Guide to the CTIO Slit Spectra Reduction Task SPECPROC

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ABSTRACT

The IRAF **specred** package is specialized for the extraction, sky subtraction, wavelength calibration, and flux calibration of CTIO slit spectra. It contains the general tools needed for each reduction step. However, the main emphasis of this package is to streamline the complete reduction by combining all the steps into a single task **specproc** and collecting all the processing, instrument, and algorithm parameters into a few parameter sets. This guide describes what this task does, it's usage, and parameters.

1. Introduction

The IRAF **specred** package is specialized for the extraction, sky subtraction, wavelength calibration, and flux calibration of CTIO slit spectra. It contains the general tools needed for each of the reduction steps. However, the main emphasis of this package is on tasks to streamline the complete data reduction. This guide describes the task **specproc** for reducing CTIO slit observations. It is primarily intended for spectrophotometry or radial velocities of single stars observed at nearly the same point on the slit; extended objects requiring accurate geometric alignment over many pixels requires using the **longslit** package. The goals of the **specproc** task are:

[1] Combine all the reduction steps into a single task.

[2] Do the interactive calibration setup first, and only as needed, and allow the repetitive extraction, wavelength calibration, and flux calibration to be done noninteractively (and possibly as a background or batch job).

[3] Perform much of the record keeping and processing checks so that only unprocessed spectra are processed.

[4] Implement special operations and algorithms for this type of data which require many steps with the general tools.

This guide describes only the special processing task **specproc**. The other reduction and analysis tasks available in the **specred** package are described in their help pages. It is assumed that the reader is familiar with the IRAF environment and command language. For new IRAF users see one of the introductory guides given in the references and the user support staff.

The guide begins with a usage outline. If you have used this package before and simply need a refresher or checklist then this section is for you. A new user can read this to see how the task will be used or skip to later sections and return to it when ready to reduce some data. The following section outlines the basic reduction steps implemented in the task. This section is kept relatively brief but does fully describe what the task does. The remaining sections describe the parameters, data files, and algorithms in varying detail. There are many options and features available; too many to be covered even superficially. This guide concentrates on the basic features and the options recommended by the author and staff. Since the reduction task is based on more general tasks, identified in the discussion, all the options and features are described more fully in the help pages for these tasks.

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2. Usage Outline

This section outlines the basic usage. Later sections go into greater depth on the parameters and what the task does. The outline may be used as a refresher or checklist for those familiar with this task.

[1] If there are many spectra per setup prepare "@ files" for the objects, comparison arcs, and standard stars.

[2] Prepare an arc assignment table if desired.

[3] Set the basic **specred** package parameters.

[4] Modify any desired algorithm parameters in the parameter set **params**.

[5] Set the parameters for **specproc** and run the task.

[6] The aperture reference spectrum (usually a bright standard star) is located and a default fixed size aperture is assigned. You are then asked if you want to resize the aperture. The default resizing is based on finding the level which is 5% of the peak. You then have the option of entering the aperture editing loop to check the aperture position, size, and background fitting parameters. Finally the spectrum is traced. You are asked if you want to review and modify the trace and function fit.

[7] If the dispersion correction option is not selected the task goes to step [10]. The first arc in the comparison arc list, called the reference arc, is extracted and the task **identify** is executed. Identify a few arc lines with 'm', use the 'l' line list identification command to automatically add additional lines and fit the dispersion function. Check the quality of the dispersion function fit with 'f'. When satisfied exit with 'q'.

[8] If the flux calibration option is not selected the task goes to step [10]. Each standard star is extracted and wavelength calibrated. The appropriate arc calibration spectra may be extracted and the dispersion function refit using the arc reference spectrum as a starting point. The standard star fluxes through the calibration bandpasses are compiled. You are queried for the name of the standard star calibration data file.

[9] After all the standard stars are processed a sensivity function is determined using the interactive task **sensfunc**. Finally, the standard star spectra are extinction corrected and flux calibrated using the derived sensitivity function.

[10] The object spectra are now automatically processed. If the `batch` flag is set and the `edit` and `splot` flag are not set then the object spectra are processed by submitting a batch job and control returns to the user. Note that the interactive options `edit` and `splot` may be turned off with "NO" during the course of processing the objects, after which any remaining spectra will be processed as a batch job.

[11] The `splot` option allows you to view each extracted spectrum using the general plotting program **splot**.

[12] Additional objects can be processed or the dispersion option can be turned on if not done previously. The task will not reprocess the standard star or object spectra unless forced by the `update` or `redo` flags.

3. Processing Outline

This section outlines the operations performed by the processing task **specproc**. One goal of this task is to minimize the number of interactive steps. The (possibly) interactive steps are marked with an asterisk below. A second goal is to skip steps and spectra done previously.

[0] The input consists of object images, a spectrum position reference image, comparison arc images, standard star images, and optional arc assignment table.

The output consists of the extracted and calibrated spectra in *multispec* format. Optional output are a verbose log file and a plot file. In addition there will be various database files and the sensitivity function created during processing containing information which may be of interest.

[1]* If there is no aperture definition in the database for the specified aperture reference spectrum then the aperture is defined and traced. The aperture is first found automatically across the center of the image and the user is given the option of automatically resizing the apertures. The user is then given the option of reviewing and possibly modifying the aperture and the background subtraction parameters. The user is also given the option of interactively reviewing and adjusting the spectrum trace and fitting function.

