Mimir NIR Spectroscopy – Data Processing Cookbook

Note: These instructions assume your Mimir data have already been processed through the Mimir Software Package Basic Data Processor (MSP-BDP) and may be found in a directory called "12_Science_Images"

1. Fetch and install the software packages needed
   a. The key elements are IDL packages or projects, named:

   i. Mimir Software Package – Wavelength Calibration Tool (MSP_WCT)
   ii. Mimir Software Package – Clean and Coadd Spectra (MSP_CCS)
   iii. Mimir Software Package – Spectrum ExtraCtor (MSP_SXC)
   iv. Mimir Software Package – Baseline Removal Tool (MSP_BRT)
   v. Mimir Software Package – Spectra Combining Tool (MSP_SCT)
   vi. Mimir Software Package – Spectrum Annotation/Analysis Tool (MSP_SAT)

   > All of these packages and installation instructions can be fetched in Zip file form from the Mimir/Software web site: http://people.bu.edu/clemens/mimir/software.html

   b. Get the SpeXTool package (from the class Blackboard web site for BU folks, from IRTF for others)

2. Use Argon lamp observations to wavelength-calibrate science observations
   a. **Download** and **install** the **MSP_WCT** package
   b. **Identify** the image numbers for the relevant Argon lamp data collection events for a particular spectroscopy observation set (a single object's observations normally consist of ABBA dithers on the target object, lights-on/lights-off dome continuum lamp images, five argon images, and a set of bias images).
   c. **Launch** the **MSP_WCT** (Wavelength Calibration Tool)
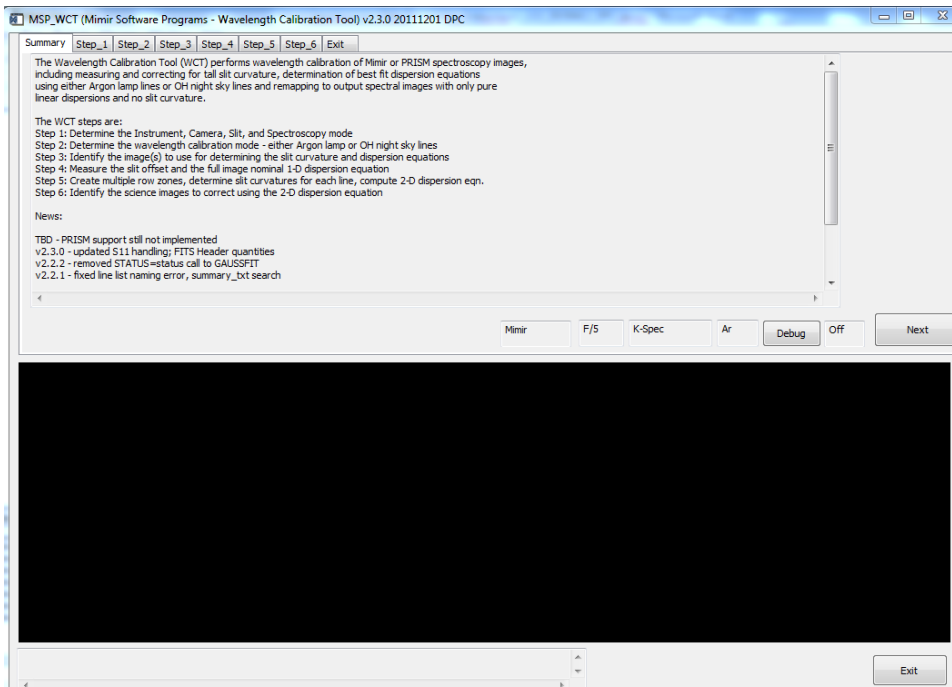
The GUI at left should appear. It has a lower draw window for displaying images and spectra and on this first "**Summary**" tab page, a text summary of the steps to follow. In the middle zone, there are a number of windows echoing configuration settings and the "**Next**" button.

d. **Click** the '**Step_1**' tab to the right of the '**Summary**' tab at the top to move to the "**Step_1**" tabbed page.

e. **Select** the correct instrument tab ('**Mimir**'). Select the correct 'radio buttons' to pick the right camera ('**F/5**'), spectroscopy mode (usually this is '**HK-Spec**'), as shown on the GUI image here.

f. **Select** the radio button for the correct slit mode (usually this is '**S1 – Tall, Narrow**')

g. **Click** '**Next**', or '**Step_2**'
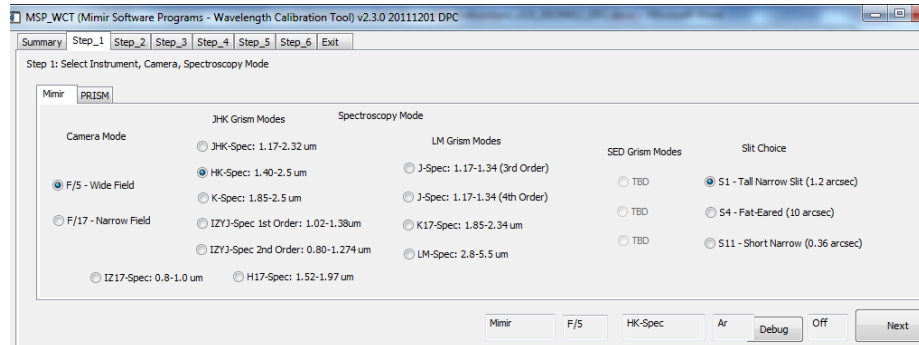
h. On the '**Step_2**' tabbed page (not shown here), **verify** that '**Argon**' is selected'

i. **click** '**Next**' or '**Step_3**'

j. On the '**Step_3**' tabbed page (see below), next to the '**Input Directory**' label, **click** '**Select**' and use the file-chooser to point to the '**12_Science_Images**' directory and **select** the night subdirectory (if data are coming from an MSP-BDP data base).

k. Next to '**Output Directory**', if this is the first set of data to process, **click** '**Create Directory**' and create a new subdirectory, parallel to '**12_Science_Images**', and **name** the new directory '**13_Wavelength_Calibrated_Images**'. If this is not the first set of data (i.e., the directory exists), then **click** '**Select**' and use the file-chooser to **select** that '**13_Wav…**' directory.
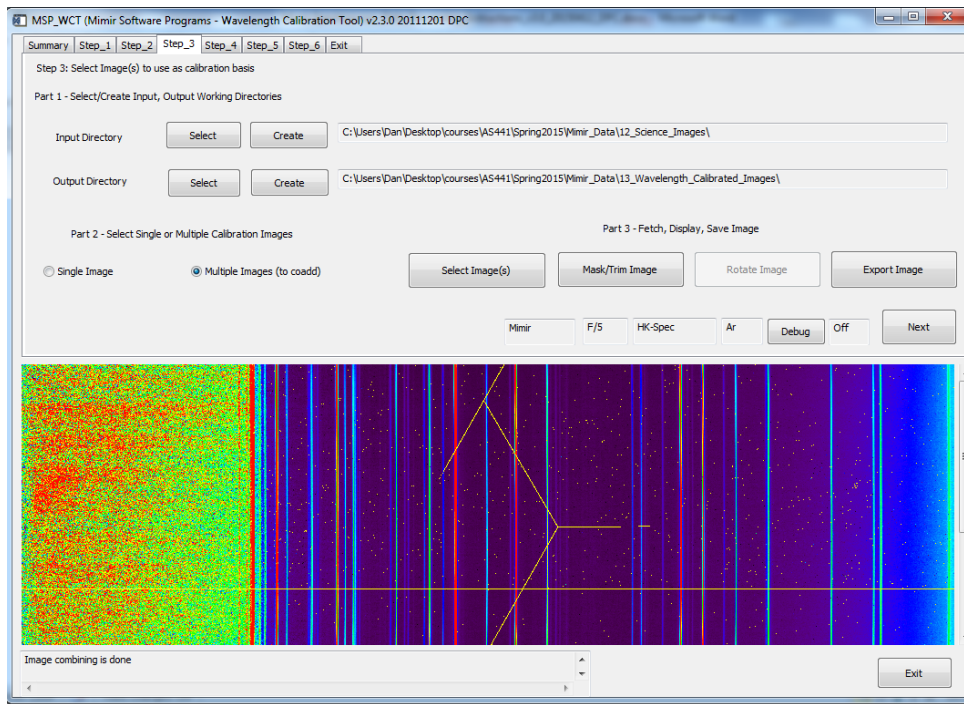
l. **Click** the '**Multiple Images**' radio button

m. **Click** the '**Select Images**' button and *use the file-chooser to **select** the (usually) five ARGON images* (NOT the science images). The images are read and coadded (see progress percentage value in lower left corner).

n. When the averaged image is displayed, **click** '**Next**' or '**Step_4**'

o. **Click** the '**Find Slit Offset**' button on this new tabbed page. The slit offset measured in the
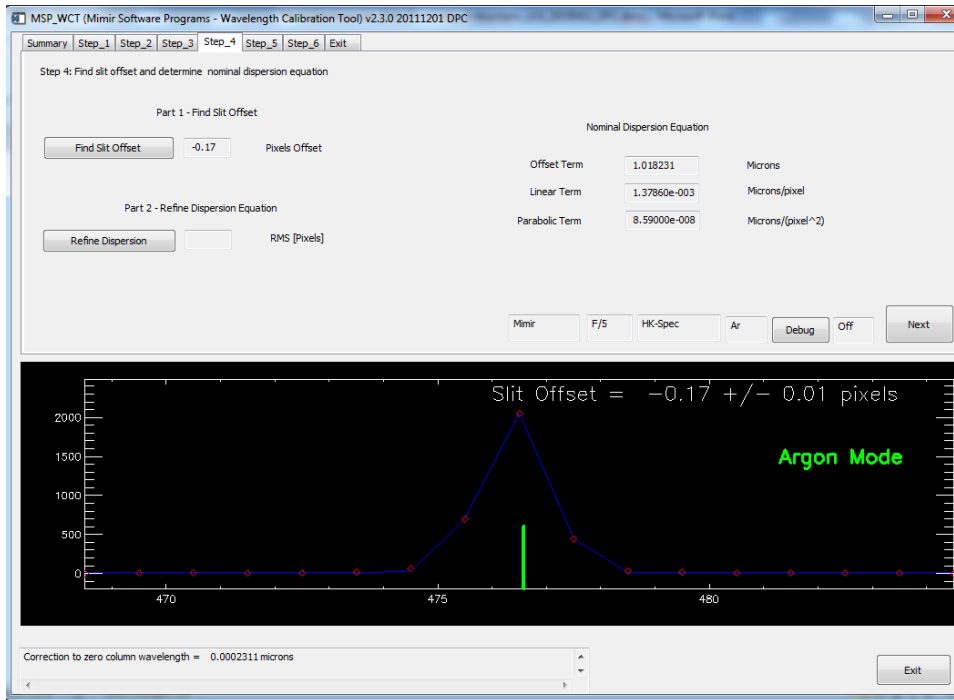

spectral image and is then listed in the textbox at upper left. The value should normally be within 1-2 pixels of zero. The plot window shows a portion of the Argon line flux (in blue, with red points) near the nominal slit position (itself a green marker).

p. **Click** '**Refine Dispersion**' to obtain a better estimate for the average dispersion equation. This will launch another window, showing the spectral channels close to each of 26 emission features, the overall match of wavelength to column number, and the residuals of the column values when the lines fit in the spectrum are corrected by the 1-D dispersion equation.

In the main GUI plot window (next page), the argon spectrum will appear, with vertical lines noting Argon spectral features. Dashed **green** lines are those included in the fitting. Those in dashed **blue** are judged too blended to be useful. Both green and blue lines should mark corresponding features in the **red** Argon spectrum plotted. The extra pop-up window can be dismissed by pressing the "Done" button.

