Guide to the HYDRA Reduction Task DOHYDRA

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ABSTRACT

The **dohydra** reduction task is specialized for scattered light subtraction, extraction, flat fielding, fiber throughput correction, wavelength calibration, and sky subtraction of *Hydra* and *Nessie* fiber spectra. It is a command language script which collects and combines the functions and parameters of many general purpose tasks to provide a single complete data reduction path. The task provides a degree of guidance, automation, and record keeping necessary when dealing with the large amount of data generated by these multifiber instruments. This guide describes what this task does, it's usage, and parameters.

1. Introduction

The **dohydra** reduction task is specialized for scattered light subtraction, extraction, flat fielding, fiber throughput correction, wavelength calibration, and sky subtraction of *Hydra* and *Nessie* fiber spectra. It is a command language script which collects and combines the functions and parameters of many general purpose tasks to provide a single, complete data reduction path. The task provides a degree of guidance, automation, and record keeping necessary when dealing with the large amount of data generated by these multifiber instruments.

The general organization of the task is to do the interactive setup steps first using representative calibration data and then perform the majority of the reductions automatically, and possibly as a background process, with reference to the setup data. In addition, the task determines which setup and processing operations have been completed in previous executions of the task and, contingent on the `redo` and `update` options, skip or repeat some or all the steps.

The following description is oriented specifically to Hydra data but applies equally well to Nessie data except for a few minor differences which are discussed in a separate section. Since **dohydra** combines many separate, general purpose tasks the description given here refers to these tasks and leaves some of the details to their help documentation.

The description is divided into a quick usage outline followed by details of the parameters and algorithms. The usage outline is provided as a checklist and a refresher for those familiar with this task and the component tasks. It presents only the default or recommended usage for Hydra since there are many variations possible.

2. Usage Outline

[1] The images are first processed with **ccdproc** for overscan, bias, and dark corrections. The **dohydra** task will abort if the image header keyword CCDPROC, which is added by **ccdproc**, is missing. If the data processed outside of the IRAF **ccdred** package then a dummy CCDPROC keyword should be added to the image headers; say with **hedit**.

[2] Set the **dohydra** parameters with **eparam**. Specify the object images to be processed, the flat field image as the aperture reference and the flat field, and one or more arc images. A throughput file or image, such as a blank sky observation, may also be specified. If there are many object or arc spectra per setup you might want to prepare "@ files". Specify the aperture identification table (a file for 4meter data or an image for WIYN data) which is provided for each Hydra configuration. You might wish to verify the geometry parameters, separations, dispersion direction, etc., which may change with different detector setups. The processing

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parameters are set for complete reductions but for quicklook you might not use the clean option or dispersion calibration and sky subtraction.

The parameters are set for a particular Hydra configuration and different configurations may use different flat fields, arcs, and aperture identification tables.

[3] Run the task. This may be repeated multiple times with different observations and the task will generally only do the setup steps once and only process new images. Queries presented during the execution for various interactive operations may be answered with "yes", "no", "YES", or "NO". The lower case responses apply just to that query while the upper case responses apply to all further such queries during the execution and no further queries of that type will be made.

[4] The apertures are defined using the specified aperture reference image. The spectra are found automatically and apertures assigned based on task parameters and the aperture identification table. Unassigned fibers will have a negative beam number and will be ignored in subsequent processing. The resize option sets the aperture size to the widths of the profiles at a fixed fraction of the peak height. The interactive review of the apertures is recommended. If the identifications are off by a shift the 'o' key is used. To exit the aperture review type 'q'.

[5] The fiber positions at a series of points along the dispersion are measured and a function is fit to these positions. This may be done interactively to adjust the fitting parameters. Not all fibers need be examined and the "NO" response will quit the interactive fitting. To exit the interactive fitting type 'q'.

[6] If scattered light subtraction is to be done the flat field image is used to define the scattered light fitting parameters interactively. If one is not specified then the aperture reference image is used for this purpose.

There are two queries for the interactive fitting. A graph of the data between the defined reference apertures separated by a specified buffer distance is first shown. The function order and type may be adjusted. After quiting with 'q' the user has the option of changing the buffer value and returning to the fitting, changing the image line or column to check if the fit parameters are satisfactory at other points, or to quit and accept the fit parameters. After fitting all points across the dispersion another graph showing the scattered light from the individual fits is shown and the smoothing parameters along the dispersion may be adjusted. Upon quiting with 'q' you have the option of checking other cuts parallel to the dispersion or quiting and finishing the scattered light function smoothing and subtraction.

If there is a throughput image then this is corrected for scattered light noninteractively using the previous fitting parameters.

[7] If flat fielding is to be done the flat field spectra are extracted. The average spectrum over all fibers is determined and a function is fit interactively (exit with 'q'). This function is generally of sufficiently high order that the overall shape is well fit. This function is then used to normalize the individual flat field spectra. If a throughput image, a sky flat, is specified then the total sky counts through each fiber are used to correct the total flat field counts. Alternatively, a separately derived throughput file can be used for specifying throughput corrections. If neither type of throughput is used the flat field also provides the throughput correction. The final response spectra are normalized to a unit mean over all fibers. The relative average throughput for each fiber is recorded in the log and possibly printed to the terminal.

[8] If dispersion correction is selected the first arc in the arc list is extracted. The middle fiber is used to identify the arc lines and define the dispersion function using the task **autoidentify**. The *crval* and *cdelt* parameters are used in the automatic identification. Whether or not the automatic identification is successful you will be shown the result of the arc line identification. If the automatic identification is not successful identify a few arc lines with 'm' and 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'.

[9] The remaining fibers are automatically reidentified. You have the option to review the line identifications and dispersion function for each fiber and interactively add or delete arc lines and change fitting parameters. This can be done selectively, such as when the reported RMS increases significantly.

[10] If the spectra are to be resampled to a linear dispersion system (which will be the same for all spectra) default dispersion parameters are printed and you are allowed to adjust these as desired.

[11] If the sky line alignment option is selected and the sky lines have not been identified for a particular aperture identification table then you are asked to mark one or more sky lines. You may simply accept the wavelengths of these lines as defined by the dispersion solution for this spectrum and fiber or you may specify knowns wavelengths for the lines. These lines will be reidentified in all object spectra extracted and a mean zeropoint shift will be added to the dispersion solution. This has the effect of aligning these lines to

optimize sky subtraction.

[12] The object spectra are now automatically scatteredl ight subtracted, extracted, flat fielded, and dispersion corrected.

