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Guide to Processing Spectra Using the BASS Software

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Applicable to BASS Project Version 1.9.7 by John Paraskeva

Available for free download from the files area of [Astrobodger Groups.io]

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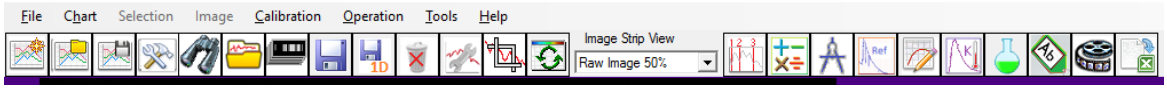
This document has been written as a tutorial for processing spectra taken with an Alpy 600 spectrograph using BASS. The same approach can be used for most slit spectrographs. Please refer to the BASS User Manual for more detailed information on any aspect of processing.

Acknowledgement of Sample Spectra

The spectra used in this tutorial were obtained from François Cochard of Shelyak Instruments during the BAA Alpy Workshop in 2016.

Notes

This tutorial specifies how to access screens using the menus. Many of the most common and useful screens are also accessible from buttons below the menu bar.



1 - Stack and Calibrate Images

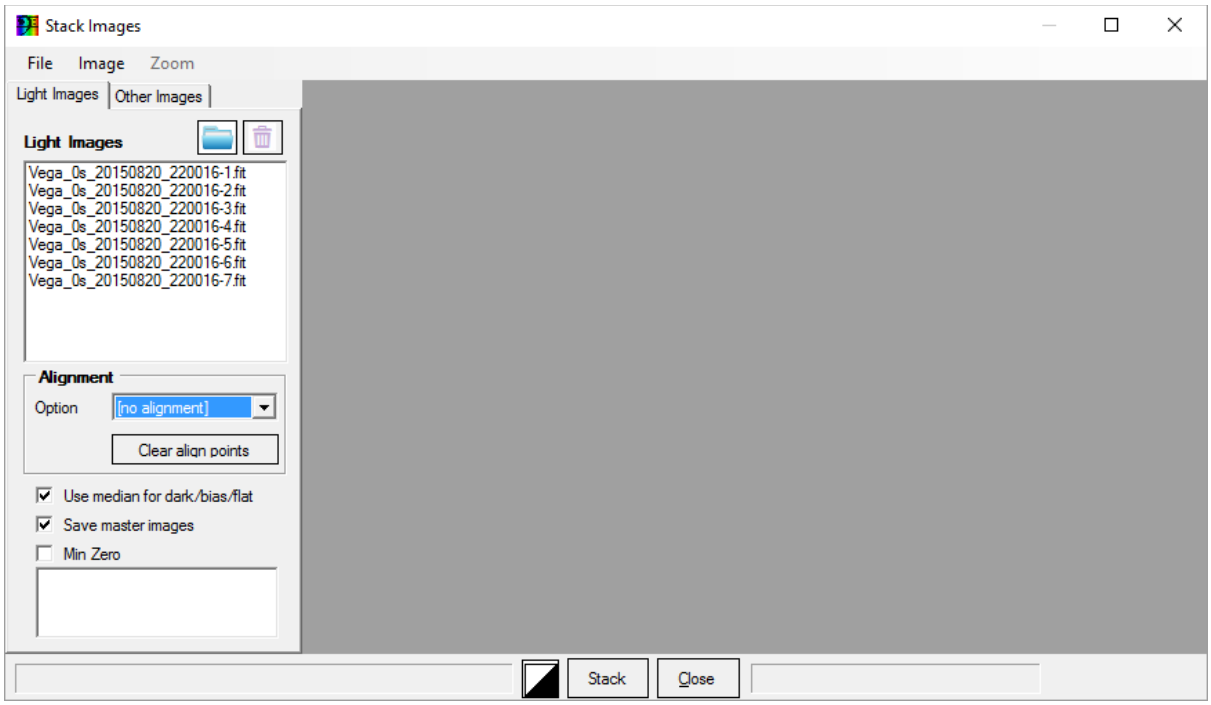
First you need to stack individual images of the same target, and apply image calibrations for bias, dark and flat field. Even if you only have 1 image of your target, then you will need to follow this process to perform the image calibrations. (Note wavelength calibration comes later.)

You can of course perform stacking and calibration in your preferred image processing software. In which case jump to section 2 or 3 as appropriate.

Menu: File -> Stack Images

First select your “Light Images”. These are the images of your target star spectrum.

Ensure that “no alignment” is selected. Any alignment would invalidate the geometric corrections to be applied later on.