3
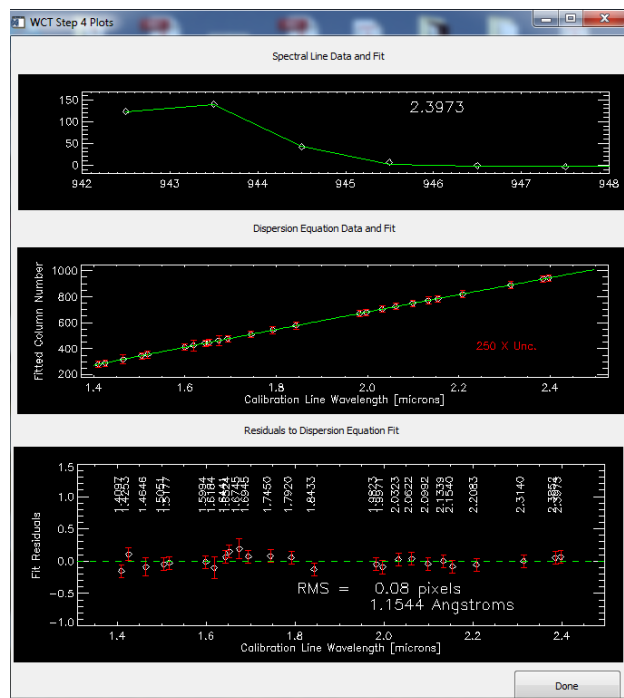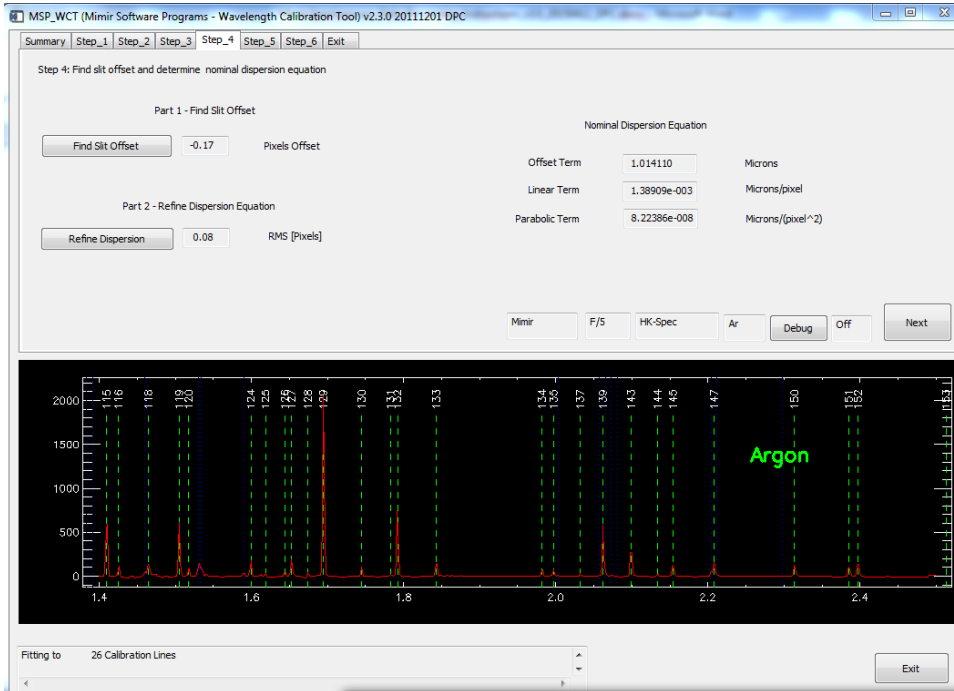
The RMS noise on the fitted dispersion equation is displayed in the textbox at left center. It should show a value between 0.04-0.15 pixels, signifying a good match.

The 1-D dispersion equation coefficients found are displayed in the three textboxes at upper right. They are the 'a', 'b', and 'c' values for the equation:

$$\text{Wavelength} = a + b * \text{column\_number} + c * (\text{column\_number})^2$$

q. **Click** '**Next**' or '**Step_5**'

r. On the '**Step_5**' tab, **Click** '**Start Line Fitting**' to start zonal fitting of the dispersion equation across the Argon spectral image, in order to develop a 2-D dispersion equation.
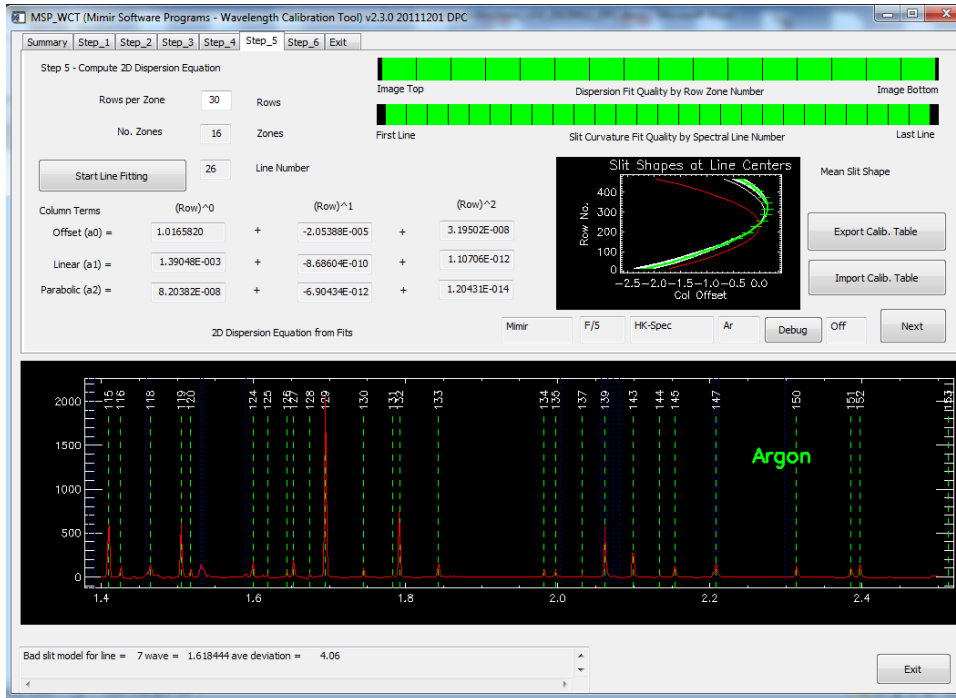
s. When this is done, **examine** the contents of the small plot, located at right center on the GUI (see previous page). If all but one or two of the curves on this plot are colored green (and no more than 2 are red), then the 2D dispersion fit is good. (If the small plot curves are wildly dispersed, then the fit is bad. Fixes are then required. Blackbelt warning…)

t. **Click** '**Next**' or '**Step 6**'
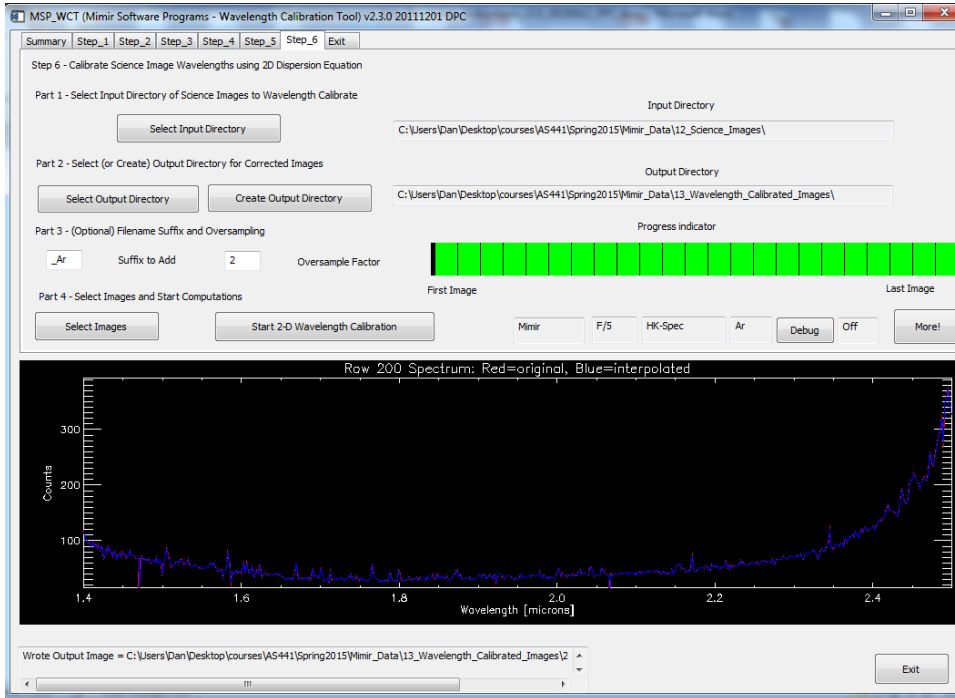

u. On the '**Step 6**' tab, the input and output directories should already be set. If not, **set** the input to the '**12_Science_Images**' directory and correct night subdirectory, and **set** the output to the '**13_Wave…**' directory

v. **Check** that the '**_Ar**' suffix and '**2**' oversample factor are both set

w. **Click** '**Select Images**' and *use the file-chooser to **select** the range of images* of the science target for which to apply this argon wavelength calibration.

x. **Click** '**Start 2-D Wavelength Calibration**'

y. When done, either **click** '**More!**' to go on to the next Argon and Science set of images for the night, or '**Exit**' to quit.

3. Difference, stack, and combine multiple spectral images

a. **Download** and **install** the **MSP_CCS** package

b. **Compile/Build** and **launch MSP_CCS**
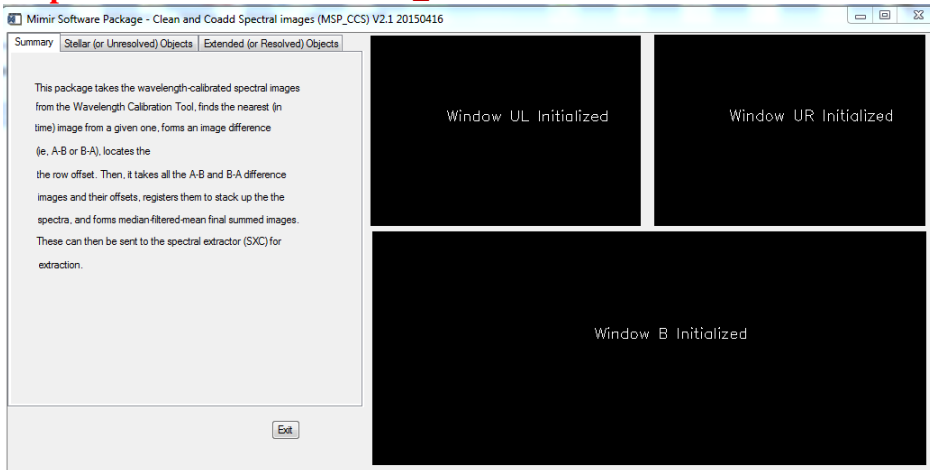
c. For processing stellar (or any other angularly-unresolved objects) **Click** the '**Stellar (or Unresolved) Objects**' tab. For extended/resolved object spectra, **jump** to section **3.x** below.
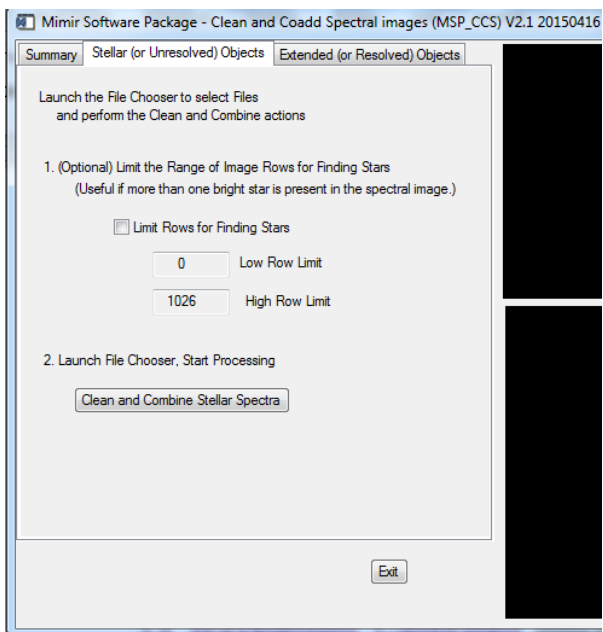
This new tabbed page will permit using the file chooser to select the input spectral images (bottom of page). It will also allow the user to limit the rows on the spectral images to be searched for stellar flux for matching across the different input spectral images. This option is rarely needed, unless multiple stellar spectra are present in the spectral images. Use DS9 to identify the range of rows (across the full image set) to delimit the acceptable range.

d. If the Limit Rows option is to be invoked, **click** the checkbox next to the "**Limit Rows for Finding Stars**" label. This turns on the two lower textboxes so they may accept input.

i. **Move the cursor** with the mouse into the "**Low Row Limit**" textbox, and **click** the left mouse button. **Swipe** across the existing text in that textbox **while holding the mouse button down**. **Release** the mouse button. **Type** the desired low row limit into the textbox and **press** the "**Enter**" key. **Repeat** this process for the "**High Row Limit**" textbox.

