SPECFOCUS: An IRAF Task for Focusing Spectrographs

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Abstract.
An IRAF task for measuring the point-spread function width along the dispersion and wavelength shifts across the dispersion in two dimensional arc spectra is described.

The IRAF[2] task **specfocus** estimates the dispersion width of spectral lines in sequences of arc spectra taken at different focus (or other parameter which affects the spectral line widths) settings. The widths can be measured at different spatial and dispersion positions, called *samples*, on the detector. The width estimates are recorded and displayed graphically in order to investigate dependencies and determine appropriate settings for the spectrograph setup. The task may also measure dispersion shifts when multiple spectral samples are specified. This task does not measure the focus point-spread function width across the dispersion.

The input images need not be bias corrected or flat fielded since the intention is to operate directly on the raw CCD images as they are obtained at the telescope. The images are specified with an image list which may consist of image names, wildcard templates, and @-files.

A *focus* value is associated with each image. This may be any numeric quantity. The focus values may be specified in several ways. If no value is given then integer numbers are assigned to the images in the order in which they appear in the image list. A range list may be specified which consists of individual values, ranges of values, a starting value and a step, and a range with a step. For example a range list could be "`500-250x-50, 225, 200-150x-10`". A long list, such as a list of individual focus values, may be placed in a file and specified with the IRAF @-file convention. Finally, a parameter in the image header may be used for the focus values by simply specifying the parameter name.

Two dimensional long slit images are summed into one or more one dimensional spectra across the dispersion. The dispersion axis is defined either by the image header parameter DISPAXIS or a task parameter with the image header parameter having precedence. The range of lines or columns across the dispersion may be specified to define the limits of the slit, otherwise the full width of

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[2]Image Reduction and Analysis Facility, distributed by the National Optical Astronomy Observatories

the image is used. This range is then divided into a number of specified spectra. Use of more than one spectrum across the dispersion allows investigation of variations along the slit. In addition, if desired, the spectrum nearest the center may be used as a reference against which shifts in the dispersion positions of the features in the other spectra are determined by crosscorrelation.

The conversion of two dimensional spectra to one dimensional spectra may also be performed separately using the tasks in the IRAF **apextract** package. This would be done typically for multifiber or echelle format spectra. If the two dimensional spectra have been extracted to one dimensional spectra then the individual spectra are used without any summation. Measuring relative shifts between spectra may also be done and makes sense for multifiber spectra but not for echelle spectra.

In addition to dividing the spatial axis into a number of spectra the dispersion axis may also be divided into a set of subspectra. This applies to both long slit and 1D extracted spectra. When the dispersion axis is divided into more than one sample, the dependence of the dispersion widths and shifts along the dispersion may be investigated.

After computing the correlation profiles, the profile widths and shifts, and the best focus values, an interactive graphics mode is entered. Upon exiting the interactive graphics the results are written to the terminal and to a logfile if one is specified. A sample execution and output is shown in Figure **??**.

Algorithms

Each spectral sample has a low order continuum subtracted using a noninteractive iterative rejection algorithm to exclude the spectral lines. This technique is the same as that commonly used in other IRAF applications such as *continuum*. The continuum subtracted spectrum is then tapered with a cosine bell function and autocorrelated. The length of the taper and the range of shifts for the correlation is set by another task parameter. This parameter should be set only slightly larger than the expected feature widths to prevent correlations between different spectral lines. The correlation profile is offset to zero at the edges of the profile and normalized to unity at the profile center. The profiles may be viewed as described below.

If there is more than one spatial sample the central spectrum is also crosscorrelated against the other spectra at the same dispersion sample. The crosscorrelation is computed in exactly the same way as the autocorrelation. The crosscorrelation profiles are only used for determining shifts between the two samples and are not used in the width determinations.

A cubic spline interpolator is fit to the profiles and this interpolation function is used to determined the profile width and center. The width is measured at a point given by a *level* parameter relative to the profile peak. The default value selects the full width at half maximum. The autocorrelation width is divided by the square root of two to yield an estimate of the width of the spectral features in the spectrum in units of pixels.

