User Manual

SpecTracer

Contents

First Time User

SpecTracer was created under Python version 2.7.8. It is important to verify that the version being used to run the code is Python 2.7, as some modules or libraries may not work as intended if a different version is used. The code was *shebanged* to run on this specific version but this may not always work. Therefore, it is required that the user verifies that the version of python is the one mentioned. If it is not this version, a virtual environment can be created. Consult the Technical Manual for instructions on how to do this. Also, the python distribution being used should have the following packages installed:

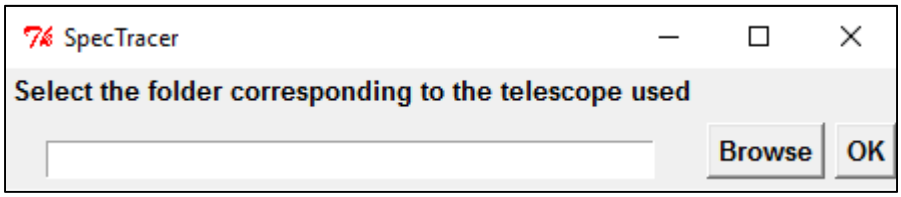
- *Astropy*
- *Numpy*
- *Tkinter*
- *Scipy*
- *Matplotlib*
- *Signal*
- *Threading*
- *Multiprocessing*
- *Mpl_Toolkits.mplot3d*
- *Pylab*

This libraries are used throughout the code, and not having them available would cause the program not to run.

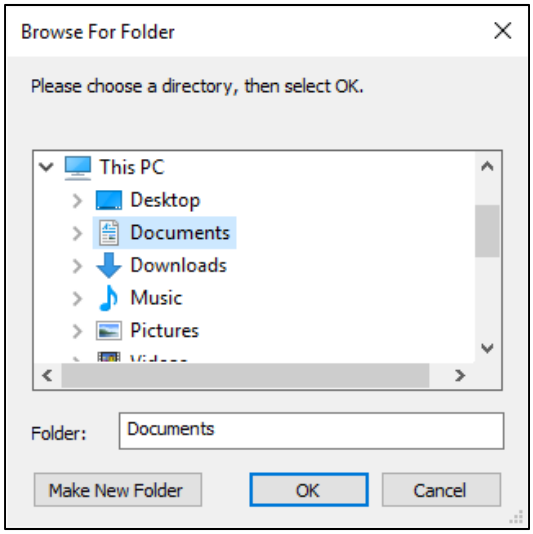
After downloading the code, it can be stored in whatever directory. There is no constraint regarding it being on the same folder as the files being used for analysis.

Running *SpecTracer*

Once the compilation is done, and the program is executed, the first dialog box shown is the one shown below.



If it is your first time using the program, you should go to browse and there create a folder. It is recommended that the folder has the name of the telescope used (i.e. SARA). If this program has been previously used, and the user wishes to retrieve the previously done calibrations, the folder created at the time of calibrations should be selected. This folder will store all the core files the program creates.The folder can be created or selected using the browse button. It is strongly encouraged, that the user employs the browse module, as that would provide the complete path of the folder and avoid errors when typing in the path.

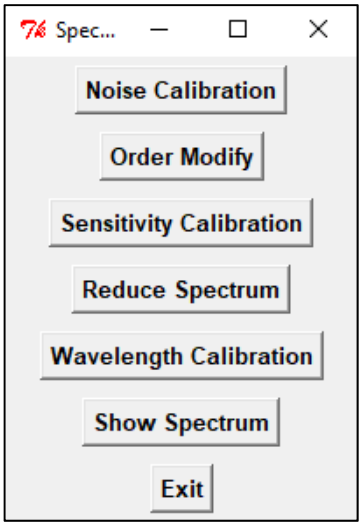


After choosing the folder, the main menu will pop up.

The Main Menu

The Main Menu contains 6 modules:

- Order Modify: This module allows you to trace the Echelle orders
- Noise Calibration: This module reads the biases, darks, and the overscan of the image
- Sensitivity Calibration: This module fits a gaussian surface to each order in order to account for inherent variations of the sensitivity.
- Reduce Spectrum: This module gets the FITS file, with the echelle spectrum of the star and reduces it.
- Wavelength Calibration: This module obtains a previously created file with a particular structure, where, order, wavelength and pixel-coordinate are related for a calibration lamp. (For more information on the structure of this file and its specifics, please refer to the Calibration File section). It allows the user to relate the known wavelengths of a calibration lamp, with the spectrum of a calibration lamp taken for a particular night.
- Show Spectrum: This module just displays the reduced spectrum.



This modules should be followed in the order displayed by the Main Menu. The modules that are lower on the menu have a high degree of dependence on the previous modules. Failure, to have all the calibration files or reduced spectra needed could make the program crash.

The Main Modules

This section deals with using each of the modules.

Noise Calibration

Needed files:

- Flat Lamp FITS File
- Bias FITS File
- Dark FITS File (optional)

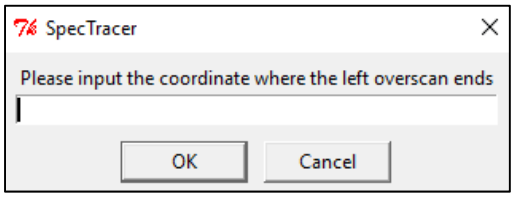
Needed directories:

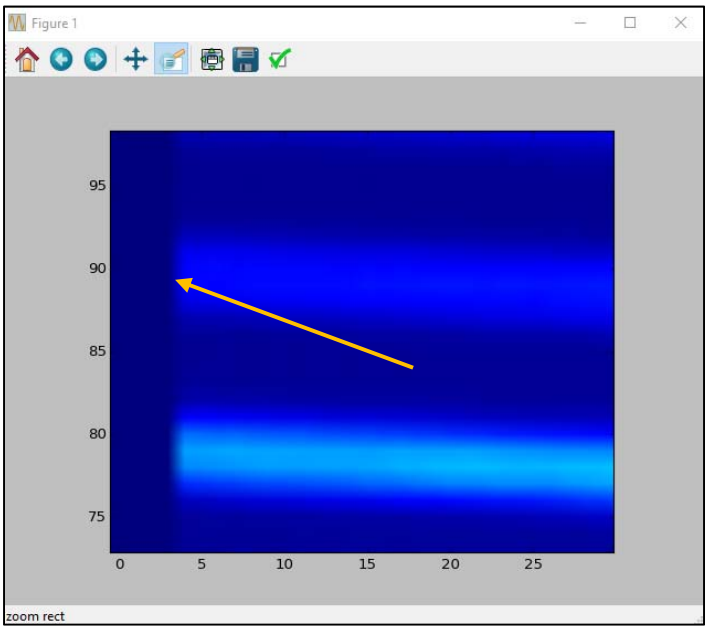
- Bias Folder (Containing all the bias files)
- Dark Folder (Containing all the dark files)

The program prompts the user for the Flat Lamp FITS file. It is strongly recommended that the user uses the browse function

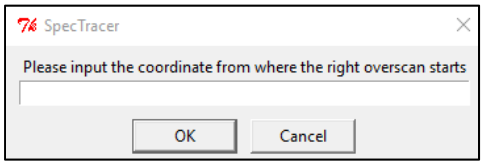
Overscan

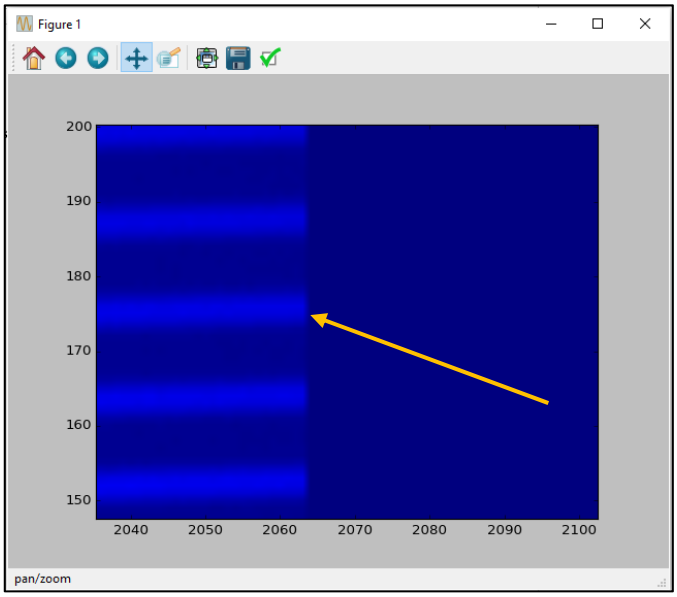
Afterwards, the user will be asked if there is an over scan on the detector. If there is, then the user will be asked to input the coordinates that delimit the over scan. The first coordinate asked is the x-coordinate of the leftmost over scan.



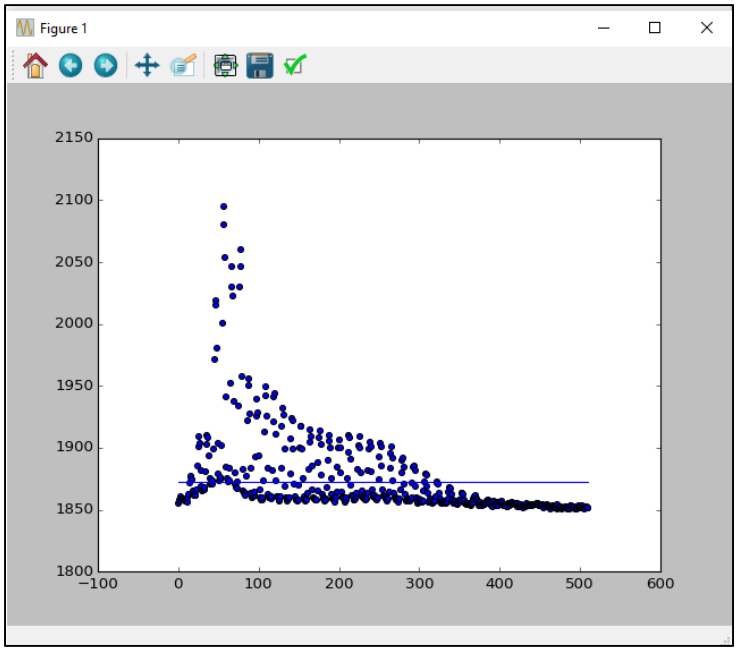


The next coordinate asked for is the rightmost part of the over scan.



