

Calibrating and Recalibrating GHRIS Data

In This Chapter...

Pipeline Calibration Process / 36-2

Calibration Steps Explained / 36-2

Recalibrating GHRIS Data / 36-13

This chapter explains what happens to GHRIS observations when they are processed through the calibration pipeline—the Routine Science Data Processing (RSDP) system at STScI. You should *always recalibrate* GHRIS observations to exploit the latest and best information available. The recalibration task, **calhrs**, is the same as the software used in RSDP, so you will need to know how it works. The distinction between “calibration” and “recalibration” is partly artificial, but by “recalibration” we mean applying **calhrs** data to observations of your choice in a way that you control. Recalibration can also include some tasks that RSDP could not do, such as applying an improved wavelength calibration or accounting for background counts in a different way.

The GHRIS calibration task **calhrs**, part of STSDAS, was developed and is maintained at STScI. For the GHRIS, the calibration process assigns 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 spectrum, wavelength solution, error estimates, and data quality images. The calibration software used in the RSDP pipeline to calibrate GHRIS observations is the same software used within the **calhrs** task. The **calhrs** task can be found within the STSDAS **hst_calib** package. We will emphasize here the calibration steps themselves, deferring a discussion of error and uncertainty to the next chapter.

36.1 Pipeline Calibration Process

The way in which the routine calibration pipeline handled data depended on how the observations were originally obtained. Please review the previous two chapters to learn more about operating modes and the details of observation specifications. As we emphasized in the previous chapter, an examination of the Phase II proposal for a particular set of observations is helpful in understanding the structure of the data. The Phase II proposal can often be retrieved over the web.

Calibrated data in the archive result from the calibration steps specified by *switches* in the raw science header (.d0h). If there were problems with the observation, it was set aside for repair. If there were missing packets (due to data transmission problems), and no further packets were forthcoming from the spacecraft, the pipeline replaced missing data with fill data. Information about missing packets and fill data can be found in the trailer file (.trl).

36.2 Calibration Steps Explained

Each calibration step is described 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 36.1.

Data Quality Initialization (DQI_CORR)

This step applies data quality initialization using the reference file *dqi.hfile*, which contains a data quality flag for each diode. Each data quality flag in the .q0h file (Table 37.10) is compared with the corresponding flag in the data quality initialization file (.r5h), and 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 (.cqh). Table 37.5 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:

$$EXPOSURE = n_{coadd} \times (0.05 \times \text{intper} - 0.002) \quad \text{Eq. 36.1}$$

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 any value contains fill, 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. If this step is omitted, then the paired pulse correction (PPC_CORR) will also be omitted, regardless of its setting.

Diode Response Correction (DIO_CORR)

The diodes within the Digicons of the GHRS do not have identical sensitivities. This calibration step divides the observed count value (or count rate) 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)

This step corrects count rate data for the finite response time of the detector electronics. The measured deadtime is 10.2 μsec , determined for detector D1 and assumed to apply to D2 as well. What this means is that the correction is only 1% at an input rate of 2,000 counts per second, which occurs only for very bright stars. The values used are stored in table `ccg2`.

Photocathode Mapping (MAP_CORR)

This step computes where the spectrum was located on the detector's photocathode. 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 the following calibration steps: ADC_CORR, VIG_CORR, PHC_CORR, and MER_CORR. If MAP_CORR is omitted, then those steps will also be omitted, in spite of their settings.

The position of the individual substep bins are mapped into photocathode space using the following:

$$\text{SAMPLE}(\text{bin}) = x_0 + b \times XD + c \times XD^2 \quad \text{Eq. 36.2}$$

$$\text{DELTAS}(\text{bin}) = e \quad \text{Eq. 36.3}$$

$$\text{LINE}(\text{bin}) = L0 + A \times YD \quad \text{Eq. 36.4}$$

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 table `ccr2`, interpolated for the given Y-deflection.
- *L0*, and *A* are coefficients in table `ccr1`.

