SSA acquisition. The SSA science observations in this case may contain just noise.

The header keyword FINCODE value indicates the success or failure of the GHRS observation. FINCODE=102 indicates the observation completed successfully as planned, but does not indicate whether the target was centered in the aperture. Any other value for FINCODE indicates a possible problem. During RSDP pipeline calibration, if a FINCODE value is encountered other than 102, a warning message is written to the trailer file (`.trl`).

From April 1989 through August 1994, OSS (now part of OPUS) created an Observation Comment file (extension `.ocx`) for every HST observation. After that time through January 1995, OSS created an `.ocx` file for degraded observations. If an `.ocx` file exists for an observation, it should be checked for anomalies. (See Chapter 5 for more information.)

If OMS Observation Logs were created for an observation, they should be checked to verify that no anomalies occurred during the target acquisition.

Carrousel Properties

The carrousel is rotated to engage the desired dispersive element or mirror and to place the requested wavelength at the center of the diode array. In the spring of 1991, the Side 1 carrousel control electronics developed an intermittent failure and the carrousel function was modified to operate the Side 1 carrousel from the Side 2 electronics. Any Side 1 observation obtained after April 1991will have different carrousel function coefficients for specific wavelengths.

During normal operation, the carrousel is commanded to rotate to a pre-selected position depending upon the Carrousel Function. The carrousel may oscillate before achieving the desired position and take an appreciable amount of time to lock at that position. This may take longer than the normal amount of allocated time and thereby, following observations are affected. Before Spring 1995, if the carrousel took an appreciable amount of time to lock, the following observations would not occur and be lost. After spring 1995, the flight software was updated to time out a set of GHRS observations if the end time of the observations was reached. The header keyword FINCODE will be set to 106 to indicate to the observer that a “time-out” occurred. The affected GHRS observation may be several observations down stream of the observation for which the carrousel took an appreciable time to lock into position. The STSDAS task **obsum** in the **hrs** package can be used to display to the screen the carrousel position and the FINCODE values.

```
> obsum z2bd010c
```

Table 26.1: GHRS FINCODE Values

FINCODE	Explanation
15	X-null balance failure during coarse locate
16	X-null balance failure during fine locate
20	number of slews to center exceeded max
101	normal beginning of observation
102	normal end of observation
104	observation ended, over-exposure
105	observation ended, too many bad data
106	observation ended, time out

Timing of GHRS Observations

Knowledge of the exact time observational activities take place onboard GHRS is not directly available. Instead, we only get timing information when data are dumped to the ground from the onboard computer from which we may infer when things happened. When data are dumped they are given time tags from the NSSC-1 computer—the spacecraft clock has a time resolution of approximately 0.125 seconds. While GHRS can operate on shorter time scales (0.050 seconds), information about these activities does not make it into the telemetry stream.

Nevertheless, as an observer, you may want answers to the timing questions posed in this section.

When did my Observation Start?

The closest time tag to the start of the exposure is the packet time (PKTTIME) on the Unique Data Log (UDL). (The UDL is the data file with the `.ulh` extension.) A UDL is always dumped from the spacecraft prior to the start of an science exposure, effectively flagging the start of the observation. The PKTTIME keyword holds an MJD value good to a spacecraft clock tick (~0.125 sec). This MJD value is converted to a date and time and stored in the EXPSTART keyword. The accuracy of the start time is limited to the accuracy of the spacecraft clock--about 0.125 seconds.

When did my Observations End?

For ACCUM mode observations, a second UDL is dumped at the end of the observation and prior to reading out any science data. Therefore, the PKTTIME of the second group of the UDL can be used to mark the end of the observation. For observations generating multiple readouts (e.g., FP-SPLITs) the UDLs come in pairs bracketing the science exposures. The MJD value in this second UDL is converted to a time and date and placed in the EXPEND keyword. The accuracy is the same as the start time--about 0.125 seconds.

