Chapter 21
STIS Calibration

In This Chapter...

This chapter describes how the STIS pipeline at STScI calibrates incoming STIS data. We begin with a high-level overview of the STIS calibration process, and subsequent sections describe the pipeline calibration steps and methodology in successively greater detail. We then discuss several reasons why you might want to recalibrate your data, and how to use the pipeline tasks for recalibration.

21.1 Pipeline Processing Overview

Science data obtained with STIS are received from the Space Telescope Data Distribution Facility and sent to the STScI pipeline, which unpacks the data, extracts keywords from the telemetry stream, reformats the data, and repackages them into raw, uncalibrated, but scientifically interpretable data files. The raw files are then calibrated, and the output files are stored in the Hubble Data Archive. What is described in this chapter is **calstis**, the program that performs the calibration of the science data and is available to the community as part of the STSDAS package.

Conceptually, **calstis** is several pipelines in one, reflecting the complexity and diversity of STIS observing modes. Your STIS data will have been calibrated to different levels, depending on their nature:

- ACQs, ACQ/PEAKs, and all available-mode data are not calibrated by **calstis**; you will get only the raw data from observations taken in these modes.

- All other science data are processed through basic two-dimensional image reduction (**basic2d**), which includes such things as bias subtraction, dark subtraction, flatfielding, and linearity correction. In the case of CCD CR-SPLIT or REPEATOBS data, your data will also be passed through cosmic ray rejection.
- All spectroscopic data (exclusive of slitless spectra or long slit echelle data) are then passed through spectroscopic reduction, to produce flux and wavelength calibrated science data. In the case of long slit data, a two-dimensional rectified image is produced. In the case of echelle data, a one-dimensional background subtracted aperture extracted spectrum is produced.
- Data taken in TIMETAG mode are output both as a raw uncalibrated event stream (to a FITS binary table), and as an ACCUM mode image which then passes through standard calibration.
- For MAMA data, the input raw data format is 2048 x 2048 (so called "high-res" pixels), while the calibrated data are binned by the pipeline to 1024 x 1024 native format pixels (see "LORSCORR" on page 21-25).

See Chapter 20 for the naming conventions of the various input, intermediate, and output calibrated files.

As with the calibration pipelines for the other HST instruments, the specific operations that are performed during calibrations are controlled by *calibration switches*, which are stored in the image headers as `keyword=value` pairs. Any given step in the calibration process may require the application of zero, one, or more *calibration reference files*, the names of which are also found in the image header. The names of the keywords containing the switches and reference file names were introduced in the previous chapter, and the section "Data Flow Through calstis" on page 21-9 will discuss them in detail. It is important to realize that only the calibration-related keywords that are relevant to the particular observation mode will appear in any given data header. Likewise, the path your data files take through the pipeline is determined by the calibration switches set in the header of the raw data, which in turn depends directly on the type of data you have.

A few other general comments are in order. STIS differs from earlier HST instruments in that some of the calibration reference data are obtained contemporaneously with the science observations. These data may be used to refine the calibration process (as with the automatic wavecals), or may require you to replace a default calibration reference file with a contemporaneously obtained one, as in the case of a CCD near infrared (NIR) fringe flat. The details of how these contemporaneous calibration files are used in **calstis** can be found in "Descriptions of Calibration Steps" on page 21-15. The STIS (and NICMOS) pipelines are also unusual in that they are re-entrant. That is, a user running **calstis** off-line may elect to reprocess STIS data partially, performing one or more of the intermediate steps without re-exercising the complete **calstis** pipeline, for instance to perform cosmic-ray rejection, or one dimensional spectral extraction. Refer to "Recalibration of STIS Data" on page 21-29 for the mechanics (and restrictions)

of this kind of processing. Finally, as with other HST pipelines, **calstis** propagates statistical errors and tracks data quality flags throughout the calibration process.

21.2 Structure of calstis

Calstis consists of a series of individual modules which:

- Orchestrate the flow through the pipeline.
- Perform basic two-dimensional image reduction.
- Reject cosmic rays from CCD data.
- Process the contemporaneously obtained wavecal data to obtain the zeropoint shifts in the spectral and spatial directions.
- Perform spectroscopic calibration, with wavelength and flux calibration.
- Perform final processing.

Table describes in more detail the individual modules in **calstis** and what they do. The IRAF task that can be used to run a particular segment of the pipeline independently is also provided (see “Rerunning Subsets of the Calibration Pipeline” on page 21-33).

Below we present a series of flow charts which provide a more complete overview of the processing of data through the **calstis** pipeline, starting with the fundamental step of two-dimensional image reduction.

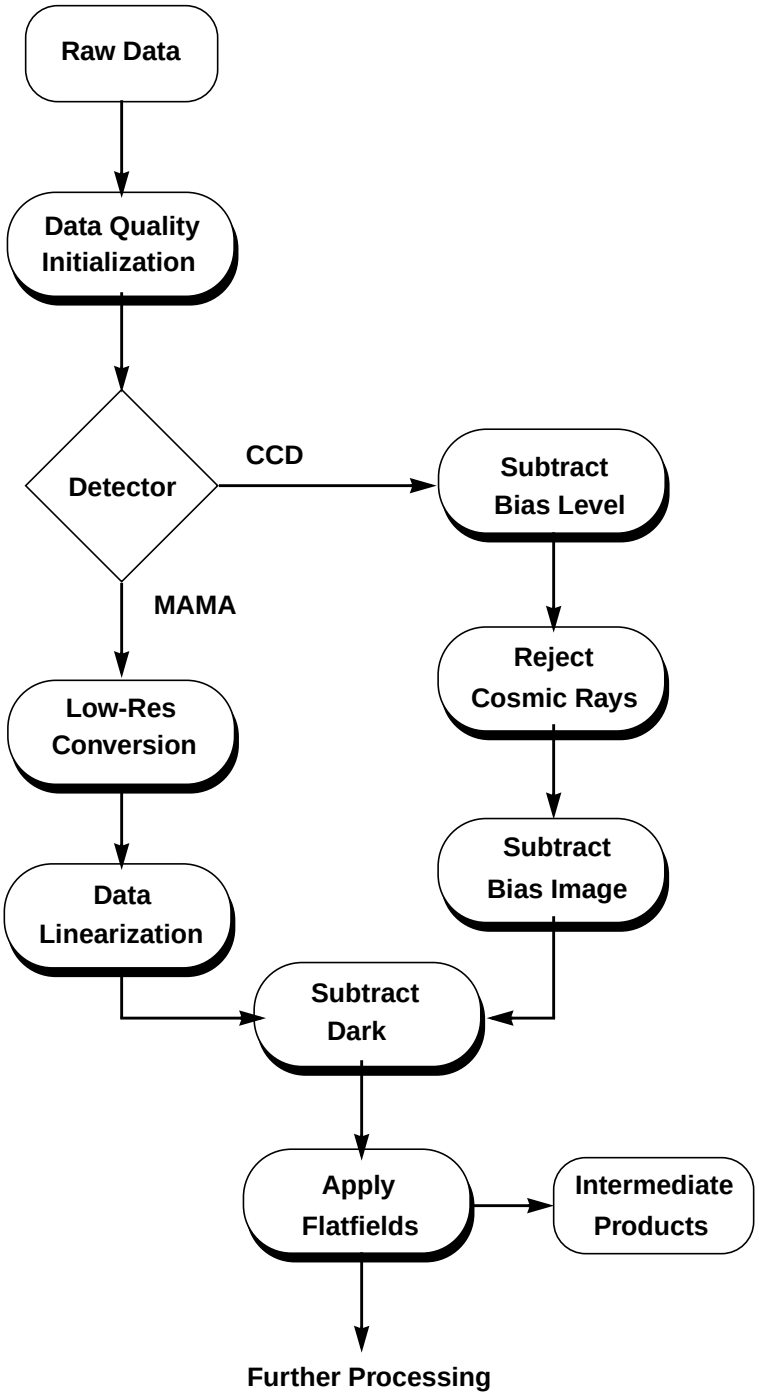
The first step is to reduce the data through flatfielding and reject cosmic rays or co-add the data as appropriate. Figure 21.1 shows the route taken by CCD and MAMA data.

Table 21.1: Calstis Module Description Summary

IRAF Task	Description of Processing Step	Module[a]
	Full Pipeline	
calstis	"**Wrapper" program calls each of the calstis tasks as needed**, according to the switches set in the *primary header* of the input file. The **calstis** constituent tasks can instead be executed independently when recalibrating.	*calstis0*
	Basic 2-D image Reduction	
basic2d	**Basic 2-D image reduction**. This step includes overscan subtraction, bias subtraction, dark subtraction, flatfield ing, initializing the data quality array from the bad-pixel table, assigning values to the error array, and computing some simple statistics. Normally, cosmic-ray rejection is applied during the course of basic image processing; however, **basic2d** can be customized to omit this step and to limit processing to overscan subtraction.	*calstis1*
	Cosmic Ray Rejection	
occreject	**Detect and remove cosmic rays in CCD data**. When multiple images at the same pointing have been taken, this module identifies cosmic rays (optionally flagging them in the input file) and co-adds the input images, writing one output image without cosmic rays.	*calstis2*
	Contemporaneous Wavecal Processing	
wavecal	**Determine MSM offset from wavecal**. This step is used in conjunction with calstis7, calstis11, and calstis12. Its purpose is to find the offset of the spectrum from the expected location, owing to nonrepeatability of the mode select mechanism. The shift is written into the SCI extension header of the input wavecal image.	*calstis4*
	Subtract science image from wavecal. For CCD wavecal observations taken with the HITM system, the detector is exposed to both the wavecal and the science target. This task reads both the wavecal and science files and subtracts the science data from the wavecal. Following this step , calstis4 can be used to determine the spectral shift.	*calstis11*
	Write spectral shift value to science header. A series of science images (i.e., CRSPLIT or REPEATOBS) and wavecals may have been taken, with the wavecals interspersed in time among the science images. For each image in the science file, this task selects the wavecal in the wavecal file that is closest in time to the science image, and it copies the keyword values for the spectral shift from that wavecal header to the science header.	*calstis12*
	Spectroscopic Calibration and Extraction	
x1d	**1-D spectral extraction**. This task is most appropriate for echelle data or for a long-slit observation of a point source. A spectrum is extracted along a narrow band, summing in the cross-dispersion direction and subtracting nearby background values to produce a 1-D array of fluxes for each spectral order. D are not resampled in the dispersion direction; instead, an array of wavelengths is generated. Each output spectrum is written to a separate row of a FITS binary table, together with the arrays of the gross, net, and background count rates.	*calstis6*
x2d	**2-D rectification**. This task performs geometric correction for imaging data, or for long-slit spectroscopic data it extracts a 2-D spectrum linear in both wavelength and spatial directions.	*calstis7*
	Final Processing	
	Sum repeatobs data. If multiple MAMA images were taken and combined into one input FITS file, this task can be used to add them together, pixel by pixel. This task would not normally be used for CCD data because they would already have been combined for cosmic ray rejection.	*calstis8*

a. Referenced in the trailer file.