e. **Click** the "**Clean and Combine Stellar Spectra**" button to launch the file chooser.

f. Use the file-chooser to **select** a group of WCT-processed spectral images from the '**13_Wavelength_Calibrated**' directory. The group should be the full set of observations for one science target. Several plots will be displayed as processing proceeds:

g. The **first plot** (upper left of the three plot windows, see below) shows the declination dither pattern executed by the telescope (from sky positions stored in the FITS headers). Images are classified as belonging to the 'A' or 'B' dither positions.
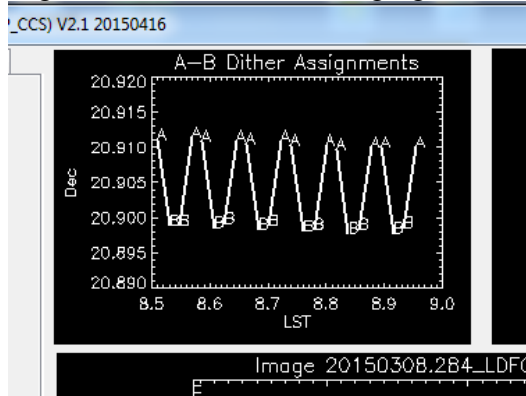

h. The **second plot** (in the bottom plot location, see below) will update with a row plot representing the average power found in each row of the image (that is, all columns in each row are averaged). This will normally reveal the presence of one star, with a bolder overlay showing a gaussian fit to the profile to better locate the centroid row for each observation.
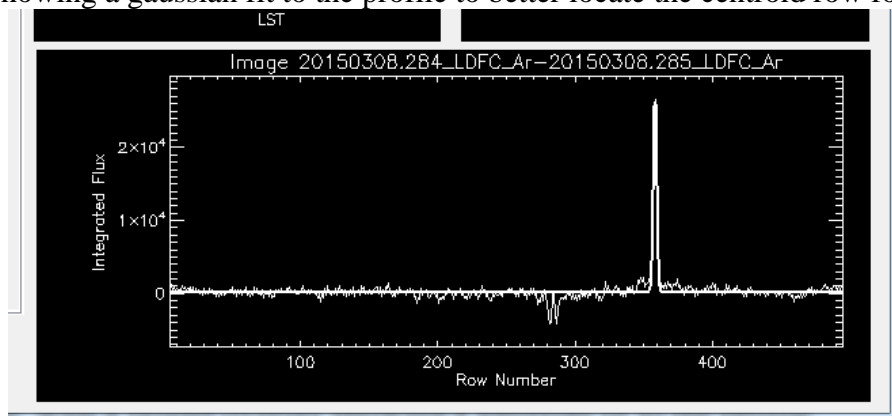

i. The **third plot** (in the upper right plot panel position, see below) will show the run of these refined row centroid positions versus spectral image number (referenced to the first). This should show the 'A-B' dither pattern as well as the row drift included as the **dDecdP** parameter when the observations were conducted.
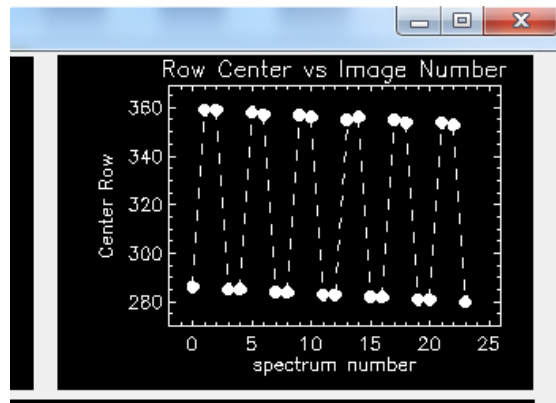
j. The **fourth plot** (overwriting the upper left plot panel, see below) shows the relative gain to be applied to each spectrum when the coadding takes place. These gains come from the integrated power seen in each gaussian fit to the row-averaged spectra. They should be not far from unity.
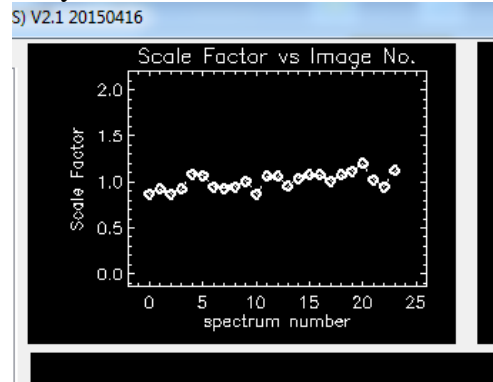

k. When the shifting and coadding is completed, the file chooser will pop up.

l. **Use** the file-chooser to **save** the final cleaned and coadded spectral image. If not yet created, **make** a new directory named '**14_Registered_Coadded_Spectral_Images**' and **name** your new file in that directory something like '**20111112_765-787.fits**' or '**20150308_Eskimo.fits**' to best identify it. *Be sure to include a '.fits' suffix*.

i. These output FITS images may be **examined** using DS9. You should note an improved signal-to-noise, smoother backgrounds, and 'downward' going spectral features above and below the 'upward' going main spectral feature. The downward spectra result from the first AB or BA differences calculated prior to registration and stacking of the upward spectral features. (See example below for a planetary nebula central star, with nebular features extending above and below the continuum from the star.)
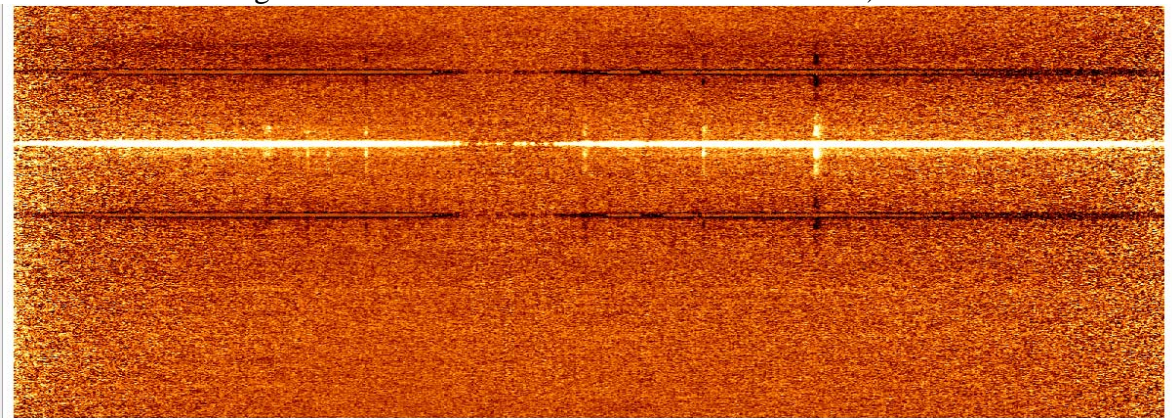
4. <u>Extract a Stellar Spectrum from the Coadded Spectral Image</u> *(N.B. This non-GUI software is slated for replacement.)*

   a. **Download** and **install** the **MSP_SXC** (Spectral eXtraCtor) package
   b. **Open, compile, and start** the '**Step_14_Extract_Stellar_Spectrum.pro**' program – *do NOT try to run MSP_SXC* – it isn't a GUI package at the moment
   c. Use the file-chooser to **select** one cleaned, coadded spectral image from the previous step
   d. Use the next instance of the file-chooser to **create** or **select** an output directory, named '**15_Extracted_Spectra**'
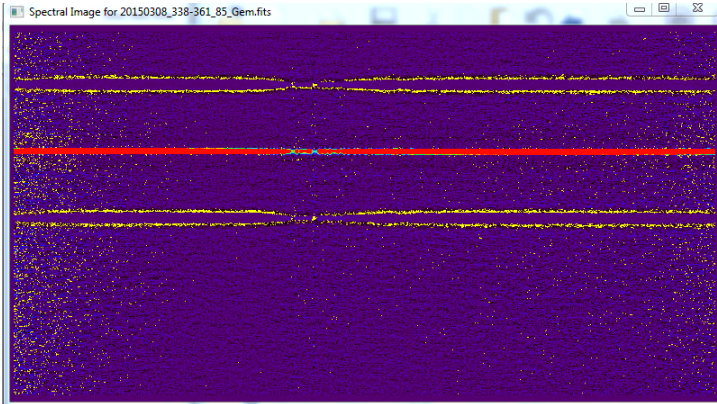
   e. A plot (at left) showing your spectral image will appear and a cursor will turn on in the image. If this looks like your image, **click the mouse button while the cursor is within the image**
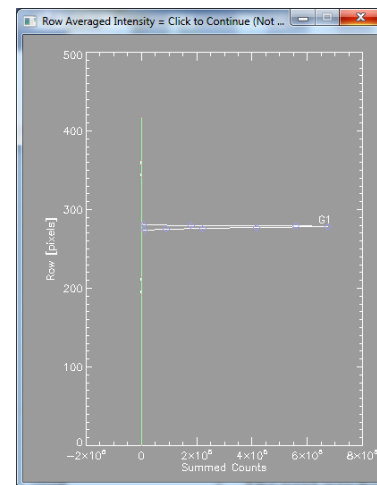
   f. The next plot (seen at right) shows the summed counts (with column) in each row of the image
   g. In the plot, gaussian-looking features will be numbered '**G1**' for the strongest, '**G2**' the next strongest, etc. Rows identified in each gaussian feature have blue circles surrounding the data points. Baseline regions are
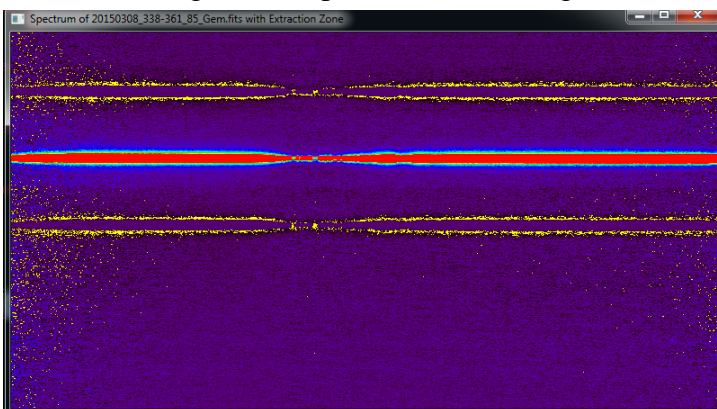
identified as the green line, with some red marks showing rejection regions.

   h. In the IDL response window, **identify which gaussian feature to extract** from the spectral image, by typing a '**1**' or '**2**' and **pressing Enter**

   i. The next window to pop up (bottom of previous page) will show the spectral image, with two red overlays (hard to see in the image shown here) identifying the set of rows from which the spectrum will be extracted from the image. These should closely parallel the region comprising the spectrum in the image.