Doppler Compensation (DOP_CORR)

This step corrects for Doppler compensation when removing photocathode nonuniformities (i.e., when PHC_CORR is set to PERFORM) or vignetting effects (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 (DPOZER and DOPMAG) keywords. The on-board Doppler compensation is needed to avoid blurring of the spectrum because of apparent shifts introduced by the spacecraft motion. The on-board compensation involves moving the spectrum on the photocathode in the opposite sense to the effect caused by the spacecraft. That means that the spectrum is not at a fixed location over the course of the exposure, and this step attempts to correct for that fact.

This DOP_CORR step computes the percentage of time spent at each Doppler offset in the original observation. 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. This step is not applied in the pipeline because GHRS observations are interruptible. We may know the start time of the observation and that it was interrupted, but we have no way of knowing when the interruption began, so we don't know where we are in Doppler space.

Photocathode Nonuniformity Removal (PHC_CORR)

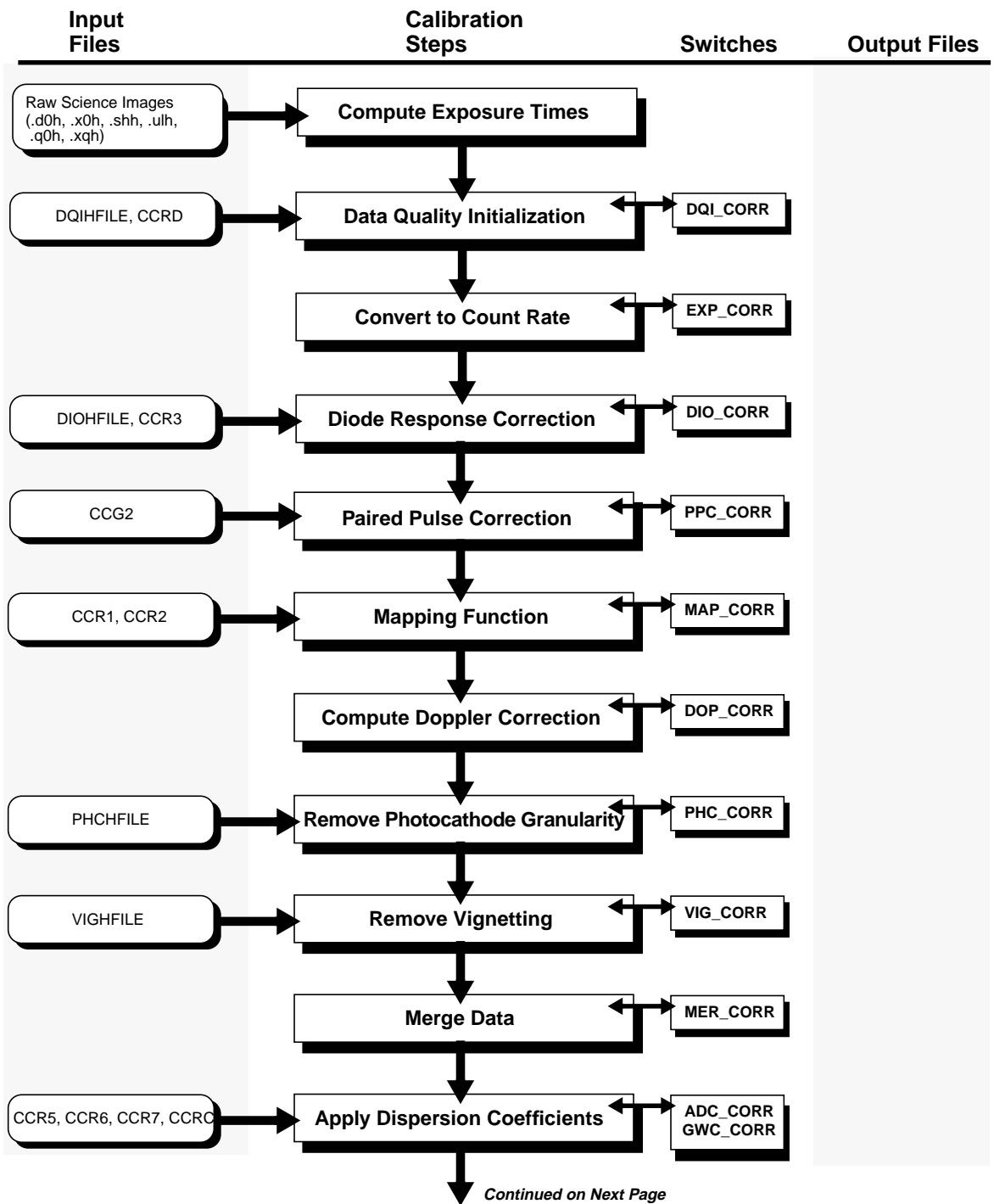
This step removes the photocathode granularity using a reference file that has a granularity map, `phchfile`, when MAP_CORR is also performed. The GHRS pipeline does not use this feature because obtaining the flatfield exposures for all possible grating positions was impractical. Therefore the `phchfile` used by the pipeline is a dummy file that is populated with ones and zeroes. FP-SPLITs were generally used for high signal-to-noise work. However, post-COSTAR G140L flatfields are available; they are especially useful for data having S/N > 30, see *GHRS ISR 076* for more information.