[2] If dispersion correction is not selected then steps [2] and [3] are skipped. Otherwise the first arc in the comparison arc list is selected as the *dispersion reference arc*. All other arcs will be reidentified against this arc. Also the final linearized wavelength coordinates are based on this reference arc. If the reference arc has been processed this step is skipped.

[2a] The reference arc is extracted.

[2b]* The task **identify** is executed and the user defines the dispersion function interactively by identifying arc lines and fitting a function. Some knowledge of this task is required.

[2c]* The user is queried for the desired final linear dispersion parameters. All spectra will ultimately be put on the same wavelength scale. The default dispersion parameters are based on the range and number of pixels in the reference arc. However, the user may select any dispersion parameters desired.

[2d] The extracted reference arc is linearized.

[3] If flux calibration is not selected then step [3] is skipped. Each standard star is processed if it has not been previously or as required by the `update` and `redo` flags. When the `redo` flag is set the compiled standard star fluxes are reinitialized otherwise any new standard stars in the list of standard stars are added to previous standard star fluxes. The spectrum extraction and dispersion calibration are done as described in [5c] and [5d] for the object spectra.

[3a]* After each standard star spectrum has been extracted and dispersion corrected the user is queried for the name of the standard star calibration file (usually the name of the standard star) and the observed and tabulated fluxes through standard bandpasses are compiled.

[3b]* Once all the standard star fluxes have been compiled a sensitivity function is fit interactively using the task **sensfunc**. Some knowledge of this task is required.

[3c] The standard stars are extinction and flux calibrated.

[4] Object spectra which have not been processed are processed noninteractively unless the `edit` or `splot` options are selected. Note that extraction, dispersion correction, extinction correction, and flux calibration may be done at separate times or simultaneously depending on the processing options selected. Also the `redo` and `update` flags may cause previously processed spectra to be reprocessed. If the `batch` flag is set and the `edit` and `splot` flags are not set then the spectra will be processed by submitting a batch job. Otherwise the task will continue in the foreground. The following steps are performed on each object.

[5] If the recentering option is selected the center of the aperture is recentered on the object spectrum. The change in position must be small.

[6] If the resize option is selected the width of the aperture will be adjusted. The default algorithm is to set the width to 5% of the peak though other choices are possible.

[7]* If the `edit` parameter is yes then the extraction apertures may be reviewed and modified using the commands of the aperture editor (see **apedit**).

[8] Recentering is usually enough to compensate for the changes in the position of the object on the slit and shifts in the detector. However, if the change in the position of the spectrum is not a simple shift across the dispersion direction then the trace option allows retracing each object spectrum. The object spectra should have a reasonable signal for tracing. This is done noninteractively using the same function fitting parameters as in the reference aperture.

[9] If the object spectra are recentered or retraced then the pixels used will differ from object to object. One must then decide if the arc spectra should be reextracted for each object over the same pixels used for the object. The `arcap` parameter selects whether arc spectra should be extracted using the reference aperture or the redefined object aperture. Recentering probably does not cause a significant difference in the dispersion solution but retracing might if instrumental flexture allows changes in the tilt of the spectra relative to the image lines or columns. Reextraction of the same arc for different objects will only occur if the `arcap` parameter is set and if at least one of the `recenter` and `trace` parameters are set.

[9] The object spectra are extracted and sky subtracted.

[10] If not dispersion correcting steps [10] to [12] are skipped.

[10a] The calibration arcs are determined either from the arc list or an arc table. The default is to interpolate from the arc lists based on the UT parameter. The selected arcs are extracted as needed. If the `arcap` parameter is set and the object aperture has been redefined by recentering or tracing, the arc spectra will be reextracted for each object even if it was previously extracted for a different object.

[10b]* The lines in the arc spectra are reidentified and the dispersion function refit. If the objects are not extracted as a batch job, a statistics line is printed and the user may decide whether to examine the dispersion fit interactively and possibly delete lines or change fitting parameters.

[10c] The object spectrum is interpolated to a linear wavelength sampling.

[11] If the extinction correction option is set the spectrum is extinction corrected.

[12] If the flux correction option is set the spectrum is flux calibrated using the sensitivity function last determined from the standard stars.

[13]* If the `splot` option is selected a query is made whether to plot and examine the object spectrum using the **splot** task. You may respond with yes or no to examine or skip this spectrum or YES or NO to always examine or never examine further objects in this execution of the task. Answering NO allows subsequent objects to be extracted as a background/batch job if the `batch` flag is set and the aperture editing has been disabled.

4. Spectra and Data Files

The basic input consists of CTIO slit stellar object and arc calibration spectra stored as IRAF images. The raw CCD images must be processed to remove overscan, bias, dark count, and flat field effects. This is generally done using the **ccdred** package (see the references for information about this package). The dispersion must be closely aligned with one of the image axes. In some cases one may correct for misalignment with the **rotate** task. More complex geometric problems and observations of extended objects should be handled by the **longslit** package.

The assignment of arc calibration exposures to object exposures is generally done by selecting the nearest in time and interpolating. There are other options possible which are described under the task **refspectra**. The most general option is to define a table giving the object image name and the one or two arc spectra to be assigned to that object. That file is called an *arc assignment table* and is an optional parameter in **specproc**.

The final reduced spectra are recorded in a *multispec* format image. This is a special two or three dimensional image in which each line in a plane is a one dimensional spectrum with aperture and dispersion information stored in special image header keywords. The third dimension is created when using cleaning or variance weighting and contains the raw (uncleaned/unweighted) spectrum and variance spectrum (see **apextract** or **apsum** for further details). This type of spectral format is accepted by most of the one dimensional spectroscopy tools such as the plotting tasks **splot** and **specplot**. The reduced multispec image has the same name as the original two dimensional image with an added `.ms` extension.