j. Next, **two plots will appear**. <u>**The top plot (below) shows the extracted spectrum**</u> as a function of wavelength, with the uncertainty for each spectral channel plotted below the value for each channel (the uncertainties may be indistinguishable from the zero line for S/N ratios > 200 or so).
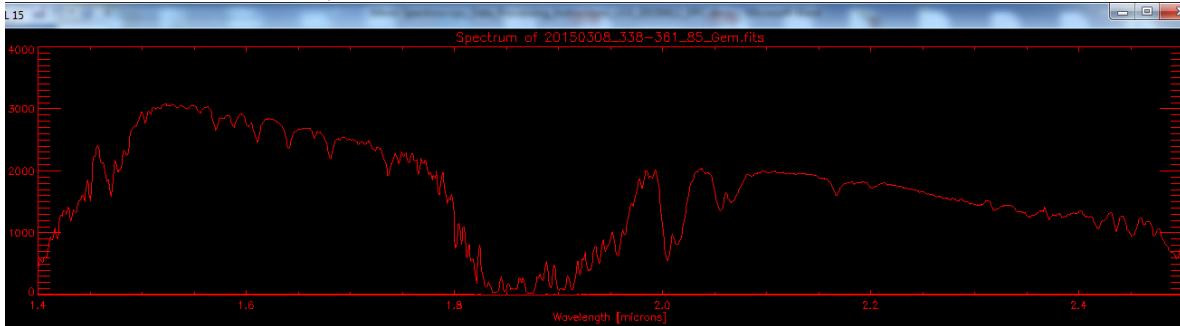
k. <u>**The bottom plot (below) will show the average sky spectrum away from the star**</u>. For these CCS-processed images, the sky spectrum should already be free of OH line emission, so the plot should look like mostly gaussian noise.
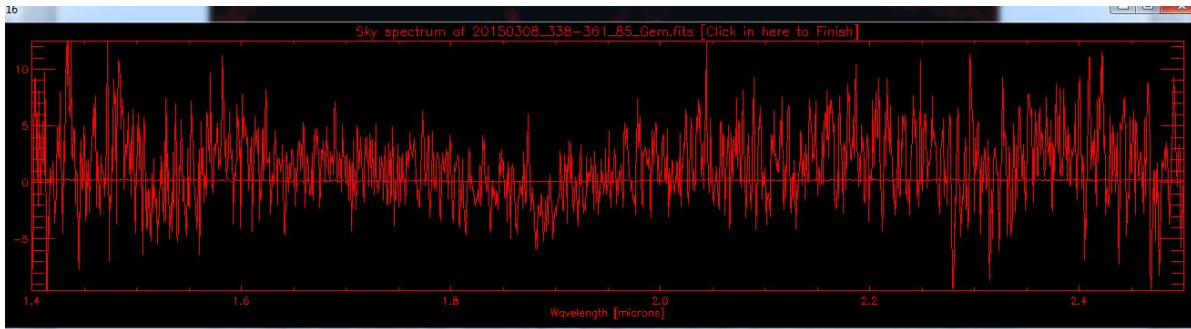

l. **Click** in the lower plot ("**Sky Spectrum of …**") to end this step

5. Use an extracted A0V star spectrum to telluric-correct a science star spectrum
[NB: Screen captures needed for this section]

   a. **Download** and **unpack** the **Spextool** package
   b. **Compile** and **launch** the '**xtellcor.pro**' program **from the 'pro' subdirectory of spextool**
   c. **Click** the '**Help**' bar at the bottom of the '**Xtellcor**' window
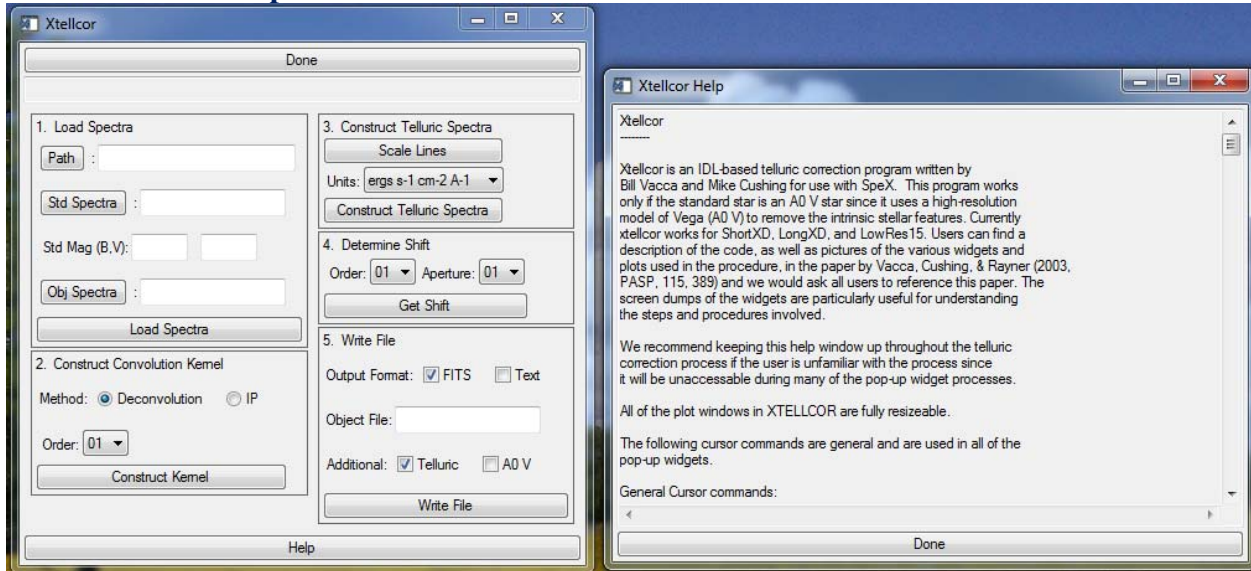
   d. Follow the steps '**1**' to '**5**' in the '**Xtellcor**' window, as described below:
      i. In the '**1. Load Spectra**' window:
         1. **Click** the '**Path**' button to use the file-chooser to **select** the '**15_Extracted…**' directory where the spectra are located
         2. **Click** the '**Std Spectra**' button to **use the file-chooser to select** the spectrum for the A0V standard star (Important: this is the A0V star, not the science star).
         3. **Click** the '**Obj Spectra**' button **to load** the spectrum for the science star
         4. **Fill in** the '**Std Mag (B,V)**' text windows with the apparent B and V magnitudes for the A0V standard star (you can fetch the numerical values of these magnitudes from SIMBAD)
         5. **Click** the '**Load Spectra**' button
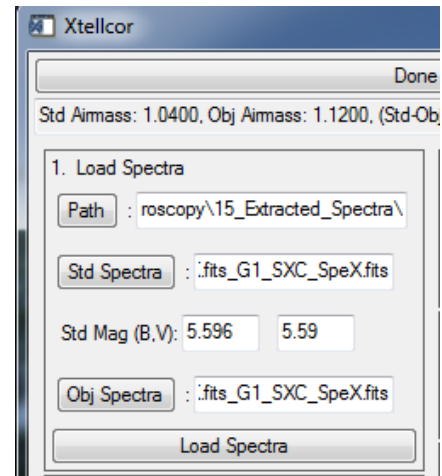
      ii. In the '**2. Construct Convolution Kernel**' window:
         1. Be sure the '**Deconvolution**' is selected and '**Order**' shows '**01**'
         2. **Click** the '**Construct Kernel**' button and a new window will appear
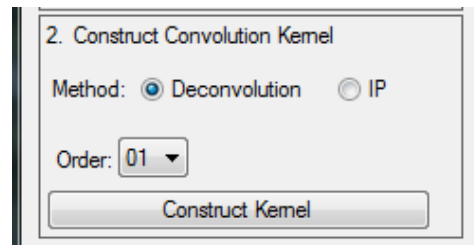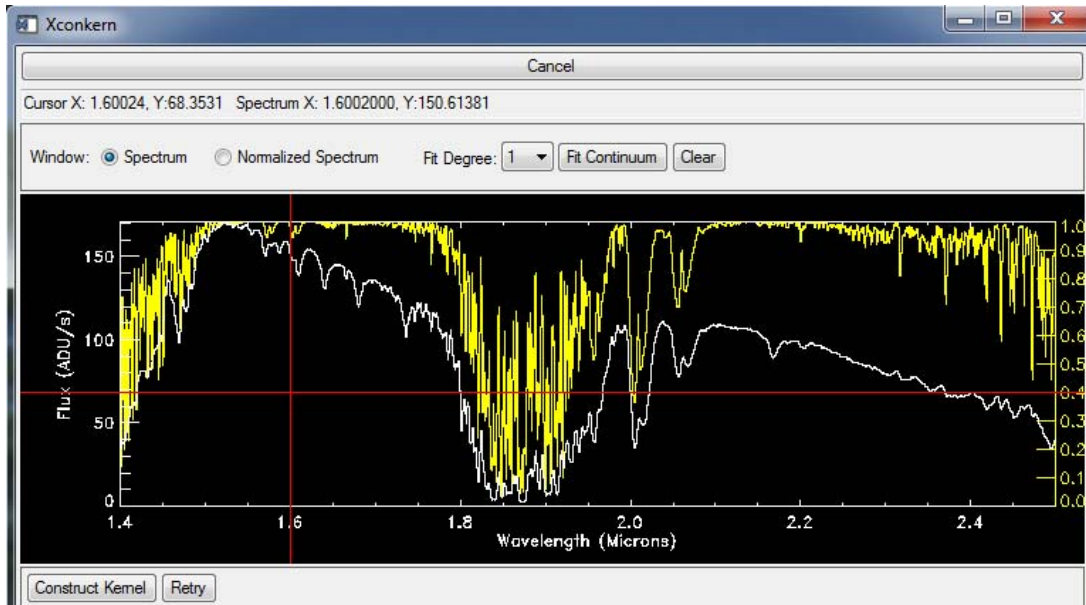
3. **Put the cursor in the upper plot (red cross-hairs will appear) and press** the '**x**' key on your keyboard

4. **Select** the left limit at about 1.60 microns and the right limit as about 1.72 microns (**move cursor to put vertical red line on 1.6 and left click the mouse; move cursor to put vertical red line on 1.72 microns and left click the mouse**).
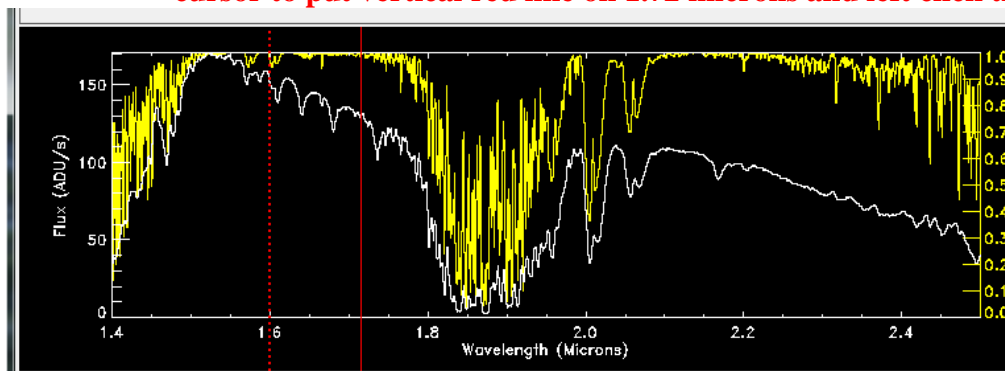
5. The plot will zoom in to show the spectra between only those limits.
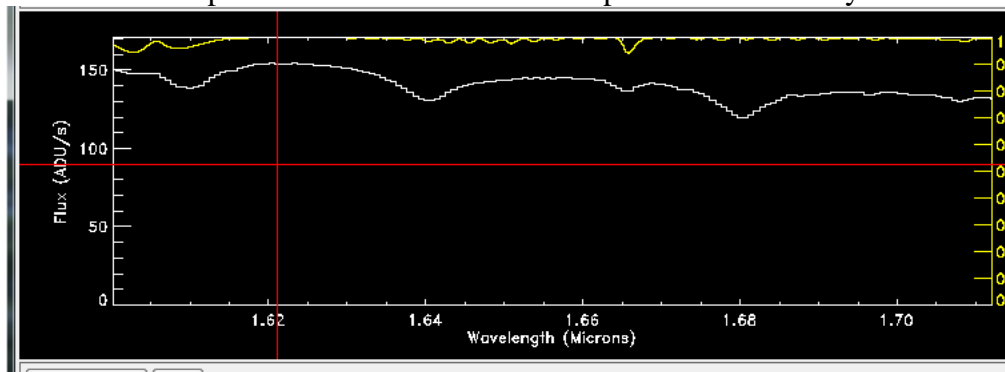
6. The yellow spectrum is a model of the sky; the white spectrum is the A0V star spectrum and should show 3 absorption lines due to Hydrogen.