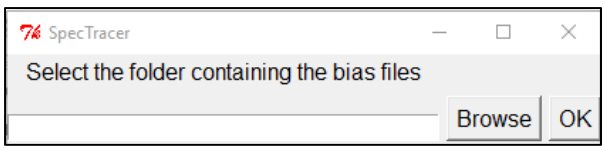


After entering the second coordinate, the values flux per pixel row of the over scan will be show, along with a fitted mean line. The value of the y-intercept of this line is the mean over scan.



Biases

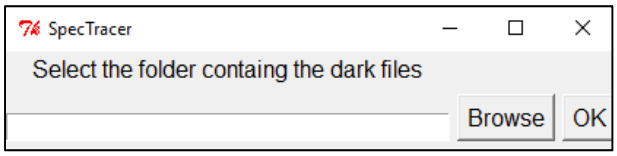
After closing the window, the program will ask for the path to the Bias Directory (a folder previously created containing all of the Bias FITS files).



The program will then scan this folder for all the Bias files contained in the folder, and then find the average value per pixel in the Bias files.

Darks

The program will then ask if there are any Dark files available. If there are, the program will then ask for the path to the Dark Directory (a folder previously created containing all the Dark FITS files).



The program will then scan this folder for all the Dark files contained in the folder, and then find the average value per pixel in the Dark Files

It is important that each folder contains only files related to their type i.e. Bias Directory contains only Bias files and no Dark files or any kind of file.

Afterwards, the program will store this two mean values of Bias and Dark, along with the information about the over scan in four files:

- *bias.npy*
- *dark.npy*
- *overscan.npy*
- *overscanloc.npy*

Order Modify

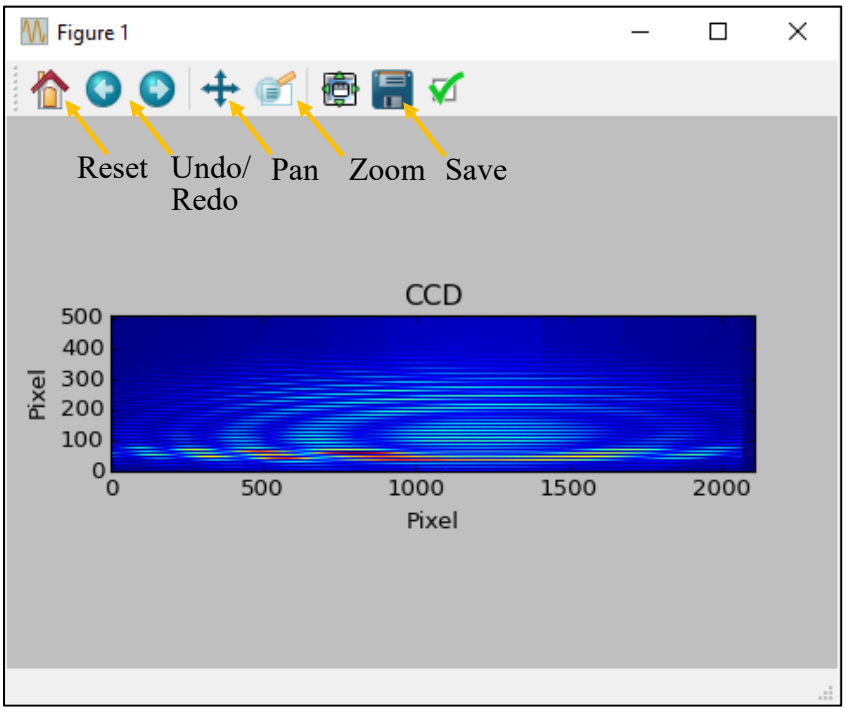
Needed files:

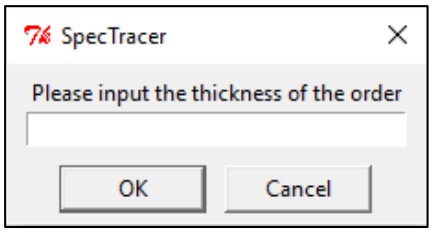
1. Flat Lamp FITS file

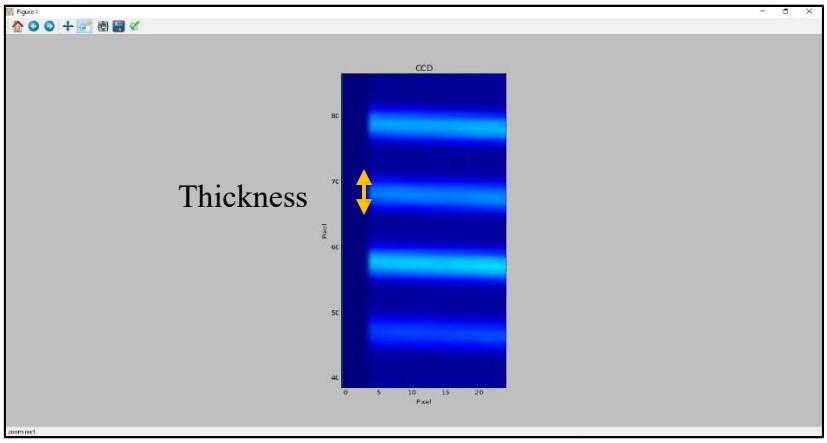
First Time User

The first time this module is accessed, it will prompt the user to select a Flat Lamp Echelle Spectra from the telescope being used. This image will be used to map the orders. Again it is strongly recommended to use the Browse button. A dialog box will appear specifying what the user will see, along with some instructions. The trace of the orders is semi-automatic. Due to the seemingly parabolic shape of the echelle orders, a second degree polynomial is fitted through 3 points.

The user is first shown an image of the Flat Lamp echelle spectra, in order to aid in determining the thickness of the order. The toolbar on top can be used to modify the viewing of the image in order for it to be easier to look at each order individually.



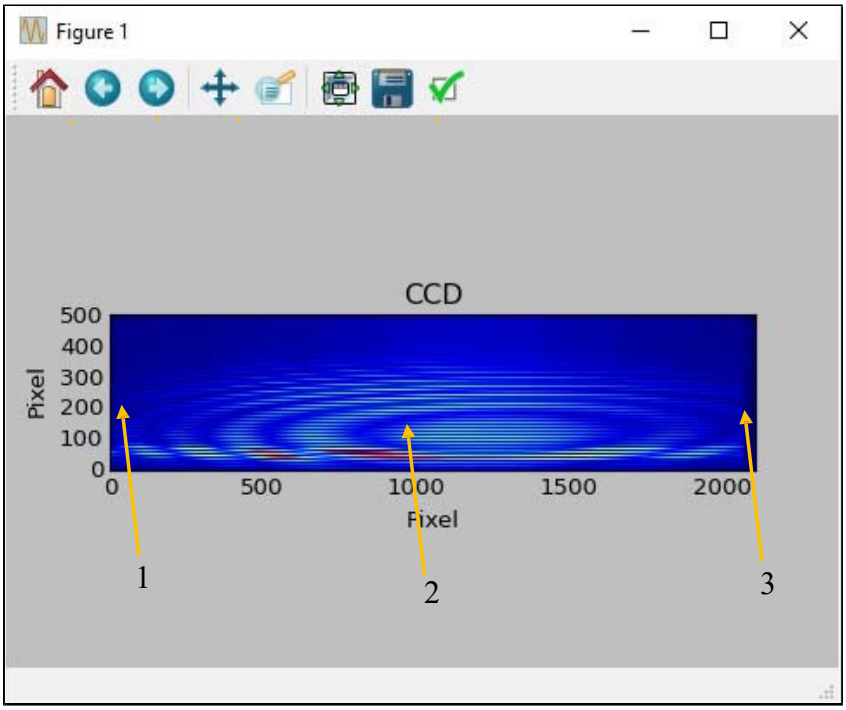




The user should enter the thickness of the order and click on OK and close the window showing the image from the Flat Lamp.