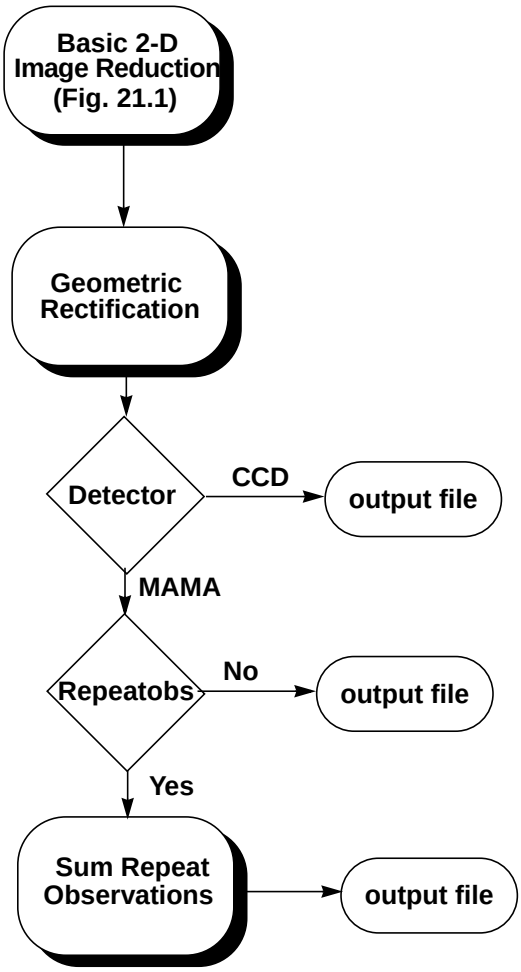
Figure 21.1: Basic 2-D Image Reduction (First Step in Subsequent Flowcharts)



The calibration beyond the basic 2-D image processing depends upon whether the data are obtained in imaging or spectroscopic mode, as illustrated in Figure 21.2. The primary operations are geometric correction and photometric calibration, and a summation of multiple MAMA exposures if NRPTEXP > 1. The output is a geometrically rectified image with header keywords that specify

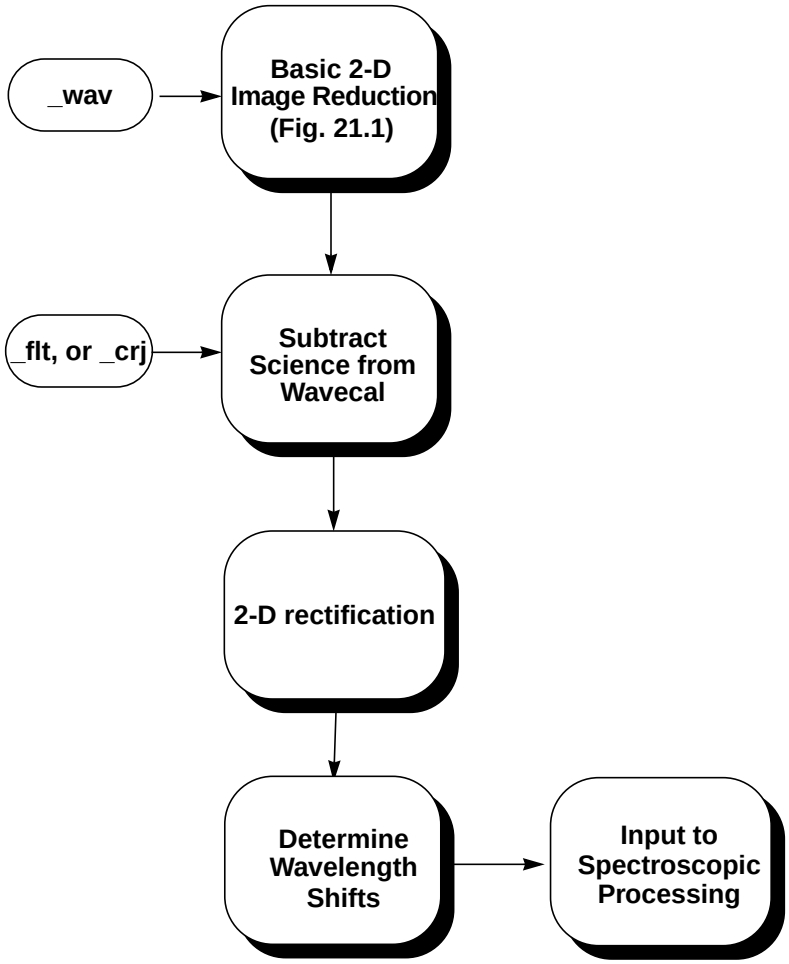
the photometric calibration. When geometric correction is not applied, the output will be photometrically calibrated flatfielded data with suffix `_crj`, `_flt`, or `_sfl`.

Figure 21.2: Schematic of calstis for Secondary Image Processing



For spectroscopic exposures, **calstis** will process the associated wavelength calibration (wavecal) exposure to determine the zero point offset of the wavelength and spatial scales in the science image, thereby correcting for the lack of repeatability of the mode select mechanism (MSM) or for thermal drift. The accompanying wavecal observations are stored in the *rootname*_`wav.fits` file.

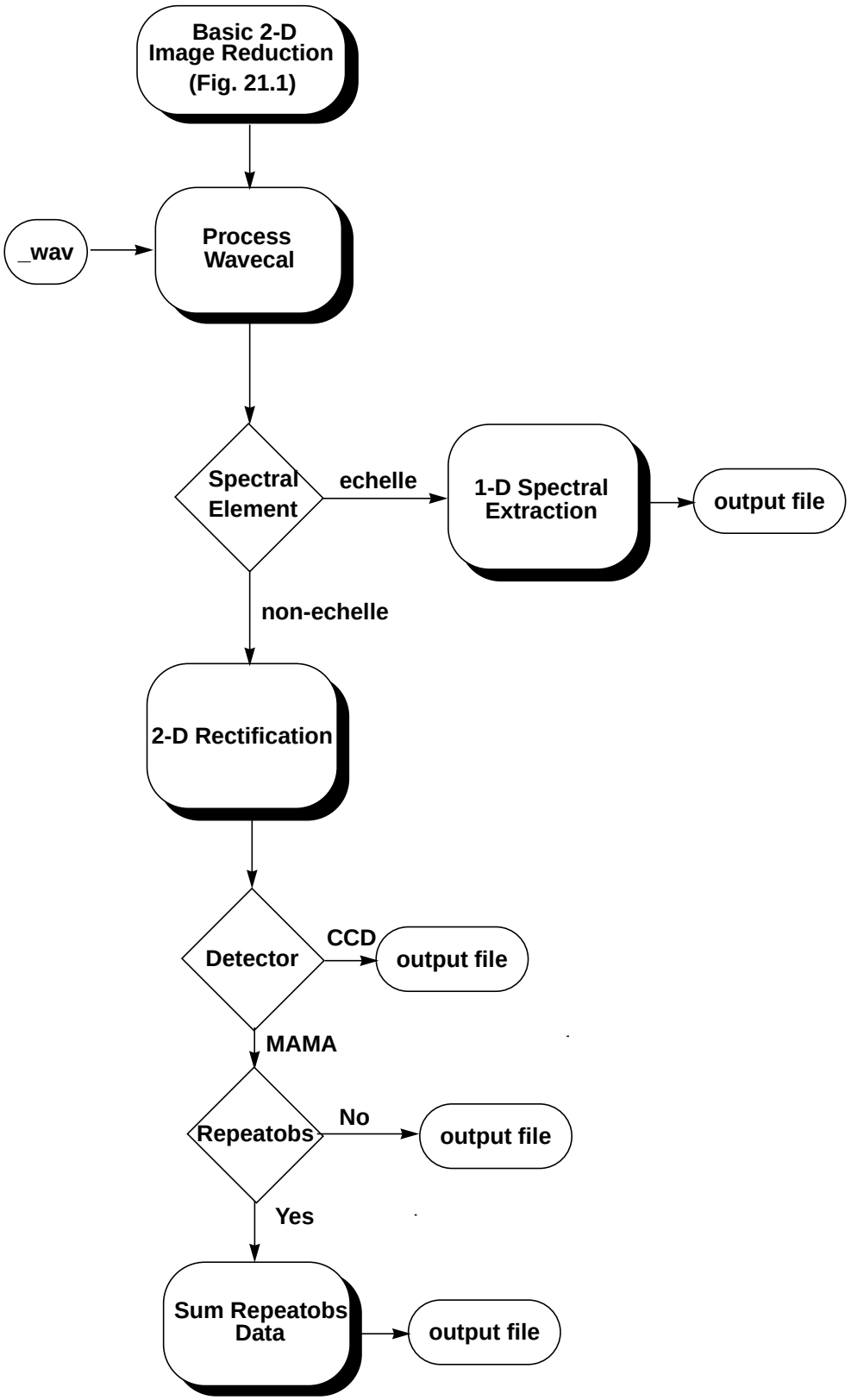
Figure 21.3: Schematic of calstis for Contemporaneous Wavecals



Two-dimensional spectral processing produces a flux-calibrated, rectified spectroscopic image with distance along the slit running linearly along the *y* axis and dispersion running linearly along the *x* axis.

One-dimensional spectral extraction produces a one-dimensional spectrum of flux versus wavelength (*rootname*_x1d.fits), uninterpolated in wavelength space, but integrated across an extraction aperture in the spatial direction. This extraction is currently performed only for echelle short slit observations in the pipeline. Future enhancements will perform the extraction for point sources in all first-order modes as well.

Figure 21.4: Schematic of calstis for Spectroscopic Data



21.3 Data Flow Through calstis

This section details the data flow through the **calstis** pipeline for each calibrated operating mode, showing the switches, the reference file inputs, the science file inputs and the output products. The next section describes the tasks corresponding to the various calibration switches.