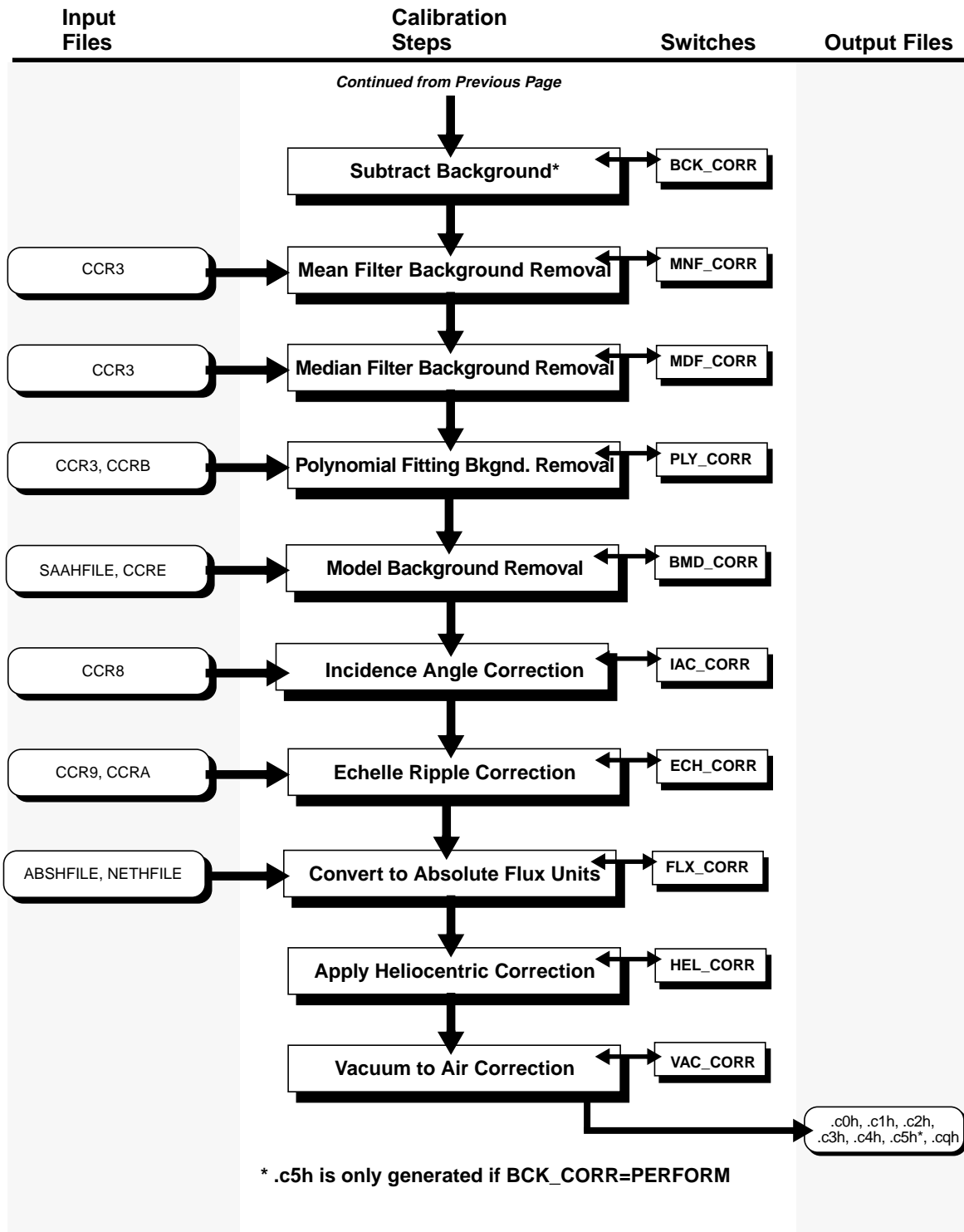
This map is intended to have a granularity vector for multiple line positions. At each line position, the granularity is tabulated with a constant starting sample for all lines and a constant delta sample. To compute the response for a given line and sample, bilinear interpolation is used within the 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.