5. Package Parameters

The **specred** package parameters set parameters which change infrequently, define the instrumental setup, and set the standard I/O functions. Figure 1 shows the default package parameters.

Figure 1: Example Package Parameter Set for SPECRED

```
cl> epar specred

                          I R A F
            Image Reduction and Analysis Facility
PACKAGE = imred
   TASK = specred

(extinct= onedstds$ctioextinct.dat) Extinction file
(caldir = onedstds$ctiocal/) Standard star calibration directory
(latitud=-30.16527778) Observatory latitude (degrees)

(databas=     database) Database
(verbose=           no) Verbose output?
(logfile=      logfile) Log file
(plotfil=              ) Plot file

(version= SPECRED V3: September 1990)
```

The extinction file and latitude are used for making extinction corrections. The standard star calibration directory contains standard star fluxes and band passes for determining the instrumental flux calibration from standard star observations. The observed standard stars must contain calibration data in this directory. There are a number of flux standard directories. Table 1 list the current set. Note that the logical directory name and the final / are required.

The verbose parameter selects whether to print everything which goes into the log file on the terminal. It is useful for monitoring everything that the task does. The log and plot files are useful for keeping a record of the

Table 1: Flux Standard Directories

```
 bstdscal - Directory of the brighter KPNO IRS standards
            (i.e. those with HR numbers) at 29 bandpasses
  ctiocal - Directory of CTIO standards
  iidscal - Directory of the KPNO IIDS standards (29 bandpasses)
   irscal - Directory of the KPNO IRS standards at 78 bandpasses
            (note that in this directory the brighter standards
            have no values - the 'bstdscal' directory must be
            used for these standards at this time )
   redcal - Directory of standard stars with flux data beyond
            8370A.  These stars are from the IRS or the IIDS
            directory but have data extending as far out into
            the red as the literature permits.
spechayescal - Spectrophotometric standards at the Hayes flux
            points, Table IV, Spectrophotometric Standards,
            Massey et al., 1988, Ap. J., Vol. 328, p. 315.
spec50cal - Spectrophotometric standards at 50 A intervals,
            Table V, Spectrophotometric Standards, Massey et al.,
            1988, Ap. J., Vol. 328, p. 315.
```

processing. A log file is highly recommended. The interactive graphics device is set by the environment variable STDGRAPH and the cursor input uses the CL parameter `gcur`.

6. Processing Parameters

Figure 2 shows the parameters and a typical setup for the processing task **specproc**. The list of objects, arcs, and standard stars can be @ files if desired. The aperture reference spectrum is a bright star. The list of arcs are the standard Th-Ar or HeNeAr comparison arc spectra (they must all be of the same type). The arc arc assignment table was described previously.

Figure 2: Example Parameter Set for SPECPROC

```
cl> epar specproc

                          I R A F
            Image Reduction and Analysis Facility
PACKAGE = specred
   TASK = specproc

objects =     @objects  List of object spectra
(apref  =       obs002) Aperture reference spectrum
(arcs   =        @arcs) List of arc spectra
(arctabl=             ) Arc assignment table (optional)
(standar=   @standards) List of standard star spectra

(recente=          yes) Recenter object apertures?
(resize =           no) Resize object apertures?
(edit   =           no) Edit/review object apertures?
(trace  =           no) Trace object spectra?
(arcap  =           no) Use object apertures for arcs?
(clean  =           no) Detect and replace bad pixels?
(dispcor=          yes) Dispersion correct spectra?
(extcor =           no) Extinction correct spectra?
(fluxcal=           no) Flux calibrate spectra?
(splot  =           no) Plot the final spectrum?
(redo   =           no) Redo operations if previously done?
(update =          yes) Update spectra if cal data changes?
(batch  =          yes) Extract objects in batch?
```

```
(listonl=           no) List steps but don't process?

(params =             ) Processing parameters
```

The next set of parameters select the processing steps and options. After defining the reference aperture there are several ways to modify it for each object and standard star spectrum. The `recenter` option shifts the reference aperture to the center of the spectrum determined at the default position. The shift must be *small*. This compensates for small errors in setting the object on the slit and flexture in the instrument. Large changes should be corrected by either a new reference aperture spectrum or interactively with the aperture editor. The shape of the trace function (change in position along the dispersion) is not affected.

The `resize` option resets the edges of the extraction aperture based on the profile at the default position. The default resizing is to the 5% point relative to the peak measured above the background. This allows following changes in the seeing. If you wish you may select the aperture editing option `edit` to interactively examine the apertures for each observation. This might be desirable if recentering. Use of this option excludes batch processing unless turned off with NO when queried for editing the apertures of an observation in a list of spectra.

In addition to tracing the aperture reference spectrum it is possible to trace each object spectrum by setting the `trace` option. The may be desirable if the spectra are relatively strong and one believes that there is some rotation of the detector relative to the spectra. Note that small shifts perpendicular to the dispersion are corrected by recentering. If the object spectra are recentered or retraced it may be desirable to extract the arc spectra used for dispersion calibrating the object using the same aperture as the object rather than the reference aperture. The `arcaps` parameter selects which aperture definition to use for the arc spectra. If the object apertures are used then the same arc spectrum may be extracted several times, once for each object.