Figure 21.5: 2-D CCD Image Reduction Process

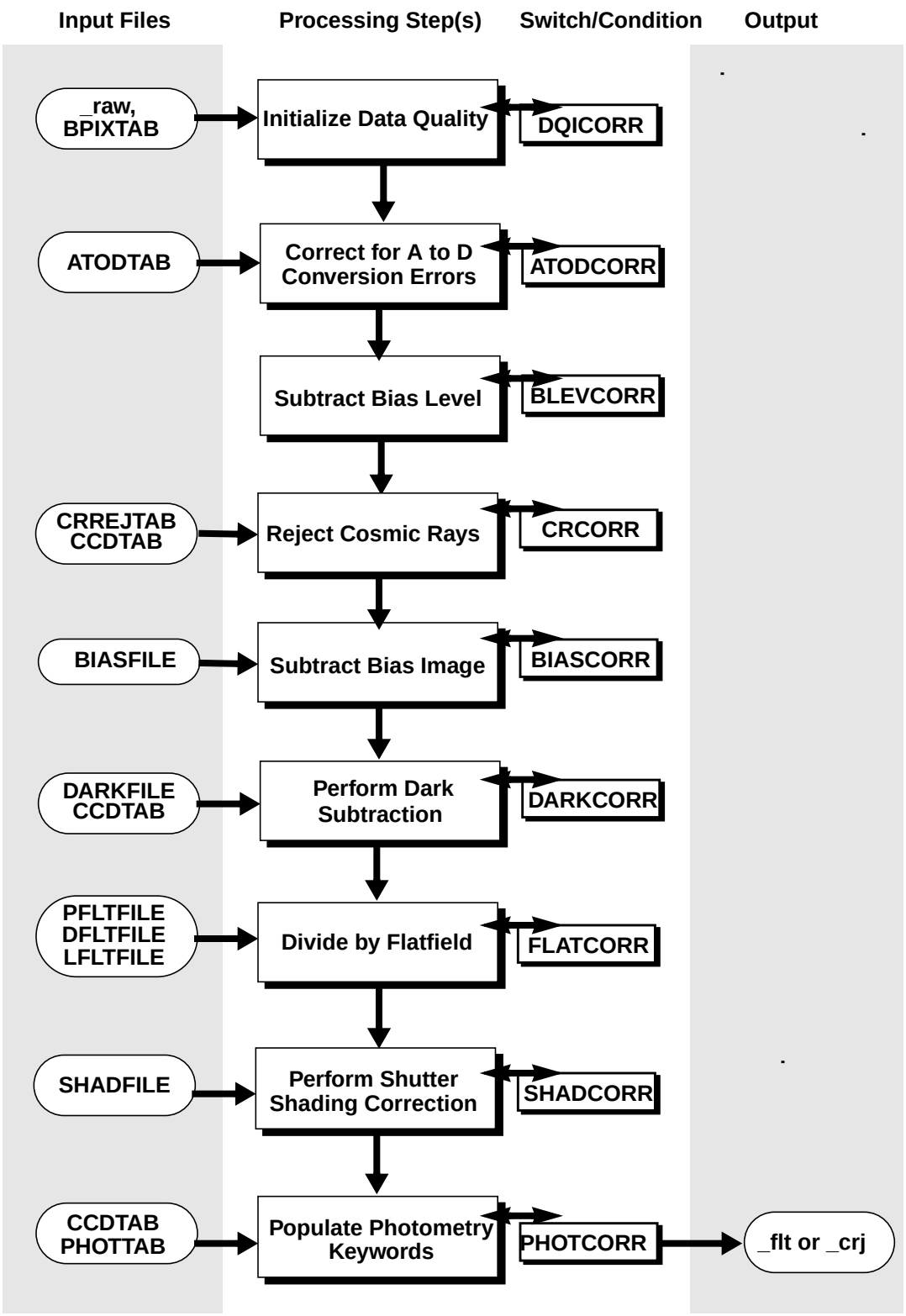


Figure 21.6: 2-D MAMA Image Data Reduction Process

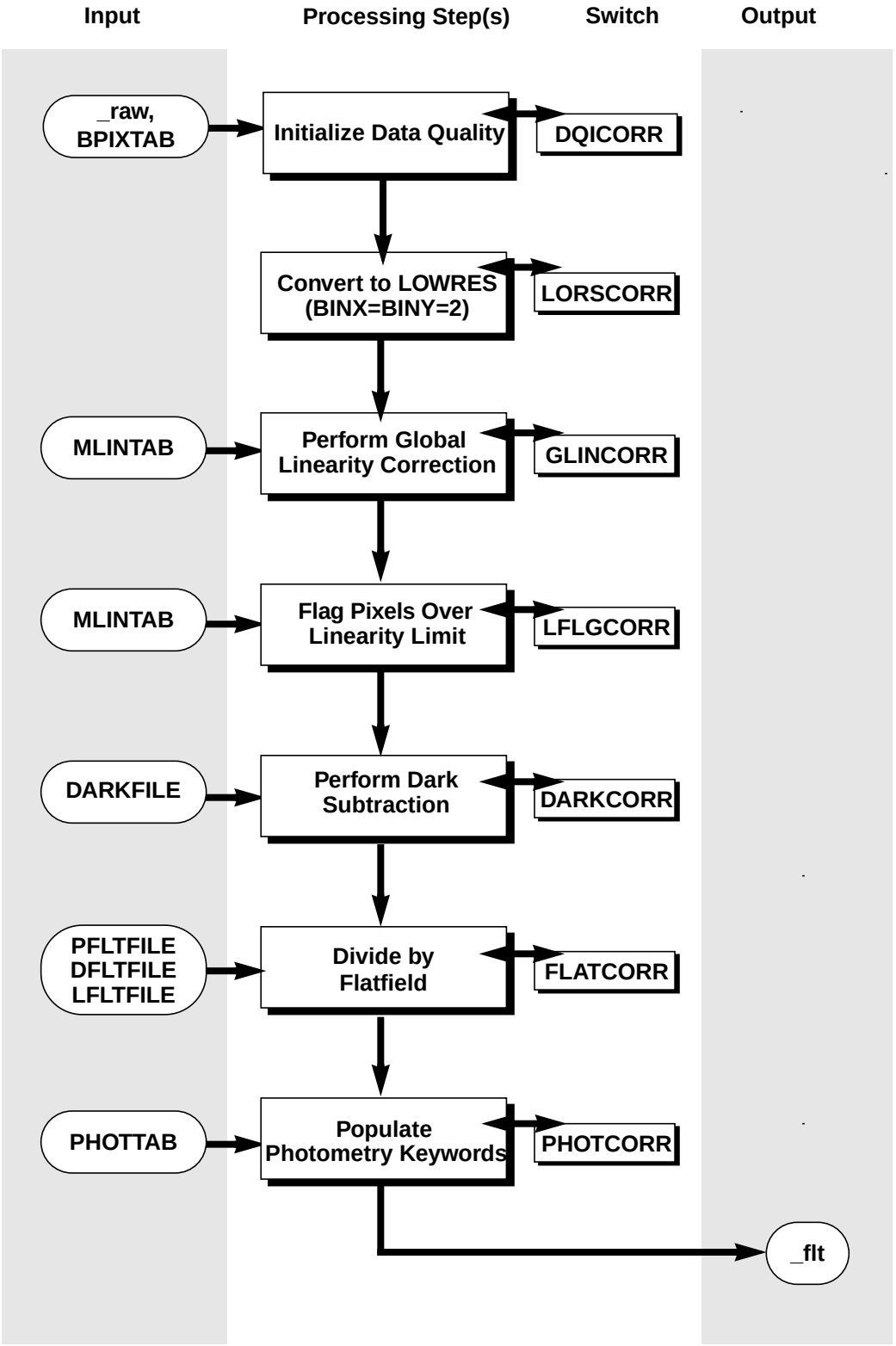


Figure 21.7: Calstis-4, wavecal Processing

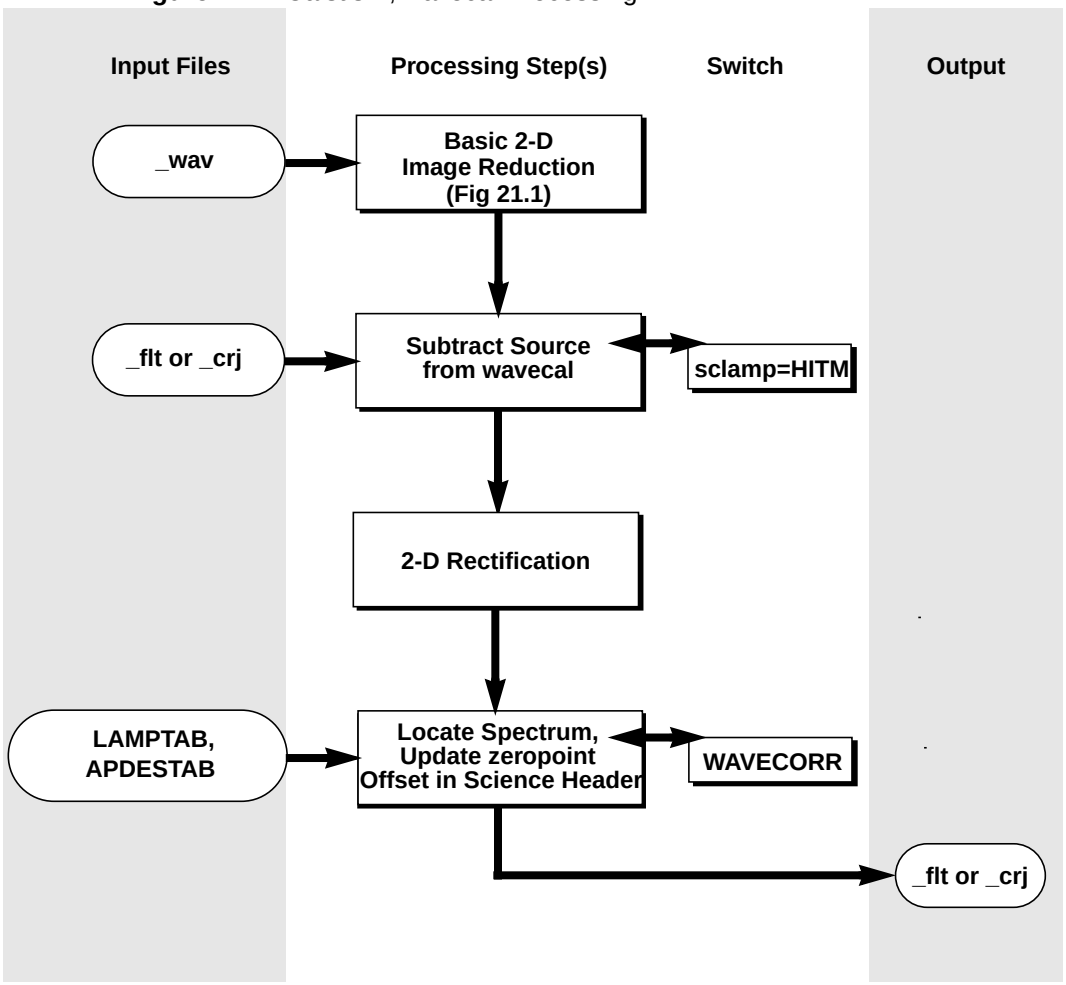


Figure 21.8: Flow Through calstis-6, 1-D Extraction

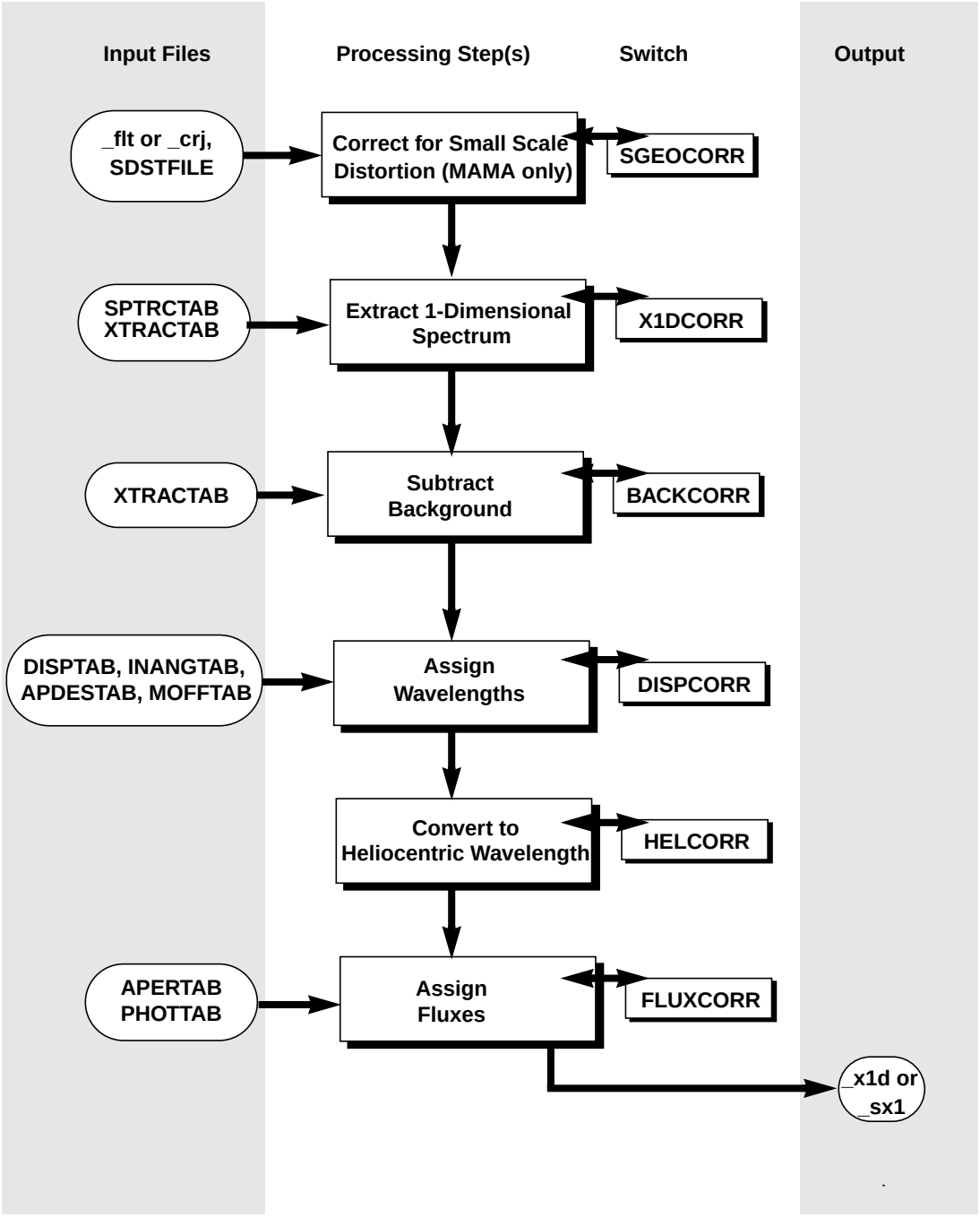


Figure 21.9: Flow Through calstis-7, 2-D Rectification

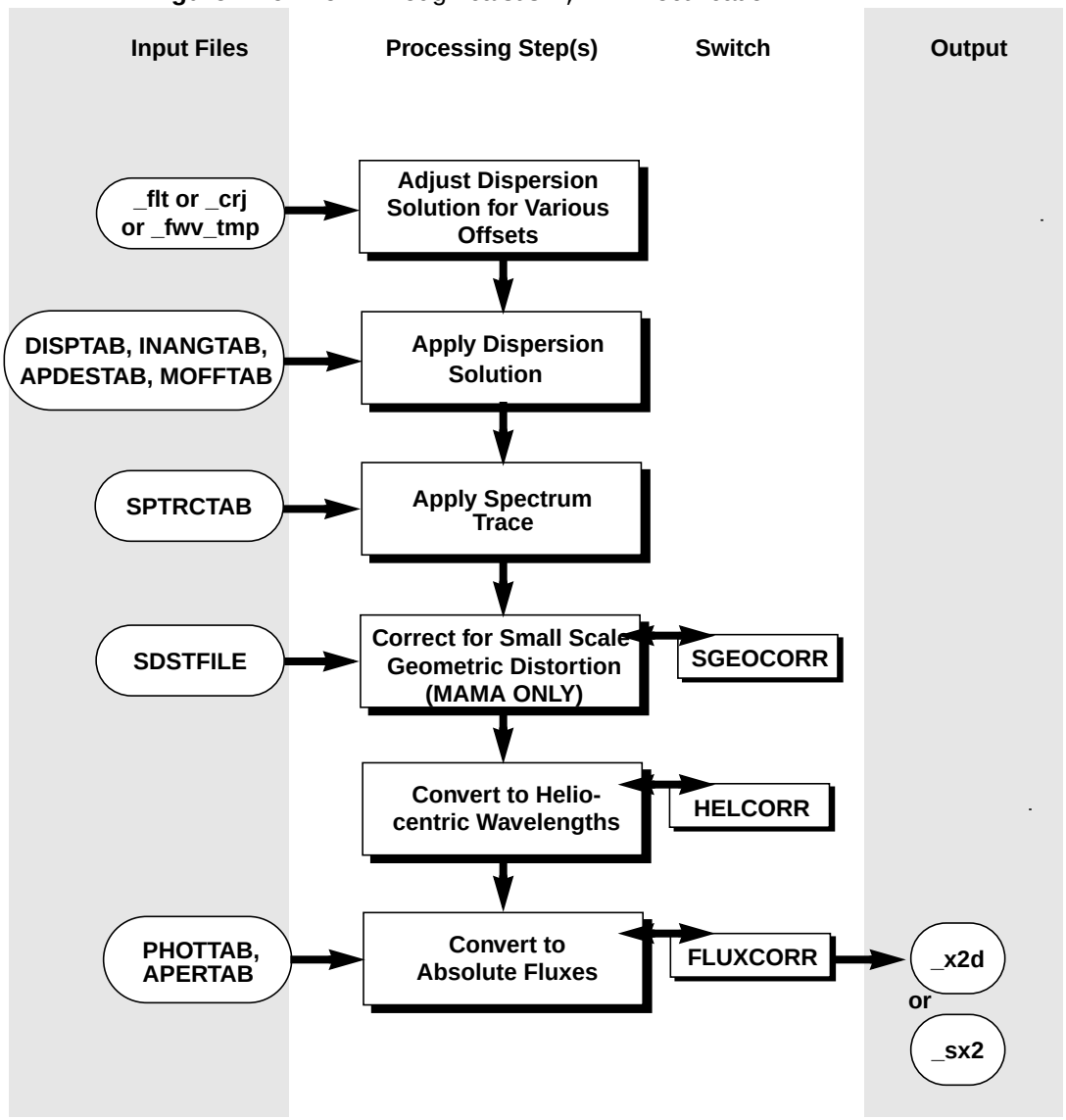
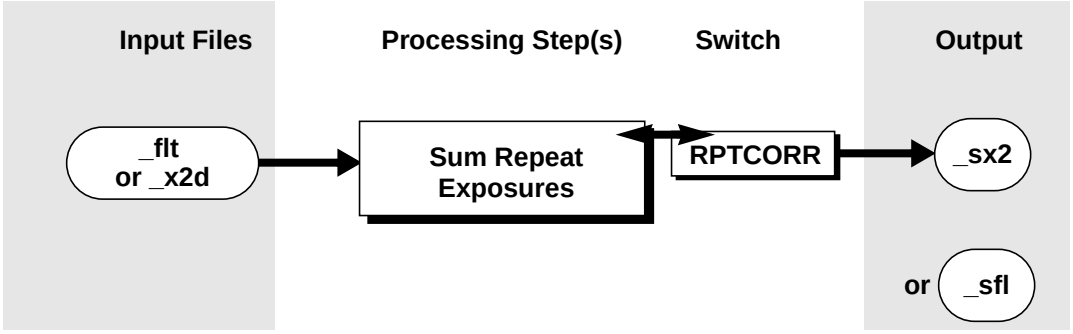


Figure 21.10: Flow through calstis-8, Summing repeatobs Exposures



21.4 Descriptions of Calibration Steps

In this section we provide a more detailed description of the algorithms applied by **calstis**. As always, a given step will be performed on your data if the corresponding calibration switch in the input data was set to PERFORM (see Chapter 2). The algorithmic descriptions below are described according to the major component of the **calstis** pipeline in which they are used, namely:

- Two-dimensional image reduction, including basic 2-D reduction, cosmic ray rejection and image co-addition.
- Processing of the contemporaneously obtained wavecal.
- Two-dimensional and one-dimensional spectral extraction, with flux and wavelength calibration.

Within each component, the individual steps are listed alphabetically, because the order in which they are performed can change for different types of data (e.g., CCD or MAMA, spectroscopic or imaging, CR-SPLIT or not).

More detailed descriptions can be found in a series of *Instrument Science Reports* (ISRs) that discuss the pipeline. Be aware, however, that while these reports describe the original design of the pipeline and the associated algorithms in detail, they do not always contain information concerning later modifications. Over time these reports will be updated to include a more complete description of the pipeline. In the meantime we refer you to the STIS WWW page, where a history of the important changes to the **calstis** pipeline code is maintained.