Having computed the width and shift for each input image at each sample, the *best focus* values (focus, width, and shift) are estimated for each sample. As mentioned later, it is possible to exclude some samples from this calculation by deleting them graphically. First the images with the smallest measured width at each distinct focus are selected since it is possible to input more than one image at the same focus. The selected images are sorted by focus value and the image with the smallest width is found. If that image has the lowest or highest focus (which will always be the case if there are only one or two images) then the best focus, width, and shift are those measured for that image. If there are three or more focus values and the minimum width focus image is not an endpoint then parabolic interpolation is used to find the minimum width. The focus at this minimum width is the *best focus.* The dispersion shift is the parabolic interpolation of the shifts at the best focus. The *average best focus* values are then the average of the best focus values over all samples.

Interactive Graphics

There are several interesting aspects of this program dealing with interactive graphics. First was the development of various informative plot formats to allow visualizing the multiparameter space. Another is that the plots had to be sensitive to the amount of data available. For instance if there is very little data some plots are inappropriate while at the other extreme of large amounts of data the plots have to be abbreviated in some ways for legibility.

The last feature to mention is that the graphics use a point-and-type interface to select data and plot formats. In all plots there is a concept of the current image and the current sample. In general there is an indication, usually a box, of which image and sample is the current one. The current image and sample are changed by pointing at a particular point, box, circle, or symbol for that image and sample and typing a key. For example to zoom on a particular subsample from a particular image one points to the appropriate symbol in the current plot and types 'z'.

There are five types of plot formats. The *width* format produces a graph showing the sample widths as a function of focus value. This is the default plot if there is only one sample over a set of images at different focus values. The top graph is a symbol plot of width verses focus. The lower portion of this format are either graphs of the autocorrelation profiles (described below) if there is only one sample per image or graphs showing the widths as circles with size proportional to the width and position corresponding to the spatial position of the samples in the image. Figure **??** shows an example of a width format plot.

The *best focus* format shows summary graphs of the best focus values (as described above) at each sample position. This is the default plot when there is sufficient data. The central graph represents the best focus (smallest) width at each sample by circles of size proportional to the width. The position of the circle indicates the central line and column of the sample and the relative shifts, if calculated, are represented by little vectors. In addition, there may be graphs along the line or column axes which, again, show the widths as circles but one axis is either the line or column and the other axis is either the best focus value or the shift. This identifies best focus trends along and across the dispersion. Figure **??** shows an example of this type of plot.

The *profile* format produces graphs of the autocorrelation profiles. This requires more than one image and more than one sample. The top graph shows the profiles of all images at a particular sample and the bottom graph shows the profiles of all samples at a particular image.

The profiles are drawn with a solid line using the interpolator function and the actual pixel lags are indicated with pluses. The profiles are drawn shifted by the amount computed from the crosscorrelation. Note that the shift is added to the autocorrelation profile and the crosscorrelation profile is not what is plotted. The zero shift position is indicated by a vertical line.

The *spectrum* format is similar to the *profile* format but shows the spectra rather than the profiles. The top graphs are the spectra of each image at a particular sample and the bottom graphs are the spectra of each sample for a particular image.

The *zoom* format graphs the autocorrelation profile and the spectrum of a single sample. This graph provides scales which are not provided with the *profile* and *spectrum* graphs. If there is only one image and one sample then this is the only plot available.

It is possible to exclude some of the images and samples from the calculation of the best focus and best average focus values. This is done with the *delete* command. There is also an *undelete* command to recall deleted data. When the task exits the printed and logged results will have the deleted data excluded.

The remaining commands give a command help, redraws the current plot, prints information about the sample nearest the cursor, and exits the task.

Figure 1. Example command and output

```
cl> specfocus @imlist focus=400x50 slit1=50 slit2=130 nspec=3 ndisp=3 shifts-
<Interactive graphics which is exited with the 'q' key>
SPECFOCUS: NOAO/IRAF V2.10EXPORT valdes Thu 19:41:41 17-Sep-92
  Best avg focus at 206.6584 with avg width of 2.91 at 50% of peak

  -- Average Over All Samples

                                 Image  Focus  Width
                            jdv010.imh   150.   3.28
                            jdv009.imh   200.   2.95
                            jdv008.imh   250.   3.17
                            jdv007.imh   300.   3.41

  -- Image jdv009.imh at Focus 200. --

        Width at 50% of Peak:

                     Columns
                      50-76       77-103    104-130
           Lines  +---------------------------------
           2-267  |    2.93        2.58        2.74
         268-533  |    3.17        2.76        2.89
         534-799  |    3.77        2.23        3.50
```