The `clean` option invokes a profile fitting and deviant point rejection algorithm as well as a variance weighting of points in the aperture. These options require knowing the effective (i.e. accounting for any image combining) read out noise and gain. For a discussion of cleaning and varinace weighted extraction see **apvariance** and **approfiles**. The dispersion correction option selects whether to extract arc spectra, determine a dispersion function, assign them to the object spectra, and rebin the spectra to a linear (or log-linear) wavelength scale.

The processing options `dispcor`, `extcor`, and `fluxcal` select whether to dispersion calibrate, extinction correct, and flux calibrated the extracted spectra. The latter operations require that dispersion correction be done. Dispersion correction requires at least one arc spectrum and flux calibration requires standard star observations.

After the selected processing operations have been completed on an object spectrum the result may be examined with the interactive plotting task **splot**. This option is selected with the `splot` parameter. As with the aperture editing parameter, this excludes batch processing unless turned off during processing with NO to the plotting query for one of the spectra in the input list. The purpose of this is purely for monitoring and getting feedback on the processing and does not affect the results.

Generally once a spectrum has been processed it will not be reprocessed if specified as an input spectrum. However, changes to the underlying calibration data can cause such spectra to be reprocessed if the `update` flag is set. The changes which will cause an update are new reference apertures, new flat fields, new arc reference, and new standard stars. If all input spectra are to be processed regardless of previous processing the `redo` flag may be used. Note that reprocessing clobbers the previously processed output spectra.

The batch processing option allows object spectra to be processed as a background or batch job. This will only occur if aperture editing and final plotting parameters are turned off, either when the task is run or by responding with "NO" to the appropriate queries during processing.

The `listonly` option prints a summary of the processing steps which will be performed on the input spectra without actually doing anything. This is useful for verifying which spectra will be affected if the input list contains previously processed spectra. The listing does not include any arc spectra which may be extracted to dispersion calibrate an object spectrum.

The last parameter (excluding the task mode parameter) points to another parameter set for the algorithm parameters. The default parameter set is called `params`. The algorithm parameters are discussed further in the next section.

7. Algorithms and Algorithm Parameters

This section summarizes the various algorithms used by the **specproc** task and the parameters which control and modify the algorithms. The algorithm parameters available to the user are collected in the parameter set **params**. These parameters are taken from the various general purpose tasks used by the **specproc** processing task. Additional information about these parameters and algorithms may be found in the help for **specproc** and the actual task executed. These tasks are identified below. The aim of this parameter set organization is to collect all the algorithm parameters in one place separate from the processing parameters and include only those which are relevant for CTIO slit data. The parameter values can be changed from the defaults by using the parameter editor,

```
cl> epar params
```

or simple typing `params`. The parameter editor can also be entered when editing the **specproc** parameters by typing `:e` when positioned at the `params` parameter. Figure 3 shows the default parameter values.

Figure 3: Default Parameter Set for PARAMS

```
cl> params
                              I R A F
                 Image Reduction and Analysis Facility
PACKAGE = specred
   TASK = params

(line   =        INDEF) Default dispersion line
(nsum   =           10) Number of dispersion lines to sum

                        -- DEFAULT APERTURE LIMITS --
(lower  =          -3.) Lower aperture limit relative to center
(upper  =           3.) Upper aperture limit relative to center

                        -- AUTOMATIC APERTURE RESIZING PARAMETERS --
(ylevel =         0.05) Fraction of peak or intensity for resizing
(peak   =          yes) Is ylevel a fraction of the peak?
(bkg    =          yes) Subtract background for resizing?
(avglimi=           no) Average limits over all apertures?

                        -- TRACE PARAMETERS --
(t_step =           10) Tracing step
(t_funct=      spline3) Trace fitting function
(t_order=            2) Trace fitting function order
(t_niter=            1) Trace rejection iterations
(t_low  =           3.) Trace lower rejection sigma
(t_high =           3.) Trace upper rejection sigma

                        -- APERTURE EXTRACTION PARAMETERS --
(weights=         none) Extraction weights (none|variance)
(lsigma =           3.) Lower rejection threshold
(usigma =           3.) Upper rejection threshold

                        -- BACKGROUND SUBTRACTION PARAMETERS --
(backgro=          fit) Background to subtract (none|average|fit)
(b_funct=     legendre) Background function
(b_order=            1) Background function order
(b_sampl=  -10:-6,6:10) Background sample regions
(b_naver=           -3) Background average or median
(b_niter=            0) Background rejection iterations
(b_low  =           3.) Background lower rejection sigma
(b_high =           3.) Background upper rejection sigma

                        -- ARC DISPERSION FUNCTION PARAMETERS --
```

```
(coordli= onedstds$idhenear.dat) Line list
(match  =          10.) Line list matching limit in Angstroms
(fwidth =           4.) Arc line widths in pixels
(i_funct=      spline3) Coordinate function
(i_order=            1) Order of dispersion function
(i_niter=            0) Rejection iterations
(i_low  =           3.) Lower rejection sigma
(i_high =           3.) Upper rejection sigma
(refit  =          yes) Refit coordinate function when reidentifying?
(addfeat=           no) Add features when reidentifying?

                        -- AUTOMATIC ARC ASSIGNMENT PARAMETERS --
(select =       interp) Selection method for reference spectra
(sort   =     utmiddle) Sort key
(time   =          yes) Is sort key a time?
(timewra=          17.) Time wrap point for time sorting

                        -- DISPERSION CORRECTION PARAMETERS --
(interpo=        poly5) Interpolation type
(log    =           no) Logarithmic wavelength scale?
(flux   =          yes) Conserve flux?

                        -- SENSITIVITY CALIBRATION PARAMETERS --
(s_funct=      spline3) Fitting function
(s_order=            1) Order of sensitivity function
(fnu    =           no) Create spectra having units of FNU?
```

7.1. Extraction

The identification of the spectra in the two dimensional images and their extraction to one dimensional spectra in multispec format is accomplished using the **apextract** tasks. The first parameters through `b_high` control the extractions.