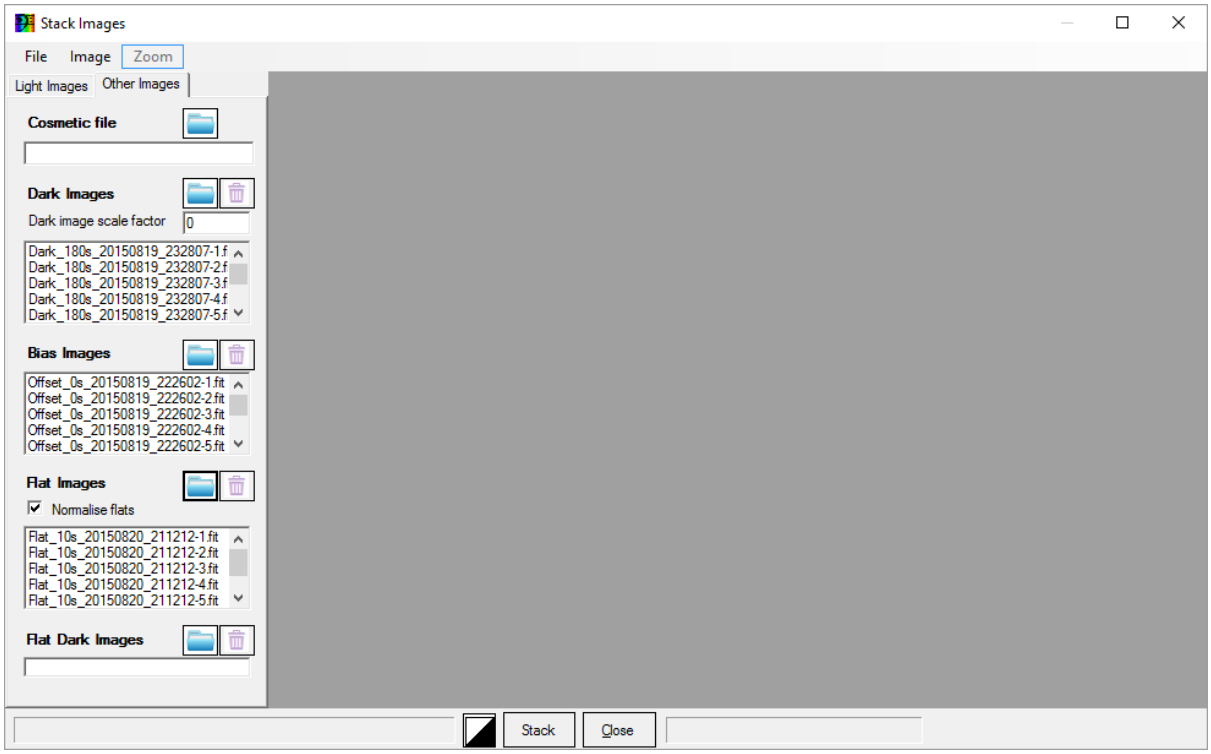


Next select your dark, bias and flat images.

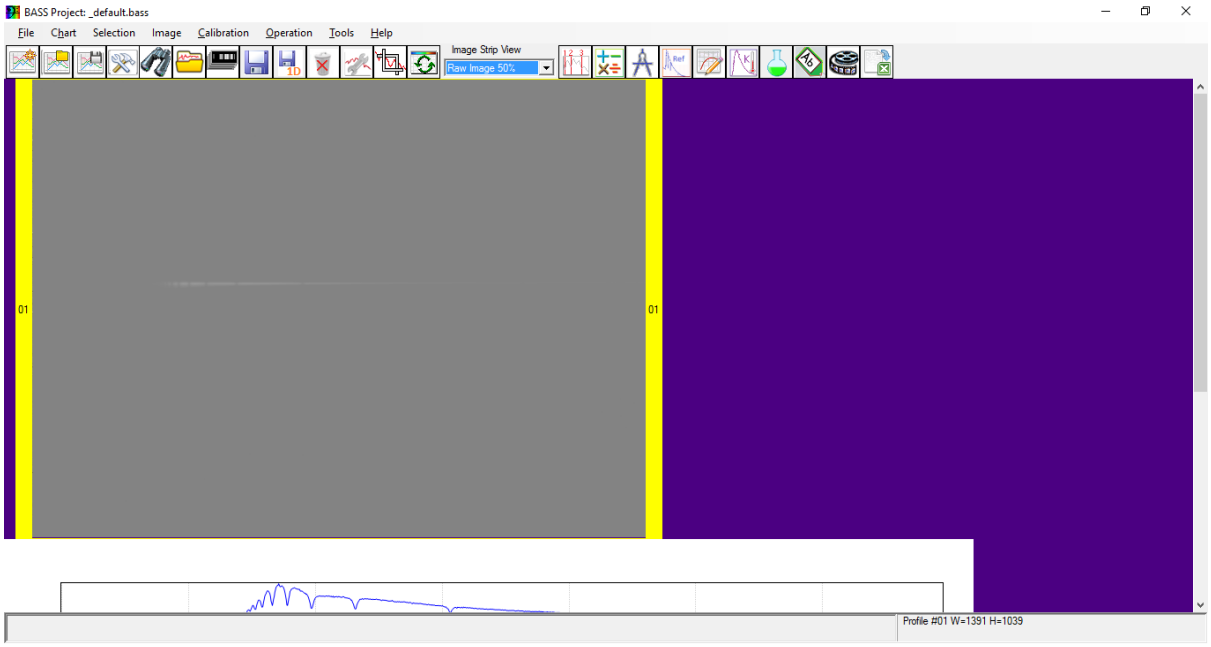
If the exposure time of your dark frames is the same as your light images then you do not need bias frames. However, including bias frames allows BASS to scale 1 set of dark frames to match any light exposure time.