7. **Press** the '**Y**' key on your keyboard. **Move the horizontal red line to just under the lowest of the Hydrogen absorption lines – click the left mouse button. Move the horizontal red line to just above the highest part of the white spectrum – click the left mouse.** This zooms the Y-axis of the A0V star spectrum to better reveal the Hydrogen absorption lines.
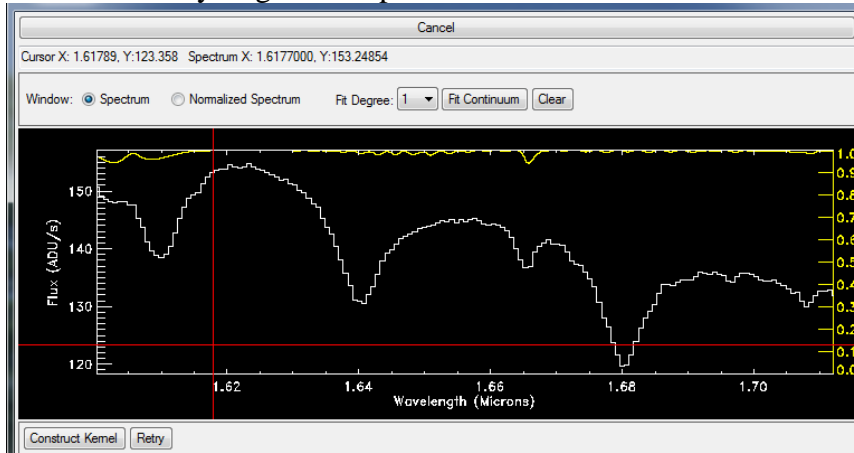
8. **Press** the '**n**' key on your keyboard to begin marking ranges for normalizing the continuum (non-line) portion
9. **Click** the mouse button to select first the left and then the right limits of a series of regions not within the Hydrogen Brackett absorption lines (for example, four zones: 1.622-1.630; 1.653-1.660; 1.669-1.671; and 1.6944-1.7068 work well)
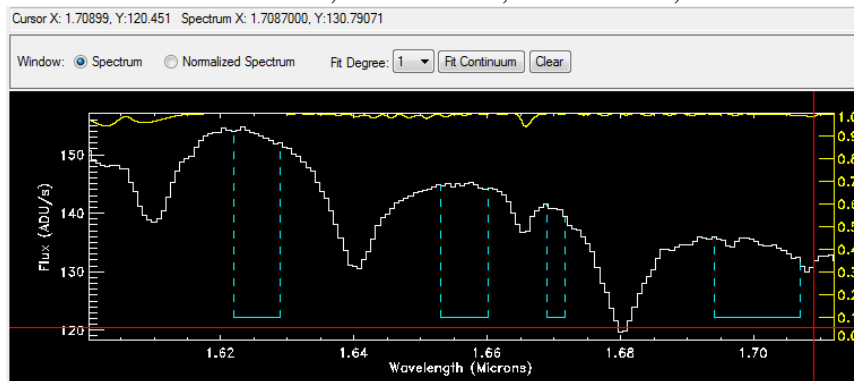
10. **Set** the '**Fit Degree**' selector to greater than 10
11. **Click** the '**Fit Continuum**' button
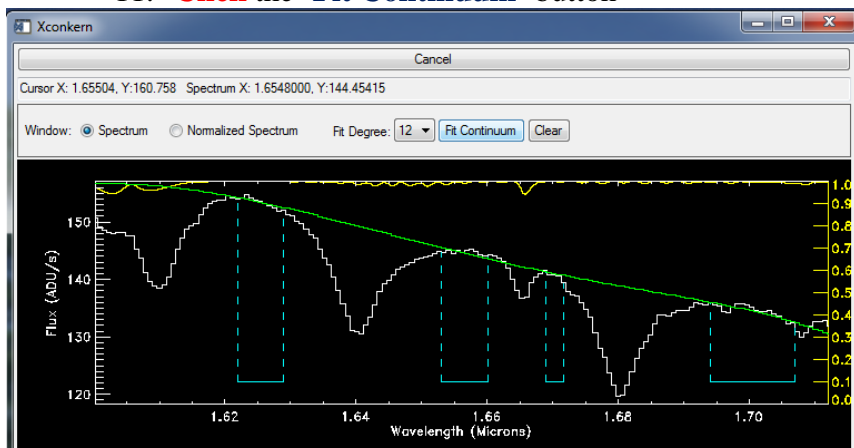
12. If the green line looks like a good model for the continuum through the region of the two absorption lines, then **click** the '**Normalized Spectrum**' radio button. If not, **change** the fit degree and **refit** the continuum.
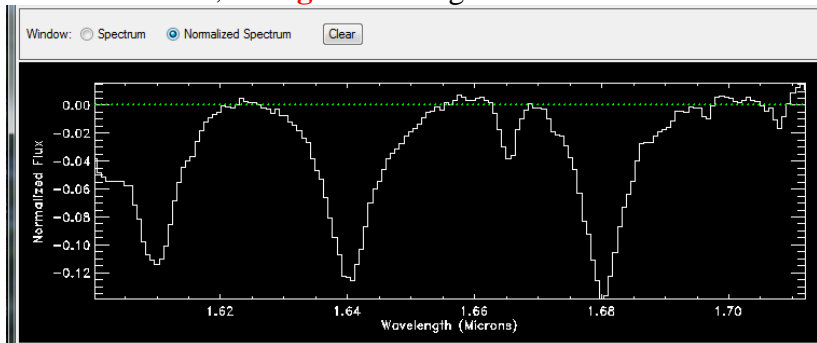
13. In the normalized spectrum plot that appears, **press** the '**s**' key to select the line limits to use for model fitting.
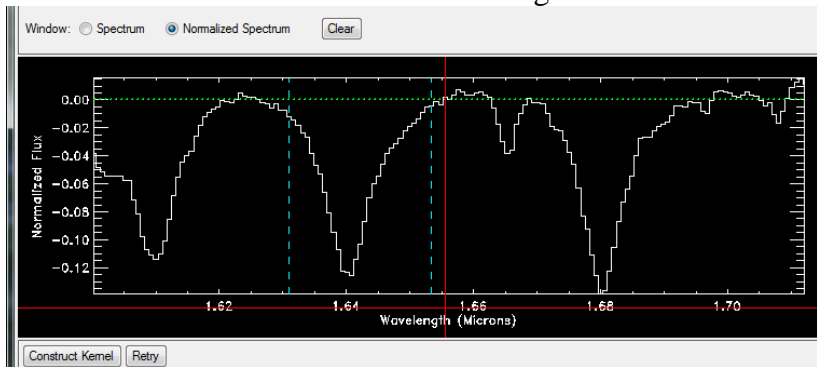
14. First, **move the vertical red line and click the left mouse button** to select the left limit where the line hits the continuum. Then, **select the similar right limit** where it does the same. For example, 1.632 microns (left) and 1.654 microns (right).

15. **Click** the '**Construct Kernel**' button between the two plots
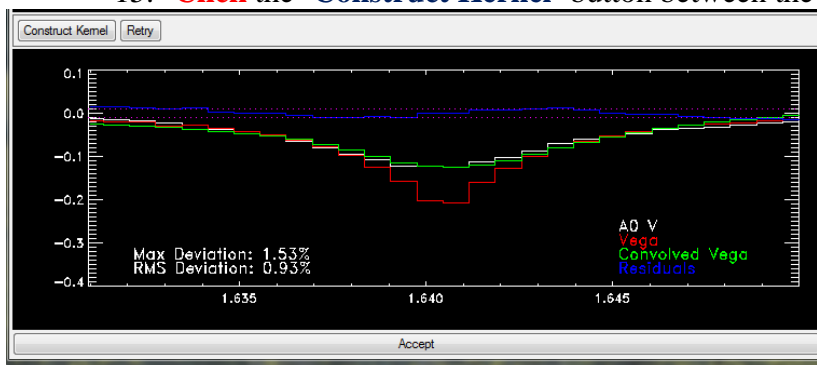
16. In that new plot, the red histogram shows the unconvolved Vega spectrum, the green histogram shows Vega convolved with the Mimir instrument response function you just selected, and the white histogram shows the Mimir data. **The blue histogram shows the difference between the convolved Vega spectrum and the Mimir spectrum**. In the lower left are listed the maximum deviation and the RMS deviation. If the RMS is under 1.5%, the model is a good one. If it is significantly larger, try re-selecting the other Hydrogen absorption line and repeating the kernel construction or try changing the left and right line limits.

17. When a suitable model is found, **click** the '**Accept**' bar at the bottom of the window. The window should disappear.

iii. In the '**3. Construct Telluric Spectra**' window:
   1. **Click** the '**Scale Lines**' button

   2. The new lower plot shows the Mimir spectrum in white and an atmospheric model spectrum in yellow.

3. **Look for the presence of any remaining Mimir absorptions in the green dotted line regions for the Hydrogen Brackett lines that are NOT dominated by absorption features in the atmosphere (usually, there are no remaining absorptions to worry about).** Brackett absorptions can be removed by mouse-grabbing the relevant green asterisk in the <u>upper</u> plot and pulling upwards. This will add a bit more model absorption for that particular spectral line, so as to smooth out the corrected Mimir spectrum a bit more.

4. **ADVICE:** The best Hydrogen line removal happens when a model line is selected in the H-band to correct the <u>H-band part of the spectrum</u>, followed by selection of the only K-band Hydrogen line as a model for the <u>K-band portion of the spectrum</u>. If you are not doing this, then some residual Hydrogen absorption is left in the K-band portion of the A0V spectrum, which shows up as anomalous Hydrogen in the final science spectrum. ***Caveat Emptor…***

5. When done, or if happy from the start, **click** the '**Accept**' bar at the bottom of the 'scalelines' window. The window will disappear.

6. **Click** the '**Construct Telluric Spectra**' button (no plots are generated)

iv. In the '**4. Determine Shift**' window:
   1. **Click** the '**Get Shift**' button
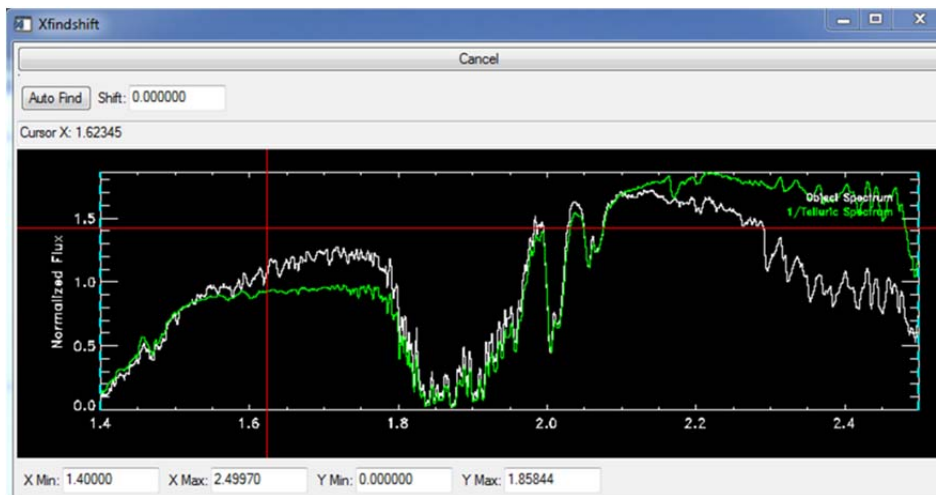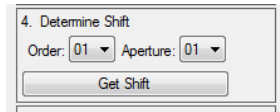
2. In the new window's upper panel, **press** the '**s**' key to select a spectral zone for shift-matching the corrected Mimir A0V spectrum (in green) to the Mimir science spectrum (in white). **Select left and right window limits**. Try to stay away from the deep absorption between the H and K windows. For example, **a suitable region would include some atmospheric absorption around 2.0 microns, say from 1.95 to 2.04 microns**. Avoid real absorption or emission lines, also.
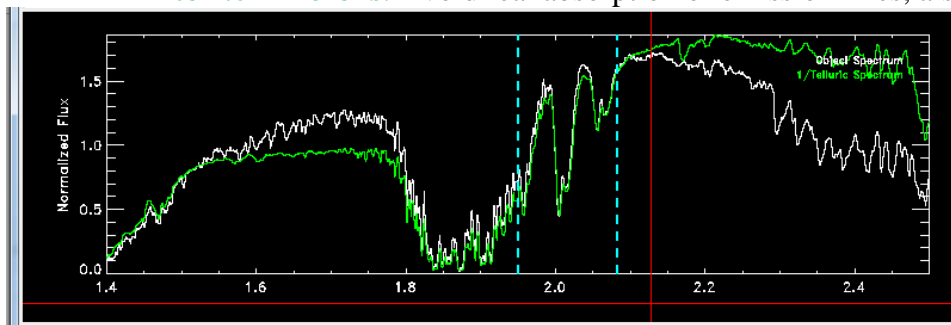
3. After selecting the region limits, (blue dashed lines should appear), **click** the '**Auto Find**' button. The plot in the bottom panel of the window will move around – look for minimum deviations in the wavelengths bounded by the blue, dashed lines.