Vignetting Removal (VIG_CORR)

The response of the detector to light of a given wavelength depends on the grating used, but there is also a dependence on position on the photocathode. The first effect is the overall sensitivity, and the second is called *vignetting*. This vignetting resembles optical vignetting in that it is not present at the center of the detector but causes lower counts (by a few percent) near the edges; however, the cause is in the detector, not in the optics. The vignetting was determined by observing standard stars at enough grating settings so that there was redundancy at any one wavelength, allowing sensitivity and vignetting to be disentangled.

Figure 36.1: GHRs Calibration Process





The VIG_CORR routine removes the vignetting and low frequency photocathode response using a reference file that has a vignetting map, `vighfile`, when MAP_CORR is also performed. The vignetting map has a vector for multiple line positions and carousel 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 carousel 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 when MAP_CORR is also performed. If MER_CORR is omitted, then the background correction (BCK_CORR) will also be omitted. Unmerged output data are then just a copy of the input data. BINID# keyword value are used by `calhrs` to determine how many groups of data are to be merged. Any STEPPATT that accumulates two or more bins of spectra as listed in Table 35.3 will generally 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 two-dimensional data array mapped into a one-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  ...
```

Determine Wavelengths (ADC_CORR, GWC_CORR)

This step converts the sample positions on the photocathode to wavelengths by applying the dispersion constants using tables `ccr5`, `ccr6`, `ccr7`, and `ccrc`; these contain spectral order, dispersion, and thermal constants. ADC_CORR computes spectral orders and wavelengths, when MAP_CORR is also performed. For the first order gratings, the spectral order is set to 1. For the echelle gratings, the spectral order is computed from the following formula:

$$order = NINT\left(\frac{b \times A \times \sin((C - carpos)/B)}{y_{def} - a - d \times A \times \sin((C - carpos)/B)}\right) \quad \text{Eq. 36.5}$$

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.
- *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:

$$s = a0 + a1m\lambda + a2(m\lambda)^2 + a3m + a4\lambda + a5m^2\lambda + a6m\lambda^2 + a7(m\lambda)^3 \quad \text{Eq. 36.6}$$

where:

- *m* is the spectral order.
- *l* is the wavelength.
- *a0, a1, ...* are the dispersion coefficients.
- *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. If ADC_CORR is omitted, then many other switches relying on it are also omitted, namely: IAC_CORR, VAC_CORR, HEL_CORR, FLX_CORR, ECH_CORR, BCK_CORR, and GWC_CORR. The subject of wavelength calibrations and their improvement is treated in the next chapter.

Background Removal (MDF_CORR, MNF_CORR, PLY_CORR, BCK_CORR, BMD_CORR)

This step removes the background, or dark counts, from the observed flux. The switch BCK_CORR determines whether or not background removal is done. The other switches, MDF_CORR, MNF_CORR, PLY_CORR, and BMD_CORR determine how the background is smoothed before subtraction. If BCK_CORR is omitted, then MDF_CORR, MNF_CORR, PLY_CORR, and BMD_CORR are all omitted, too. If the dispersion constants are not applied (ADC_CORR is omitted), then no background subtraction is done.

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. However, if any of the above are set to PERFORM and BMD_CORR is set to PERFORM, then the background model correction is omitted.

There are three ways to calculate the background counts: the first involving resampling by linear interpolation and the other two internally measuring the background.

Resampling Method

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:

$$B_{scale} = B_{res} \times N_{aper} \quad \text{Eq. 36.7}$$