ATODCORR

This step is part of 2-D image reduction and applies only to CCD data. An analog to digital correction would be applied if the CCD electronic circuitry which performs the analog to digital conversion were biased toward the assignment of certain DN (data number) values. Ground test results show that this correction is not currently needed, so the ATODCORR switch will always be set to OMIT.

BACKCORR

This step is a part of spectral extraction and applies to one-dimensional extraction only. If the calibration switch BACKCORR is PERFORM the background is calculated and subtracted from the extracted spectrum. The background is extracted above and below the spectrum, and a function is fit to the variation of the background along the spatial axis (AXIS2). The fitting function is restricted to a zeroth or first order polynomial. The polynomial order, BACKORD, is read from the XTRACTAB reference able and written to a header keyword of the same name in the output spectrum table. Average background values (in counts/sec/pixel) are calculated from each background bin, and account for fractional pixel contributions. In the case of BACKORD=0, a simple average of the two background bins is computed. For BACKORD=1, the background value at the center of each pixel that contributes to the extracted spectrum is derived from the linear fit to the background. The background in the spectrum extraction box is

totaled and subtracted from the sum of the spectrum box. The total background at each pixel in the output spectrum is written to the output data table.

In general, the background or sky is not aligned with the detector pixels. To accommodate this misalignment, the definition of the background extraction apertures includes not only a length and offset (center-to-center) but also a linear tilt to assist in properly subtracting the background. This tilt is taken into account when calculating the average background in the background extraction boxes.