4. **The resulting shift** (look in the 'Shift' field at the top of upper panel in the figure) **should be under 1 pixel**. If not, change selection region and retry.
5. When happy, **click** the '**Accept**' bar at bottom

  v. In the '**5. Write File**' window:
1. **Be sure** the '**FITS**' box **is checked**
2. You can **uncheck** the "**Telluric**" box
3. **Type** a reasonable file name into the '**Object File**' field (you do not need to include the '.fits' suffix, as this is added automatically).

```
5. Write File

Output Format:  ☑ FITS    ☐ Text

Object File: My_Star.fits

Additional:  ☐ Telluric    ☐ A0 V

              Write File
```
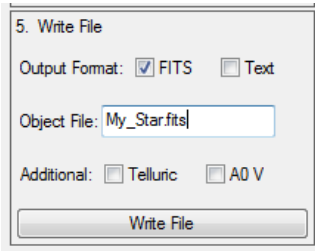
4. **Click** the '**Write File**' button
5. The corrected spectrum is displayed in the '**Xvspec**' window. You can select, zoom, and explore with **Xvspec**. When done, **click** the '**Done**' button.
  vi. Either **begin again**, with a new A0V+Science image pair, **or click** the '**Done**' bar at top
  vii. This leaves the final spectrum (or spectra) in the original directory.
  viii. **Move the final spectral files** to a new directory ("**16_Corrected_Spectra**")

6. For Extended Objects, Extract Spectra From A Row Zone in Each Spectral
   Image *(N.B.: This non-GUI software will be updated along with the stellar
   SXC soon.)*

   a. Open the **MSP_SXC** project, then **compile and launch**
      '**Step_14_Extract_Zonal_Spectrum.pro**'
   b. Use the file-chooser to **select** one extended object spectral image
   c. Use the next pop-up file-chooser to **select a directory and output file name**. It is wise to
      put these extracted spectra in the '**15_Extracted_Spectra**' directory, but even wiser to
      create a subdirectory in that directory, called '**Extended_Objects_Spectra**' and store
      the output there. Safest is to keep the same image name, but add an 'internal' suffix like
      '**_zone**' to the filename. (e.g., a file name might become
      '**20111112.001_Eskimo_South_zone.fits**'
   d. An image appears and the user is asked to operate the cursor and mouse to **mark first the
      Upper-Left row zone boundary**, then the **Lower-Right row zone boundary**. (since only
      the row boundaries are used, the column information is ignored)
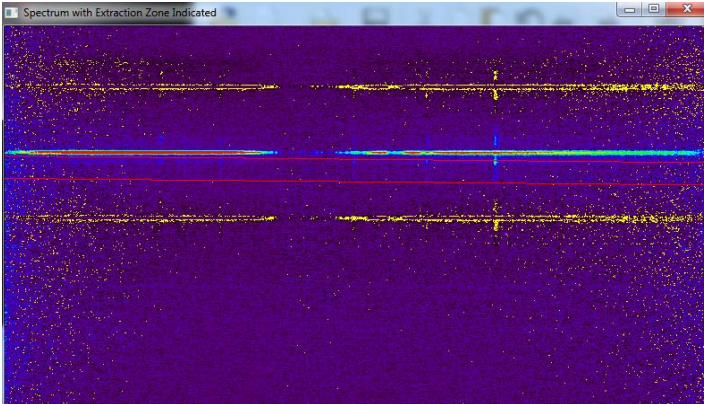

   e.   After selection, two red lines
   are overlaid on the image (see figure
   at left) to show the region to be
   extracted into the object spectrum.
   [Note that at this time, spatially-
   resolved spectral extractions are not
   supported.] The lines are tilted to
   account for the known JHK grism
   tilt. If this enclosed zone looks
   correct, **type 'Y'** in the IDL response
   text region.

   f. Next, **two plots will appear**. <u>**The top plot shows the extracted spectrum**</u> as a function of
      wavelength, with the uncertainty for each spectral channel plotted below the value for each
      channel (the uncertainties may be indistinguishable from the zero line for S/N ratios > 200
      or so). <u>**The bottom plot will show the average sky spectrum away from the star**</u>. For
      these CCS-processed images, the sky spectrum should already be free from OH line
      emission, so the plot should look like mostly gaussian noise.
   g. **Click in the lower plot** ("**Sky Spectrum of …**") to end this step

7. <u>Spectra may be examined/plotted at this point, using any of:</u>
   a. The '**xvspec.pro**' program in the Spextool/pro directory (plot shown below)
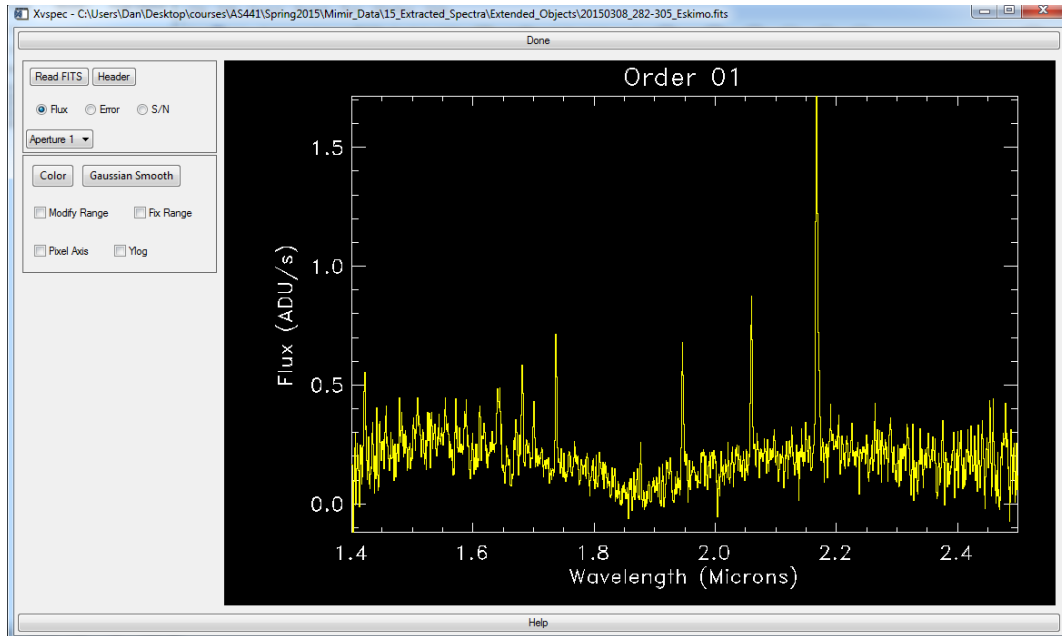
   b. MSP_BRT (see 8., below)
   c. MSP_SCT (see 9., below)
   d. MSP_SAT (see 10., below)

8. <u>To better isolate spectral lines, remove baselines</u>
   a. **Load** and **launch** the **MSP_BRT** package
   b. If the spectrum to process is an **emission line spectrum**, **jump** to part **8.u** below
   c. On the "**Read/Save/Exit**" tab, **click** the "**Select, Read SpeX Spectrum File**" button and use the file chooser to select a spectrum file (of FITS format, SpeX type). The spectrum will appear in the plot window, as below.
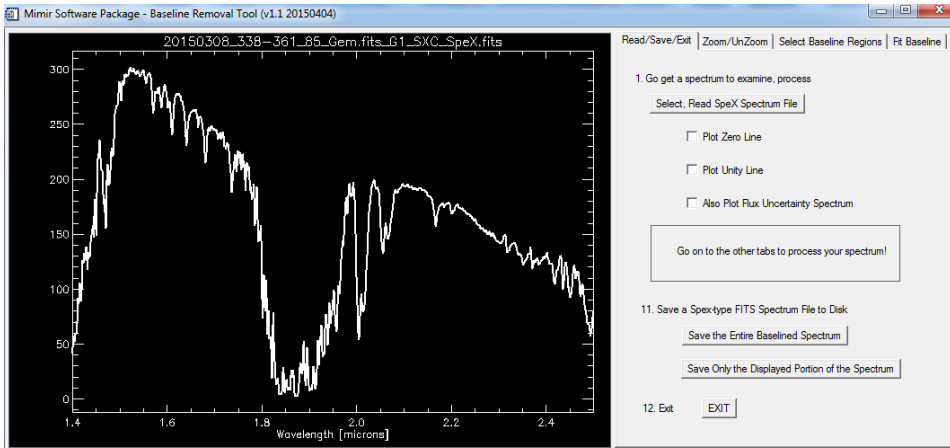
d. Horizontal lines at zero or unity may be displayed by **clicking** in the checkboxes to the left of those options on this tab.

e. **Click** the "**Zoom/UnZoom**" tab to move to that tabbed page

f. **Click** the "**Select Left (short wavelength) limit**" button and **use the mouse cursor** in the draw window to identify the left limit for zooming. When the cursor is positioned as desired, **click** the left mouse button.

g. **Click** the "**Select Right (long wavelength) limit**" button and **use the mouse cursor** in the draw window to identify the right limit for zooming. **Click** the mouse button when desired.

h. **Click** the "**Zoom to Left-Right Limits**" button to zoom into that portion of the spectrum.
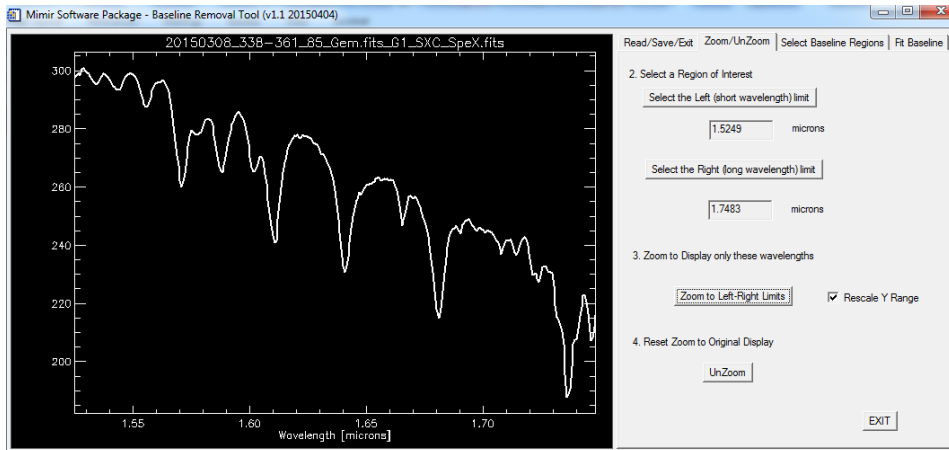
This figure shows the zoomed portion of the spectrum after choosing limits at 1.5249 and 1.7483 microns. The hydrogen Brackett lines in this A0V star are quite strong in absorption.

To remove a baseline, portions of the spectrum that are free of emission and/or absorption lines must be identified. These 'zones' will provide the line-free part of the spectrum for finding the model baseline.

i. **Click** the "**Select Baseline Regions**" tab to move to that tabbed page.

j. **Identify** a line-free region. **Click** the "**Set Start (Left) Wavelength**" button and **move the mouse cursor** to the starting wavelength of the line-free region. **Click** the left mouse button when the cursor is positioned properly. A vertical dashed green line with the letter 'S' (for start) at its top will appear.

k. **Click** the "**Set Stop (Right) Wavelength**" button and repeat the process. A dashed blue line, labeled 'E' (for end) will appear.

l. If these mark the region desired, **click** the "**Keep this Region**" button. This will replace the vertical green and blue dashed lines with a magenta open rectangle identifying the region.
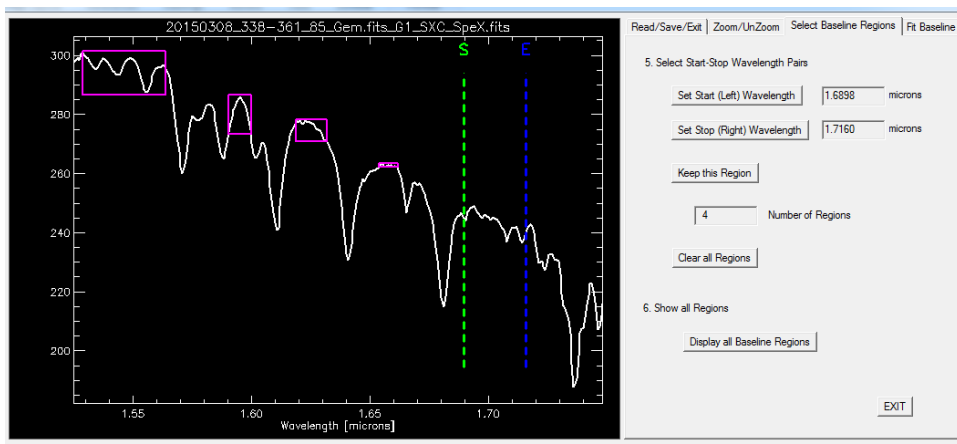

m. **Repeat** the Start-Stop-Keep set of button and mouse actions until all regions have been identified.