The dispersion line is that used for finding the spectra, for plotting in the aperture editor, and as the starting point for tracing. The default value of `INDEF` selects the middle of the image. The aperture finding, adjusting, editing, and tracing operations also allow summing a number of dispersion lines to improve the signal. The number of lines is set by the `nsum` parameter.

When the aperture for the reference spectrum is first identified and defined, the edges of the aperture relative to the center of the spectrum (measured in pixels) are set by the parameters `lower` and `upper` (see **apfind**). The reference aperture may be be automatically resized for each object. The automatic resizing can be set at a fraction of the peak pixel or as an absolute data level with or without a background subtracted (see **apresize**). The default is to resize the apertures at 5% of the peak pixel.

The next set of parameters control the tracing and function fitting of the aperture reference positions along the dispersion direction. The position of a spectrum across the dispersion is determined by the centering algorithm (see **center1d**) at a series of evenly spaced steps, given by the parameter `t_step`, along the dispersion. The step size should be fine enough to follow position changes but it is not necessary to measure every point. The fitted points may jump around a little bit due to noise and cosmic rays even when summing a number of lines. Thus, a smooth function is fit. The function type, order, and iterative rejection of deviant points is controlled by the other trace parameters. For more discussion consult the help pages for **aptrace** and **icfit**. The default is to fit a cubic spline of two pieces with a single iteration of 3 sigma rejection.

The actual extraction of the spectra by summing across the aperture at each point along the dispersion is controlled by the next set of parameters. The default extraction simply sums the pixels using partial pixels at the ends. The options allow selection of a weighted sum based on a Poisson variance model using the `readnoise` and `gain` detector parameters. Note that if the `clean` option is selected the variance weighted extraction is used regardless of the `weights` parameter. The sigma threshold for cleaning are also set in the **params** parameters. For more on the variance weighted extraction and cleaning see **apvariance** and **approfiles** as well as **apsum**.

Normally the sky background is determined from points just outside the extraction aperture. The background subtraction options are to do no background subtraction, subtract the average of the pixels in the background regions,

or to fit a function and subtract the function from under the extracted object pixels (the default). The background regions are specified in pixels from the aperture center and follow changes in center of the spectrum along the dispersion. The syntax is colon separated ranges with multiple ranges separated by a comma or space. The background fitting uses the **icfit** routines which include medians, iterative rejection of deviant points, and a choice of function types and orders. The fitting parameters can be set at the default display line using the 'b' command when in the aperture editing mode. This is useful for careful placement of background regions around contaminating objects.

7.2. Dispersion Correction

Dispersion corrections are applied to the extracted spectra if the `dispcor` processing parameter is set. This is a complicated process which the **specproc** task tries to simplify for you. There are three basic steps involved; determining the dispersion functions relating pixel position to wavelength, assigning the appropriate dispersion function to a particular observation, and resampling the spectra to evenly spaced pixels in wavelength.

The first arc spectrum in the arc list is used to define the reference dispersion solution. It is extracted using the reference aperture definition. Note extractions of arc spectra are not background subtracted. The interactive task **identify** is used to define the dispersion function. The idea is to mark some lines whose wavelengths are known (with the line list used to supply additional lines after the first few identifications define the approximate wavelengths) and to fit a function giving the wavelength from the pixel position. This is a complex program and you should consult the help for this task.

The arc dispersion function parameters are for **identify** and it's related partner **reidentify**. The parameters define a line list for use in automatically assigning wavelengths to arc lines, a centering width (which should match the line widths), the dispersion function type and order, parameters to exclude bad lines from function fits, defining whether to refit the dispersion function, as opposed to simply determining a zero point shift, and the addition of new lines from the line list when reidentifying additional arc spectra. The defaults should generally be adequate and the dispersion function fitting parameters may be altered interactively. One should consult the help for the two tasks for additional details of these parameters and the operation of **identify**.

Once the reference dispersion function is defined other arc spectra are extracted as required by the object spectra. The assignment of arcs is done either explicitly with an arc assignment table (parameter `arctable`) or based on a header parameter. The task used is **refspectra** and the user should consult this task if the default behavior is not what is desired. The default is to interpolate linearly between the nearest arcs based on the universal time (corrected to the middle of the exposure).

If the object spectra are recentered or retraced then the pixels used will differ from object to object. One must then decide if the arc spectra should be reextracted for each object over the same pixels used for the object. The `arcap` parameter selects whether arc spectra should be extracted using the reference aperture or the redefined object aperture. Recentering probably does not cause a significant difference in the dispersion solution but retracing might if instrumental flexture allows changes in the tilt of the spectra relative to the image lines or columns. Reextraction of the same arc for different objects will only occur if the `arcap` parameter is set and if at least one of the `recenter` and `trace` parameters are set. When reextracting arcs based on individual object traces the extractions are not kept and the dispersion database information is recorded under the name of the object concatenated with the arc.