For RAPID mode observations, a second UDL is not dumped until the last spectrum has been dumped. In this case, the end of the observation is merely the time that the last spectrum has been read out and is contained in the PKTTIME for this last spectrum. Note that the PKTTIME for the science data is the tag when the science data are dumped and this must wait until the end of the exposure.

How Long did my Observation Last?

The extent of an observation is reported in the EXPTIME keyword. This time may not be the same as the simple difference between the EXPEND and EXPSTART. (See “Was my observation interrupted”.) The exposure time in the header is simply the exposure time you requested in your proposal times the number of exposures. To verify that you got the exposure time you expected you can calculate the EXPTIME using available header keywords as shown below:

ACCUM mode

EXPTIME = (RPTOBS + 1) x (*fpsplits*) x MAXGSS x INFOB x STEPTIME

where,

- RPTOBS = Number of exposures – 1 (i.e., the number of repeats)
- *fpsplits* = 1 (FP_SPLIT=DEF) or 2 (FP_SPLIT=TWO or DSTWO) or 4 (FP_SPLIT=FOUR or DSFOUR)
- MAXGSS and INFOB contain information concerning the STEPPATT and COMB used. If you want more details about these contact a GHRS instrument scientist via the STScI Help Desk (`help@stsci.edu`).
- STEPTIME = the step time used (by default = 0.2 seconds).

RAPID mode

EXPTIME = (*groups*) x STEPTIME

where:

- *groups* – is the number of spectra read out (i.e., the number of groups in the multi-group image.
- *STEPTIME* – is the integration time for each spectrum (specified as SAMPLE-TIME in the proposal).

What is the Exposure Time Per Pixel?

The exposure per pixel is found in the EXPOSURE keyword in the calibrated flux header. This number is not equal to the EXPTIME because of the multiplicity of step pattern, FP-SPLITs and repeated observations.

This value is calculated by **calhrs** during pipeline calibration. To double check you may calculate EXPOSURE as follows:

EXPOSURE = INFOC x MAXGSS x (STEPTIME – 0.002)

where,

- INFOC and MAXGSS contain information about the STEPPATT and COMB used. (Note: INFOB and INFOC are different keywords containing similar information.)
- STEPTIME = the step time specified.
- 0.002 = the time in seconds of the internal overhead for integrating a single STEPTIME

If you are interested in the exposure per diode, you must rebin the data from substep pixels to diodes.

Was my Observation Interrupted?

By design GHRS is interruptible—a given exposure may begin, be interrupted, and then resume. Observations are routinely interrupted for SAA passages and earth occultations. In general, this is of no concern. Still, there may be times when you want to know the details of a given observation. Unfortunately, it is nearly impossible to determine when an observation was actually stopped and restarted--this information is just not available in the telemetry stream. The simplest way to determine if you exposure was interrupted at all is to compare the difference of EXPEND and EXPSTART to EXPTIME. If these values differ by more than a couple of spacecraft clock ticks (~0.25 seconds) then it is likely that the exposure was interrupted and restarted during execution. The duration of the interruption can range from a few minutes when skirting the SAA to about half the orbit for an earth occultation.

Additional details are available in the OMS Observation Logs as discussed in Chapter 5. It is also possible that a given observation may end prematurely. This information is encoded in the EXPFLAG keyword. We routinely see observations "time-out" due to carrousel resets. If you have additional questions about interruptions, contact the STScI Help Desk (`help@stsci.edu`).

SPYBAL

To compensate for the fact that thermal drifts cause a spectrum to "move" on the photocathode, GHRS routinely performs a SPYBAL (spectrum y-balance) to properly center the spectrum on the diode array. This centering is especially important because a given spectrum is tilted with respect to the GHRS x-direction and lack of proper centering could result in the ends of the spectrum falling off the diode array. Again, this is routinely corrected for and only becomes a problem if SPYBALs are suppressed for long exposures (i.e. several orbits). More details can be found in GHRS ISR-072.