The figure shows four marked regions and the

limits in place to identify a fifth.

    n. Users can **click** back to the "**Zoom/UnZoom**" tab to zoom in more, or unzoom, to aid region selections.

    o. When returning to the "**Select Baseline Regions**" tab, users can highlight all the previously identified regions by **clicking** the "**Display all Baseline Regions**" button.

   p. When all regions have been created, **click** to the "**Fit Baseline**" tab
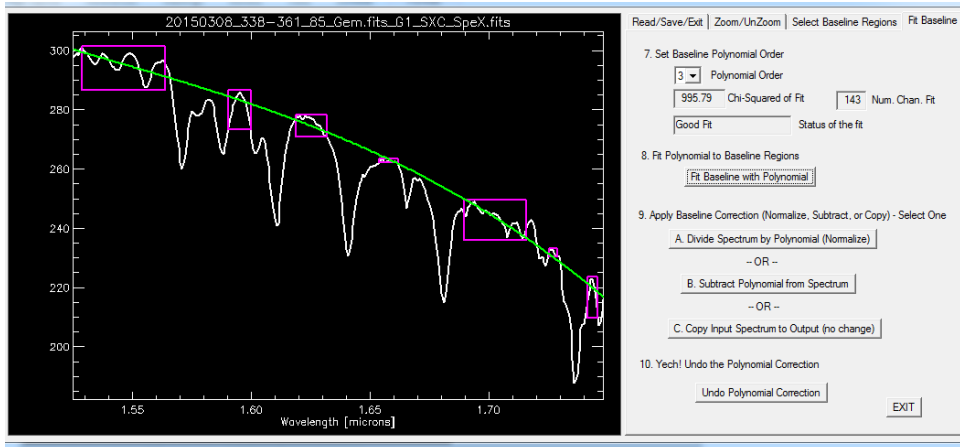
    q. On that tab, you can **select** the polynomial order of the baseline you wish to fit. The quality of the baseline model fit will depend on the number of fitting zones and the nature of the baseline shape variations.

    r. **Click** the "**Fit Baseline with Polynomial**" button to do the fit. In the plot region, the green line shows the model baseline, based on fitting to the data in the magenta zones.

    s. Note the text in the "**Status of the fit**" textbox. It is usually a good indicator of whether the fit is reasonable or whether the polynomial order is set too high (this is the usual failure mode). If the textbox does not state "**Good Fit**", then **use** the "**Polynomial Order**" pull down menu to **reduce** the order of the polynomial fit. **Click** the "**Fit Baseline…**" button again, and recheck the "**Status…**" textbox. **Repeat** until the fit is good.

    t. For stellar spectra with absorption lines (as shown above), one would normally **divide** the measured spectrum by the model baseline to create a unity-centered baseline with absorption lines departing below that line. To do this, **click** the "**Divide Spectrum by Polynomial (Normalize)**" button.
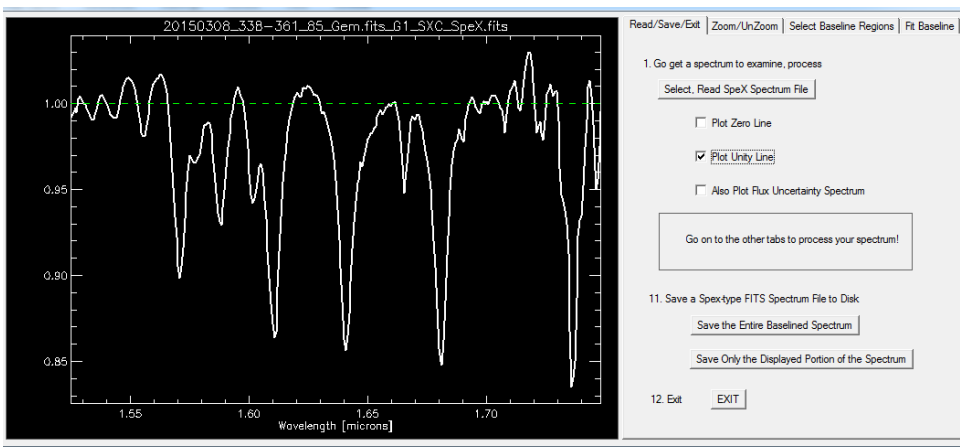

A result similar to that at left should appear. Here the "**Show Unity Line**" option was selected on the "**Read/Save/ Exit**" tab to produce the dashed green horizontal line.

u. For removing baselines from emission line objects (having little continuum), the baseline zone selection is unchanged, as is the baseline fitting. The only real change is to **subtract** the model baseline instead of dividing. This nulls the apparent continuum, yielding emission lines that rise up from zero flux. For this option, **click** the "**Subtract Polynomial from Spectrum**" button.
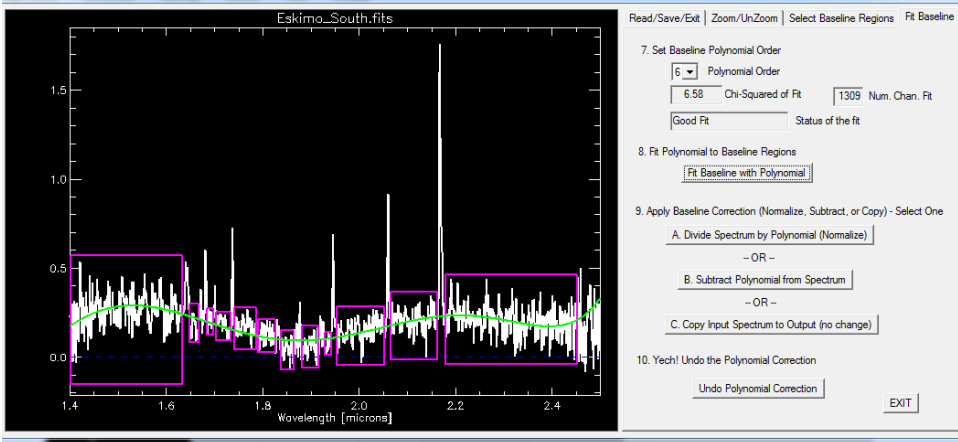
Example plot (at left) of the baseline zones and the 6th order baseline model (green line).

The baseline subtracted spectrum (for this planetary nebula) is shown below.
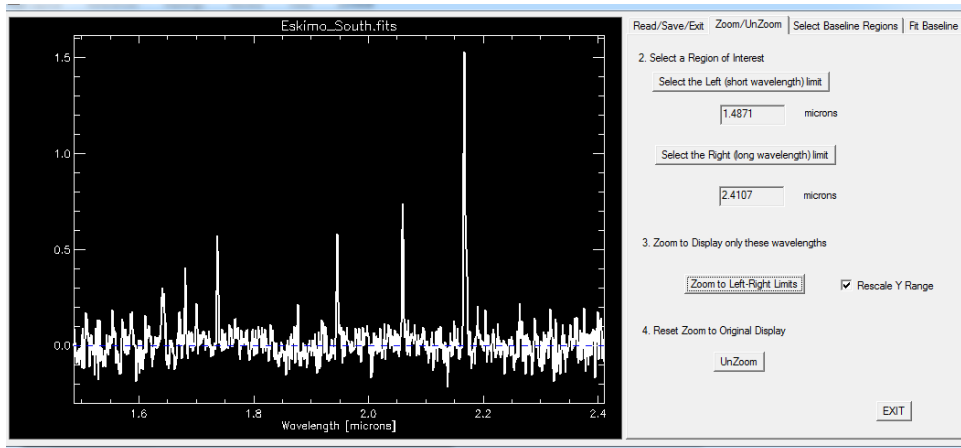
v. To **save** the observed spectrum after finding and applying the desired baseline correction, click to the "**Read/Save/Exit**" tab.

w. If the full spectrum is desired, **click** the "**Save the Entire Baselined Spectrum**" button. This launches the file chooser and allows the user to name a file. Note that the "**.fits**" suffix is automagically appended to the filename, so there is no need to type it in. Also note that the file chooser filters filenames, so directories might appear empty if there are no FITS files in them. Not to worry… your files are still there…

x. If only a portion of the spectrum is all you want to write to a disk file, **click** to the "**Zoom/UnZoom**" tab. Then, **use** the left/right selectors and the "**Zoom…**" button to display in the plot window the portion of the spectrum desired. **Click** back to the "**Read/Save/Edit**" tab and then **click** the "**Save Only the Displayed Portion of the Spectrum**" button.

y. The **MSP_BRT** may also be used to re-baseline or zoom into spectra <u>after</u> they have been chopped into smaller pieces, individually baselined, and connected back into a single spectrum, as described in later steps below. If the spectrum is re-baselined with the **BRT**, then all previous steps will work fine.

z. But, if a spectrum is read in, zoomed into, and then the zoomed portion is desired to be written to disk without fitting a new baseline, the user must <u>FIRST</u> **click** to the "**Fit Baseline**" tab and **click** the button labeled "**Copy Input Spectrum to Output (no change)**". Not doing so will cause an error when selecting the "**Save Only the Displayed Portion of the Spectrum**" button.

9. <u>Recombine the baselined, band-based spectra back into a single spectrum</u>
    a. **Load** and **launch** the MSP_SCT.
    b. **Click** the "**Select Spex-type FITS Files**" button to launch the file chooser.
    c. **Select** all the SpeX-type spectra (e.g., the H-band and K-band portions of an HK-spectrum)
    d. The spectra will load and be displayed in the plotting window. Each different spectrum file will be colored a different color, just to identify them. The plot below shows two spectra, one in white, one in red, that are being prepared for combination.
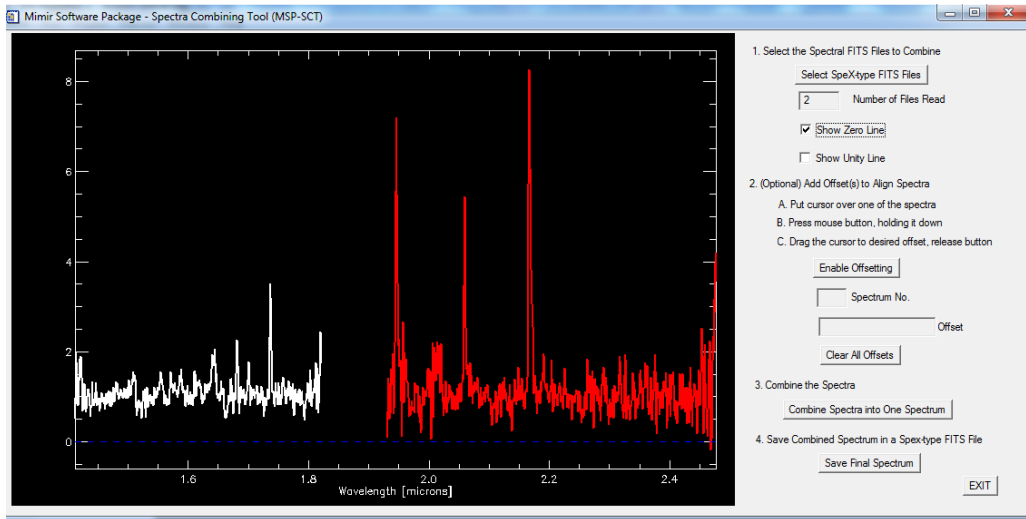

    e. **(Optional)** Vertical offsets for each separate spectrum may be enabled, if needed (usually not). To do so, **click** the "**Enable Offsetting**" button.
        i. **Move** the cursor into the plotting window and over/within one of the spectra. The "**Spectrum No.**" textbox should identify the spectrum number.
        ii. **Click** and **release** the left mouse button to initiate active offsetting.
        iii. **Move** the cursor up or down to drag the spectrum to the desired offset or baseline value.
        iv. The value of the offset is reported in the "**Offset**" textbox.
        v. To stop the active offsetting and freeze/keep the offset, **click** and **release** the left mouse button again.
        vi. Repeat (**click/release**, **move mouse**, **click/release**) with any other spectra that need offsetting. The plot on the top to the next page shows the same spectra as in the plot above, but after offsets have been applied to bring the spectra closer to the zero line.