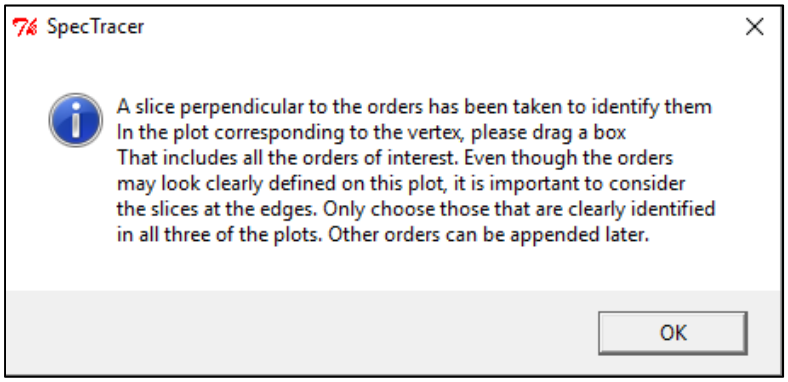
Order Selection

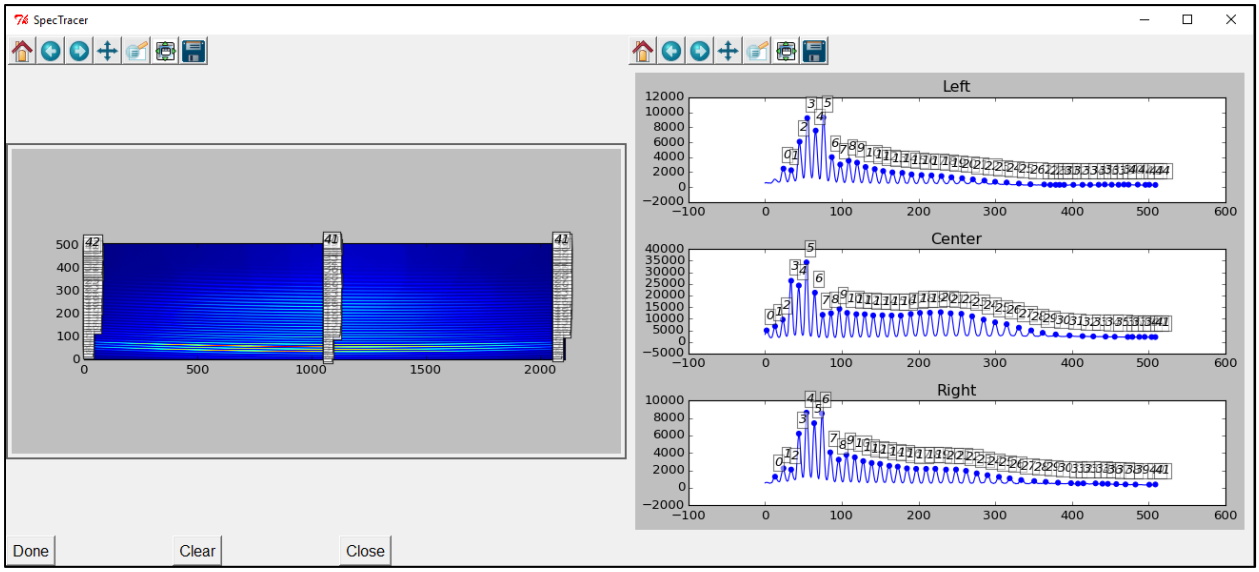
The program will identify potential location of the orders by taking a slice through three regions of the echelle spectra of the Flat Lamp. The regions at which the slices are taken are:



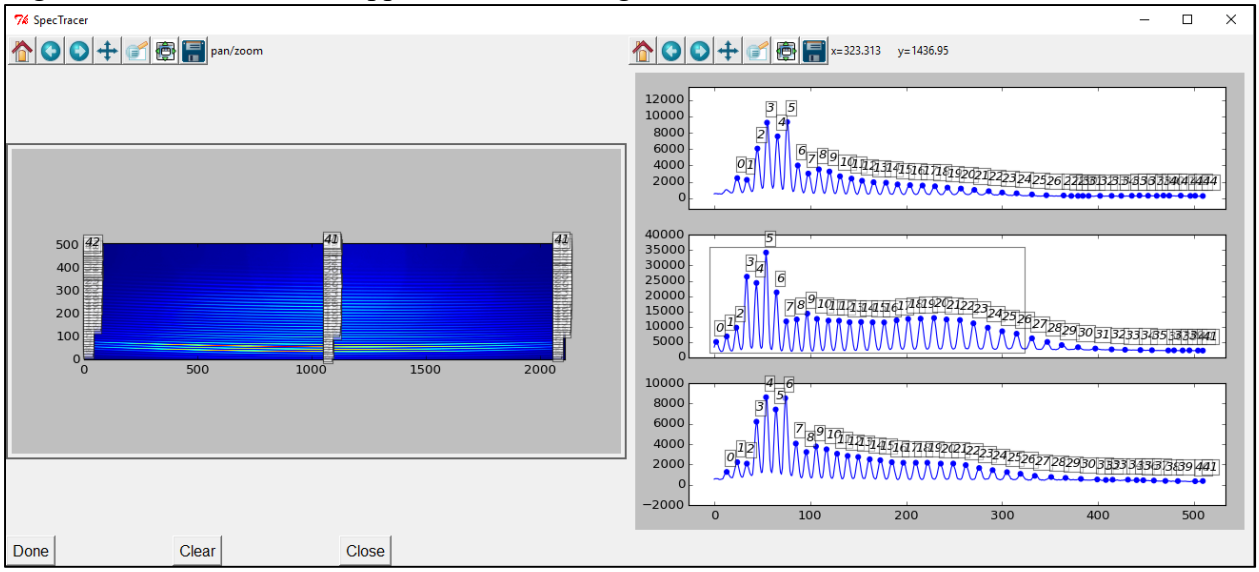
1. One of the leftmost pixel columns (once the overscan is removed)
2. At the middle of the image
3. At the rightmost pixel column (once the overscan is removed)

Once the thickness is entered and the window closed, another window will pop up along with a set of instructions explaining what should be done.





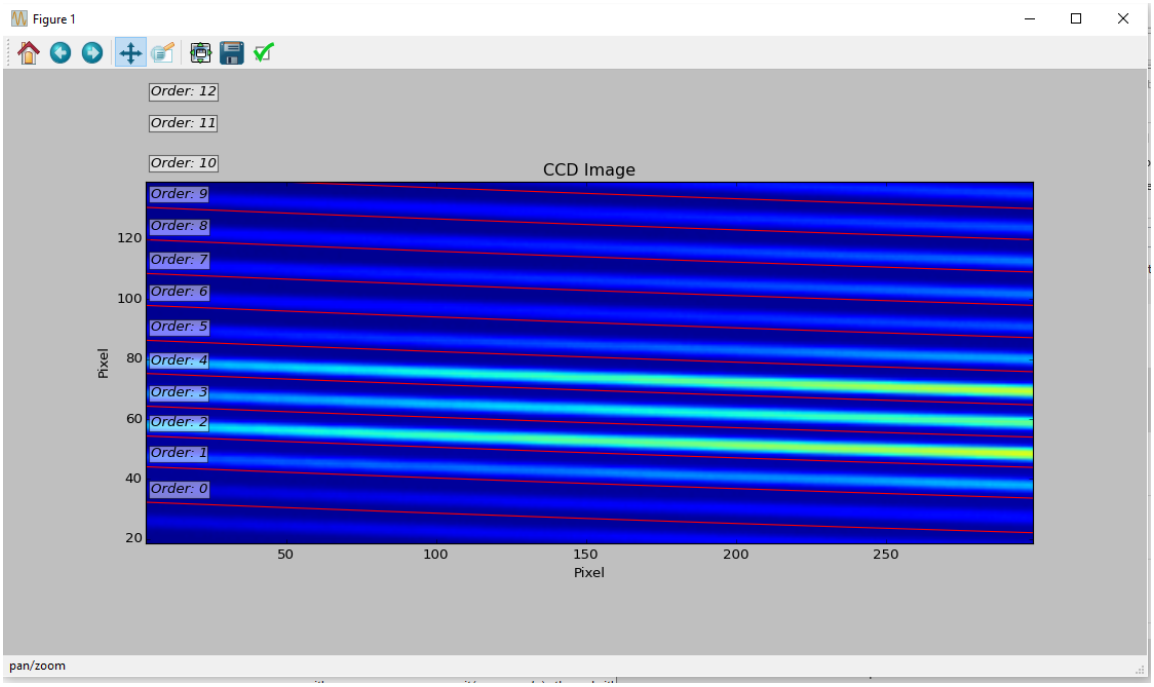
On the left side is an image of the Flat Lamp as captured by the CCD. Each number is related to an order candidate. Regions with higher flux have clearly identified orders, whereas in regions with lower signal, the numbers are not necessarily tied to an order. For example, the upper left and right corners have very little flux and the order candidates don't correspond to actual orders. Only orders that are complete (that is are not cutoff from the detector, are shown. Each number on all the slices corresponds directly with each other, that is, the 0^{th} peak on all of them is part of the same order. All orders coming before it that are truncated at the edge of the detector (i.e. the full order is not available) are not considered. The user should consider all three slices when selecting the range of orders used to obtain data. A rectangle should be dragged across the plot titled 'Center' in order to select viable order candidates. It is okay to leave out orders on the upper edge that are clearly identifiable in the center region but are messy on the left or right edges. These orders can be appended later through another module.



Once the selection is done, the points selected will turn green on the plot. In case a mistake was made when selecting the points, the clear button can be used. Once the selection is satisfying the Done button should be clicked.

Order Correction

The next window will display the traces and label them in order for the user to modify the fit to make it more accurate (the upper and lower orders will have significant deviations from the fit). The user is asked to type in the number of the order that will be modified. Then 3 prompts will be asked from the user. The following picture shows some order traces, along with their identifying number.



1. Increase/Decrease the eccentricity of the fit
2. Move up/down the fit
3. Move left/right the fit

From the experience on fitting the echelle orders, the greatest effect comes from moving the fit right to left. Even though, some might seem that the fit has an eccentricity problem many of this issues can be solved by moving the fit left to right. Also, when moving the fit horizontally, it is required to try different values and see the amount the fit moves i.e. the fits used up to now were only moved ~0.0004, as the fit coordinates are not the same as the x-axis on the image. Also the eccentricity should be varied lightly, ~1.0005. Once all the fits are placed correctly and improved, the correction procedures can be terminated by typing a -1.