BIASCORR

This step is part of basic 2-D image reduction and is performed only for CCD data. The BIASCORR step removes any two-dimensional additive stationary pattern in the electronic zeropoint of each CCD readout after the BLEVCORR step is applied. To remove this pattern a bias reference image is subtracted. The bias reference file (BIASFILE) is a full-format *superbias* image created from many bias frames to assure low noise. If the science image is a subarray or is binned, a section of the bias image is extracted and binned to match the science image, prior to bias subtraction. If a CCD gain other than one is used, the bias reference file is scaled by the gain factor from the CCDTAB reference table prior to subtraction. The bias image has an associated data quality image extension: bad pixels in the bias image are flagged in the science data quality image.

BLEVCORR

This step is part of basic 2-D image reduction and is performed only for CCD data. The BLEVCORR step subtracts the electronic bias level for each line of the CCD image and trims the overscan regions off of the input image, leaving only the exposed portions of the image.

Because the electronic bias level can vary with time and temperature, its value is determined from the overscan region in the particular exposure being processed. A raw STIS CCD taken in full frame unbinned mode will have 20 rows of virtual parallel overscan in the AXIS2, or image *y*, direction, which is created by over-clocking the readout of each line past its physical extent, and 19 leading and trailing columns of serial physical overscan in the AXIS1 or image *x* direction, which arise from unilluminated pixels on the CCD. Thus the size of the uncalibrated and unbinned full frame CCD image is 1062 (serial) by 1044 (parallel) pixels, with 1024 x 1024 exposed science pixels.

Only the serial (physical) overscan is used for the overscan bias level determination; the virtual parallel overscan is not used. A line-by-line subtraction is performed in the following way. An initial value of the electronic bias level, or overscan, is determined for each line of the image, using only the physical serial overscan, and a function, currently a straight line, is fit to these values as a function of image line. The actual overscan value subtracted from an image line is the value of the linear fit at that image line. The initial value for each line is found by taking the median of a predetermined subset of the trailing serial overscan pixels. Currently, that region includes most of the trailing overscan region, however the first and last two pixels are skipped, as they have been shown to be subject to problems, and pixels flagged as bad in the input data quality flag are also skipped. The region used changes with binning or subarray use (see

Table 21.2). The mean value of all overscan levels is computed, and the mean is written to the output SCI extension header as MEANBLEV.

In addition to subtracting the electronic bias level, the BLEVCORR step also trims the image of overscan. The sizes of the overscan regions depend on binning and whether the image is full-frame or a subimage. The locations of the overscan regions depend on which amplifier was used for readout. The number of pixels to trim off each side of the image (before accounting for readout amplifier) is given in Table 21.3. The values of NAXIS1, NAXIS2, BINAXIS1, and BINAXIS2 are obtained from image header keywords. Because the binning factor does not divide evenly into 19 and 1062, when on-chip pixel binning is used the raw image produced will contain both pure overscan pixels, overscan plus science pixels and science pixels. The **calstis** pipeline will only calibrate pixel binnings of 1, 2, and 4 in either AXIS1 or AXIS2.

The CRPIX*i* and LTV*i* keywords are updated in the output; these depend on the offset from removing the overscan.

Table 21.2: Raw Image Pixels Used to Determine Line by Line Bias Level

Columns in Raw Image	Binning
2 through 16	Unbinned
2 through 8	All other supported binnings

Table 21.3: Pixels Trimmed During CCD Bias Level Correction for Amp D

Side	Full Image	Subarray Images	Binned Images
Right	19	18	(19 + 1) / BINAXIS1
Left	19	18	NAXIS1 - (1024 / BINAXIS1 - 1) - Right
Top	0	0	0
Bottom	20	0	NAXIS2 - 1024 / BINAXIS2

CRCORR

The CRCORR step is part of basic 2-D image reduction and is applicable only to CCD data. This step sums the individual CR-SPLIT exposures in an associated dataset, producing a single cosmic ray rejected file (`_crj.fits`). The **ocrreject** task in the **calstis** pipeline is similar to the WFPC2 **crrej** task, except that **ocrreject** uses the input data quality flags to discard pixels from the input images when forming the output image, it outputs an error array for the cosmic ray rejected image using the input error arrays, and it reads the controlling input parameters (`SCALENSE`, `INITIAL`, `SKY`, `SIGMAS`, `RADIUS`, `PFACTOR`, `BADINPDQ`, and `MASK`) from the `CRREJTAB` reference file.

The CRCORR step does the following:

- Forms a stack of images to be combined (the CR-SPLIT or REPEATOBS exposures in the input file).
- Forms an initial guess image (minimum or median).
- Forms a summed CR-rejected image, using the guess image to reject high and low values in the stack, based on sigma and the radius parameter which governs whether to reject neighboring pixels to pixels identified as cosmic ray (see below).
- Performs one or more rejection cycles, using different (usually decreasing) rejection thresholds, producing a new guess image at each iteration.
- Produces a final cosmic ray rejected image, including science, data quality and error extensions, which is the weighted sum of the input images.
- Flags the data quality arrays of the individual (non-CR-rejected) input files to indicate where an outlier has been found (pixels which were rejected because of cosmic ray hits can be identified by looking for data quality bit = 14 in the `_flt.fits` file).

The cosmic-ray-rejected image is created by setting the value at each pixel to the sum of the values of all good pixels in the stack whose values are within plus or minus `sigmas`**noise* of the initial guess image. Deviant (out of range) stack pixels are flagged as cosmic ray impacted by setting their stack data quality flags to 8192 in the input file.

The value of *noise* (in DN) is computed as:

$$noise = \sqrt{\left(\frac{READNSE}{ATODGAIN}\right)^2 + \left(\frac{DN}{ATODGAIN}\right) + (SCALENSE \times 0.01 \times DN)^2}$$

Where:

- DN = the data number of the stack pixel value.
- `READNSE` is the read noise in electrons, read from the primary header.
- `ATODGAIN` is the calibrated conversion from electrons to DN, read from the primary header.
- `SCALENSE` is an input parameter, read from the CRREJTAB calibration reference file.

The `sigmas` parameter is read from the CRREJTAB calibration reference file; `sigmas` is a string, e.g., `sigmas = "4,3"`. The number of entries in the string dictates the number of iterations to be performed (in this example two) and the values in the string indicate the value of `sigmas` for each iteration. In this example, stack values that deviate from the guess image value by more than 4**noise* in the first iteration are considered to be outliers and are excluded from the average on the first iteration, and an improved guess image is formed. A second iteration is then performed in which `sigmas` is set to 3 and good stack values disparate by more than +/– 3**noise* from the guess image are excluded

when determining the average. In each iteration, if RADIUS is >=1, then pixels neighboring rejected pixels are also excluded in forming the average.

SCALENSE is a string containing a multiplicative factor in the noise relation. If SCALENSE = “2.0”, then the term 0.02*value is added in quadrature to the *noise*. This term accounts for multiplicative effects, such as would be expected if this rejection were applied to flat-fielded data. It is important to include to properly flag well-exposed regions (such as the centers of stars, where jitter from the telescope may slightly change the pointing from image to image).

The combination of the individual CRSPLIT or REPEATOBS exposures into a single cosmic-ray rejected frame is performed early in the **calstis** flow. The cosmic ray rejection is performed after each exposure has had its data quality file initialized and the overscan bias level subtraction (BLEVCORR) performed upon it, but prior to subtraction of a bias frame (BIASCORR), dark (DARKCORR) and flatfielding of the data (FLATCORR). The CR-rejected, bias level subtracted image is then passed through the remainder of the two-dimensional image reduction (**calstis-1**) to produce a flatfield ed CR-rejected image (*_crj.fits). This CR-rejected flatfield ed image is then passed through the subsequent processing steps in **calstis**. If EXPSCORR is set to PERFORM (see below), then the individual flatfielded but not cosmic ray rejected exposures are also produced.

DARKCORR

The DARKCORR step is part of basic 2-D image reduction and removes the dark signal (count rate created in the detector in the absence of photons from the sky) from the uncalibrated science image. If the science image is a subarray or was binned, the relevant section of the dark reference image must be extracted and binned to match the science image. If Doppler correction was applied on-board for the science data (i.e., if DOPPON = T), the Doppler smearing function is computed and convolved with the dark image to account for the contributions of various detector pixels to a particular image pixel. This applies only to MAMA data taken with the first order medium resolution gratings or in the echelle gratings. The Doppler convolution is done before binning the dark image. The science data quality file is updated for bad pixels in the dark reference file.

The mean of the dark values subtracted is written to the SCI extension header with the keyword MEANDARK. For CCD data, the dark image is multiplied by the exposure time and divided by the atodgain (from the CCD parameters table) before subtracting. For MAMA data, the dark image will be multiplied by the exposure time before subtracting; it will also be convolved with the Doppler smoothing function if DOPPCORR is PERFORM.

DISPCORR

This step is a part of spectral extraction. Wavelengths are assigned using dispersion coefficients from the reference table DISPTAB when the calibration switch DISPCORR is PERFORM; if DISPCORR is OMIT, no wavelengths are assigned. The DISPTAB table contains dispersion solutions for a defined reference aperture. Offsets introduced by using apertures other than a reference aperture are removed using coefficients in the inangtab reference table. In the case of echelle observations, small shifts introduced by the tilt of the spectral features are removed using coefficients in the XTRACTAB reference table.

For MAMA data, offsets of the projection of the spectrum onto the detector in both the spectral and spatial directions are deliberately introduced by offsetting the Mode Select Mechanism (grating wheel) tilts. This is done approximately monthly to assure a more uniform charge extraction from the microchannel plate over time. For MAMA observations, these induced offsets are removed using coefficients in the MOFFTAB table.

The DISPTAB table of dispersion contains coefficients for fits to the following dispersion solution:

$$s = A_0 + A_1 m\lambda + A_2 (m\lambda)^2 + A_3 m + A_4 \lambda + A_5 m^2 \lambda + A_6 m\lambda^2$$

where

- λ is the wavelength in Angstroms.
- s is the detector AXIS1 position.
- m is the spectral order.
- A_i are the dispersion coefficients.

For each pixel in the AXIS1 direction, a wavelength is calculated. First, any modification to the dispersion coefficients due to spectrum offsets must be made. Table 21.4 lists the possible offsets and the appropriate corrections. For each integer value of *s* in the AXIS1 direction, a wavelength is solved for iteratively using the Newton-Raphson method.