Note that these offsets do not constitute a 'baseline fit' but are merely user-controlled vertical (additive) displacements.
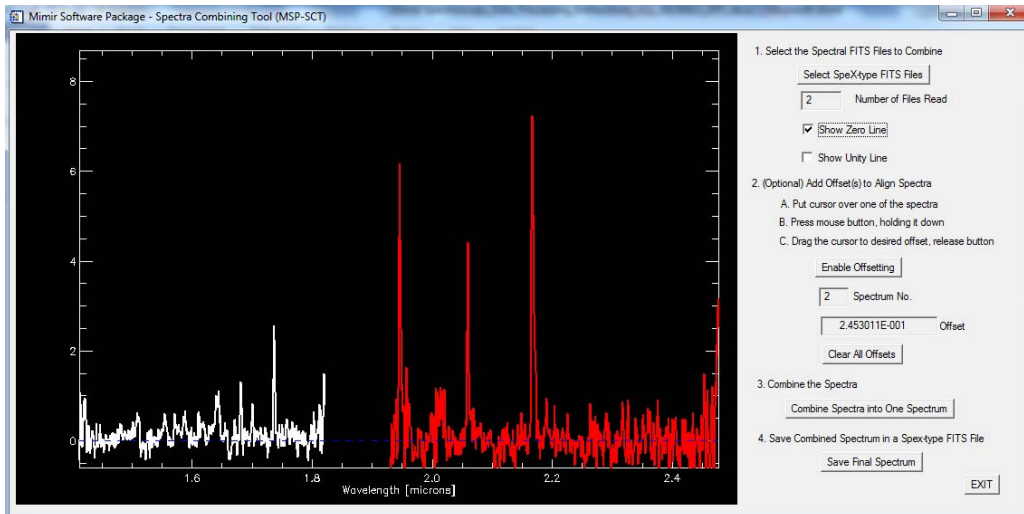
f. To combine the multiple constituent spectra into one combined spectrum, click the "**Combine Spectra into One Spectrum**" button

   i. The new combined spectrum is shown in the plot window (see example below). As indicated in the legend at upper right, spectral channels that were uniquely represented in the original spectra are copied to the combined spectrum and shown in **white**. Channels for which no spectral information was present in any of the input spectra are set to zero intensity and shown in **blue**. Spectral channels which were present in two or more input spectra are shown as **red**. The spectral intensities copied into the combined spectrum are those associated with the lowest intensity uncertainty in the input spectra. Thus, they are not averages or weighted averaged, but are the 'best choice' values.
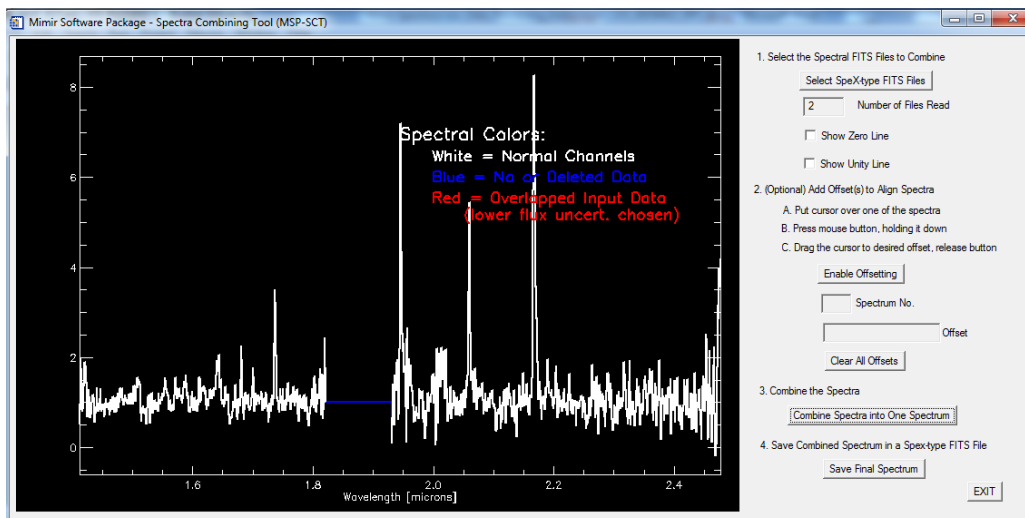
g. To save this final, combined spectrum (absent the color-coding), click the "**Save Final Spectrum**" button. This launches the file chooser, allowing the user to name an output file. Note that the program automagically adds the ".fits" file suffix, so the user need not do so. Also, again the file chooser display has been filtered to only show ".fits" files, so all other files will be hidden.

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10. Plot and Annotate the final spectrum

    a. **Compile** and **launch** the '**MSP_SAT'** project
    b. On the "**Get Spectrum**" tabbed page, **click** the "**Get Spectrum**" button and use the file chooser to **select** a SpeX-type FITS spectral file.
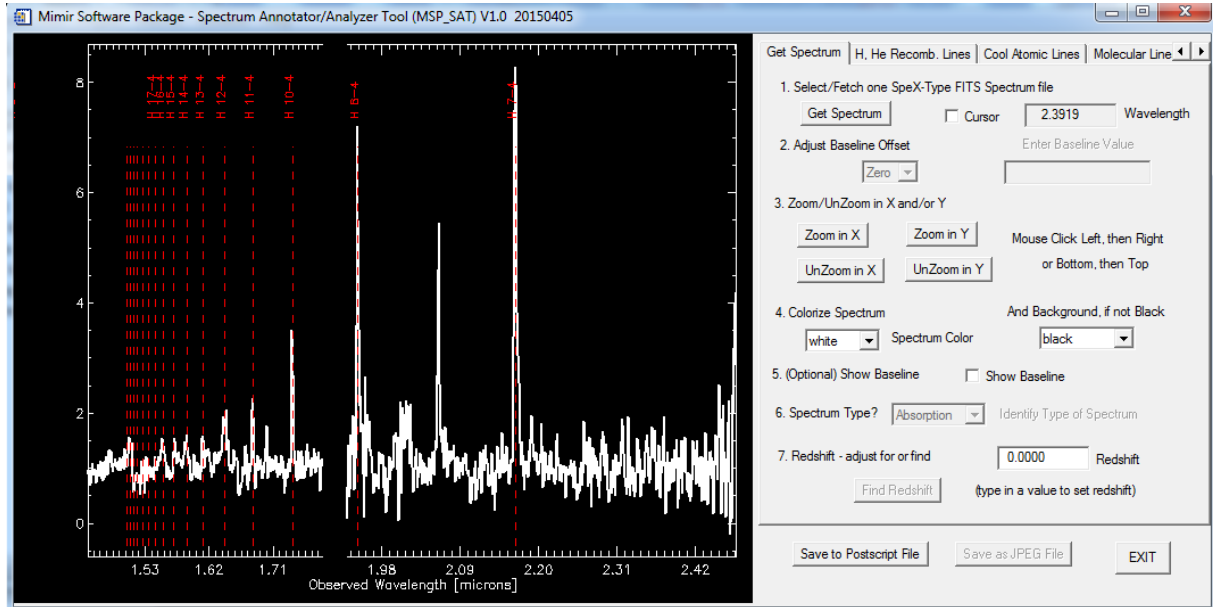

    c. The spectrum is shown, along with default Hydrogen Brackett line annotations (vertical dashed red lines and level transition information).

    The horizontal axis is gapped to exclude atmospheric opaque wavelengths (e.g., between the J and H bands, and between the H and K bands), to enable focusing on wavelengths bringing the highest quality spectral information.

    Options on this tabbed page include (in descending vertical order on that page):
      i. Using the mouse/cursor to actively explore spectral feature observed wavelengths. **Click** the checkbox next to "**Cursor**" near the top of the page. When the check appears in the checkbox, the cursor is enabled to report wavelengths to the "**Wavelength**" textbox next to the "**Cursor**" checkbox.
      ii. (re)adjusting the baseline offset value – *not currently implemented*

iii. Zooming/UnZooming in X and Y. **Click** the "**Zoom in X**" button. **Move the cursor** to the
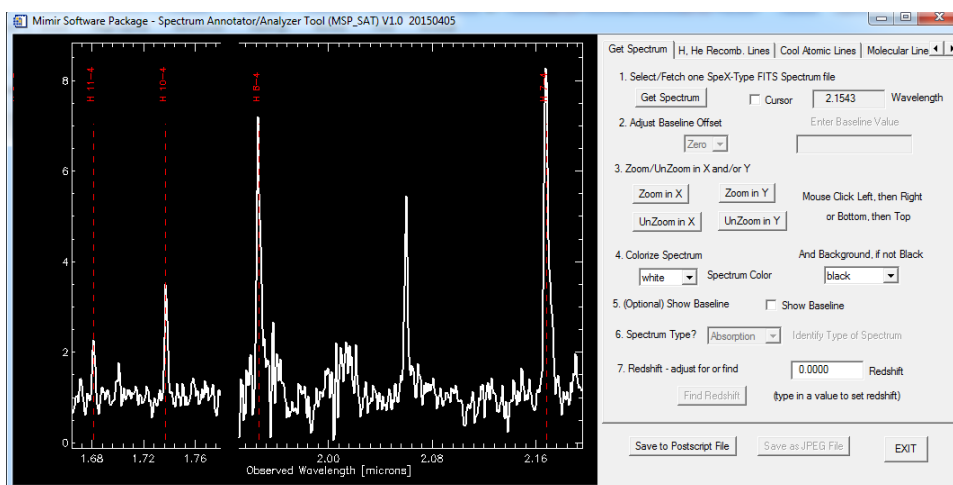
desired left (short) wavelength limit. **Click** and **release** the mouse button. A vertical dashed cyan line with an "L" label is shown at that wavelength. **Move the cursor** to the desired right (long) wavelength limit. **Click** and **release** the mouse button. A vertical dashed olive line with an "R" label is shown (briefly). The display is automagically zoomed to those limits. Repeating with the "**Zoom in Y**" button will allow setting the bottom ("B") and top ("T") limits before auto-zooming. There is no limit to the number of times either X or Y zoom may be applied. Zooming across atmospheric wavelength gaps is fully supported. To unzoom in either axis, **click** the appropriate "**UnZoom in …**" button. The plot below shows a zoomed spectrum, including across the HK window gap.

iv. (Optional) **Change** the color of the spectrum and/or the background. **Use the pulldown menus** under "**Colorize Spectrum**" and/or "**And Background, if not Black**" to change those color settings. (note: it is NOT necessary to change white->black and black->white in order to save the spectrum to a Postscript file. That conversion is handled automagically.)

v. (Optional) *Show Baseline – doesn't seem to work anymore… TBD*

vi. (Optional) *Set Spectrum Type – not currently implemented – intended to let the annotations be applied 'smartly' based on whether the spectrum is absorption or emission dominated. This will take some thinking and time…*

vii. (Optional) Set or clear redshift value. A redshift may be entered in the textbox and will be applied to shift the line annotations to indicate rest frame line identifications. The horizontal spectrum axis is unchanged. To enter a redshift, **click** in the "**Redshift**" textbox, **swipe** over the values in the box, **type** in a new value, and **press** the "**Enter**" key on the keyboard. *(not yet implemented is a tabbed page to allow identifying lines and their designations in order to fit for a redshift – TBD).*

viii. To save a Postscript version of the plot, with annotations, **click** the "**Save to Postscript File**" button. This brings up the file chooser, allowing the user to name a file to be saved. Note, as before, there is no need to add ".ps" to the filename, as that is done automagically. Also, as before, the file chooser display is filtered to only show existing ".ps" type files in the indicated directory.

d. The next six tab pages control spectral feature annotations onto the spectrum. These pages are:

i. "**H, He Recomb. Lines**" – options on this page allow **turning on/off** the Hydrogen recombination lines, the Helium-I recombination lines, and the He-II recombination lines, **using the checkboxes**. Also, the colors of the vertical dashed line identifiers and the text/transition labels may be changed using the "**Colors for Lines**" **pulldown menus**. Text labels may be **turned on/off** using the "**Show Line Designations**" checkboxes.

ii. "**Cool Atomic Lines**" – lines from neutral species other than H and He may be turned on/off, colored, and labeled on this tabbed page, using the same selection methods.

iii. "**Molecular Lines**" – allows marking/annotating lines of H_2, CO, ^{13}CO, and OH

iv. "**Ionic Lines**" – allows marking/annotating lines of Fe II, N III, and He II

v. "**Stellar Lines**" – allows coordinated on/off display of many types of lines, based roughly on whether the stellar spectrum is 'cool', 'warm', or 'hot'. Different sets of lines turn on/off when these various options are selected. These are crude guesses, however, so caveat emptor!

vi. "**Emission Line Regions**" – allows selecting lines likely to trace hot HII-like zones and/or lines often seen in shocked gas.

Note that in all of these designations, there is no attempt to match line strengths and features. The annotations are merely those corresponding to wavelengths found in NIST line lists – some features may be strong, some may be weak, some may be absent – all depending on the physical conditions in the material emitting or absorbing the radiation. Use of the MSP_SAT should not be construed as endorsement of any particular physical insight, model, or conclusion. You are so on your own to be an accurate and effective astrophysicist!

e. The "**Redshift Determination**" tabbed page is under construction. Check back in a year or so…

Below is an annotated spectrum from the MSP_SAT, to enjoy as eye-candy…