Redefining the dispersion function for an arc uses the task **reidentify**. This may be done completely noninteractively or, if not in batch mode and using the `refit` option, you may review the fitting based on the statistics of the new dispersion fit.

The last step of dispersion correction (interpolating the spectrum to evenly spaced pixels in wavelength) is relatively straightforward. The algorithm parameters allow selecting the interpolation function type, whether to conserve flux per pixel by integrating across the extent of the final pixel, and whether to linearize to equal linear or logarithmic intervals. The latter may be appropriate for radial velocity studies. The default is to use a fifth order polynomial for interpolation, to conserve flux, and to not use logarithmic wavelength bins. These parameters are described fully in the help for the task **msdispcor** which performs the correction.

7.3. Flux Calibration

Flux calibration consists of an extinction correction and an instrumental sensitivity calibration. The extinction correction only depends on the extinction function defined by the package parameter `extinct` and determination of the airmass from the header parameters. The sensitivity calibration depends on a sensitivity calibration spectrum determined from standard star observations for which there are tabulated absolute fluxes. The task that applies both the extinction correction and sensitivity calibration to each extracted object spectrum is **calibrate**. Consult the manual page for this task for more information.

Generation of the sensitivity calibration spectrum is done before processing any object spectra since it has two interactive steps and requires all the standard star observations. The first step is tabulating the observed fluxes over the same bandpasses as the calibrated absolute fluxes. This is done after each standard star is extracted and dispersion corrected. You are asked for the name of the standard star as tabulated in the absolute flux data files in the directory `caldir` defined by the package parameters. The tabulation of the standard star observations over the standard bandpasses is done by the task **standard**. The tabulated data is stored in the file `std`. Note that if the `redo` flag is not set any new standard stars specified in subsequent executions of **specproc** are added to the previous data in the data file, otherwise the file is first deleted. Modification of the tabulated standard star data, such as by adding new stars, will cause any spectra in the input list which have been previously calibrated to be reprocessed if the `update` flag is set.

After the standard star calibration bandpass fluxes are tabulated the information from all the standard stars is combined to produce a sensitivity function for use by **calibrate**. The sensitivity function determination is interactive and uses the task **sensfunc**. This task allows fitting a smooth sensitivity function to the ratio of the observed to calibrated fluxes verses wavelength. The types of manipulations one needs to do include deleting bad observations, possibly removing variable extinction (for poor data), and possibly deriving a revised extinction function. This is a complex operation and one should consult the manual page for **sensfunc**. The sensitivity function is saved as a spectrum with the root name `sens`. Deletion of this file will also cause reprocessing to occur if the `update` flag is set.

8. References

8.1. IRAF Introductory References

Work is underway on a new introductory guide to IRAF. Currently, the work below is the primary introduction.

P. Shames and D. Tody, *A User's Introduction to the IRAF Command Language*, Central Computer Services, NOAO, 1986.

8.2. CCD Reductions

F. Valdes, *The IRAF CCD Reduction Package -- CCDRED*, Central Computer Services, NOAO, 1987.

F. Valdes, *User's Guide to the CCDRED Package*, Central Computer Services, NOAO, 1988. Also on-line as `help ccdred.guide`.

P. Massey, *A User's Guide to CCD Reductions with IRAF*, Central Computer Services, NOAO, 1989.

8.3. Aperture Extraction Package

F. Valdes, *The IRAF APEXTRACT Package*, Central Computer Services, NOAO, 1987.

8.4. Task Help References

Each task in the **specred** package and tasks used by **specproc** have help pages describing the parameters and task in some detail. To get on-line help type

`cl> help` *taskname*

The output of this command can be piped to **lprint** to make a printed copy.

```
     apall - Extract 1D spectra (all parameters in one task)
 apdefault - Set the default aperture parameters
    apedit - Edit apertures interactively
    apfind - Automatically find spectra and define apertures
aprecenter - Recenter apertures
  apresize - Resize apertures
     apsum - Extract 1D spectra
   aptrace - Trace positions of spectra

     bplot - Batch plot of spectra with SPLOT
 calibrate - Apply extinction and flux calibrations to spectra
 continuum - Fit and normalize the continuum of multispec spectra
  identify - Identify arc lines and determine a dispersion function
 msdispcor - Dispersion correct multispec format spectra
refspectra - Assign reference spectra to observations
```

```
reidentify - Reidentify arc lines and determine new dispersion functions
     scopy - Copy spectra including aperture selection and format changes
  sensfunc - Create sensitivity function
     slist - List spectra headers
  specplot - Stack and plot multiple spectra
     splot - Plot and analyze spectra
  standard - Identify standard stars to be used in sensitivity calc

  specproc - Process CTIO slit spectra
     demos - Demonstrations and tests
```

9. Appendix A: SPECPROC Parameters

objects
: List of object spectra to be processed. Previously processed spectra are ignored unless the *redo* flag is set or the *update* flag is set and dependent calibration data has changed. Extracted spectra are ignored.

apref = ""
: Aperture reference spectrum. This spectrum is used to define the basic extraction apertures and is typically a bright star spectrum.

arcs = "" (at least one if dispersion correcting)
: List of primary arc spectra. These spectra are used to define the dispersion functions. The first spectrum is used to mark lines and set the dispersion function interactively and dispersion functions for all other arc spectra are derived from it.

arctable = "" (optional) (refspectra)
: Table defining which arc spectra are to be assigned to which object spectra (see **refspectra**). If not specified an assignment based on a header parameter, *params.sort*, such as the observation time is made.