[13] When sky subtracting, the individual sky spectra may be reviewed and some spectra eliminated using the 'd' key. The last deleted spectrum may be recovered with the 'e' key. After exiting the review with 'q' you are asked for the combining option. The type of combining is dictated by the number of sky fibers.

[14] The option to examine the final spectra with **splot** may be given. To exit type 'q'.

[15] If scattered light is subtracted from the input data a copy of the original image is made by appending "noscat" to the image name. If the data are reprocessed with the *redo* flag the original image will be used again to allow modification of the scattered light parameters.

The final spectra will have the same name as the original 2D images with a ".ms" extension added. The flat field and arc spectra will also have part of the aperture identification table name added to allow different configurations to use the same 2D flat field and arcs but with different aperture definitions. If using the sky alignment option an image "align" with the aperture identification table name applied will also be created.

3. Spectra and Data Files

The basic input consists of Hydra or Nessie object and calibration spectra stored as IRAF images. The type of image format is defined by the environment parameter *imtype*. Only images with that extension will be processed and created. The raw CCD images must be processed to remove overscan, bias, and dark count effects. This is generally done using the **ccdred** package. The **doargus** task will abort if the image header keyword CCDPROC, which is added by **ccdproc**, is missing. If the data processed outside of the IRAF **ccdred** package then a dummy CCDPROC keyword should be added to the image headers; say with **hedit**. Flat fielding is generally not done at this stage but as part of **dohydra**. If flat fielding is done as part of the basic CCD processing then a flattened flat field, blank sky observation, or throughput file should still be created for applying fiber throughput corrections.

The task **dohydra** uses several types of calibration spectra. These are flat fields, blank sky flat fields, comparison lamp spectra, auxiliary mercury line (from the dome lights) or sky line spectra, and simultaneous arc spectra taken during the object observation. The flat field, throughput image or file, auxiliary emission line spectra, and simultaneous comparison fibers are optional. If a flat field is used then the sky flat or throughput file is optional assuming the flat field has the same fiber illumination. It is legal to specify only a throughput image or file and leave the flat field blank in order to simply apply a throughput correction. Because only the total counts through each fiber are used from a throughput image, sky flat exposures need not be of high signal per pixel.

There are three types of arc calibration methods. One is to take arc calibration exposures through all fibers periodically and apply the dispersion function derived from one or interpolated between pairs to the object fibers. This is the usual method with Hydra. Another method is to use only one or two all-fiber arcs to define the shape of the dispersion function and track zero point wavelength shifts with *simultaneous arc* fibers taken during the object exposure. The simultaneous arcs may or may not be available at the instrument but **dohydra** can use this type of observation. The arc fibers are identified by their beam or aperture numbers. A related and mutually exclusive method is to use *auxiliary line spectra* such as lines in the dome lights or sky lines to monitor shifts relative to a few actual arc exposures. The main reason to do this is if taking arc exposures through all fibers is inconvenient as is the case with the manual Nessie plugboards.

The assignment of arc or auxiliary line 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 it is one of the optional setup files which can used with **dohydra**.

The first step in the processing is identifying the spectra in the images. The *aperture identification table* (which may be a file or an image) contains information about the fiber assignments. This table is created for you when using Hydra but must be prepared by the user when using Nessie. A description of this table as a text file is given in the section concerning Nessie.

The final reduced spectra are recorded in two or three dimensional IRAF images. The images have the same name as the original images with an added ".ms" extension. Each line in the reduced image is a one dimensional spectrum with associated aperture, wavelength, and identification information. When the `extras` parameter is set the lines in the third dimension contain additional information (see **apsum** for further details). These spectral formats are accepted by the one dimensional spectroscopy tools such as the plotting tasks **splot** and **specplot**. The special task

scopy may be used to extract specific apertures or to change format to individual one dimensional images.

4. Package Parameters

The **hydra** package parameters, shown in Figure 1, set parameters affecting all the tasks in the package.

Figure 1: Package Parameter Set for HYDRA

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

(dispaxi=            2) Image axis for 2D images
(observa=  observatory) Observatory of data
(interp =        poly5) Interpolation type

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

(records=             )
(version= HYDRA V1: January 1992)
```

The dispersion axis parameter defines the image axis along which the dispersion runs. This is used if the image header doesn't define the dispersion axis with the DISPAXIS keyword. The observatory parameter is only required for data taken with fiber instruments other than Hydra or Nessie. The spectrum interpolation type might be changed to "sinc" but with the cautions given in **onedspec.package**. The other parameters define the standard I/O functions. The verbose parameter selects whether to print everything which goes into the log file on the terminal. It is useful for monitoring what the **dohydra** task does. The log and plot files are useful for keeping a record of the processing. A log file is highly recommended. A plot file provides a record of apertures, traces, and extracted spectra but can become quite large. The plotfile is most conveniently viewed and printed with **gkimosaic**.

5. Processing Parameters

The **dohydra** parameters are shown in Figure 2.

Figure 2: Parameter Set for DOHYDRA

```
                              I R A F
            Image Reduction and Analysis Facility
PACKAGE = hydra
   TASK = dohydra

objects =               List of object spectra
(apref  =             ) Aperture reference spectrum
(flat   =             ) Flat field spectrum
(through=             ) Throughput file or image (optional)
(arcs1  =             ) List of arc spectra
(arcs2  =             ) List of shift arc spectra
(arcrepl=             ) Special aperture replacements
(arctabl=             ) Arc assignment table (optional)

(readnoi=      RDNOISE) Read out noise sigma (photons)
(gain   =         GAIN) Photon gain (photons/data number)
(datamax=        INDEF) Max data value / cosmic ray threshold
(fibers =           97) Number of fibers
(width  =          12.) Width of profiles (pixels)
(minsep =           8.) Minimum separation between fibers (pixels)
(maxsep =          15.) Maximum separation between fibers (pixels)
```

```
(apidtab=             ) Aperture identifications
(crval  =        INDEF) Approximate wavelength
(cdelt  =        INDEF) Approximate dispersion
(objaps =             ) Object apertures
(skyaps =             ) Sky apertures
(arcaps =             ) Arc apertures
(objbeam=          0,1) Object beam numbers
(skybeam=            0) Sky beam numbers
(arcbeam=             ) Arc beam numbers

(scatter=           no) Subtract scattered light?
(fitflat=          yes) Fit and ratio flat field spectrum?
(clean  =          yes) Detect and replace bad pixels?
(dispcor=          yes) Dispersion correct spectra?
(savearc=          yes) Save simultaneous arc apertures?
(skysubt=          yes) Subtract sky?
(skyedit=          yes) Edit the sky spectra?
(savesky=          yes) Save sky spectra?
(splot  =           no) Plot the final spectrum?
(redo   =           no) Redo operations if previously done?
(update =          yes) Update spectra if cal data changes?
(batch  =           no) Extract objects in batch?
(listonl=           no) List steps but don't process?