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.

Internal Measurement Methods

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

$$B_i = 0.5(a \times U_i + b \times L_i) - c \times N_i + d \times N_{ave} \quad \text{Eq. 36.8}$$

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:

$$N_i = D_i - 0.5(U_i + L_i) \quad \text{,Eq. 36.9}$$

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

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

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

$$B_{corner} = B_{ncorner}/n \quad \text{Eq. 36.10}$$

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:

$$U_i = \frac{(C - C_1) \times (B_{UR} - B_{UL})}{(C_2 - C)} + B_{UL} \quad \text{Eq. 36.11}$$

and

$$L_i = \frac{(C - C_1) \times (B_{LR} - B_{LL})}{(C_2 - C)} + B_{LL} \quad \text{Eq. 36.12}$$

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 36.1. If no specific corner diodes are specified, then all four corner diodes are used for each science substep bin.

Table 36.1: 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

- The background can be calculated using a model. There are good reasons for doing this. Sometimes the number of counts accumulated in the background diodes is very small because the exposures are fairly short. When this occurs, the counting statistics limit the accuracy of the background correction. The model, on the other hand, is based on the cumulative experience of the GHRS in orbit. There are also reasons to avoid the model. In particular, if the observations span a range of orbital conditions, then the model's estimate of background may be significantly wrong. This is especially a problem in the region around the South Atlantic Anomaly. Also, for longer observations, the measured background may be well-measured anyway.

BMD_CORR is provided as a recalibration option; it controls the application of the background count rate model available in **calhrs** v.1.3.11 (March 1997). When performed, the background model correction will calculate and subtract a model background based on location of the telescope in its orbit instead of using the background bins obtained with an observation. Because results from the background count rate model are not reliable in or near the SAA, the SAA Model 7 contour (defined in SAAHFILE) is used to issue warning messages per readout of an observation. The **ccre** table contains mean derived background count rates as a function of geomagnetic latitude and longitude. The model is actually the blue FOS model derived by Rosenblatt, et al. (1992) multiplied by a GHRS-detector-specific scaling factor. Header keywords in the table contain the multiplicative scaling factors required to scale the results from the model to the appropriate GHRS detector. See *GHRS ISR 084*.

Apply the Incident Angle Correction (IAC_CORR)

All GHRS wavelengths are referenced to the SSA. After the dispersion constants are applied (ADC_CORR is performed), this routine adjusts the zero-point of the wavelength array for the effects on wavelength of the difference in incidence angle of apertures LSA, SC1, and SC2 from the SSA. New post-COSTAR LSA offsets were determined in 1997 and are now available (*GHRS ISR 080*).

The **ccr8** table is searched for the correct grating, spectral order, aperture, and carousel position to obtain two coefficients, *A* and *B*. Interpolation of the coefficients (in carousel position) is used if an exact match is not found. These coefficients are then used to compute an offset using the following formula:

$$\lambda = \lambda + (A + Bs)/m \quad \text{Eq. 36.13}$$

where:

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

Echelle Blaze Correction (ECH_CORR)

This step is appropriate only for observations made with an echelle grating. The large-scale change of response with wavelength is characterized as *sensitivity*, while *vignetting* accounts for minor detector effects. An echelle grating, however, produces a spectrum that drops as one goes away from the blaze peak; this is the *blaze function*, sometimes called the *ripple function*.