Table 21.4: Modifications to the Dispersion Coefficients Caused by Offsets

Correction	Ref Table	Algorithm	Definitions
Incidence Angle	INANGTAB	$A_0 = A_0 + c_2(1) \times s + c_2(2) \times s^2$ $A_i = A_i + \sum_{i=1}^{N} c_1(i) \times s$	A_i dispersion coefficients c_i incidence angle coefficients s aperture offsets in the axis 1 direction calculated as difference of relative aperture centers (arcsec)
MAMA Offsets	MOFFTAB	$A_i = A_i + \sum_{i=1}^{N} o_1(i) \times x_1 + o_2(i) \times x_2$	A_i dispersion coefficients o_i MAMA offset coefficients x_1 MAMA offset (MOFFSET1) (pixels) x_2 MAMA offset (MOFFSET2) (pixels)
Echelle Spectrum Tilt	XTRACTAB	$A_0 = A_0 + y \tan\theta$	A_i dispersion coefficients y axis 2 offset from nominal A2CENTER during spectrum locate process (pixels) θ spectrum tilt angel

DOPPCORR

This step is part of basic 2-D image reduction and is performed only for spectroscopic data taken with the MAMA detectors. When MAMA data are taken in ACCUM mode in the first order medium (M) gratings or the echelle modes, the MAMA flight software corrects the location of each photon for the Doppler shift induced by the spacecraft motion, prior to updating the counter in the ACCUM

mode image being produced. Therefore, during basic two-dimensional image reduction of the MAMA data, the darks and flats must be processed with the same Doppler smoothing as the science data prior to application of the reference image.

The first step is to compute an array containing the Doppler smearing function. The expression below gives the computed Doppler shift, where the time *t* begins with the value of the header keyword `EXPSTART` and is incremented in one-second intervals up to `EXPSTART + EXPTIME` inclusive. At each of these times, the Doppler shift in unbinned pixels is computed as:

$$shift = \mathrm{DOPMAG} \times \sin(2\pi(t - \mathrm{DOPZERO})/\mathrm{ORBITPER})$$

The value of *shift* is rounded to the nearest integer.

DQICORR

The DQICORR step is part of basic 2-D image reduction and takes the initial data quality file output for the science data and bit-wise ORs it with the values in the bad pixel reference file table (BPIXTAB) to initialize the science data quality file for propagation through subsequent steps in **calstis**. If DOPPFLAG=T, **calstis** will combine data quality information from neighboring pixels to accomodate Doppler smearing prior to performing the OR operation with the (unsmeared) science input data quality image. The DQICORR step also appropriately combines data quality flags in neighboring pixels if the images are binned.

EXPSCORR

The EXPSCORR step is a part of basic 2-D image reduction. If the EXPSCORR calibration switch in the header is set to PERFORM, the pipeline will also process the SCI extensions in the `*_raw.fits` files as individual exposures through **calstis**, outputting an intermediate product, `*_flt.fits`. This file contains the individual flatfielded CRSPLIT exposures in successive imsets of a single file. This file will not be passed through the subsequent calibration steps (e.g., spectroscopic reduction), but will be retained as an intermediate data product, to allow users to examine the effects of the pipeline cosmic-ray rejection and to re-perform the cosmic ray rejection and subsequent calibration steps as desired.

FLATCORR

The FLATCORR step is part of basic 2-D image reduction and corrects for pixel-to-pixel and large-scale sensitivity gradients across the detector by dividing the data by a flatfield image. The flatfield image used to correct the data is created from three flatfield reference files:

- PFLTFILE - This flat is a configuration (grating, central wavelength and detector) dependent pixel-to-pixel flatfield image, from which any large-scale sensitivity variations have been removed (i.e., it will have a local mean value of unity across its entirety). Such configuration dependent flats are expected to be produced infrequently, perhaps once per year.

- DFLTFILE - This file is a *delta flat* which gives the changes in the small scale flatfield response relative to the pixel to pixel flat (PFLTFILE). Delta flats will be taken relatively frequently (approximately monthly, though less frequently for the MAMAs); there will be a single delta flat for each detector, CCD, NUV-MAMA, and FUV-MAMA. They will be used only if needed.
- LFLTFILE - This flat is a subsampled image containing the large-scale sensitivity variation across the detector. It is usually grating- and central wavelength-dependent (for spectroscopic data) and aperture (filter) dependent for imaging data.

To flatfield science data, **calstis** creates a single flatfield image from these three files[1] as described below and then divides the science image by the flat so created. The pixels of the science data quality file are updated to reflect bad pixels in the input reference files and the errors in the science data are updated to reflect the application of the flat. Blank values of PFLTFILE, DFLTFILE, or LFTFILE in the science data, indicate that type of flat is not to be used.

To create the single combined flatfield file, **calstis** first expands the large-scale sensitivity flat (LFTFILE) to full format. The pixel-to-pixel flat, delta flat, and expanded low-order flat are then multiplied together. For MAMA data, the product of the flatfield images will be convolved with the Doppler smoothing function if DOPPCORR = PERFORM. If a subarray or binning was used, after taking the product of all the flatfields that were specified, a subset is taken and binned if necessary to match the uncalibrated image, and the uncalibrated data are then divided by the binned subset.

FLUXCORR

This step is part of spectral extraction. If FLUXCORR is PERFORM, the raw counts are corrected to F_λ (erg cm^{-2} sec^{-1} Å^{-1}) using the reference files PHOTTAB and APERTAB. Execution of this calibration step requires that wavelengths have been assigned. Corrections for vignetting and echelle blaze are handled within the PHOTTAB reference files. The conversion to absolute flux for a point source is calculated as:

$$F_\lambda = \frac{hc \cdot G}{A_{HST} R_\lambda T_\lambda \lambda \Delta\lambda} C_\lambda$$

where:

- F_λ is the calibrated flux at a particular wavelength. This quantity is also multiplied by the ATODGAIN if the data were obtained with the CCD.
- h is Planck's constant.
- c is the speed of light.

1. The rationale for maintaining three types of flatfield reference files rather than a single integrated reference file is described in detail in *STIS ISR* 95-09 "Calibration Plans for Flat Fielding STIS Data."

- G is the detector gain, which is unity for MAMA observations. For the CCD, this is the conversion from counts to electrons, the value for which is given in the header keyword ATODGAIN.
- A_{HST} is the area of the unobstructed HST primary mirror (45238.93416 cm^2).
- R_λ is the throughput of the STIS instrument configuration at a particular wavelength when a clear full aperture is in place.
- λ is the wavelength in Angstroms.
- $\Delta\lambda$ is the dispersion (Å/pixel) at a particular wavelength.
- C_λ is the net count rate at a particular wavelength.
- T_λ is the aperture throughput at a particular wavelength.

The flux correction is applied somewhat differently for 1-D and 2-D extractions. See “Working with Two Dimensional Extracted Spectra” on page 23-3 for details.

The flux calibration applied for one-dimensional extraction (X1DCORR) applies to a point source only; there is no simple conversion at present for diffuse sources. The data in the two-dimensional rectified, flux-calibrated images are appropriate for diffuse, continuum sources. The keyword DIFF2PT is written to the `_x2d` (or `_sx2`) image header to allow the extraction of point source flux from the 2-D rectified data. DIFF2PT is *not* found in the output written during one-dimensional extraction. See “Working with Two Dimensional Extracted Spectra” on page 23-3 for details.

GEOCORR

Geometric correction is part of secondary 2-D image reduction and is applicable to all ACCUM mode imaging and spectroscopic data, but imaging data is not currently rectified because suitable reference files do not yet exist.

The method used is similar to 2-D rectification of spectroscopic data (see “X2DCORR” on page 21-29). For each pixel in the output rectified image, the corresponding point is found in the input distorted image, and bi-linear interpolation is used on the four nearest pixels to determine the value to assign to the output. Mapping from an output pixel back into the input images specified by two-dimensional Chebyshev polynomials stored in the format generated by the IRAF **gsurfit** package.

GLINCORR and LFLGCORR

These steps are part of basic 2-D image reduction and are performed only for the MAMA detectors. The MAMAs are photon counting detectors. At high photon (pulse) rates, the MAMA response becomes nonlinear due to three effects:

- Pore paralysis in the micro channel plates arises when charge cannot flow rapidly enough to replenish channels whose electrons have been depleted due to high local photon rates. This depletion produces a *local* non-linear-

ity. The local count rate is roughly linear up to counts rates of ~200 counts/second/pixel and then turns directly over, showing an inverted V shape. Thus it is not possible to reliably correct for or flag pixels which have exceeded the local linearity limit in the pipeline (because the relation is bi-valued).

- The electronic processing circuitry has a dead-time of roughly 350 nano-seconds between pulses; thus at global count rates (across the detector) of 300,000 counts (pulses) per second, the electronic circuity counts roughly 90% of the pulses.
- The MIE electronics and flight software can process at most 300,000 pulses per second (i.e., it is matched to the expected global count rate performance of the electronic circuitry). At count rates higher than this, the MIE will still count only 300,000 pulses per second—this represents a hard cutoff beyond which no information is available to allow correction to the true count rate. In practice, at count rates approaching 270,000 counts/sec the flight software begins losing counts due to the structure of its data buffers. Further work is needed to understand this effect.

  For subarrays, the hard cutoff limit of the MIE electronics and software will differ from that for full frame processing, but will still be dependent on the total global rate in addition to the rate within the subarray. The **calstis** pipeline currently applies the full frame correction to subarray data.

The global count rate (across the entire detector) is determined as part of the bright object protection sequence and is passed down with the exposure as a header keyword, GLOBRATE in the science header. If either GLINCORR or LFLGCORR is PERFORM, the global count rate will be checked; a correction for global non-linearity applied if GLINCORR is PERFORM, using the parameters GLOBAL_LIMIT, LOCAL_LIMIT, TAU, and EXPAND read from the MLINTAB reference table.

If the value of the SCI extension header keyword GLOBRATE is greater than GLOBAL_LIMIT, the keyword GLOBLIM in the SCI extension header will be set to EXCEEDED; otherwise, GLOBLIM will be set to NOT-EXCEEDED, and a correction factor will be computed and multiplied by each pixel in the science image and error array. The correction factor is computed by iteratively solving GLOBRATE = X * exp (-TAU * X) for X, where X is the true count rate. This algorithm has not yet been updated to account for the linearity effects from the flight software data buffer management.

If LFLGCORR is PERFORM, each pixel in the science image is also compared with the product of LOCAL_LIMIT and the exposure time EXPTIME. That count rate limit is then adjusted for binning by dividing by the pixel area in high-res pixels. If the science data value is larger than that product, that pixel and others within a radius of EXPAND high-res pixels are flagged as nonlinear. Because our understanding of the MAMA processing electronics is currently incomplete, accurate fluxes (global linearity) at count rates exceeding 270,000 count/sec cannot be expected from the **calstis** pipeline.

HELCORR

This step is part of spectral extraction. The correction of wavelengths to a heliocentric reference frame is controlled by calibration switches HELCORR and DISPCORR—if both switches are set to PERFORM then the correction is made. The functional form of the correction (shown below) requires the calculation of the heliocentric velocity (v) of the earth in the line of sight to the target.

$$\lambda_{helio} = \lambda\left(1 + \frac{v}{c}\right)$$

where:

- λ_{helio} is the heliocentric wavelength.
- λ is a particular wavelength.
- v is the component of the velocity of the earth in the direction of the target.
- c is the speed of light.