(params =             ) Algorithm parameters
```

The list of objects and arcs can be @ files if desired. The aperture reference spectrum is usually the same as the flat field spectrum though it could be any exposure with enough signal to accurately define the positions and trace the spectra. The first list of arcs are the standard Th-Ar or HeNeAr comparison arc spectra (they must all be of the same type). The second list of arcs are the auxiliary emission line exposures mentioned previously and in the Nessie section.

The arc replacement file is described in the Nessie section and the arc assignment table was described in the data file section. Note that even if an arc assignment table is specified, *all arcs to be used must also appear in the arc lists* in order for the task to know the type of arc spectrum.

The detector read out noise and gain are used for cleaning and variance (optimal) extraction. The default will determine the values from the image itself. The variance weighting and cosmic-ray cleanning are sensitive to extremely strong cosmic-rays; ones which are hundreds of times brighter than the spectrum. The *datamax* is used to set an upper limit for any real data. Any pixels above this value will be flagged as cosmic-rays and will not affect the extractions. The dispersion axis defines the wavelength direction of spectra in the image if not defined in the image header by the keyword DISPAXIS. The width and separation parameters define the dimensions (in pixels) of the spectra (fiber profile) across the dispersion. The width parameter primarily affects the centering. The maximum separation parameter is important if missing spectra from the aperture identification table are to be correctly skipped. The number of fibers can be left at the default (for Hydra) and the task will try to account for unassigned or missing fibers.

The approximate central wavelength and dispersion are used for the automatic identification of the arc reference. They may be specified as image header keywords or values. The INDEF values search the entire range of the coordinate reference file but the automatic line identification algorithm works much better and faster if approximate values are given.

The task needs to know which fibers are object, sky if sky subtraction is to be done, and simultaneous arcs if used. One could explicitly give the aperture numbers but the recommended way, provided an aperture identification table is used, is to select the apertures based on the beam numbers. The default values are those appropriate for the identification files generated for Hydra configurations. Sky subtracted sky spectra are useful for evaluating the sky subtraction. Since only the spectra identified as objects are sky subtracted one can exclude fibers from the sky subtraction. For example, if the *objbeams* parameter is set to 1 then only those fibers with a beam of 1 will be sky subtracted. All other fibers will remain in the extracted spectra but will not be sky subtracted.

The next set of parameters select the processing steps and options. The scattered light option allows fitting and subtracting a scattered light surface from the input object and flat field. If there is significant scattered light which is not subtracted the fiber throughput correction will not be accurate. The flat fitting option allows fitting and removing the overall shape of the flat field spectra while preserving the pixel-to-pixel response corrections. This is useful for maintaining the approximate object count levels and not introducing the reciprocal of the flat field spectrum into the object spectra. 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 variance 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, possibly, resample the spectra to a linear (or log-linear) wavelength scale. If simultaneous arc fibers are defined there is an option to delete them from the final spectra when they are no longer needed.

The sky alignment option allows applying a zeropoint dispersion shift to all fibers based on one or more sky lines. This requires all fibers to have the sky lines visible. When there are sky lines this will improve the sky subtraction if there is a systematic error in the fiber illumination between the sky and the arc calibration.

The sky subtraction option selects whether to combine the sky fiber spectra and subtract this sky from the object fiber spectra. *Dispersion correction and sky subtraction are independent operations.* This means that if dispersion correction is not done then the sky subtraction will be done with respect to pixel coordinates. This might be desirable in some quick look cases though it is incorrect for final reductions.

The sky subtraction option has two additional options. The individual sky spectra may be examined and contaminated spectra deleted interactively before combining. This can be a useful feature in crowded regions. The final combined sky spectrum may be saved for later inspection in an image with the spectrum name prefixed by **sky**.

After a spectrum has been processed it is possible to examine the results interactively using the **splot** tasks. This option has a query which may be turned off with "YES" or "NO" if there are multiple spectra to be processed.

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 a new aperture identification table, a new reference image, new flat fields, and a new arc reference. 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 sky spectra editing and **splot** review (interactive operations) are turned off, either when the task is run or by responding with "NO" to the 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 way **dohydra** works this may not have any value and the parameter set **params** is always used. The algorithm parameters are discussed further in the next section.

6. Algorithms and Algorithm Parameters

This section summarizes the various algorithms used by the **dohydra** 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 **dohydra** processing task. Additional information about these parameters and algorithms may be found in the help for the actual task executed. These tasks are identified in the parameter section listing in parenthesis. 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 Hydra or Nessie 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 **dohydra** parameters by typing `:e params` or simply `:e` if positioned at the `params` parameter. Figure 3 shows the parameter set.

Figure 3: Algorithm Parameter Set

```
                              I R A F
                Image Reduction and Analysis Facility
PACKAGE = hydra
   TASK = params

(line   =         INDEF) Default dispersion line
(nsum   =            10) Number of dispersion lines to sum
(order  =    decreasing) Order of apertures
(extras =            no) Extract sky, sigma, etc.?

                         -- DEFAULT APERTURE LIMITS --
(lower  =           -5.) Lower aperture limit relative to center
(upper  =            5.) Upper aperture limit relative to center

                         -- AUTOMATIC APERTURE RESIZING PARAMETERS --
(ylevel =          0.05) Fraction of peak or intensity for resizing

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

                         -- SCATTERED LIGHT PARAMETERS --
(buffer =            1.) Buffer distance from apertures
(apscat1=              ) Fitting parameters across the dispersion
(apscat2=              ) Fitting parameters along the dispersion

                         -- APERTURE EXTRACTION PARAMETERS --
(weights=          none) Extraction weights (none|variance)
(pfit   =         fit1d) Profile fitting algorithm (fit1d|fit2d)
(lsigma =            3.) Lower rejection threshold
(usigma =            3.) Upper rejection threshold
(nsubaps=             1) Number of subapertures

                         -- FLAT FIELD FUNCTION FITTING PARAMETERS --
(f_inter=           yes) Fit flat field interactively?
(f_funct=       spline3) Fitting function
(f_order=            10) Fitting function order

                         -- ARC DISPERSION FUNCTION PARAMETERS --
(coordli=linelists$idhenear.dat) Line list
(match  =           10.) Line list matching limit in Angstroms
(fwidth =            4.) Arc line widths in pixels
(cradius=           10.) Centering radius in pixels
(i_funct=       spline3) Coordinate function
(i_order=             3) Order of dispersion function
(i_niter=             2) 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   =           jd) Sort key
(group  =          ljd) Group key
(time   =           no) Is sort key a time?
(timewra=          17.) Time wrap point for time sorting

                         -- DISPERSION CORRECTION PARAMETERS --
(lineari=          yes) Linearize (interpolate) spectra?
(log    =           no) Logarithmic wavelength scale?
(flux   =          yes) Conserve flux?