Tables `ccr9` and `ccra` contain echelle blaze constants. This step performs the echelle ripple removal (if the data were taken with one of the echelle gratings) after the dispersion constants are applied (`ADC_CORR` is performed) by dividing the flux by the following echelle ripple function:

$$\text{ripple} = \text{gnorm} \times \text{sinc}(ax + b)^2 \quad \text{Eq. 36.14}$$

where

$$\text{gnorm} = \frac{\cos(\theta + \beta + \delta)}{\cos(\theta + \beta - \delta + e)} \quad \text{Eq. 36.15}$$

$$x = \pi m \left(\frac{\cos(\theta + \beta + \delta) \times \sin(\theta + e/2)}{\sin(\theta + \beta + e/2)} \right) \quad \text{Eq. 36.16}$$

$$e = \text{atan}((\text{samp} - 280.0)/f) \quad \text{Eq. 36.17}$$

$$\theta = \frac{2\pi \times (r0 - \text{carpos})}{65536.0} \quad \text{Eq. 36.18}$$

and

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

The blaze 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 carousel 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, after the dispersion constants are applied (`ADC_CORR` is performed), by dividing the input count rate 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.

The nature and quality of the flux calibrations is treated in the next chapter.

Heliocentric Correction (HEL_CORR)

This step converts wavelengths to a heliocentric system after the dispersion constants are applied (ADC_CORR is performed). This step corrects for the Earth's motion around the Sun and its rotation, and modifies the wavelengths appropriately. The wavelength correction is computed as follows:

$$\lambda = \frac{\lambda_{obs}}{1 - \left(\frac{V}{c}\right)} \quad \text{Eq. 36.19}$$

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.
- c is the velocity of light.

Vacuum Correction (VAC_CORR)

This step converts vacuum wavelengths to air wavelengths above 2000 Å, after the dispersion constants are applied (ADC_CORR is performed). This correction is *not* applied in the calibration pipeline. GHRs data are routinely calibrated to vacuum wavelengths. This step is provided as a recalibration option. The following formula is used:

$$\frac{\lambda_{vac}}{\lambda_{air}} = 1.0 + 2.735182 \times 10^{-4} + \frac{131.4182}{\lambda_{vac}^2} + \frac{2.76249 \times 10^8}{\lambda_{vac}^4} \quad \text{Eq. 36.20}$$

36.3 Recalibrating GHRs Data

The pipeline used the calibration reference files available at the time the observation was received. However, a number of factors about the instrument came to light as more experience was gained. For example, monitoring of the GHRs showed that it was stable over the lifetime of the instrument. However, some instrumental properties have changed slightly over time. Archive users 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 on data taken within specific range of dates.

Updated or more timely reference files sometimes become available after the data were processed. If there are unusual features in the data, or if your analysis requires a high level of accuracy, or if wavecal observations were obtained with the science observation, then you may want to determine whether or not a better calibration is possible and then recalibrate the data.

All users should perform a StarView search and check the list of reference files used during 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, retrieve the recommended and used calibration files and compare them to see if the differences are important.

All information needed 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.

You can use the current set of calibration switches and specified reference files in the header file, or you can change certain keyword values. The STSDAS task **chcalpar** can be used to edit calibration parameters simply and reliably.

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