standards = "" (at least one if flux calibrating)
: List of standard star spectra. The standard stars must have entries in the calibration database.

readnoise = 0. (apsum)
: Read out noise in photons. This parameter defines the minimum noise sigma. It is defined in terms of photons (or electrons) and scales to the data values through the gain parameter. A image header keyword (case insensitive) may be specified to get the value from the image.

gain = 1. (apsum)
: Detector gain or conversion factor between photons/electrons and data values. It is specified as the number of photons per data value. A image header keyword (case insensitive) may be specified to get the value from the image.

dispaxis = 2 (apextract)
: Default dispersion axis. The dispersion axis is 1 for dispersion running along image lines and 2 for dispersion running along image columns. If the image header parameter DISPAXIS is defined it has precedence over this parameter.

width = 6. (apedit)
: Approximate full width of the spectrum profiles. This parameter is used for the profile centering algorithm.

recenter = yes (aprecenter)
: Recenter each object observation to correct for shifts across the dispersion?

resize = no (apresize)
: Resize the aperture for each object based on the spectrum profile?

edit = no (apedit)
: Query whether to examine the extraction apertures for each object processed before extracting? This option may be turned off during processing by answering NO to the query.

trace = no (aptrace)
: Allow tracing each object spectrum separately? If not set then the trace from the aperture reference is used with a possible recentering to allow for shifts across the dispersion.

arcap = no
: If recentering or tracing is done on an object extract the arc calibration spectra using the revised object aperture definition? If not set the arc spectra are extracted using the reference aperture and the same extracted arc spectrum may be used for multiple object spectra. If set then each object spectrum will cause the reference arc spectrum to be extracted even if previously done for a different object. This will insure that exactly the same pixels in the arc images are used for wavlength calibration as are extracted in the object spectrum.

clean = yes (apsum)
Detect and correct for bad pixels during extraction? This is the same as the clean option in the **apextract** package. If yes this also implies variance weighted extraction.

dispcor = yes
Dispersion correct spectra (rebin to uniform wavelength coordinates)?

extcor = no
Extinction correct the spectra?

fluxcal = no
Flux calibrate the spectra using standard star observations?

splot = no
Plot the final spectra with the task **splot**?

redo = no
Redo operations previously done? If no then previously processed spectra in the objects list will not be processed (unless they need to be updated).

update = yes
Update processing of previously processed spectra if aperture, or dispersion reference, or standard star calibration data are changed?

batch = yes
Process spectra as a background or batch job provided there are no interactive options (*edit* and *splot*) selected.

listonly = no
List spectra to be processed but don't process?

params = "" (pset)
Name of parameter set containing additional processing parameters. The default is parameter set **params**. The parameter set may be examined and modified in the usual ways (typically with **eparam** or ":e params" from the parameter editor). The parameters are described below.

-- GENERAL PARAMETERS --

line = INDEF, nsum = 1
The dispersion line (line or column perpendicular to the dispersion axis) and number of adjacent lines (half before and half after unless at the end of the image) used in finding, recentering, resizing, editing, and tracing operations. A line of INDEF selects the middle of the image along the dispersion axis.

nspectra = 1
Number of spectra in each image. This should always be 1.

-- DEFAULT APERTURE LIMITS --

lower = -3., upper = 3. (apdefault)
Default lower and upper aperture limits relative to the aperture center. These limits are used when the apertures are first found.

-- AUTOMATIC APERTURE RESIZING PARAMETERS --

ylevel = 0.05 (apresize)
Data level at which to set aperture limits during automatic resizing. It is a fraction of the peak or an actual data level depending on the parameter *peak*. It may be relative to a local background or to zero depending on the parameter *bkg*.

peak = yes (apresize)
Is the data level specified by *ylevel* a fraction of the peak?

bkg = yes (apresize)
Subtract a simple background when interpreting the **ylevel** parameter. The background is a slope connecting the first minima away from the aperture center.

avglimits = no (apresize)
Apply the average lower and upper aperture limits to all apertures.

-- TRACE PARAMETERS --

t_step = 10 (aptrace)
Step along the dispersion axis between determination of the spectrum positions. Note the *nsum* parameter is also used to enhance the signal-to-noise at each step.

t_function = "spline3" , t_order = 2 (aptrace)

Default trace fitting function and order. The fitting function types are "chebyshev" polynomial, "legendre" polynomial, "spline1" linear spline, and "spline3" cubic spline. The order refers to the number of terms in the polynomial functions or the number of spline pieces in the spline functions.

t_niterate = 1, t_low = 3., t_high = 3.

Default number of rejection iterations and rejection sigma thresholds.

-- APERTURE EXTRACTION PARAMETERS --

weights = "none" (apsum)

Type of extraction weighting. Note that if the *clean* parameter is set then the weights used are "variance" regardless of the weights specified by this parameter. The choices are:

"none"

The pixels are summed without weights except for partial pixels at the ends.

"variance"

The extraction is weighted by the variance based on the data values and a poisson/ccd model using the *gain* and *readnoise* parameters.

lsigma = 3., usigma = 3. (apsum)

Lower and upper rejection thresholds, given as a number of times the estimated sigma of a pixel, for cleaning.