                         -- SKY SUBTRACTION PARAMETERS --
(combine=      average) Type of combine operation
(reject =    avsigclip) Sky rejection option
(scale  =         none) Sky scaling option
```

6.1. Extraction

The identification of the spectra in the two dimensional images and their scattered light subtraction and extraction to one dimensional spectra in multispec format is accomplished using the tasks from the **apextract** package. The first parameters through `nsubaps` 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.

The `order` parameter defines whether the order of the aperture identifications in the aperture identification table (or the default sequential numbers if no file is used) is in the same sense as the image coordinates (increasing) or the opposite sense (decreasing). If the aperture identifications turn out to be opposite to what is desired when viewed in the aperture editing graph then simply change this parameter.

The basic data output by the spectral extraction routines are the one dimensional spectra. Additional information may be output when the `extras` option is selected and the cleaning or variance weighting options are also selected. In this case a three dimensional image is produced with the first element of the third dimension being the cleaned and/or weighted spectra, the second element being the uncleaned and unweighted spectra, and the third element being an estimate of the sigma of each pixel in the extracted spectrum. Currently the sigma data is not used by any other tasks and is only for reference.

The initial step of finding the fiber spectra in the aperture reference image consists of identifying the peaks in a cut across the dispersion, eliminating those which are closer to each other than the `minsep` distance, and then keeping the specified `nfibers` highest peaks. The centers of the profiles are determined using the **center1d** algorithm which uses the `width` parameter.

Apertures are then assigned to each spectrum. The initial edges of the aperture relative to the center are defined by the `lower` and `upper` parameters. The trickiest part of assigning the apertures is relating the aperture identification from the aperture identification table to automatically selected fiber profiles. The first aperture id in the file is assigned to the first spectrum found using the `order` parameter to select the assignment direction. The numbering proceeds in this way except that if a gap greater than a multiple of the `maxsep` parameter is encountered then assignments in the file are skipped under the assumption that a fiber is missing (broken). In Hydra data it is expected that all fibers will be found in flat fields including the unassigned fibers and the assignment file will then identify the unassigned fibers. The unassigned fibers will later be excluded from extraction. For more on the finding and assignment algorithms see **apfind**.

The initial apertures are the same for all spectra but they can each be automatically resized. The automatic resizing sets the aperture limits at a fraction of the peak relative to the interfiber minimum. The default *ylevel* is to resize the apertures to 5% of the peak. See the description for the task **apresize** for further details.

The user is given the opportunity to graphically review and adjust the aperture definitions. This is recommended. As mentioned previously, the correct identification of the fibers is tricky and it is fundamentally important that this be done correctly; otherwise the spectrum identifications will not be for the objects they say. An important command in this regard is the 'o' key which allows reordering the identifications based on the aperture identification table. This is required if the first fiber is actually missing since the initial assignment begins assigning the first spectrum found with the first entry in the aperture file. The aperture editor is a very powerful tool and is described in detail as **apedit**.

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 three 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 thresholds 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**.

The last parameter, `nsubaps`, is used only in special cases when it is desired to subdivide the fiber profiles into subapertures prior to dispersion correction. After dispersion correction the subapertures are then added together. The purpose of this is to correct for wavelength shifts across a fiber.

6.2. Scattered Light Subtraction

Scattered light may be subtracted from the input two dimensional image as the first step. This is done using the algorithm described in **apscatter**. This can be important if there is significant scattered light since the flat field/throughput correction will otherwise be incorrect. The algorithm consists of fitting a function to the data outside the defined apertures by a specified *buffer* at each line or column across the dispersion. The function fitting parameters are the same at each line. Because the fitted functions are independent at each line or column a second set of one dimensional functions are fit parallel to the dispersion using the evaluated fit values from the cross-dispersion step. This produces a smooth scattered light surface which is finally subtracted from the input image. Again the function fitting parameters are the same at each line or column though they may be different than the parameters used to fit across the dispersion.

The first time the task is run with a particular flat field (or aperture reference image if no flat field is used) the scattered light fitting parameters are set interactively using that image. The interactive step selects a particular line or column upon which the fitting is done interactively with the **icfit** commands. A query is first issued which allows skipping this interactive stage. Note that the interactive fitting is only for defining the fitting functions and orders. When the graphical **icfit** fitting is exited (with 'q') there is a second prompt allowing you to change the buffer distance (in the first cross-dispersion stage) from the apertures, change the line/column, or finally quit.

The initial fitting parameters and the final set parameters are recorded in the **apscat1** and **apscat2** hidden parameter sets. These parameters are then used automatically for every subsequent image which is scattered light corrected.

The scattered light subtraction modifies the input 2D images. To preserve the original data a copy of the original image is made with the same root name and the word "noscat" appended. The scattered light subtracted images will have the header keyword "APSCATTE" which is how the task avoids repeating the scattered light subtraction during any reprocessing. However if the *redo* option is selected the scattered light subtraction will also be redone by first restoring the "noscat" images to the original input names.

6.3. Flat Field and Fiber Throughput Corrections

Flat field corrections may be made during the basic CCD processing; i.e. direct division by the two dimensional flat field observation. In that case do not specify a flat field spectrum; use the null string "". The **dohydra** task provides an alternative flat field response correction based on division of the extracted object spectra by the extracted flat field spectra. A discussion of the theory and merits of flat fielding directly verses using the extracted spectra will not be made here. The **dohydra** flat fielding algorithm is the *recommended* method for flat fielding since it works well and is not subject to the many problems involved in two dimensional flat fielding.

In addition to correcting for pixel-to-pixel response the flat field step also corrects for differences in the fiber throughput. Thus, even if the pixel-to-pixel flat field corrections have been made in some other way it is desirable to use a sky or dome flat observation for determining a fiber throughput correction. Alternatively, a separately derived throughput file may be specified. This file consists of the aperture numbers (the same as used for the aperture reference) and relative throughput numbers.

The first step is extraction of the flat field spectrum, if specified, using the reference apertures. Only one flat field is allowed so if multiple flat fields are required the data must be reduced in groups. After extraction one or more corrections are applied. If the `fitflat` option is selected (the default) the extracted flat field spectra are averaged together and a smooth function is fit. The default fitting function and order are given by the parameters `f_function` and `f_order`. If the parameter `f_interactive` is "yes" then the fitting is done interactively using the **fit1d** task which uses the **icfit** interactive fitting commands.

The fitted function is divided into the individual flat field spectra to remove the basic shape of the spectrum while maintaining the relative individual pixel responses and any fiber to fiber differences. This step avoids introducing the flat field spectrum shape into the object spectra and closely preserves the object counts.