```
to> imheader rootname.d0h 1+ | page
```

Here is an excerpt from a GHRs science data header file showing the calibration reference files and switches:

Figure 36.2: GHRs Science Data Header

```
CALIBRATION REFERENCE FILES
DIOHFILE= 'zref$ccel504az.r0h' / diode response header file
PHCHFILE= 'zref$bcc11275z.r1h' / photocathode response header file
VIGHFILE= 'zref$e751116dz.r2h' / vignetting response header file
ABSHFILE= 'zref$e5v0936rz.r3h' / absolute flux header file
NETHFILE= 'zref$e5v0936az.r4h' / absolute flux wavelength net header file
DQIHFILE= 'zref$ccel505kz.r5h' / data quality initialization header file
CCR1 = 'ztab$aaul3518z.cz1' / photocathode line mapping parameters table
CCR2 = 'ztab$ba412190z.cz2' / photocathode sample parameters table
CCR3 = 'ztab$c7f1130oz.cz3' / detector parameters table

CCR4 = 'ztab$a3d11045dz.cz4' / wavelength ranges table
CCR5 = 'ztab$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$e3u1430lz.czc' / global wavelength coefficients table
CCRD = 'ztab$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 intended to be self-documenting. The data processing steps performed are listed within the headers as is the state of the telescope and instrumentation at the time of the observation. The trailer file (.tr1) contains the history of the RSDP pipeline processing, including the history of the calibration steps executed.

36.3.1 Selecting the “Best” Reference Images and Tables

Over the past four years, several changes were made to both the reference images and tables and the calibration software that uses 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 always run properly with old data or old reference files. This is most likely to be a problem for 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. StarView can retrieve calibration images and tables from the HST Archive: the GHRIS 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 StarView |**Searches**| menu and follow the “GHRIS” sub-menu to the “Reference Files” option. Type the proposal ID or observation rootname in the “Dataset Name” field and then choose [**Begin Search**] to list the calibration reference files and tables used during pipeline processing and the recommended reference files for calibration.

These files can be obtained from the HST Archive through a StarView retrieval request. Chapter 1 describes how to use the Archive.

StarView’s Reference file screen contains four columns of useful information: Used and Recommended reference file names, Level of Change, and an indication if the correction associated with the files was performed. You will also find, for early science data, that not all the calibration switches currently used by the latest version of **calhrs** are in your raw science header. The StarView reference file screen will, however, retrieve all the latest recommended files that you need. By using **chcalpar** on the raw science file, the new switches and reference file keywords will automatically be placed in your header, including CCRE, SAAHFILE, and BMD_CORR keywords, which can be used to apply the model background subtraction instead of the pipeline default (see “Background Removal” on page 36-8) as well as the GWC_CORR and CCRD keywords used in the dispersion solution (see “Determine Wavelengths” on page 36-7). You will need to fill in the values of the switches and reference files within **chcalpar** (see “Running the STScI Recalibration Software” on page 36-16) before recalibrating, populating the names of the recommended reference files in place of those originally used by

the pipeline. We are now providing information on the Level of Change (SEVERE, MODERATE, TRIVIAL) for calibration images and table rows.



Currently, **calhrs** looks for the incidence angle correction table for all science data taken through the SSA and the LSA. However, a correction does not need to be applied in the case of SSA data and the StarView Reference File screen will not, therefore, return a recommended reference file for data taken through the SAA. You will therefore need to set the IAC_CORR to “OMIT” before recalibrating data taken in the small science aperture.

Reference files consist of images and tables stored in FITS format in the HST Archive. You should probably run **strfits** on the files retrieved from the Archive before running **calhrs**. A calibration reference image is an STSDAS image (IRAF `imtype = "hhh"`). Once **strfits** is run, an image 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 suffix of a reference image begins with the letter “r” and that of a reference table begins with the letter “c.” More information about FITS and STSDAS formats is provided in Chapter 2.

Running the STScI Recalibration Software

calhrs is a task in STSDAS. The STSDAS software runs under IRAF and is free to the astronomical community; it can be retrieved through the STSDAS web page. See Chapter 3 for information about setting up and using IRAF and 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 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.

If you want to add or 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 software takes as input the raw data images (.d0h, .q0h, .shh, .ulh, .x0h, .xqh) and the calibration reference images and tables. The calibration software determines which calibration steps to perform and which reference files to use from 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.