A simple calculation can give us some idea of how large this effect can be. For example, the G140L spectrum of a point source may fall off the diode array due to drift. Ignoring the width of the spectrum (something on the order of the size of the SSA or about 8 deflection units) the ends of the spectrum will differ by about 45 defection units and will be within about 9 deflection units of the edge of the diode array. If we assume a worst case drift of about 25 deflection units (seen over 10 hours), we find that at the end of this time about 25% of the spectrum will have fallen off the edge of the diode array!

In the case of an extended object uniformly filling the LSA, the effect is much more pronounced. In this case the width of the spectrum cannot be ignored. The width is equal to the size of the aperture or about 64 deflection units. For the case of a G140L observation of an extended object in the LSA, we start out with a loss of light. The spectrum is already falling off the array with the ends experiencing about 30% light loss. In the time it takes to drift 25 deflection units, some part or all of the spectrum may fall off the array, resulting in a significant reduction in signal!

Calibration Anomalies

Geomagnetically Induced Motion

The displacement of the image relative to the diodes due to the earth's magnetic field, Geomagnetic Image Movement (GIM) problem, may affect a GHRS observation depending upon the length of the exposure and the HST orbit during the observation. The rate of drift of an image across the diodes is small enough that there is no significant smearing of data on time scales of five minutes or less. Very long exposures may exhibit GIM related symptoms and should be investigated by the user. No correction for GIM has been incorporated into either the operations of the GHRS or in the data reduction procedures.

Dead or Noisy Diodes

Each diode of the linear array (containing 512 diodes, diodes 7-506 are science diodes) is independently monitored via its own electronics chain. Diodes may exhibit anomalous behavior or fail. These diodes are grouped together into the "Dead or Noisy Diode" category. Diodes that show anomalous behavior over an extended time are turned off for science observations. In practice, the threshold voltage for anomalous diode is set to a high value so that it does not detect electrons from the photocathode. The GHRS calibration software corrects for known anomalous diodes. If anomalous absorption features are present in the calibrated data, new noisy or dead diodes may be at fault. The non-standard thresholds for detector diodes are listed in Table 26.2.

Table 26.2: Non-Standard Thresholds for D1 & D2 Diodes

Science Diode #[a]	Diode # 1-512[b]	AMP/CH[c]	Threshold[d]	Comments
				D1
	1	24/07	46	Large background diode (50% peak +3)
	2	24/08	44	Large background diode (50% +3)
	3	27/07	120	Gold coat radiation diode
	4	00/08	255	Diode not connected by design
85	91	30/00		Dead—BDT[e] `r0h`, `r5h` change May 29, 1995 (95149 SMS)
123	129	22/05	50	Threshold 60% stops noise
262	268	15/12	255	Dead electronics—in BDT
273	279	11/04	255	Bad contact—crosstalk when contact made. In crosstalk table
436	442	00/15	52	Threshold 60% stops noise
445	451	00/03	44	Bad 4096 bit—in bad diode table (BDT)

Table 26.2: Non-Standard Thresholds for D1 & D2 Diodes

Science Diode #[a]	Diode # 1-512[b]	AMP/CH[c]	Threshold[d]	Comments
487	493	08/07	255	Very noisy—in BDT
	510	04/08	120	Gold coat radiation diode—not functional
	511	04/07	42	Large background diode (50% peak +3)
	512	08/08	47	Large background diode (50% +3)
				D2
	1	24/07	46	Large background diode (50% +2)
	2	24/08	44	Large background diode (50% +2)
	3	27/07	120	Gold coat radiation diode
	4	00/08	255	Diode not connected by design
80	86	30/14		Threshold 60% stops noise April 20, 1992, `r0h`
104	110	27/11	255	Bad diode—in BDT
140	146	24/13	40	Threshold 80%, crosstalk noise
144	150	25/12	255	Bad diode in BDT
146	152	16/09	49	Threshold 50%, occasionally noisy
168	174	24/10	43	Threshold 50%
237	243	16/00	44	Threshold 50% April 20, 1992; threshold 100% May 15, 1995
273	279	11/04	255	Bad contact—crosstalk April 20, 1992
342	348	11/10		Threshold 100% April 20, 1992
440	446	00/14	41	Threshold 50%
441	447	01/02		Threshold 70% April 20, 1992
442	448	02/13	44	Bad 16384 bit—in bad diode table
	510	04/08	120	Gold coat radiation diode
	511	04/07	43	Large background diode (50% peak +2)
	512	08/08	41	Large background diode (50% peak +2)