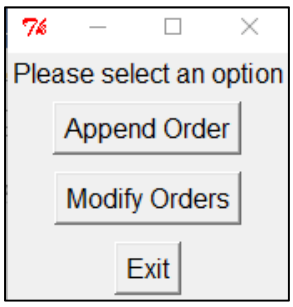
5 files will be created:

- *fit.npy*
- *thick.npy*
- *drift.npy*

- *displacement.npy*
- *correction.npy*

Returning User

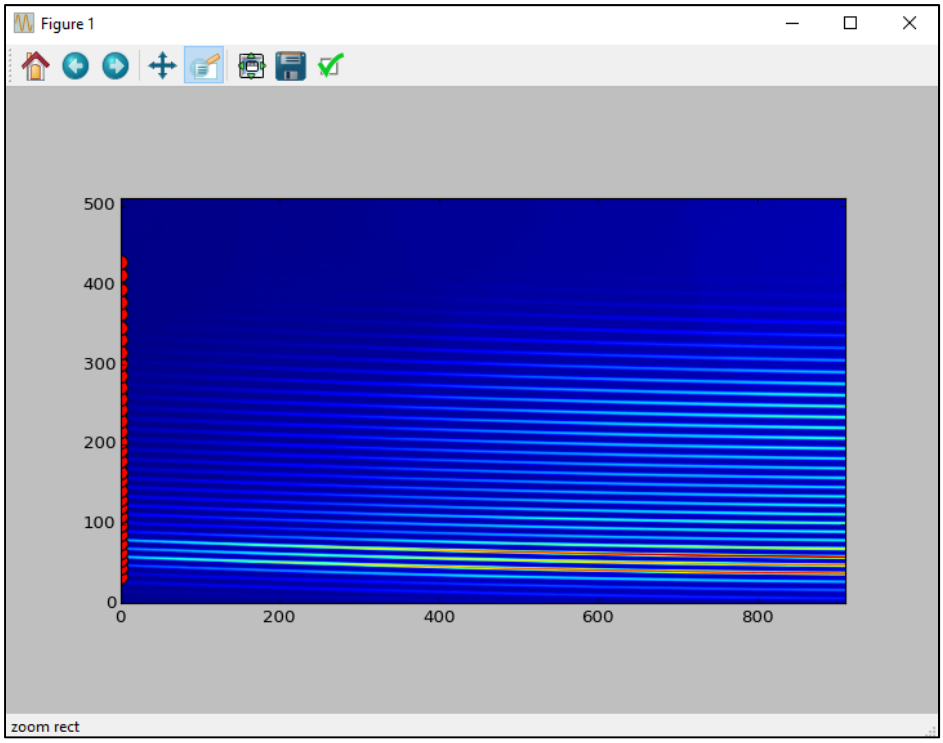
If the calibration procedures were already followed before, the previously calibrated orders can be modified or new orders can be appended. A menu presenting this two options will pop up.



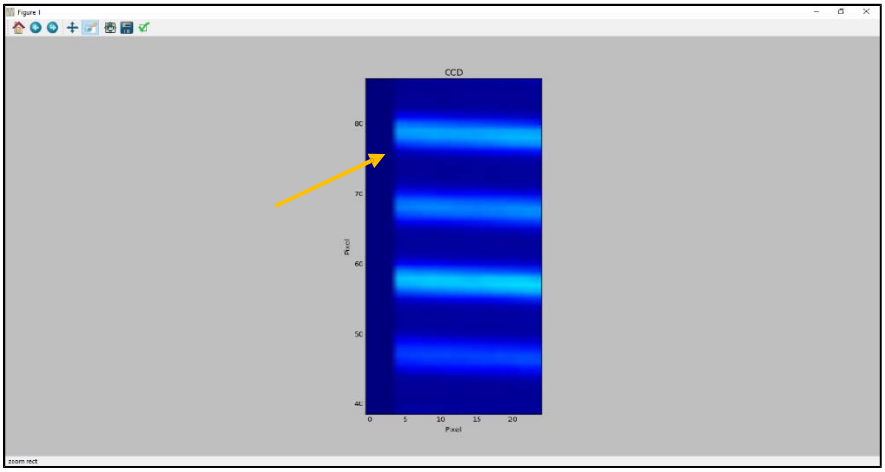
It is important to note, that if an order is modified or appended all, except bias and dark calibration, should be carried out again (sensitivity, reduction, wavelength calibration).

Append Order

The program will prompt the user for the Flat Lamp FITS file, and then display the image contained in it. It is strongly encouraged that the user uses the browse button. Each already traced order will be identified with a red point, in order to avoid the repetition of an order.



To select a new order, just the location of the new order should be double clicked at the leftmost edge.



Afterwards, the program will continue to order modification procedures, again with the same instructions as for the Order Corrections.

Modify Order

The program will prompt the user for theFlat Lamp FITS file, and then display the image contained in it. It is strongly encouraged that the user uses the browse button. The program will display all the traced orders, and the user will be prompted for the order to be modified.

The same instructions should be followed as forthe Order Corrections

Click on Exit once no more modifications of orders are wanted.

Sensitivity Calibration

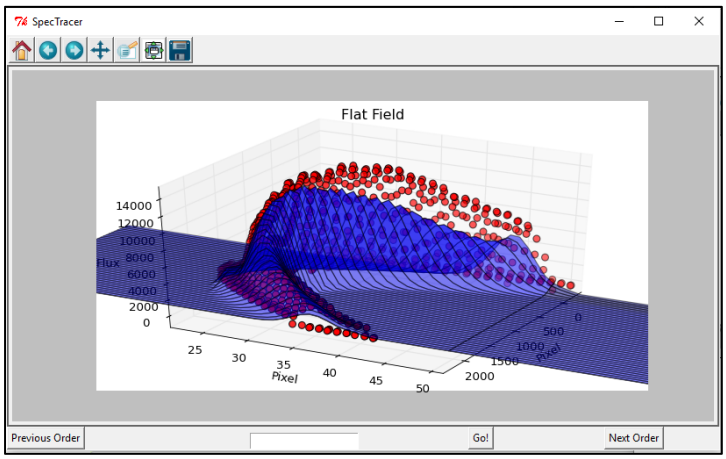
Needed files:

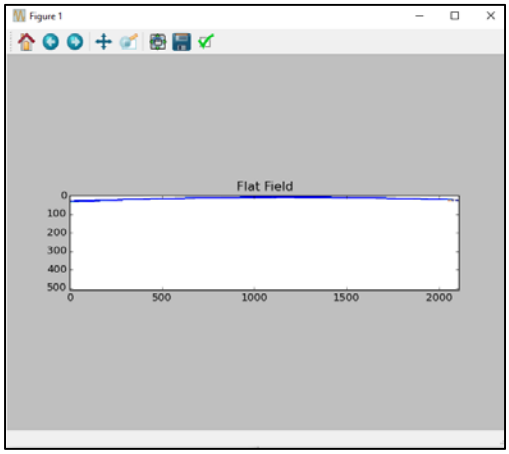
- Flat Lamp FITS
- *fit.npy*
- *thick.npy*
- *drift.npy*
- *displacement.npy*
- *correction.npy*
- *bias*
- *dark*
- *overscan.npy*
- *overscanloc.npy*

The program will ask the user to input the path to the Flat Lamp file. It is strongly encouraged that the browse button is used.

The program will then process each order individually and apply a Gaussian filter to each of the orders, in order to get a curve representing the sensitivity variations from pixel to pixel for each order. This process takes ~1 min total to process all of the orders.

The 3D plot is completely interactive. This means that the user can rotate the view by pressing on it and moving the mouse while living the left mouse button pressed. Also, the surface shows just the relevant location for each order.To move between orders use the buttons on the bottom. The entry box and go button are used to go to a specific order.





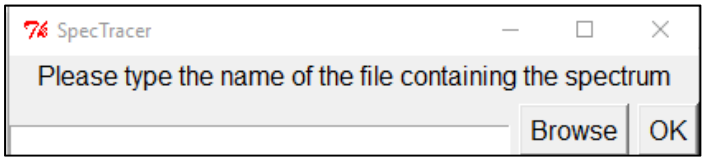
After all the orders are fitted (and their fits shown to the user) an image of one of the flat fields is shown. Once this window is closed, the flatfield file is created and the user is returned to the Main Menu.

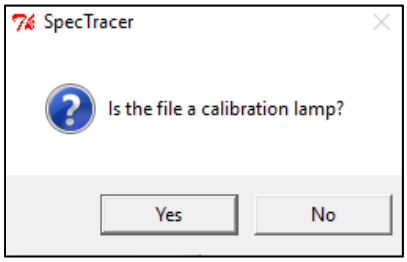
Reduce Spectrum

Needed files:

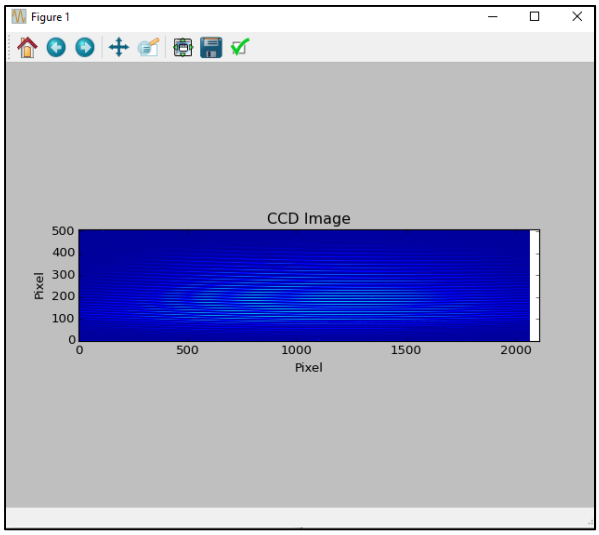
- Flat Lamp FITS
- FITS file of the Star or Calibration Lamp
- *fit.npy*
- *thick.npy*
- *drift.npy*
- *displacement.npy*
- *correction.npy*
- *bias*
- *dark*
- *overscan.npy*
- *overscanloc.npy*
- *flatfield*

The program asks the user for the Flat Lamp FITS file. Then it asks for the FITS file that has the unreduced spectrum of the star or calibration lamp. It is strongly recommended that the browse button is used. Afterwards, the program will ask if the file chosen is a calibration lamp or not.