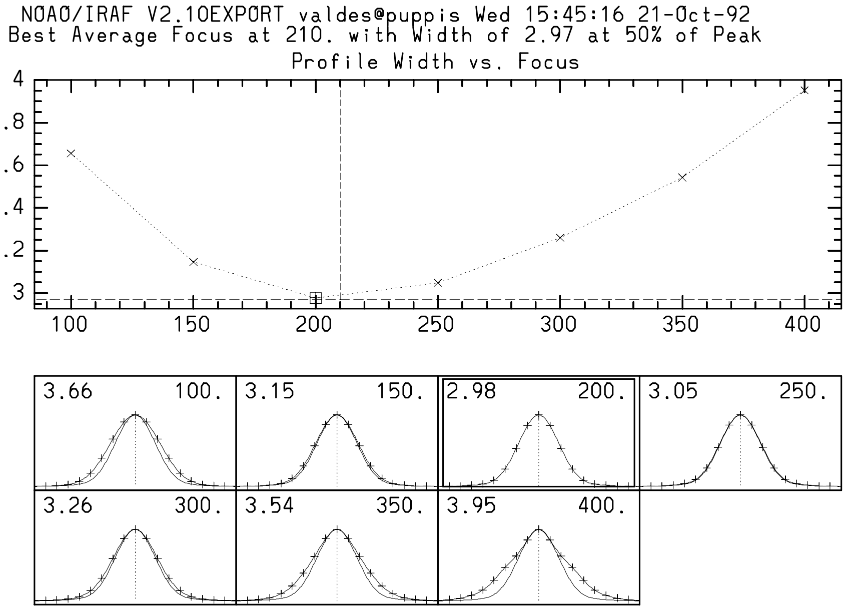

Figure 2. Width/profile plot with multiple spectra and one sample

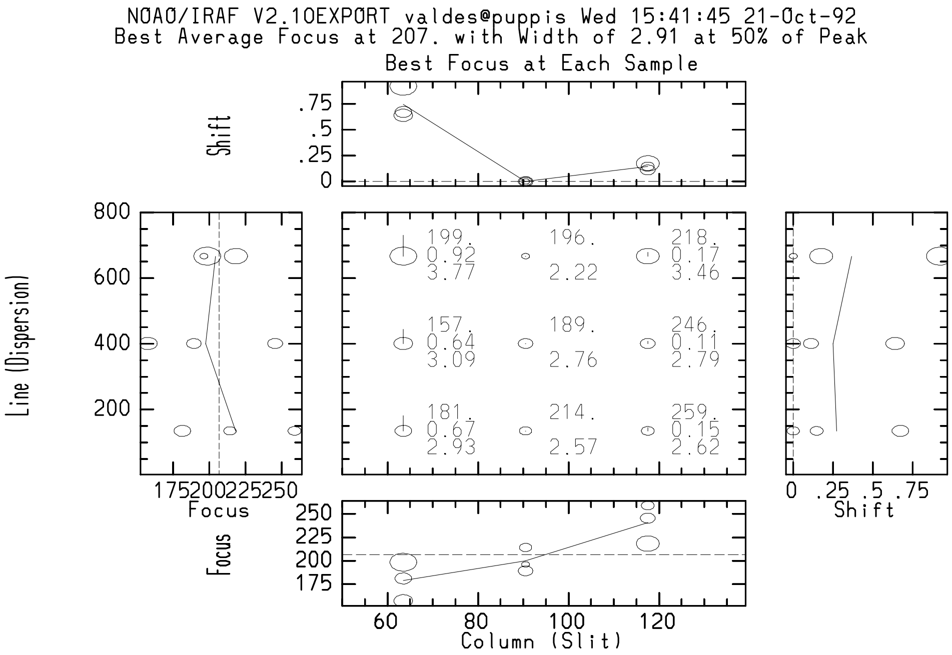

Figure 3. Best focus plot with multiple spectra and samples