a. Science Diode: diodes 7–506 used for science observations.
b. Diode: the entire (1–512) diode array.
c. AMP/CH: Amplifier/channel, onboard electronic location of diode.
d. Threshold: Discriminator threshold voltage setting for channel.
e. BDT: Bad diode table.

Low Count Rate

Observations with low count rates, containing mostly noise, contain few detected or no counts from the target. Calibrated data may have a bell or U-shaped appearance, quantized data values, or extremely low flux values. These data indicate a missed target, a target too faint for the GHRS, or inappropriate use of the GHRS.

Vignetting

GHRS calibration data indicate spectra taken at the blue end of the G270M grating seem to fall off the diode array. This is due to QE gradients on the photocathode, optical vignetting, and possibly the photoelectron image of the spectrum broadened by the PSF falling off the diode array at the ends. The net variation from the center towards the ends of spectra is referred to as vignetting.

Observations requiring wavelengths near the edge of a grating will suffer from vignetting problems during execution and calibration. Vignetting functions were derived for most gratings. However, it is left up to users to fully correct the data.

Blemishes

Scratches, pits, and other microscopic imperfections in the detector window and on the photocathode surface are referred to as blemishes. The magnitude of blemishes upon spectra depend on how the spectrum illuminates the photocathode near a blemish. Many blemishes have spatial structures and depths that would make them difficult to distinguish from real stellar or interstellar features. Therefore, it is difficult to automatically correct data for the effect of blemishes. In the absence of independent information, individual subexposures can be displayed in diode space to identify non-real spectral features. The calibration code does not correct for blemishes. However, the data quality file (`.cqh`) contains data quality values marking which pixels are affected by known blemishes. See Table 24.2 on page 367 for information about data quality flags.

Doppler Compensation

Since HST orbits the earth with a velocity of 7.5 km s^{-1}, spectra obtained with GHRS may see a Doppler shift of up to 15 km s^{-1}. The effect of the spacecraft velocity is corrected for in real time for ACCUM mode observations by deflecting the image of the spectrum an amount equal to the Doppler shift so that the spectrum appears fixed with respect to the diode array which is recording the spectrum. RAPID mode observations are not corrected for this effect. Unfortunately, it was discovered that GHRS spectra obtained prior to the end of March 1993 suffered from incorrect Doppler compensation.

The problem became visible in a set of high dispersion spectra obtained with short exposure times, where one could actually see a doubling of spectral features corresponding to the different Doppler shifts applied. At the maximum required correction, the flight software was mistakenly applying zero correction. Affected data will be obvious only in extreme cases, but the problem may degrade your data even when the effect is not obvious.

An on-board fix to the first problem was implemented in the flight software as of April 1993. Observations made after the update should not suffer from the Doppler compensation error. However, a cumulative error in the onboard Doppler compensation still exists, which causes the accuracy of the Doppler compensation to be reduced for long exposures.

The **obsum** task in the STSDAS **hrs** package can be used to identify GHRS spectra which are potentially corrupted by the first Doppler compensation problem. This task identifies periods when the Doppler compensation should have been maximal and provides information to allow you to estimate the fraction of the data in each group that is contaminated by incorrect Doppler compensation. If a substantial fraction of the data are corrupted for a given period of time, the only recourse is to discard the affected groups and reduce the remaining good data. See the help file of **obsum** for a detailed description of its use.