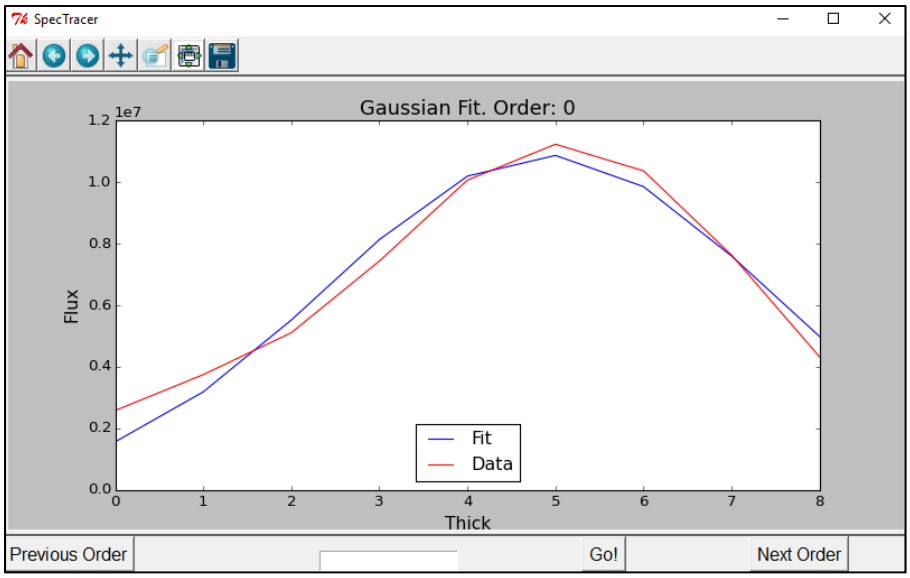




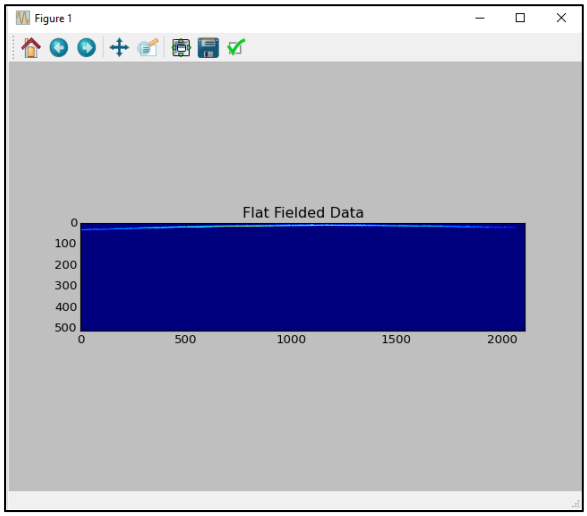
Once the file is selected, the code will show the image contained in the FITS file containing the spectrum of the star or calibration lamp cutting out the overscan.



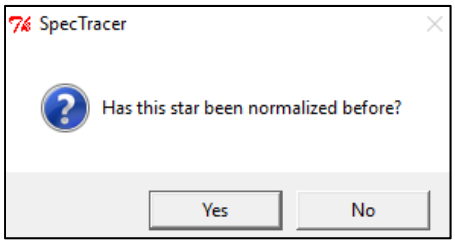
When the plot is closed, the program will create a gaussian curve fitting each of the orders. This is done so that at the time of spectra reduction, the reduction process uses a weighted sum, giving more importance to the pixels containing more light flux, than those at the edges of the order. For each order, the gaussian curve will be shown where the red curve is the actual data, and the blue curve is the gaussian fit. To change from one order to the next, the buttons at the bottom should be used.

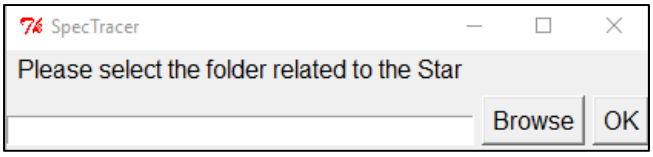


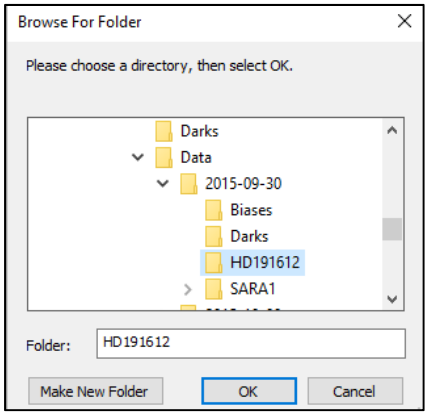
Once the plot is closed, the program shows and image of a flat fielded order.



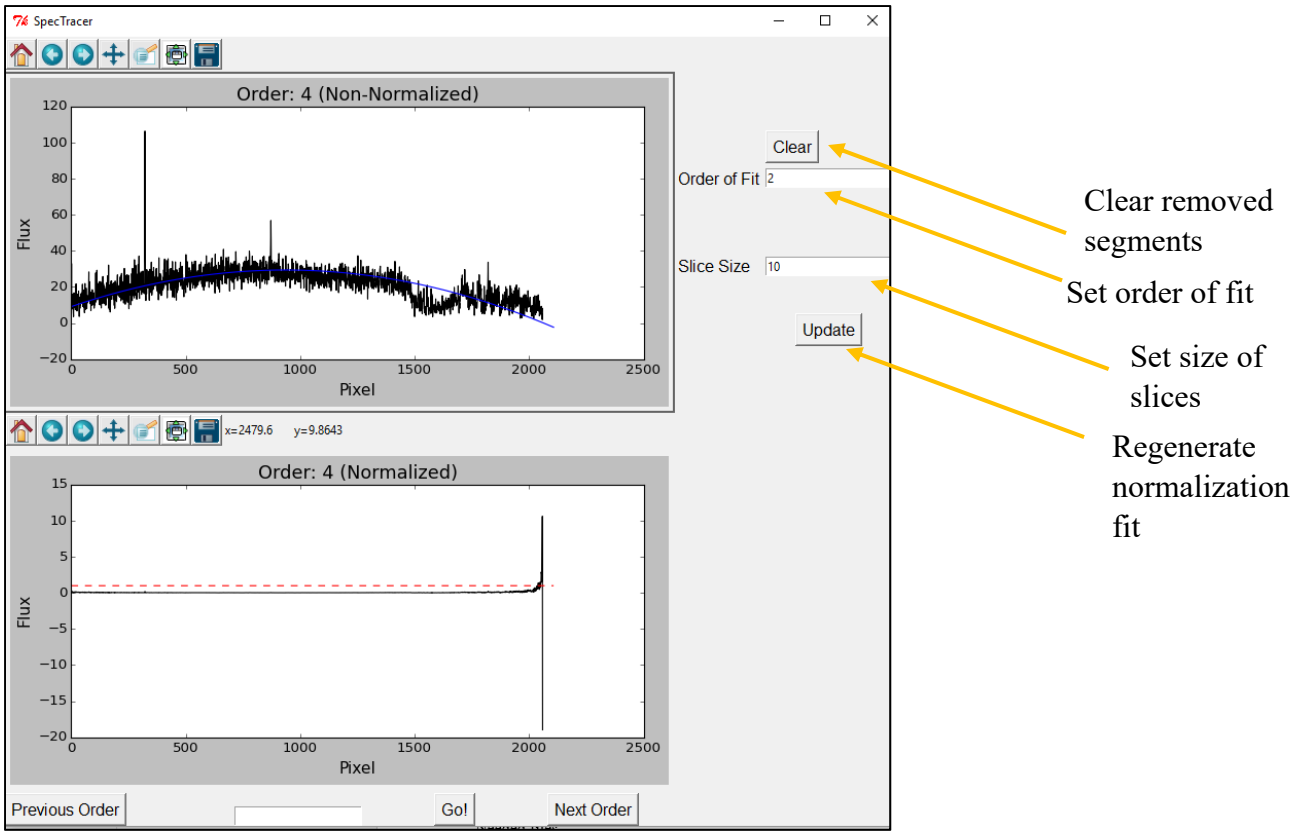
Once this plot is closed, if the file is not a calibration lamp, the user is asked if the star has been normalized before. If it has, then the user is asked to select the folder created to store the normalization files. If the star hasn't been normalized, then the user is asked to create a folder to create the normalization files (it is recommended to name this folder the same as the star).