The derivatives of low-precision formulae for the sun's coordinates described in the *Astronomical Almanac* are used to calculate the velocity vector of the earth in the equatorial coordinate system of the epoch J2000. The algorithm does not include earth-moon motion, sun-barycenter motion, nor light-time correction from the earth to the sun. This value for the Earth's velocity should be accurate to ~0.025 km/sec during the lifetime of STIS. (Note that the uncertainty of 0.025 km/s is much less than the ~2.6 km/s resolution obtained with the STIS high dispersion echelle gratings.) The value of heliocentric velocity, v, is written to the trailer file.

LORSCORR

This step is part of basic 2-D image reduction and is performed for MAMA data only. MAMA data are, by default, taken in high resolution mode (2048 x 2048 pixels), in which the individual microchannel plate pixels are subsampled by the anode wires. This mode produces an image with improved sampling but with appreciably worse flatfielding properties (see the *STIS Instrument Handbook* for more details). If LORSCORR is set to PERFORM, **calstis** simply adds the counts in pairs of adjacent pixels to produce images in the native format (or so-called *reference format*) of the MAMA detectors, with 1024 x 1024 pixels.

The binning of the uncalibrated image is determined from the LTM1 and LTM2 keywords in the SCI extension header of the raw data file. LTM*i* = 1 implies the reference pixel size, and LTM*i* = 2 means the pixels are subsampled into high-res format. In this step, if either or both axes are high-res, they will be binned down to low-res. The binning differs from binning reference files to match an uncalibrated image, in that the pixel values in this step are summed rather than averaged.

PHOTCORR

This step is part of basic 2-D image reduction and is applicable only for OBSTYPE=IMAGING data. For image mode, the total system throughput is read

in from the PHOTTAB reference table. The photometric keywords PHOTFLAM, PHOTBW, and PHOTPLAM are computed using a **synphot** routine to determine the inverse sensitivity, reference magnitude, pivot wavelength, and rms bandwidth. Each quantity is written to a keyword in the primary header.

RPTCORR

This step is part of secondary 2-D image reduction and is applicable only for MAMA data. If the number of repeat exposures is greater than one, then **calstis** will sum the final calibrated output file—either the flatfielded data in the case of image mode data (producing a `_sfl.fits` file) or the two-dimensionally extracted data (producing a `_sx2.fits` file) in the case of long-slit data. RPTCORR just applies a straight pixel-to-pixel addition of the science values, bit-wise ORs the data quality files and determines the error as the square root of the sum of the squares of the errors in the individual exposures.

SGEOCORR

This step is part of spectral extraction and applies only to MAMA data, but it is not presently performed. If SGEOCORR were PERFORM, a correction would be applied for the small scale geometric distortions in the MAMA detectors. These distortions are not adequately removed by the dispersion or spectrum or the two dimensional tracings. The corresponding reference file, SDSTFILE, contains the distortion offsets for each pixel in the MAMA image. For one-dimensional spectral extraction, all AXIS2 positions in the input image must be modified by the AXIS2 small scale distortion deltas in the small-scale distortion file. Because we do not interpolate pixels in the dispersion direction for one dimensional spectral extractions, no corrections are made to the AXIS1 positions prior to reading or extracting pixel values. Instead, the AXIS1 deltas are used to correct the assigned wavelengths.

SHADCORR

This step is part of basic 2-D image reduction and applies only to CCD data, but it is not currently performed. It is designed to correct for shading by the CCD shutter in very short integration time exposures. The STIS CCD shutter is specified to produce exposure non-uniformity less than or equal to 5 milliseconds for any integration time: the shortest possible STIS CCD exposure time is 100 milliseconds. Ground testing has shown that this step is not currently required.

WAVECORR

This step is a part of WAVECAL processing and applies only to spectroscopic data. The purpose of wavecal processing is to determine the shift of the image on the detector along each axis owing to uncertainties in positioning by the Mode Select Mechanism (MSM) and to thermal motions. It requires one or more contemporaneous wavecal (line lamp) observations, taken without moving the MSM from the setting used for the science data.

Basic two-dimensional image reduction (**basic2d**) is first applied to the wavecal. For CCD data taken with the hole in the mirror (HITM) system the external shutter is ordinarily open, so the detector will have been exposed to radiation from both the science target and the line lamp. In this case, the next step is to scale the flatfield ed science image by the ratio of exposure times and subtract

it from the flatfield ed wavecal. Two-dimensional rectification (**x2d**, see X2DCORR below) is then applied to the flatfielded (and possibly science subtracted) wavecal.

Because wavecal data are not CR-SPLIT, cosmic rays must be identified and eliminated by looking for outliers within columns, i.e., in the cross-dispersion direction. Since the data have been rectified, the image can be collapsed along columns to get a long-slit integrated spectrum or along rows to get an outline of the slit (in the cross-dispersion direction).

The shift in the dispersion direction is found by cross-correlating the observed wavecal spectrum with a template spectrum. In the cross dispersion direction, edge location is used for medium and long slits, and cross correlation is used for very short, echelle, slits. The long slits have two occulting bars, and it is the edges of these bars that are used for finding the location. Edges are found by convolving the cross-dispersion profile with the array [–1, 0, +1]. The peak in cross correlation and the edge location are obtained to subpixel level by fitting a quadratic polynomial to the three pixels nearest the extremum.

The shifts are initially measured in units of pixels of the wavecal image, but they are then scaled (depending on the binning of the wavecal) to the reference pixel size (unbinned CCD or low-res MAMA). They are subsequently written to the extension header of the 2-D rectified wavecal in the keywords SHIFTA1 (the shift in pixels along AXIS1, or dispersion direction) and SHIFTA2 (the shift in pixels along AXIS2, or spatial direction). The SHIFTA1 and SHIFTA2 keyword values are also copied from the 2-D rectified wavecal file to the flatfielded science extension header. This is the final step performed on the science data prior to 2-D rectification or 1-D extraction of the science data in the pipeline.

Either or both the wavecal file and science file can contain multiple exposures, and the image can drift across the detector over time due to such things as, thermal effects, so it is necessary to select the most appropriate wavecal exposure for each science exposure. Currently, the wavecal exposure nearest in time to a given science exposure is the one selected. Future enhancements may include interpolation of the appropriate shift.

X1DCORR

This step is part of spectral extraction. If X1DCORR is PERFORM, **calstis** will locate a one-dimensional spectrum to extract, and extract and flux calibrate the spectrum.

Locate the Spectrum

The nominal location of the spectrum is specified in the spectrum trace table, SPTRCTAB and is given by (A1CENTER, A2CENTER) from this table. These coordinates are not constrained to be integers. The nominal position along the slit must be modified to include the previously updated position information found in the header. The nominal A2CENTER position of the spectrum (i.e., the position of the target along AXIS2, or the slit direction) is calculated as follows:

$$A2CENTER = A2CENTER + SHIFTA2 + MOFFSET2$$

where the variables are as described in Table 21.2 `sptrctab` also contains the description of the distorted shape of the spectrum. The shape is stored as an array consisting of pixel offsets (in the AXIS2 direction) relative to the nominal center of the spectrum (A2CENTER). This spectrum trace is used to find, and eventually to extract, the 1-D spectrum.

The location of the spectrum is improved by searching in the vicinity of the nominal location of the spectrum by performing a cross-correlation between the distortion vector and the input spectrum image. The search extends for $\pm n$ pixels around the nominal center, where *n* is read from the MAXSEARCH column in the XTRACTTAB table. At each AXIS2 position in the search range (which differs from the nominal center by an integer number of pixels) a sum of the counts along the spectrum shape is formed. This sum is created by adding the value of one pixel's worth of data at each of the AXIS1 pixel positions. The pixel extracted in the AXIS2 direction is centered on the spectrum position (A2CENTER + pixel offset) and may include fractional contributions from two pixels. Quadratic refinement is used to locate the spectrum to a fraction of a pixel.

The final A2CENTER becomes:

$$A2CENTER = A2CENTER + CRSCROFF$$

where CRSCROFF is the offset found during the cross correlation. If the cross correlation fails, the value of CRSCROFF is set to zero, a warning message is written to the output, and the A2CENTER calculated prior to the cross correlation attempt is used as the location of the spectrum. CRSCROFF is written to the output science header.

An alternate method for performing the cross correlation may be employed. In this case a 2-D template is created from the spectrum trace table. The cross correlation is carried out between the 2-D template and input image. Quadratic refinement is used as above to refine the position of the center of the spectrum to a fraction of a pixel.

Extract the 1-D Spectrum

The extraction of the spectrum is defined by a triplet of extraction *boxes* found in the reference table, XTRACTAB. For each pixel in the dispersion direction, **calstis** sums the values in the spectrum extraction box. The extraction box is one pixel wide and has a height determined from the EXTRSIZE parameter in XTRACTAB, centered on the spectrum. (Remember that we determined the center of the spectrum in the previous step.) The height of the extraction box may include a fractional part of one or two pixels. In the case of a fractional pixel, **calstis** will scale the counts in the given pixel by the fraction of the pixel extracted. Thus, each pixel in the output spectrum consists of the sum of some number (or fraction) of pixels in the input image.

The extraction of the spectrum allows for unweighted or optimal extraction. The extraction algorithm is selected based on the value of the reference table parameter XTRACALG. This flag has possible values of UNWEIGHTED and OPTIMAL. The value of XTRACALG is written to the header of the output spectrum data file. At present, **calstis** performs an unweighted extraction of the 1-D spectra; the optimal extraction algorithm has not yet been implemented. At the end of the 1-D extraction step, a spectrum of gross counts/second is produced.

X2DCORR

This step is part of spectral extraction and applies to two-dimensional extraction. If X2DCORR is PERFORM, a two dimensional rectified image will be produced for spectroscopic data. The two-dimensional rectified output image (`_x2d.fits` or `_sx2.fits`) will have a linear wavelength scale and uniform sampling in the spatial direction. The dispersion direction is the first image axis (AXIS1). The size of the rectified image is made somewhat larger (the increase can be substantial for subarrays) than the input in order to allow for variations in heliocentric correction and offsets of the spectrum on the detector. The binning of the output image will be approximately the same as the input. For each pixel in the output rectified image, the corresponding point is found in the input distorted image and bi-linear interpolation is used on the four nearest pixels to determine the value to assign to the output. No correction for flux conservation is applied, as this is accounted for in the flatfield.

Mapping from an output pixel back into the input image makes use of the dispersion relation and one-dimensional trace table. The dispersion relation gives the pixel number as a function of wavelength and spectral order. The one-dimension trace is the displacement in the cross dispersion direction at each pixel in the dispersion direction. Both of these can vary along the slit, so the dispersion coefficients and the one-dimensional trace are linearly interpolated for each image line. Corrections are applied to account for image offset, binning, and subarray. The spectrum can be displaced from its nominal location on the detector for several reasons, including Mode Select Mechanism (MSM) uncertainty, deliberate offsets for distribution of charge extraction for MAMA data, and the aperture location relative to a reference aperture. These offsets are accounted for by modifying the coefficients of the dispersion relations and by adjusting the location of the one-dimensional trace. See also DISPCORR and FLUXCORR for algorithmic details. The process of dispersion solution, spatial rectification, and wavelength calibration is similar for one-dimensional and two-dimensional spectral-extracted data; the flux calibration is somewhat different for one- and two-dimensional extractions, however. See “Working with Two Dimensional Extracted Spectra” on page 23-3 for details.