Also, all observations of moving targets made before July, 1994, were compensated incorrectly. The fix to this problem was implemented in July 1994 and moving target observations since then do not exhibit that problem. For help identifying and correcting moving target observations, please contact the STScI Help Desk via e-mail to `help@stsci.edu`.

GHRS Point Spread Function (PSF)

The post-COSTAR Point Spread Function (PSF) has a sharp core and weak wings. Observations through the SSA show a Gaussian core with a FWHM of 0.975 diodes and wings that fall off (in intensity) as r^{-3} at radii larger than 1 arcsec. When this measured profile is deconvolved from the square SSA aperture, we find a sharp core with a FWHM of about 0.375 diodes-- this amounts to about 0.08 arcsec. For a detailed description of the analysis of the PSF please see, Robinson, R. “Investigating the Post-COSTAR Point Spread Function for the GHRS” in *Calibrating Hubble Space Telescope: Post Servicing Mission*, 1995.

GHRS Line Spread Function (LSF)

The LSFs for the GHRS gratings describe the instrumental broadening for a delta-function spectral feature. Knowledge of such a blurring function is necessary for quantitative studies of GHRS spectral line profiles. The resolution element (one diode) for GHRS was matched to the width of the SSA. By using substepping strategies, it is possible to get properly sampled spectra, obtaining the minimum of two sample points per resolution element. A delta-function spectra line observed through the SSA can be described by a Gaussian with a FWHM of about 0.925 diodes which is about 3.7 quarter-stepped pixels. (See Gilliland 1992, PASP, 104, 367).

Since an SSA spectrum is the best resolution we can obtain with GHRS, it is useful to describe the LSA LSF in terms of the SSA PSF. Consequently, we have measured the LSA-SSA differential LSF for a number of gratings and at a sample of wavelengths. This differential LSF satisfies the relationship: LSF * SSA = LSA; i.e., the differential LSF is the LSF that when convolved with an observed SSA spectrum produces the best match to an identical spectrum obtained through the LSA. By combining the intrinsic LSF for the SSA with the empirical differential LSF we can obtain the intrinsic LSF for the LSA. Since the SSA and differential LSF are Gaussians, we obtain an LSA LSF that is also a Gaussian with a FWHM that is slightly greater than that of the SSA.

The pre-COSTAR LSF of the GHRS was characterized by a Gaussian core nearly twice as broad as that provided by the instrumental resolution limit, provided by the SSA, with extended non-Gaussian wings. The post-COSTAR LSF for the LSA is only 19-51 percent broader in a Gaussian core than spectra from the SSA and the extended wings are absent. Additional information about the GHRS LSF can be found in GHRS ISR 063. Table 26.3 summaries the post-COSTAR LSF for the SSA and the LSA-SSA differential LSF.

Table 26.3: GHRS post-COSTAR Differential LSF

Grating	**Wavelength** (Å)	**FWHM Differential LSF (diodes)**	**Relative FWHM (LSA/SSA)**
G140L	1200	1.0	1.51
G140L	1500	1.0	1.51
G160M	1360	0.60	1.19
G160M	1900	0.72	1.27
G200M	1900	0.60	1.19
ECH-B	1900	0.60	1.19
ECH-B	2680	0.82	1.34

Deconvolution of GHRS spectra was investigated after the spherical aberration was found in the primary mirror. With COSTAR, the need for deconvolution has become less pressing, however, for the best spectral resolution, it is possible to deconvolve LSA spectra to the level of SSA spectra. See, “The Restoration of HST Images and Spectra”, (proceedings of the HST Calibration Workshop at STScI), STScI, 1990. The STSDAS task, **lucy**, can be used to deconvolve GHRS spectra.

High Signal-to-Noise Observations

It is possible to use discrete grating movements in addition to FP-SPLITs to achieve S/N of 1,000 or more. See, e.g., Lambert et al. 1994, *ApJ*, 420, 756.

Spatial deconvolution: Both a point spread function (PSF) and a line spread function (LSF) exist for the GHRS. They are discussed in the proceedings of the HST Calibration Workshops.