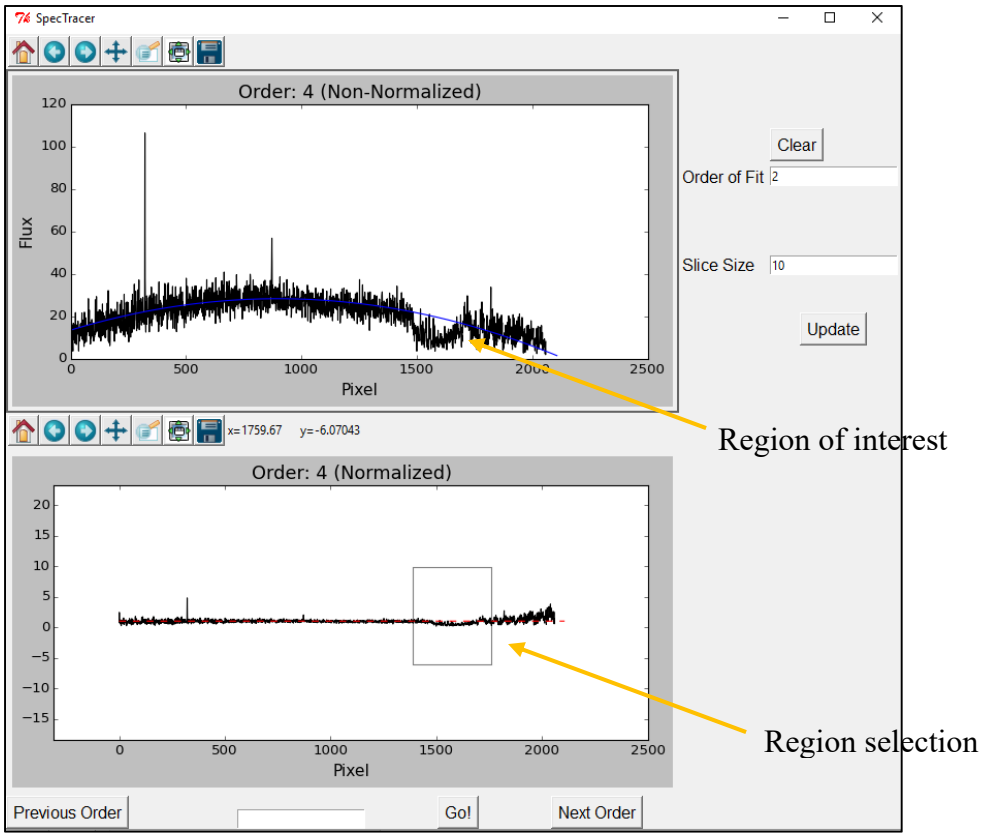




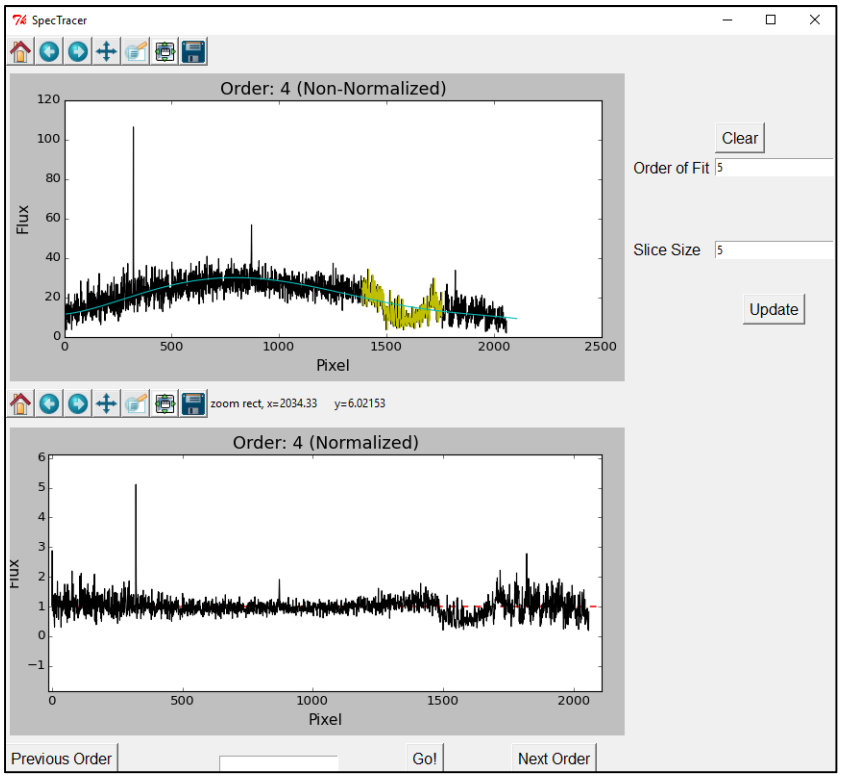
Afterwards, the user is taken to the normalization routine. A window with the unnormalized spectrum is shown on the top, and the normalized spectrum is shown on the bottom, as the image below.



The initial normalization is not always the best due to the structure of the order. Spectral features should not be considered on the fit, since the normalization should preserve these features. Therefore, this segments should be removed from the data being fitted. To do so, a rectangle should be drawn on the lower plot encompassing the region of interest. It is important that none of the plot tools are slected (pan, zoom, etc).

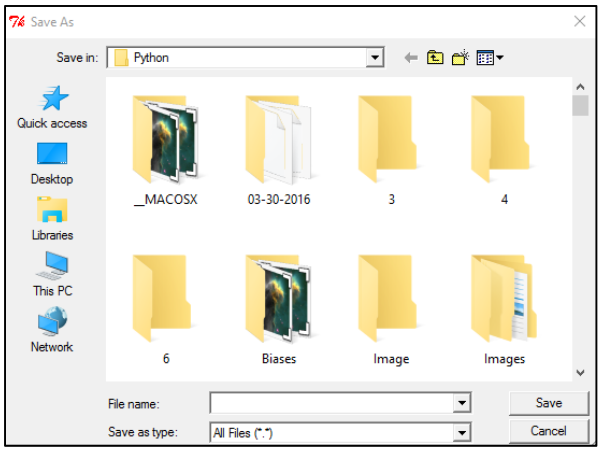


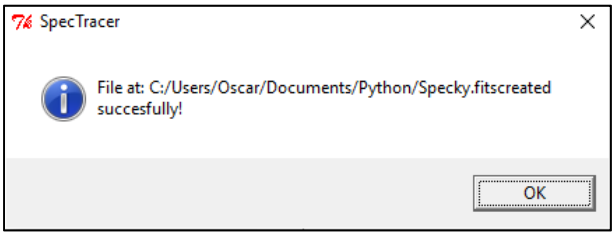
Once this is done, the removed segment changes color to yellow. Next, the user can either update the plot and evaluate the new fit, or tweak the parameters of order and slice size. The order of fit modifies the degree of the polynomial being fit, and the slice size modifies the number of data points being used on the fit. Lower slice sizes translate to a greater number of data points. After every modification (segment removal or parameter modification), the user should click on update to regenerate the plot.



The goal of the normalization routines is to remove the structure of the spectrum and leave only the spectral features deviating from the 1 line. Once the user is satisfied with the normalization of the order, the rest of the orders have to be normalized. After all the orders are normalized the user can close the window.

The normalized spectrum will be saved in a file with the name specified by the user in a directory specified also by the user. A confirmation message is shown, to verify that the file was stored.





Along with saving the spectrum, the program stores the normalization files in order to be used for other files for the same star.

9 files will be created:

- *colored_X.npy*
- *colored_Y.npy*
- *masked_X.npy*
- *masked_Y.npy*
- *normalization.npy*
- *normalization_order.npy*
- *normalization_bool.npy*
- *slice.npy*
- *[Star Spectrum].fits*

After clicking OK, the user is returned to the Main Menu. Please do not type a name that has been already been used inside the same folder. This will cause the program to crash as it is not yet ready to deal with this scenario.

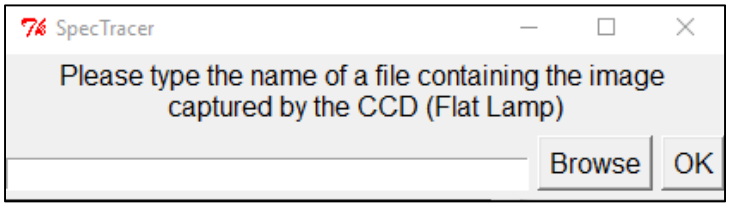
Wavelength Calibration

Needed files:

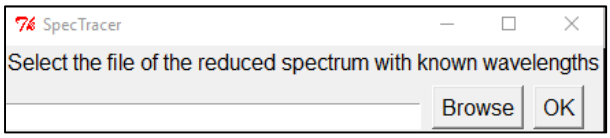
- Flat Lamp FITS
- The following files are obtained by going through the reduce routine of calibration lamps:
  - Reduced Spectrum of a Calibration Lamp with known wavelengths (FITS)

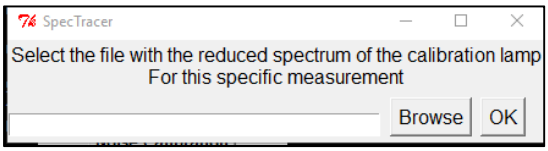
    - Reduced Spectrum of a Calibration Lamp (Same elements i.e. Thorium Argon) (FITS)
- Master.txt (For more information on this file refer to Master File Creation section)
- *fit.npy*
- *thick.npy*
- *drift.npy*
- *displacement.npy*
- *correction.npy*
- *bias*
- *dark*
- *overscan.npy*
- *overscanloc.npy*
- *flatfield*

The program will ask for the FITS file containig the Flat Lamp image.

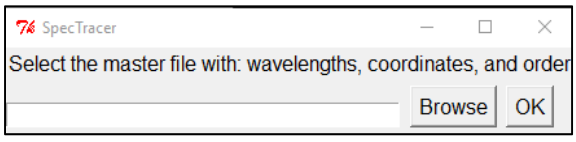


Afterwards the program will ask for the FITS file containing the reduced spectrum of the calibration lamp with known wavelengths. Then, the program will ask for the FITS file containing the reduced spectrum of the calibration lamp for a particular measurement. It is strongly encouraged that the browse button is used.