All users should determine the values of the calibration switches and reference file keywords in the raw data and calibrated headers. Each observation mode will have calibration switches set to default values. Prior to calibration (.d0h), the cal-

ibration switches will have the value OMIT or PERFORM. 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 (these are noted in the descriptions of each step, “Calibration Steps Explained” on page 36-2). In this case, the calibration switch value will remain set to PERFORM in the output product (.c*h). 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 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.

calhrs will write informational messages to the screen as it runs. 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.

```
hr> calhrs oldrootname newrootname > output
```

The calibration process can logically be thought of in terms of two distinct steps: flux calibration and wavelength calibration. The file that contains the wavelength coefficients has the suffix .c0h, while the flux-calibrated image has .c1h.

Each calibration step is described in the section “Calibration Steps Explained” on page 36-2, along with the corresponding calibration switch and various reference files required by that step.

36.3.2 SPYBALs and Wavecals

GHRIS wavelength calibrations come in two varieties: SPYBAL and wavecals.

- **SPYBAL**: Automatic centering of a calibration lamp spectrum on the diode array in the direction perpendicular to the array (the *y*-direction) is called spectrum *Y*-balancing, or **SPYBAL**. This action ensures that the main spectrum features will be *y*-centered on the diode array during the acquisition of science data. The spectrum obtained during this action is dumped as science data with an observation mode called SPYBAL. In general, SPYBALs will be obtained at some wavelength that is different from the one at which you obtained your observations, at a specified setting for a particular grating.
- **wavecals**: Some programs requested wavelength calibrations (often called *wavecals*) at the same wavelength as the science observation. These data can then be used to obtain a better wavelength calibration for the science, with either a wavelength offset or complete redefinition of the dispersion coefficients (see “Using Wavelength Calibration Exposures” on page 36-18). However, the primary changes in wavelength occur in the zero point, not to the dispersion. As a result, if a program lacks wavecals, SPYBALs may still be used to derive a zero-point correction to the default wavelengths that ends up being nearly as good as if a full wavelength cali-

bration had been obtained. By “nearly as good” we mean that the rms difference in wavelength between SPYBALs and wavecal when both were available was 19 mÅ, or about 3 km s⁻¹; see *GHRs ISR 053* for details.

You may notice that a wavecal does not have exactly the same wavelength range as the science observations. This difference is primarily due to the incidence angle correction (the two spectra are through different apertures), with a slight contribution from the heliocentric wavelength correction (which is performed for science targets but not internal calibrations). *This difference in wavelength scales is not an error.*

The LSA had a shutter to block light from entering the spectrograph, while the SSA was always open. Therefore, scattered light from a target in the SSA sometimes contaminated a wavelength calibration exposure if the target was very bright. Usually the lines from the spectral cal lamp are strong enough to still be detected (by the **hrs.wavecal** task, for example) over the contaminating light; if, however, it interferes, the user can attempt to subtract the star’s spectrum to decontaminate the wavelength calibration exposure.

36.3.3 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: **calhrs** *does not do this automatically*. In addition, if a wavecal observation was deliberately obtained with the same carousel 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 double check that the science data and the wavecal observation were obtained at the same carousel 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.

hrs.waveoff prints 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.

Rederiving 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 carousel 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 carousel 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.clh,z29h0108t.clh $I,carpos,fp_split\
>>> yes
z29h0107t.clh    50680    NO
z29h0108t.clh    50680    NO
```

After running **zwavecal**, you can use **chcalpar** 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 carousel position as science observation z29h0108t, you could use the commands shown in Figure 36.3 to improve the wavelength solution.

Figure 36.3: Improving the Wavelength Solution

```
cl> zwavecal z29h0107t.clh newdisp_0107
zwavecal: aperture SC2 carousel 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
```

36.3.4 Putting FP-SPLITS Together

If your data were taken in FP-SPLIT mode, then your calibrated data will have multiple groups that contain independent subintegrations taken at slightly offset carousel 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 carousel 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. When the individual FP-SPLIT spectra are combined into a single spectrum, the effects of the granular-

ity 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 two **stdas** 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 the 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. This topic was also discussed in “Putting FP-SPLITs Back Together” on page 35-32.