If a throughput image is available (an observation of blank sky usually at twilight) it is extracted. If no flat field is used the average signal through each fiber is computed and this becomes the response normalization function. Note that a dome flat may be used in place of a sky in the sky flat field parameter for producing throughput only corrections. If a flat field is specified then each sky spectrum is divided by the appropriate flat field spectrum. The total counts through each fiber are multiplied into the flat field spectrum thus making the sky throughput of each fiber the same. This correction is important if the illumination of the fibers differs between the flat field source and the sky. Since only the total counts are required the sky or dome flat field spectra need not be particularly strong though care must be taken to avoid objects.

Instead of a sky flat or other throughput image a separately derived throughput file may be used. It may be used with or without a flat field.

The final step is to normalize the flat field spectra by the mean counts of all the fibers. This normalization step is simply to preserve the average counts of the extracted object and arc spectra after division by the response spectra. The final relative throughput values are recorded in the log and possibly printed on the terminal.

These flat field response steps and algorithm are available as a separate task called **msresp1d**.

6.4. Dispersion Correction

Dispersion corrections are applied to the extracted spectra if the **dispcor** parameter is set. This can be a complicated process which the **dohydra** 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 comparison arc spectra are used to define dispersion functions for the fibers using the tasks **autoidentify** and **reidentify**. The interactive **autoidentify** task is only used on the central fiber of the first arc spectrum to define the basic reference dispersion solution from which all other fibers and arc spectra are automatically derived using **reidentify**. **Autoidentify** attempts to automatically identify the arc lines using the *crval* and *cdelt* parameters. Whether or not it is successful the user is presented with the interactive identification graph. The automatic identifications can be reviewed and a new solution or corrections to the automatic solution may be performed.

The set of arc dispersion function parameters are from **autoidentify** and **reidentify**. The parameters define a line list for use in automatically assigning wavelengths to arc lines, a parameter controlling the width of the centering window (which should match the base line widths), the dispersion function type and order, parameters to exclude bad lines from function fits, and parameters 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 **autoidentify**.

Generally, taking a number of comparison arc lamp exposures interspersed with the program spectra is sufficient to accurately dispersion calibrate Hydra spectra. However, there are some other calibration options which may be of interest. These options apply additional calibration data consisting either of auxiliary line spectra, such as from dome lights or night sky lines, or simultaneous arc lamp spectra taken through a few fibers during the object exposure. These options add complexity to the dispersion calibration process and were provided primarily for Nessie data. Therefore they are described later in the Nessie section.

When only arc comparison lamp spectra are used, dispersion functions are determined independently for each fiber of each arc image and then assigned to the matching fibers in the program object observations. The assignment consists of selecting one or two arc images to calibrate each object image. When two bracketing arc spectra are used the dispersion functions are linearly interpolated (usually based on the time of the observations).

The arc assignments may be 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 Julian date (corrected to the middle of the exposure). The Julian date and a local Julian day number (the day number at local noon) are computed automatically by the task **setjd** and recorded in the image headers under the keywords JD and LJD. In addition the universal time at the middle of the exposure, keyword UTMIDDLE, is computed by the task **setairmass** and this may also be used for ordering the arc and object observations.

An optional step is to use sky lines in the spectra to compute a zeropoint dispersion shift that will align the sky lines. This may improve sky subtraction if the illumination is not the same between the arc calibration and the sky. When selected the object spectrum is dispersion corrected using a non-linear dispersion function to avoid resampling the spectrum. The sky lines are then reidentified in wavelength space from a template list of sky lines. The mean shift in the lines for each fiber relative to the template in that fiber is computed to give the zeropoint shift. The database file is created when the first object is extracted. You are asked to mark the sky lines in one fiber and then the lines are automatically reidentified in all other fibers. Note that this technique requires the sky lines be found in all fibers.

The last step of dispersion correction (resampling the spectrum to evenly spaced pixels in wavelength) is optional and relatively straightforward. If the `linearize` parameter is no then the spectra are not resampled and the nonlinear dispersion information is recorded in the image header. Other IRAF tasks (the coordinate description is specific to IRAF) will use this information whenever wavelengths are needed. If linearizing is selected a linear dispersion relation, either linear in the wavelength or the log of the wavelength, is defined once and applied to every extracted spectrum. The resampling 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 **dispcor** which performs the correction. The interpolation function options and the nonlinear dispersion coordinate system is described in the help topic **onedspec.package**.

6.5. Sky Subtraction

Sky subtraction is selected with the `skysubtract` processing option. The sky spectra are selected by their aperture and beam numbers and combined into a single master sky spectrum which is then subtracted from each object spectrum. If the `skyedit` option is selected the sky spectra are plotted using the task **specplot**. By default they are superposed to allow identifying spectra with unusually high signal due to object contamination. To eliminate a sky spectrum from consideration point at it with the cursor and type 'd'. The last deleted spectrum may be undeleted with 'e'. This allows recovery of incorrect or accidental deletions.

The sky combining algorithm parameters define how the individual sky fiber spectra, after interactive editing, are combined before subtraction from the object fibers. The goals of combining are to reduce noise, eliminate cosmic-rays, and eliminate fibers with inadvertent objects. The common methods for doing this to use a median and/or a special sigma clipping algorithm (see **scombine** for details). The scale parameter determines whether the individual skys are first scaled to a common mode. The scaling should be used if the throughput is uncertain, but in that case you probably did the wrong thing in the throughput correction. If the sky subtraction is done interactively, i.e. with the `skyedit` option selected, then after selecting the spectra to be combined a query is made for the combining algorithm. This allows modifying the default algorithm based on the number of sky spectra selected since the "avsigclip" rejection algorithm requires at least three spectra.

The combined sky spectrum is subtracted from only those spectra specified by the object aperture and beam numbers. Other spectra, such as comparison arc spectra, are retained unchanged. One may include the sky spectra as object spectra to produce residual sky spectra for analysis. The combined master sky spectra may be saved if the `saveskys` parameter is set. The saved sky is given the name of the object spectrum with the prefix "sky".

7. Nessie Data

Reducing Nessie data with **dohydra** is very similar. The differences are that additional setup and calibration are required since this instrument was a precursor to the more developed Hydra instrument. The discussion in this section also describes some features which may be applicable to other fiber instruments outside of the NOAO instruments.

The Nessie comparison lamp exposures suffer from vignetting resulting in some fibers being poorly illuminated. By rearranging the fibers in the calibration plugboard and taking additional exposures one can obtain good arc spectra through all fibers. The task will merge the well exposed fibers from the multiple exposures into a single final extracted arc calibration image. One of the exposures of a set is selected as the primary exposure. This is the one specified in list of arcs, `arc1`. The other exposures of the set are referenced only in a a setup file, called an *arc replacement file*.

The format of the arc replacement file is lines containing the primary arc image, a secondary arc image, and the apertures from the secondary arc to be merged into the final arc spectra. There can be more than one secondary exposure though it is unlikely. Figure 4 gives an example of this setup file.

Figure 4: Example Arc Aperture Replacement File