21.5 Recalibration of STIS Data

Sometimes the default pipeline calibration, performed shortly after the data were obtained from the telescope, is not the best possible calibration for your science program. There are a number of reasons why it may be desirable to recalibrate your data. The most likely reasons include:

- More appropriate reference files have become available since the pipeline calibration was performed. CCD darks, biases, and hot pixel tables are examples of reference files that are updated frequently, but they require some time to be installed in the pipeline. Likewise we expect to be delivering updated sensitivity files during Cycle 7, updated flatfields, updated

aperture throughputs, and so on. In short, over the next year or so, we expect regular improvements in reference files as we carry out the initial on-orbit calibration of STIS.

- Contemporaneous CCD flatfields were obtained with the science data for G750L or G750M NIR observations to remove fringing.
- Some steps need to be repeated with different input parameters. For example, you may wish to re-perform the cosmic ray rejection or the 1-D spectral extraction after adjusting the input parameters. The best target and background extraction regions for extracting 1-D spectra can depend on the science goals of the program. In addition, no extraction is currently performed for first-order spectral modes, so GOs with first-order spectra of standard stars will commonly also wish to perform one-dimensional extraction.
- The calibration software has been enhanced; here again we expect frequent updates over the course of the next year (see Chapter 25).

The STIS calibration pipeline was designed to accommodate the need for full or partial recalibration. As mentioned at the beginning of this chapter, **calstis** is re-entrant, so that certain calibration steps can be performed outside of the pipeline, and others can be executed multiple times, depending upon the science goals.

Generally, the calibration switches in the header control the operations that **calstis** performs on the data. There are three basic ways to select which operations are performed during calibration:

- Edit the calibration switches and run the **calstis** task.
- Use one or more of the pipeline subset tasks described below, managing the calibration through task parameters.
- Run the **calstis** sub-tasks at the host level (i.e., outside of IRAF) using the command-line switches and flags to control the processing.

This section describes the first two methods. In the end, the calibration switches in the headers of the calibrated data files will reflect the operations performed on the calibrated data and the reference files used.

21.5.1 Mechanics of Full Recalibration

You have chosen to fully recalibrate your STIS data. There is a certain amount of set-up required for **calstis** to run properly. The operations mentioned in the checklist below will be described in detail in the following subsections:

1. Set up a directory with the required reference files.
2. Determine which reference files are needed and retrieve them from the Archive.
3. Set the environment variable `oref` to point to your reference file directory. *Note:* you must do this before starting an IRAF session!
4. In an IRAF session, update the input data file headers using **chcalpar**:

- Set the calibration switches to perform the needed steps.
- Update the reference file names.

5. Run **calstis** or a subset of its constituent tasks.

Retrieve Reference Files

To recalibrate your data, you will need to retrieve the reference files used by the different calibration steps to be performed. The names of the reference files to be used during calibration must be specified in the primary header of the input files, under the section "CALIBRATION REFERENCE FILES." Note that the data headers will already be populated with the names of the reference files used during pipeline calibration at STScI.

Chapter 1 describes how to obtain the best available reference files from the HST Data Archive using StarView. For each dataset in the Archive, StarView will list both the reference files used in the initial calibration and the ones currently recommended. This list also indicates in the "Level of Change" column how much the reference files used differ from the recommended ones.

If better calibration reference files have become available since the original pipeline calibration, they can be retrieved from the HST Data Archive as explained in Chapter 1. These files might contain updated information about the instrument signatures, such as an updated hot pixel list or a bad pixel table, or an improved background bias level in a bias frame. Note that "new" does not necessarily mean that the data need to be recalibrated. Use the "Level of Change" information provided by StarView to help determine if recalibration is necessary.

The STIS reference files are all in FITS format, and can be in either IMAGE or BINTABLE extensions. The names of these files along with their corresponding primary header keywords, extensions, and format (image or table), are listed in Chapter 2. The (somewhat obscure) rootname of a reference file is based on the time that the file was delivered to the Calibration Data Base System (CDBS).

Edit the Calibration Header Keywords

To edit file headers in preparation for recalibration, use the STSDAS task **chcalpar**. The **chcalpar** task takes a single input parameter—the name(s) of the raw data files to be edited. When you start **chcalpar**, the task automatically determines that the data are from STIS, determines the detector used and whether the observing mode was SPECTROSCOPIC or IMAGING, and opens one of four STIS-specific parameter sets (*pset*) that will load the current values of all the calibration-related keywords. To edit the calibration keyword values:

1. Start the **chcalpar** task, specifying a list of images in which you want to change calibration keyword values. If you specify more than one image, (using wildcards, for example) the task will read the initial keyword values from the first image in the list. For example, you could change keywords for all STIS raw science images in the current directory (with initial values from the first image), using the command:

```
ct> chcalpar o*_raw.fits
```

2. After starting **chcalpar**, you will be placed in **eparam**—the IRAF parameter editor; from there you will be able to edit the set of calibration key-

words. Change the values of any calibration switches, reference files or tables to the values you wish to use for recalibrating your data.

3. Exit the editor when you are done making changes by typing "`:q`" two times. The task will ask if you wish to accept the current settings. If you type "y", the settings will be saved and you will return to the IRAF `cl` prompt. If you type "n", you will be placed back in the parameter editor to redefine the settings. If you type "a", the task will abort and any changes will be discarded.

The parameter editor screen for STIS MAMA spectroscopy is illustrated in Figure 21.11. The characters "`oref$`" preceding the names of the reference files specify a logical directory for the location of the reference files. The method for setting a corresponding environment variable is given in the next subsection.

Figure 21.11: Editing Calibration Keywords with chcalpar

It is also possible to use **hedit** to update the input file keywords. The example below illustrates how to turn on the bias correction switch and update the name of the bias image reference file for all STIS raw images in the current directory that begin with the characters "o3y."

```
cl> hedit o3y*_raw.fits[0] biascorr PERFORM up+
cl> hedit o3y*_raw.fits[0] biasfile "oref$new_bias.fits" up+
```

It is dangerous to change keyword values with **hedit** if the keywords reside in the FITS primary header unit, as is the case with all calibration keywords. The correct way to use this task on inherited keywords is to edit the primary header explicitly by appending "[0]" to the FITS file name.

For each task (except **calstis**) it is not necessary to specify which calibration steps to perform in the primary header keywords of the input files. The execution of each step can be specified in the input parameters task of each stand-alone. The only exception is **calstis** where the switches in the primary header control the calibration steps to be performed.

The reference file names for all the stand-alone tasks and **calstis** have to be specified in their corresponding header keywords. See Table 20.5 for the list of reference files that correspond to each executable.

Running calstis in IRAF

Before running **calstis**, you will need to define an environment variable to indicate the location of the directory containing the needed calibration reference files. The names of the calibration files are preceded with the logical path name "`oref$`" in the STIS science headers. Ordinarily you would define this directory in an IRAF session to be, for example., "`/data/vega3/stis/cal_ref`" using the **set** command:

```
cl> set oref "/data/vega3/cal_ref/" # Won't work!
```

Note the trailing slash (/). However, **calstis** and all of its modules are actually foreign tasks and as such do not access IRAF environment variables. Therefore, *before invoking the **cl***, you will need to define an environment variable from the host command line (see below) that is appropriate to your host machine. For Unix systems, the appropriate command for the example above is:

```
% setenv oref /data/vega3/cal_ref/
```

Then start IRAF.

When running **calstis** or any of its modules, you must define environment variables (such as `oref$`) *before* starting the **cl**. It is *not* possible to define them within IRAF using the **set** command, nor is it possible to define them with an escape to the host level, such as: `!setenv oref /data/vega3/cal_ref/`

21.5.2 Rerunning Subsets of the Calibration Pipeline

Selected portions of the pipeline can be executed with special tasks in the STSDAS **stis** package. The tasks that can be simply used in this fashion are listed

in Table 21.5 below. See also Table for the association between **basic2d**, **ocrreject**, **wavecal**, **x1d**, and **x2d** and the components of the **calstis** pipeline. When you run these tasks individually, many of the calibration parameters usually read from the reference file can be entered either as command line arguments or via **epar**.

The **inttag** task for TIMETAG data will accumulate selected events from the raw event table, writing the results as one or more image sets (imsets) in a single, output FITS file. You can optionally specify an explicit starting time, time interval, and number of intervals over which to integrate, and the collection of imsets will be written to the output file, simulating a REPEATOBS ACCUM observation. Breaking the data into multiple, short exposures can be useful not only for variables but also to improve the flatfielding when the Doppler shift is significant. Once the images have been created, it is straightforward to process them with **calstis** and to analyze the output image or spectra, as appropriate.

The screen messages that appear when running any **calstis** module are equivalent to the trailer file contents delivered with the data.

Table 21.5: calstis Pipeline Calibration Tasks

Task	Description
basic2d	Perform basic 2-D calibration.
inttag	Integrate TIMETAG event list to form an image.
ocrreject	Combine images, rejecting cosmic rays.
wavecal	Process wavecal images.
x1d	Extract 1-D spectrum.
x2d	Rectify spectral images.

Combining Images to One File

Each calibration task (including **calstis** itself) takes only one science file as input, though it is sometimes useful to perform only part of **calstis**, such as cosmic ray rejection, on a set of images as if they were part of a repeated series. The prescription is to copy the relevant input files to a single FITS file with multiple imsets, per the format described in Figure 20.6 and Figure 20.7, and then run the relevant calibration task on the combined file. (Such a procedure is, in fact, useful for constructing bias and dark reference files for the CCD.) The easiest way to do this, while preserving the correct file format, is to use the **mstools.msjoin** task. For example, to combine two FITS files while removing cosmic rays:

```
cl> msjoin file1.fits,file2.fits big_file.fits
cl> ocrreject big_file.fits combined.fits
```

21.6 Updates to calstis

We expect **calstis** modules to evolve and improve with time, particularly during Cycle 7, as we understand and characterize more fully the on-orbit performance of STIS. It is possible, even likely, that improvements in the **calstis** software will improve the calibration of your data. To determine the version of the software used to calibrate your data, note the value of the CAL_VER keyword in the data header. The following example uses **hselect** to print the rootname, the optical element, and the version of **calstis** for all `_flt` files in the current directory:

```
cl> hselect o*_flt.fits[0] "rootname,opt_elem,cal_ver" yes
```

Watch the Space Telescope Analysis Newsletters (STANs) or consult the STIS WWW pages for any announcement of enhancements to **calstis.** If you are uncertain whether a given enhancement to **calstis** merits recalibrating your data, contact the Contact Scientist for your program. Often, it is instructive to recalibrate and to determine empirically whether the revised calibration files or software affect the scientific interpretation of your data. If you need to upgrade your version of the **stis** package, contact your IRAF system administrator.