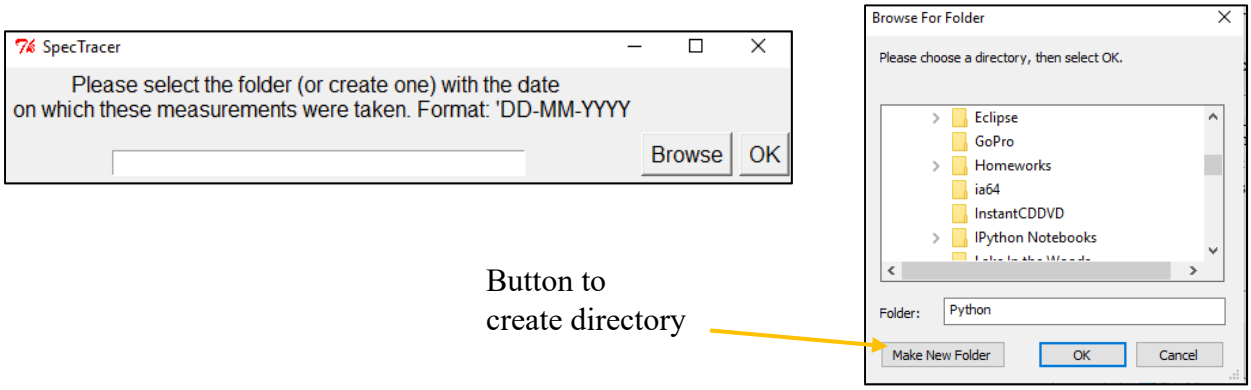


Once both files are given to the program, the master file containing the relationship between wavelength, pixel-coordinate and the orders of the spectrum, is requested.

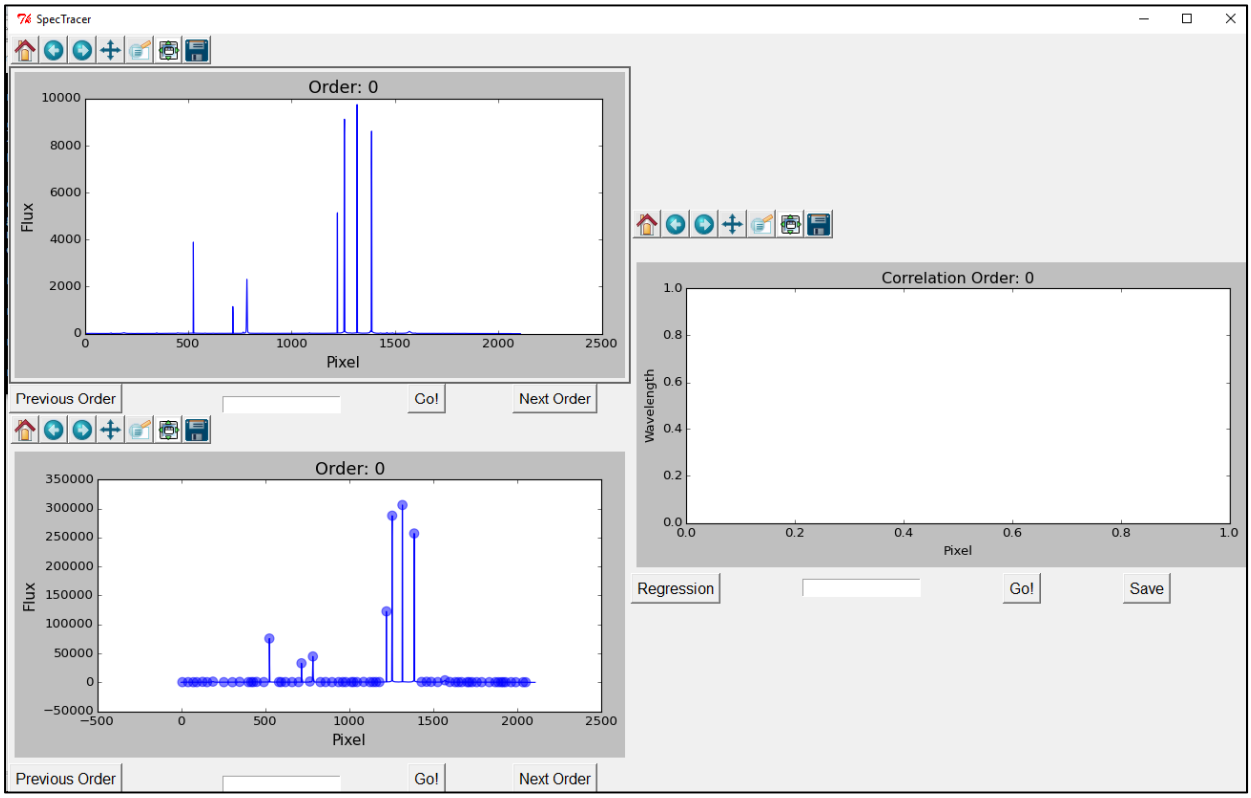


The program will then ask to create a folder corresponding to the date of the measurment. In this directory all the relationships generated between the orders, pixel-coordinates and wavelengths will be stored. From the browse button it is possible to create a folder.

It is recommended to follow the suggested name format, or something similar. This calibrations could vary from night to night depending on the orientation of the instrument, calibration lamp, order traces etc. This is why it should be particular to each night a measurment is taken.



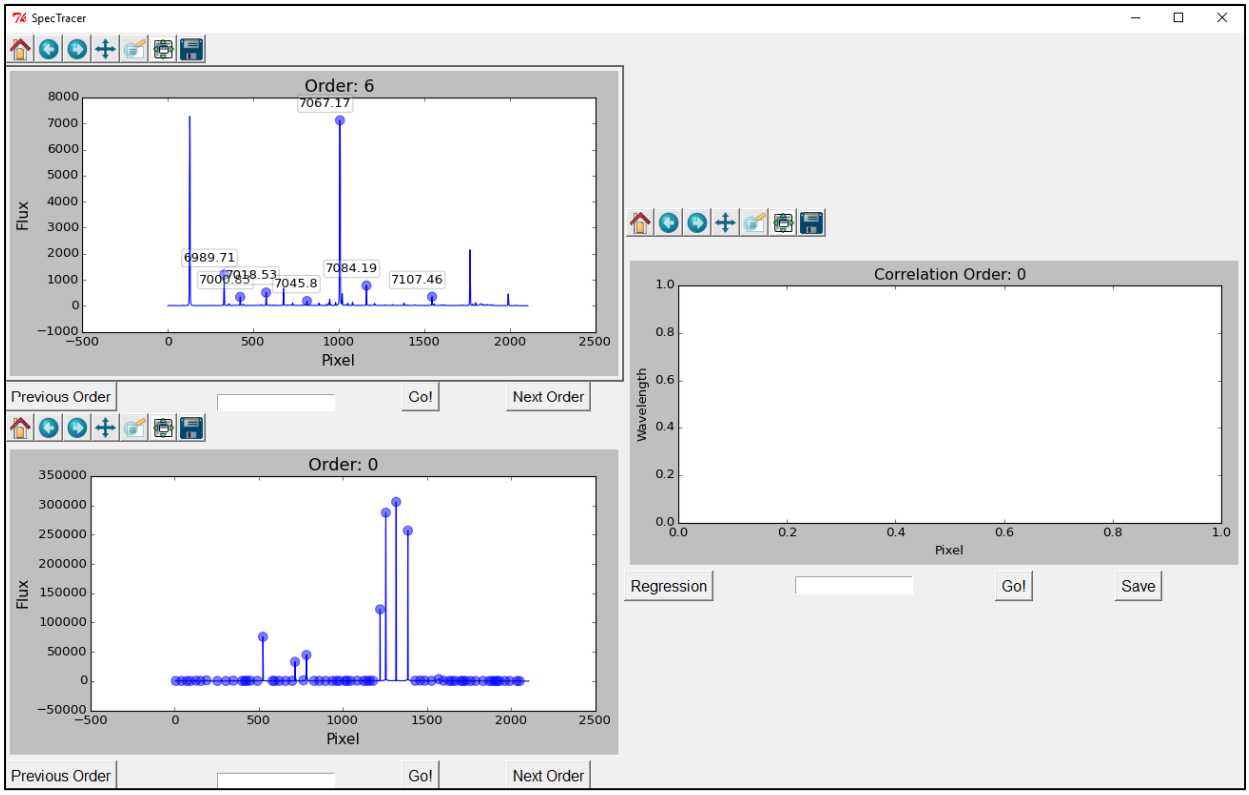
Once the folder is created, the following window will appear.



The top plot is the one of the known wavelength file, the bottom plot the calibration lamp for a particular night. The plot on the right will show the relationship between the points and the wavelength assigned. All the interactive buttons of the toolbar work the same as before. The upper and bottom plot have the same navigation buttons. The Previous Order and Next Order

button allow the user to cycle through the orders. The entry box and the Go! Button allow the user to go to a specific order. The right plot, has different buttons. The Regression button finds the best fit line for the set of points given from the relations made. The save button, stores the best fit line into a file in the folder specified. The entry box allows the user to specify the degree of polynomial to be fit, and the Go! Button applies the degree.