```
cl> type arcreplace
nesjun042c nesjun049c 1,7,9,13,17,19,28,34
```

The primary arc exposure is `nesjun042c`, the secondary arc is `nesjun049c`, and the secondary apertures are 1, 7, etc. The syntax for the list of apertures also includes hyphen delimited ranges such as "8-10".

With Hydra the aperture identification table is produced for the user. With Nessie this is not the case, hence, the user must prepare a file manually. The aperture identification file is not mandatory, sequential numbering will be used, but it is highly recommended for keeping track of the objects assigned to the fibers. The aperture identification file contains lines consisting of an aperture number, a beam number, and an object identification. These must be in the same order as the fibers in the image. The aperture number may be any unique number but it is recommended that the fiber number be used. The beam number is used to flag object, sky, arc, or other types of spectra. The default beam numbers used by the task are 0 for sky, 1 for object, and 2 for arc. The object identifications are optional but it is good practice to include them so that the data will contain the object information independent of other records. Figure 5 shows an example for the *blue* fibers from a board called M33Sch2.

Figure 5: Example Aperture Identification File

```
cl> type m33sch2
1 1 143
2 1 254
3 0 sky
4 1 121
5 2 arc
   .
   .
   .
44 1 s92
49 -1 Broken
45 1 156
46 2 arc
47 0 sky
48 1 phil2
```

Note the identification of the sky fibers with beam number 0, the object fibers with 1, and the arc fibers with 2. Also note that broken fiber 49 is actually between fibers 44 and 45. The broken fiber entries, given beam number -1, are optional but recommended to give the automatic spectrum finding operation the best chance to make the correct identifications. The identification file will vary for each plugboard setup. Additional information about the aperture identification table may be found in the description of the task **apfind**.

An alternative to using an aperture identification table is to give no name, the "" empty string, and to explicitly give a range of aperture numbers for the skys and possibly for the sky subtraction object list in the parameters `objaps, skyaps, arcaps, objbeams, skybeams,` and `arcbeams`.

Because taking comparison exposures with Nessie requires replugging the fibers, possibly in more than one configuration, and the good stability of the instrument, there are two mutually exclusive methods for monitoring shifts in the dispersion zero point from the basic arc lamp spectra other than taking many arc lamp exposures. One is to use some fibers to take a simultaneous arc spectrum while observing the program objects. The fibers are identified by aperture or beam numbers. The second method is to use *auxiliary line spectra*, such as mercury lines from the dome lights. These spectra are specified with an auxiliary shift arc list, `arc2`.

When using auxiliary line spectra for monitoring zero point shifts one of these spectra is plotted interactively by **identify** with the reference dispersion function from the reference arc spectrum. The user marks one or more lines which will be used to compute zero point wavelength shifts in the dispersion functions automatically. The actual wavelengths of the lines need not be known. In this case accept the wavelength based on the reference dispersion function. As other observations of the same features are made the changes in the positions of the features will be tracked as zero point wavelength changes such that wavelengths of the features remain constant.

When using auxiliary line spectra the only arc lamp spectrum used is the initial arc reference spectrum (the first image in the `arcs1` list). The master dispersion functions are then shifted based on the spectra in the `arcs2` list (which must all be of the same type). The dispersion function assignments made by **refspectra** using either the arc assignment file or based on header keywords is done in the same way as described for the arc lamp images except using the auxiliary spectra.

If simultaneous arcs are used the arc lines are reidentified to determine a zero point shift relative to the comparison lamp spectra selected, by **refspectra**, of the same fiber. A linear function of aperture position on the image across the dispersion verses the zero point shifts from the arc fibers is determined and applied to the dispersion functions from the assigned calibration arcs for the non-arc fibers. Note that if there are two comparison lamp spectra (before and after the object exposure) then there will be two shifts applied to two dispersion functions which are then combined using the weights based on the header parameters (usually the observation time).

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 (out-of-date).

8.4. Task Help References

Each task in the **hydra** package and tasks used by **dohydra** 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
  apscatter - Fit and subtract scattered light
      apsum - Extract 1D spectra
    aptrace - Trace positions of spectra

      bplot - Batch plots of spectra
  continuum - Fit the continuum in spectra
    dispcor - Dispersion correct spectra
     dopcor - Doppler correct spectra
   identify - Identify features in spectrum for dispersion solution
   msresp1d - Create 1D response spectra from flat field and sky spectra
 refspectra - Assign wavelength reference spectra to other spectra
 reidentify - Automatically identify features in spectra
 sapertures - Set or change aperture header information
     sarith - Spectrum arithmetic
   scombine - Combine spectra having different wavelength ranges
```

```
      scopy - Select and copy apertures in different spectral formats
 setairmass - Compute effective airmass and middle UT for an exposure
      setjd - Compute and set Julian dates in images
      slist - List spectrum header parameters
   specplot - Stack and plot multiple spectra
      splot - Preliminary spectral plot/analysis

    dohydra - Process HYDRA spectra
      demos - Demonstrations and tests

        Additional help topics

   onedspec.package - Package parameters and general description of package
  apextract.package - Package parameters and general description of package
 approfiles - Profile determination algorithms
 apvariance - Extractions, variance weighting, cleaning, and noise model
   center1d - One dimensional centering algorithm
      icfit - Interactive one dimensional curve fitting
```