-- DEFAULT BACKGROUND PARAMETERS --

background = "fit" (apsum)

Type of background subtraction. The choices are "none" for no background subtraction, "average" to average the background within the background regions, or "fit" to fit across the dispersion using the background within the background regions. Note that the "average" option does not do any medianing or bad pixel checking; it is faster than fitting however. Background subtraction also requires that the background fitting parameters are properly defined. For the "average" option only the background sample regions parameter is used.

b_function = "chebyshev" , b_order = 1 (apsum)

Default background fitting function and order. The fitting function types are "chebyshev" polynomial, "legendre" polynomial, "spline1" linear spline, and "spline3" cubic spline. The order refers to the number of terms in the polynomial functions or the number of spline pieces in the spline functions.

b_sample = "-10:-6,6:10" (apsum)

Default background sample. The sample is given by a set of colon separated ranges each separated by either whitespace or commas. The string "*" refers to all points. Note that the background coordinates are relative to the aperture center and not image pixel coordinates so the endpoints need not be integer.

b_naverage = -3 (apsum)

Default number of points to average or median. Positive numbers average that number of sequential points to form a fitting point. Negative numbers median that number, in absolute value, of sequential points. A value of 1 does no averaging and each data point is used in the fit.

b_niterate = 0 (apsum)

Default number of rejection iterations. If greater than zero the fit is used to detect deviant fitting points and reject them before repeating the fit. The number of iterations of this process is given by this parameter.

b_low_reject = 3., b_high_reject = 3. (apsum)

Default background lower and upper rejection sigmas. If greater than zero points deviating from the fit below and above the fit by more than this number of times the sigma of the residuals are rejected before refitting.

-- ARC DISPERSION FUNCTION PARAMETERS --

coordlist = "onedstds$idhenear.dat" (identify)

Arc line list consisting of an ordered list of wavelengths. Some standard line lists are available in the directory "onedstds$".

match = 10. (identify)

The maximum difference for a match between the dispersion function prediction value and a wavelength in the coordinate list.

fwidth = 4. (identify)

Approximate full base width (in pixels) of arc lines.

i_function = "spline3" , i_order = 1 (identify)

The default function and order to be fit to the arc wavelengths as a function of the pixel coordinate. The functions choices are "chebyshev", "legendre", "spline1", or "spline3".

i_niterate = 0, i_low = 3.0, i_high = 3.0

Number of rejection iterations and sigma thresholds for rejecting arc lines from the dispersion function fits.

refit = yes (reidentify)
Refit the dispersion function? If yes and there is more than 1 line and a dispersion function was defined in the arc reference then a new dispersion function of the same type as in the reference image is fit using the new pixel positions. Otherwise only a zero point shift is determined for the revised fitted coordinates without changing the form of the dispersion function.

addfeatures = no (reidentify)
Add new features from a line list during each reidentification? This option can be used to compensate for lost features from the reference solution. Care should be exercised that misidentified features are not introduced.

-- AUTOMATIC ARC ASSIGNMENT PARAMETERS --

select = "interp" (refspectra)
Selection method for assigning wavelength calibration spectra. Note that an arc assignment table may be used to override the selection method and explicitly assign arc spectra to object spectra. The automatic selection methods are:

average
Average two reference spectra without regard to any sort parameter. If only one reference spectrum is specified then it is assigned with a warning. If more than two reference spectra are specified then only the first two are used and a warning is given. This option is used to assign two reference spectra, with equal weights, independent of any sorting parameter.

following
Select the nearest following spectrum in the reference list based on the sorting parameter. If there is no following spectrum use the nearest preceding spectrum.

interp
Interpolate between the preceding and following spectra in the reference list based on the sorting parameter. If there is no preceding and following spectrum use the nearest spectrum. The interpolation is weighted by the relative distances of the sorting parameter.

match
Match each input spectrum with the reference spectrum list in order. This overrides the reference aperture check.

nearest
Select the nearest spectrum in the reference list based on the sorting parameter.

preceding
Select the nearest preceding spectrum in the reference list based on the sorting parameter. If there is no preceding spectrum use the nearest following spectrum.

sort = "utmiddle" (refspectra)
Image header keyword to be used as the sorting parameter for selection based on order. The header parameter must be numeric but otherwise may be anything. Common sorting parameters are times or positions.

time = yes (refspectra)
Is the sorting parameter a time?

timewrap = 17. (refspectra)
The time origin for sorting time values. This time should precede the first observation and follow the last observation in a 24 hour cycle.

-- DISPERSION CORRECTION PARAMETERS --

interpolation = "poly5" (msdispcor)
Wavelength dispersion correction interpolation type. The interpolation types are "linear" for linear, "poly3" for cubic polynomial, "poly5", for quintic polynomial, and "spline3" for cubic spline.

log = no (msdispcor)
Use linear logarithmic wavelength coordinates? Linear logarithmic wavelength coordinates have wavelength intervals which are constant in the logarithm of the wavelength.

flux = yes (msdispcor)
Conserve the total flux during interpolation? If *no* the output spectrum is interpolated from the input spectrum at each output wavelength coordinate. If *yes* the input spectrum is integrated over the extent of each output pixel. This is slower than simple interpolation.

-- SENSITIVITY CALIBRATION PARAMETERS --

s_function = "spline3" , s_order = 1 (sensfunc)
Function and order used to fit the sensitivity data. The function types are "chebyshev" polynomial, "legendre" polynomial, "spline3" cubic spline, and "spline1" linear spline. Order of the sensitivity fitting function. The value corresponds to the number of polynomial terms or the number of spline pieces. The default values may be changed interactively.

fnu = no (calibrate)

The default calibration is into units of F-lambda. If *fnu* = yes then the calibrated spectrum will be in units of F-nu.