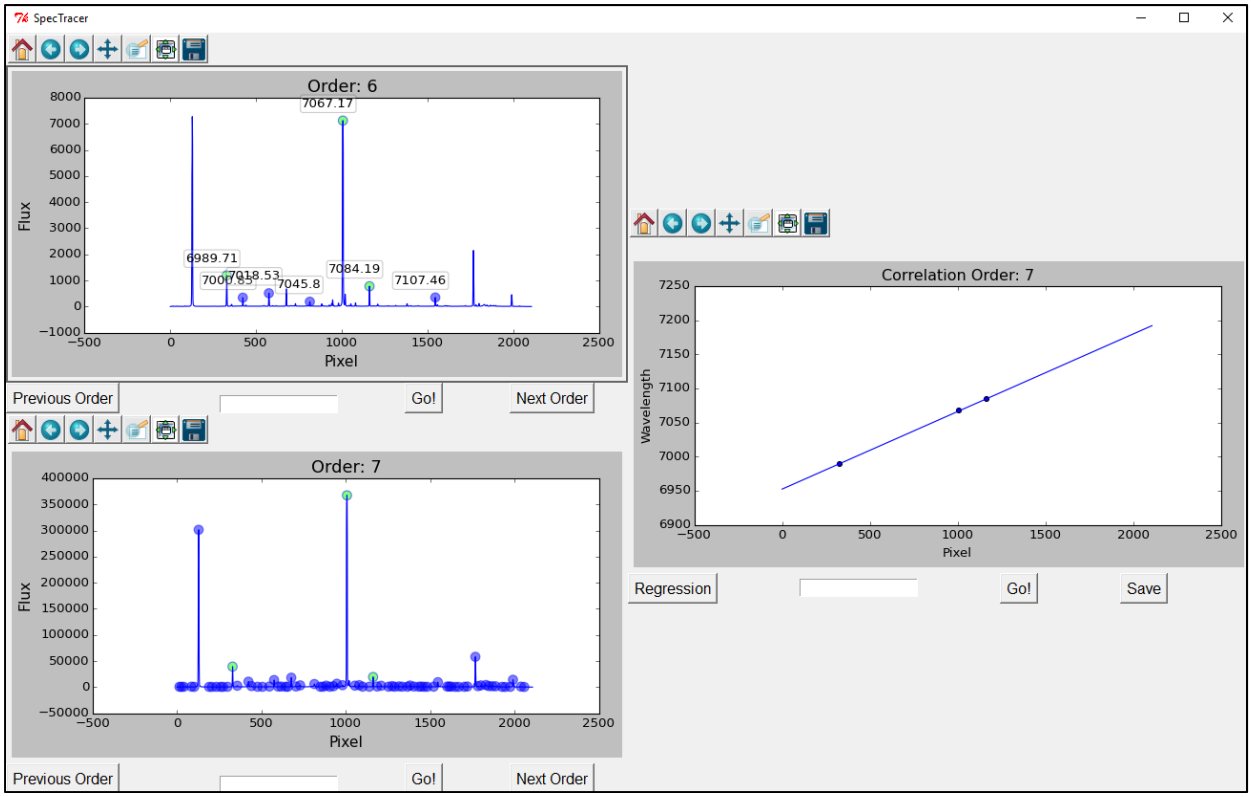
If there is no information in the master file for a particular order, it will appear without any information. In case there is information about it it will look like this:



The upper plot will have the spectral features identified with particular wavelengths and the bottom plot will have local maxima identified with dots. To relate a known wavelength coordinate with the one of the measurment:

1. Click on the upper plot's identified spectral feature
2. Click on the lower plot's matching feature.

It is important to be careful when selecting points in the lower plot. Some points may be overlapping due to theri size and clickable area. To solve this, zoom in into the target area before clicking the point. The related points will start to scatter in the right plot also, they will turn green in the other two plots to make sure spectral features are not repeated. If either order is changed, the right plot is reset, so in case a mistake is made simply by moving from one order to the next it is possible Once enough spectral features for a particular order have been related, the regression button should be clicked. An example is shown below.



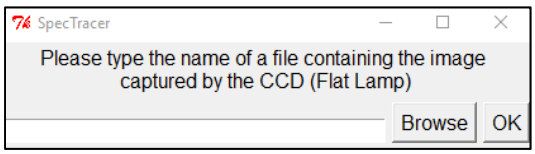
To save a regression, the save button should be clicked. It is important to click on the button, if not, the information won't be stored. A confirmation message will appear to show the file saved successfully. Once done, the window should be closed and the user is returned to the Main Menu.

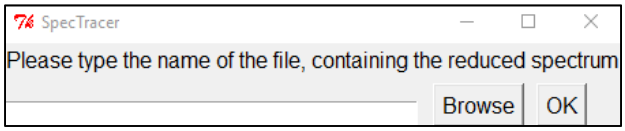
Show Spectrum

Needed Files:

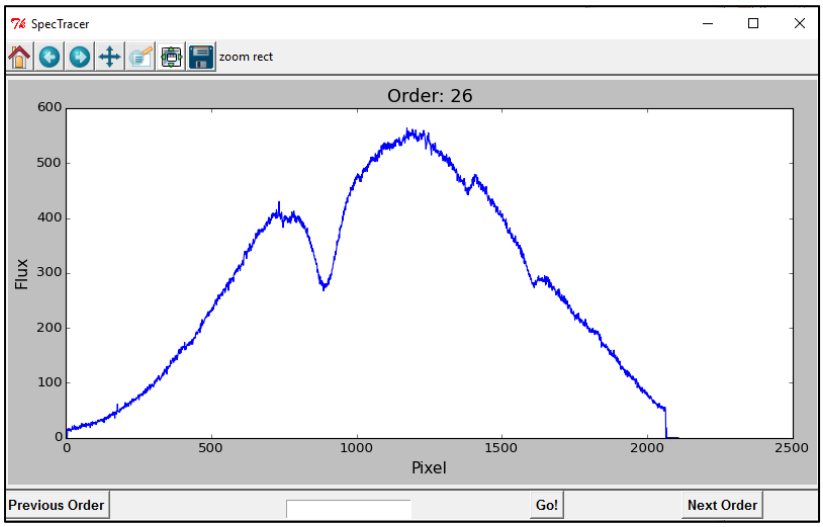
- Flat Lamp FITS
- FITS containing spectrum image
- Master.txt (optional)
- Directory of the measurement (wavelength calibrations)

The program asks for the FITS file containing the Flat Lamp image. It is strongly encouraged that the browse button is used. Then it asks for the FITS file containing the reduced spectrum either of the calibration lamp or of a star.





The program requests that the user choses the folder corresponding to the date of the measurement. This folder is supposed to contain all the correlated wavelength and pixel coordinates for each order. In case this has not been done for some reason i.e. preparing the *masterFile.txt* , then create an empty folder and select it. Using the browse button is strongly encouraged. After clicking okay, the following plot will appear.



If there is a file containing information about the relation between pixel and wavelength for a particular order, the x-axis will change to wavelength instead of pixel coordinates. The plot has four navigation buttons along with the interactive toolbar. Previous and next order will allow the user to cycle through the orders. The entry box and Go! Button allow the user to go to a specific order. Once the user is done viewing the plots and/or saving them, the process is terminated by closing the window and the user is returned to the Main Menu.

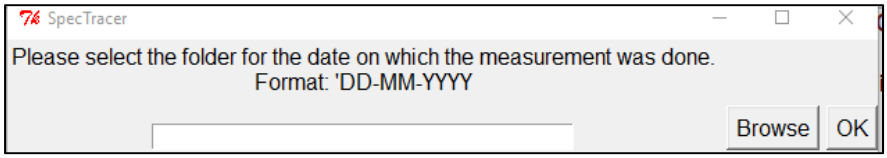
Master File

Needed Files:

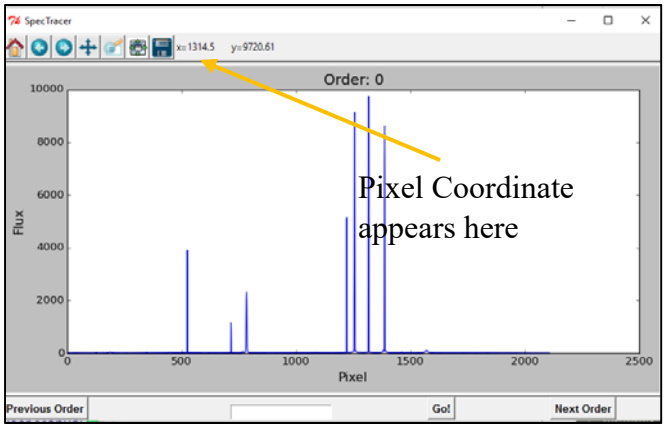
- Flat Lamp FITS
- FITS containing spectrum image of Calibration Lamp
- Directory of the measurement (wavelength calibrations)

flatfield

The Master File, is a text file containing the relationship between the pixel coordinates and the wavelength at each pixel coordinate for each order. This file is crucial for the last two modules of *SpecTracer*. To create this file, first run the Reduce Spectrum module and reduce the spectrum of a calibration lamp. Then run the Show Spectrum module and select the reduced spectrum FITS file from the calibration lamp. It is important to create an empty directory with the date of the observation, at the time the user is prompted for the folder containing all the related wavelength and pixel coordinate functions.



Once the empty folder is selected, the plot showing the spectrum of the calibration Lamp will appear.



It is assumed that by some way, the wavelength of certain spectral features of the calibration lamp are known. The user should open a text editor i.e. notepad in order to be able to create the master file. The user should then type:

1. The order
2. The pixel-coordinate
3. The wavelength of the spectral feature

The order is shown in the title of the plot. The pixel coordinate can be determined by hovering the mouse over the spectral feature. The wavelength is known from a calibration lamp and/or from a the spectrum of the particular elements. This three data should be written into a text file in the order specified (order, pixel-coordinate, wavelength), separated by a comma, with no spaces. Below an example is shown.

```
6,329,6989.71
6,423,7000.83
6,575,7018.53
6,814,7045.80
6,1007,7067.17
6,1162,7084.19
6,1546,7107.46
7,1180,6871.29
7,1213,6874.74
7,1572,6911.24
7,1622,6914.36
7,1844,6937.62
7,1906,6943.63
12,329,5885.66
12,358,5888.55
12,387,5891.45
12,471,5899.90
12,529,5905.58
```

There should be no blank lines in between. The file should be saved as a .txt file, with any name, although it is recommended to save it using the following format *master[ElementSymbols].txt*.

Contact

Should any problems with the code arise or bugs identified please contact the developer of *SpecTracer*, at:

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