Appendix A: DOHYDRA 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 flat field spectrum.

flat = "" (optional)
: Flat field spectrum. If specified the one dimensional flat field spectra are extracted and used to make flat field calibrations. If a separate throughput file or image is not specified the flat field is also used for computing a fiber throughput correction.

throughput = "" (optional)
: Throughput file or image. If an image is specified, typically a blank sky observation, the total flux through each fiber is used to correct for fiber throughput. If a file consisting of lines with the aperture number and relative throughput is specified then the fiber throughput will be corrected by those values. If neither is specified but a flat field image is given it is used to compute the throughput.

arcs1 = "" (at least one if dispersion correcting)
: List of primary arc spectra. These spectra are used to define the dispersion functions for each fiber apart from a possible zero point correction made with secondary shift spectra or arc calibration fibers in the object spectra. One fiber from the first spectrum is used to mark lines and set the dispersion function interactively and dispersion functions for all other fibers and arc spectra are derived from it.

arcs2 = "" (optional for Nessie)
: List of optional shift arc spectra. Features in these secondary observations are used to supply a wavelength zero point shift through the observing sequence. One type of observation is dome lamps containing characteristic emission lines.

arcreplace = "" (optional for Nessie)
: Special aperture replacement file. A characteristic of Nessie (though not Hydra) spectra is that it requires two exposures to illuminate all fibers with an arc calibration. The aperture replacement file assigns fibers from the second exposure to replace those in the first exposure. Only the first exposures are specified in the `arcs1` list. The file contains lines with the first exposure image name, the second exposure image name, and a list of apertures from the second exposure to be used instead of those in the first exposure.

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

readnoise = "RDNOISE" (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 = "GAIN" (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.

datamax = INDEF (apsum.saturation)
: The maximum data value which is not a cosmic ray. When cleaning cosmic rays and/or using variance weighted extraction very strong cosmic rays (pixel values much larger than the data) can cause these operations to behave poorly. If a value other than INDEF is specified then all data pixels in excess of this value will be excluded and the algorithms will yield improved results. This applies only to the object spectra and not the flat field or arc spectra. For more on this see the discussion of the saturation parameter in the **apextract** package.

fibers = 97 (apfind)
: Number of fibers. This number is used during the automatic definition of the apertures from the aperture reference spectrum. It is best if this reflects the actual number of fibers which may be found in the aperture reference image. The interactive review of the aperture assignments allows verification and adjustments to the automatic aperture definitions.

width = 12. (apedit)
: Approximate base full width of the fiber profiles. This parameter is used for the profile centering algorithm.

minsep = 8. (apfind)
: Minimum separation between fibers. Weaker spectra or noise within this distance of a stronger spectrum are rejected.

maxsep = 15. (apfind)
: Maximum separation between adjacent fibers. This parameter is used to identify missing fibers. If two adjacent spectra exceed this separation then it is assumed that a fiber is missing and the aperture identification assignments will be adjusted accordingly.

apidtable = "" (apfind)
: Aperture identification table. This may be either a text file or an image. A text file contains the fiber number, beam number defining object (1), sky (0), and arc (2) fibers, and a object title. An image contains the keywords SLFIBnnn with string value consisting of the fiber number, beam number, optional right ascension and declination, and an object title. For Nessie the user had to prepare the file for each plugboard, for Hydra at the 4meter the file was generated for the user, and for Hydra at the WIYN the image header contains the information. Unassigned and broken fibers (beam of -1) should be included in the identification information since they will automatically be excluded.

crval = INDEF, cdelt = INDEF (autoidentify)
: These parameters specify an approximate central wavelength and dispersion. They may be specified as numerical values, INDEF, or image header keyword names whose values are to be used. If both these parameters are INDEF then the automatic identification will not be done.

objaps = "", skyaps = "", arcaps = ""
: List of object, sky, and arc aperture numbers. These are used to identify arc apertures for wavelength calibration and object and sky apertures for sky subtraction. Note sky apertures may be identified as both object and sky if one wants to subtract the mean sky from the individual sky spectra. Typically the different spectrum types are identified by their beam numbers and the default, null string, lists select all apertures.

objbeams = "0,1", skybeams = "0", arcbeams = 2
: List of object, sky, and arc beam numbers. The convention is that sky fibers are given a beam number of 0, object fibers a beam number of 1, and arc fibers a beam number of 2. The beam numbers are typically set in the `apidtable`. Unassigned or broken fibers may be given a beam number of -1 in the aperture identification table since apertures with negative beam numbers are not extracted. Note it is valid to identify sky fibers as both object and sky.

scattered = no (apscatter)
: Smooth and subtracted scattered light from the object and flat field images. This operation consists of fitting independent smooth functions across the dispersion using data outside the fiber apertures and then smoothing the

individual fits along the dispersion. The initial flat field, or if none is given the aperture reference image, are done interactively to allow setting the fitting parameters. All subsequent subtractions use the same fitting parameters.

fitflat = yes (flat1d)
Fit the composite flat field spectrum by a smooth function and divide each flat field spectrum by this function? This operation removes the average spectral signature of the flat field lamp from the sensitivity correction to avoid modifying the object fluxes.

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 and requires reasonably good values for the readout noise and gain. In addition the datamax parameters can be useful.

dispcor = yes
Dispersion correct spectra? Depending on the `params.linearize` parameter this may either resample the spectra or insert a dispersion function in the image header.

savearcs = yes
Save any simultaneous arc apertures? If no then the arc apertures will be deleted after use.

skyalign = no
Align sky lines? If yes then for the first object spectrum you are asked to mark one or more sky lines to use for alignment. Then these lines will be found in all spectra and an average zeropoint shift computed and applied to the dispersion solution to align these lines. Note that this assumes the sky lines are seen in all fibers.

skysubtract = yes
Subtract sky from the object spectra? If yes the sky spectra are combined and subtracted from the object spectra as defined by the object and sky aperture/beam parameters.

skyedit = yes
Overplot all the sky spectra and allow contaminated sky spectra to be deleted?

saveskys = yes
Save the combined sky spectrum? If no then the sky spectrum will be deleted after sky subtraction is completed.

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, flat field, or dispersion reference definitions are changed?

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

listonly = no
List processing steps 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 "epar params" or ":e params" from the parameter editor). Note that using a different parameter file is not allowed. The parameters are described below.

-- PACKAGE PARAMETERS

Package parameters are those which generally apply to all task in the package. This is also true of **dohydra**.

dispaxis = 2
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. The default value defers to the package parameter of the same name.

observatory = "observatory"
Observatory at which the spectra were obtained if not specified in the image header by the keyword OBSERVAT. For Hydra data the image headers identify the observatory as "kpno" so this parameter is not used. For data from other observatories this parameter may be used as describe in **observatory**.

interp = "poly5" (nearest|linear|poly3|poly5|spline3|sinc)
Spectrum interpolation type used when spectra are resampled. The choices are:

```
nearest - nearest neighbor
 linear - linear
  poly3 - 3rd order polynomial
  poly5 - 5th order polynomial
spline3 - cubic spline
   sinc - sinc function
```

database = "database"
Database (directory) used for storing aperture and dispersion information.

verbose = no
Print verbose information available with various tasks.

logfile = "logfile", plotfile = ""
Text and plot log files. If a filename is not specified then no log is kept. The plot file contains IRAF graphics metacode which may be examined in various ways such as with **gkimosaic**.

records = ""
Dummy parameter to be ignored.

version = "HYDRA: ..."
Version of the package.

PARAMS PARAMETERS

The following parameters are part of the **params** parameter set and define various algorithm parameters for **dohydra**.

-- GENERAL PARAMETERS --

line = INDEF, nsum = 10
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.

order = "decreasing" (apfind)
When assigning aperture identifications order the spectra "increasing" or "decreasing" with increasing pixel position (left-to-right or right-to-left in a cross-section plot of the image).

extras = no (apsum)
Include extra information in the output spectra? When cleaning or using variance weighting the cleaned and weighted spectra are recorded in the first 2D plane of a 3D image, the raw, simple sum spectra are recorded in the second plane, and the estimated sigmas are recorded in the third plane.

-- DEFAULT APERTURE LIMITS --

lower = -5., upper = 5. (apdefault)
Default lower and upper aperture limits relative to the aperture center. These limits are used when the apertures are first found and may be resized automatically or interactively.

-- 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 relative to a local background.

-- 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 = 3 (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. (aptrace)
: Default number of rejection iterations and rejection sigma thresholds.

-- SCATTERED LIGHT PARAMETERS --

buffer = 1. (apscatter)
: Buffer distance from the aperture edges to be excluded in selecting the scattered light pixels to be used.

apscat1 = "" (apscatter)
: Fitting parameters across the dispersion. This references an additional set of parameters for the ICFIT package. The default is the "apscat1" parameter set.

apscat2 = "" (apscatter)
: Fitting parameters along the dispersion. This references an additional set of parameters for the ICFIT package. The default is the "apscat2" parameter set.

-- 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.

pfit = "fit1d" (apsum) (fit1d|fit2d)
: Profile fitting algorithm for cleaning and variance weighted extractions. The default is generally appropriate for Hydra/Nessie data but users may try the other algorithm. See **approfiles** for further information.

lsigma = 3., usigma = 3. (apsum)
: Lower and upper rejection thresholds, given as a number of times the estimated sigma of a pixel, for cleaning.

nsubaps = 1 (apsum)
: During extraction it is possible to equally divide the apertures into this number of subapertures.

-- FLAT FIELD FUNCTION FITTING PARAMETERS --

f_interactive = yes (fit1d)
: Fit the composite one dimensional flat field spectrum interactively? This is used if `fitflat` is set and a two dimensional flat field spectrum is specified.

f_function = "spline3", f_order = 10 (fit1d)
Function and order used to fit the composite one dimensional flat field spectrum. The functions are "legendre", "chebyshev", "spline1", and "spline3". The spline functions are linear and cubic splines with the order specifying the number of pieces.

-- ARC DISPERSION FUNCTION PARAMETERS --

threshold = 10. (autoidentify/identify/reidentify)
In order for a feature center to be determined the range of pixel intensities around the feature must exceed this threshold.

coordlist = "linelists$idhenear.dat" (autoidentify/identify)
Arc line list consisting of an ordered list of wavelengths. Some standard line lists are available in the directory "linelists$".

match = -3. (autoidentify/identify)
The maximum difference for a match between the dispersion function prediction value and a wavelength in the coordinate list.

fwidth = 4. (autoidentify/identify)
Approximate full base width (in pixels) of arc lines.

cradius = 10. (reidentify)
Radius from previous position to reidentify arc line.

i_function = "spline3", i_order = 3 (autoidentify/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 = 2, i_low = 3.0, i_high = 3.0 (autoidentify/identify)
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 = "jd", group = "ljd" (refspectra)
Image header keywords to be used as the sorting parameter for selection based on order and to group spectra. A null string, "", or the word "none" may be use to disable the sorting or grouping parameters. The sorting parameter must be numeric but otherwise may be anything. The grouping parameter may be a string or number and must simply be the same for all spectra within the same group (say a single night). Common sorting parameters are times or positions. In **dohydra** the Julian date (JD) and the local Julian day number (LJD) at the middle of the exposure are automatically computed from the universal time at the beginning of the exposure and the exposure time. Also the parameter UTMIDDLE is computed.

time = no, timewrap = 17. (refspectra)
Is the sorting parameter a 24 hour time? If so then the time origin for the sorting is specified by the timewrap parameter. This time should precede the first observation and follow the last observation in a 24 hour cycle.

-- DISPERSION CORRECTION PARAMETERS --

linearize = yes (dispcor)
Interpolate the spectra to a linear dispersion sampling? If yes the spectra will be interpolated to a linear or log linear sampling If no the nonlinear dispersion function(s) from the dispersion function database are assigned to the input image world coordinate system and the spectral data are not interpolated.

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

flux = yes (dispcor)
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.

-- SKY SUBTRACTION PARAMETERS --

combine = "average" (scombine) (average|median)
Option for combining sky pixels at the same dispersion coordinate after any rejection operation. The options are to compute the "average" or "median" of the pixels. The median uses the average of the two central values when the number of pixels is even.

reject = "none" (scombine) (none|minmax|avsigclip)
Type of rejection operation performed on the pixels which overlap at each dispersion coordinate. The algorithms are discussed in the help for **scombine**. The rejection choices are:

```
      none - No rejection
    minmax - Reject the low and high pixels
 avsigclip - Reject pixels using an averaged sigma clipping algorithm
```

scale = "none" (none|mode|median|mean)
Multiplicative scaling to be applied to each spectrum. The choices are none or scale by the mode, median, or mean. This should not be necessary if the flat field and throughput corrections have been properly made.

ENVIRONMENT PARAMETERS

The environment parameter *imtype* is used to determine the extension of the images to be processed and created. This allows use with any supported image extension. For STF images the extension has to be exact; for example "d1h".