Flat darks can improve the quality of your flat field, but they must match the exposure time of your flat images.

If you have a master cosmetic file listing the hot pixels in your camera, then this should be selected in the Cosmetic file box. Creating a cosmetic file is explained in the next section.

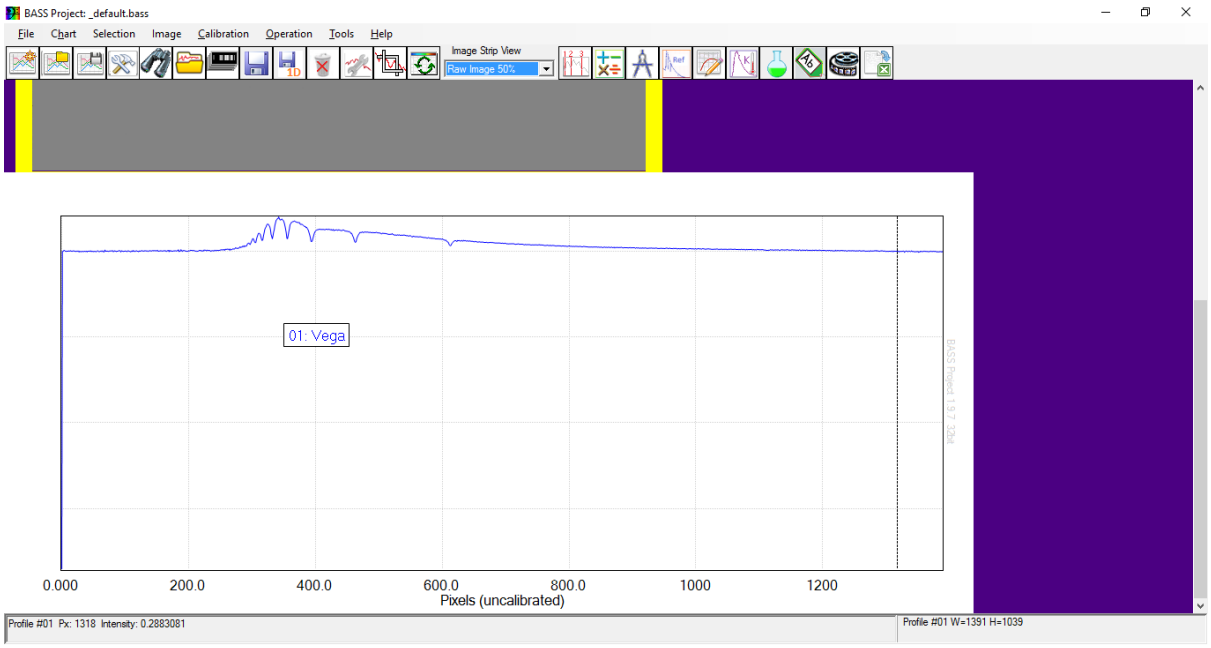


Now press stack.



Change the caption of your stacked image to a sensible name, in this case Vega. To do this, simply double click the image and then change the Caption box.

This will update the legend on the plot.



Finally save your image with an appropriate name.

Menu: File -> Save image as…

It is good practice to include the object, the date and sometimes the time, and a description of the processing step, e.g. Vega_20150820_Stack.fit.

2 - Hot Pixel and Cosmic Ray Removal

This step is often needed to clean up the image. Without this step you may have spikes in your final spectrum due to hot pixels or cosmic ray hits.

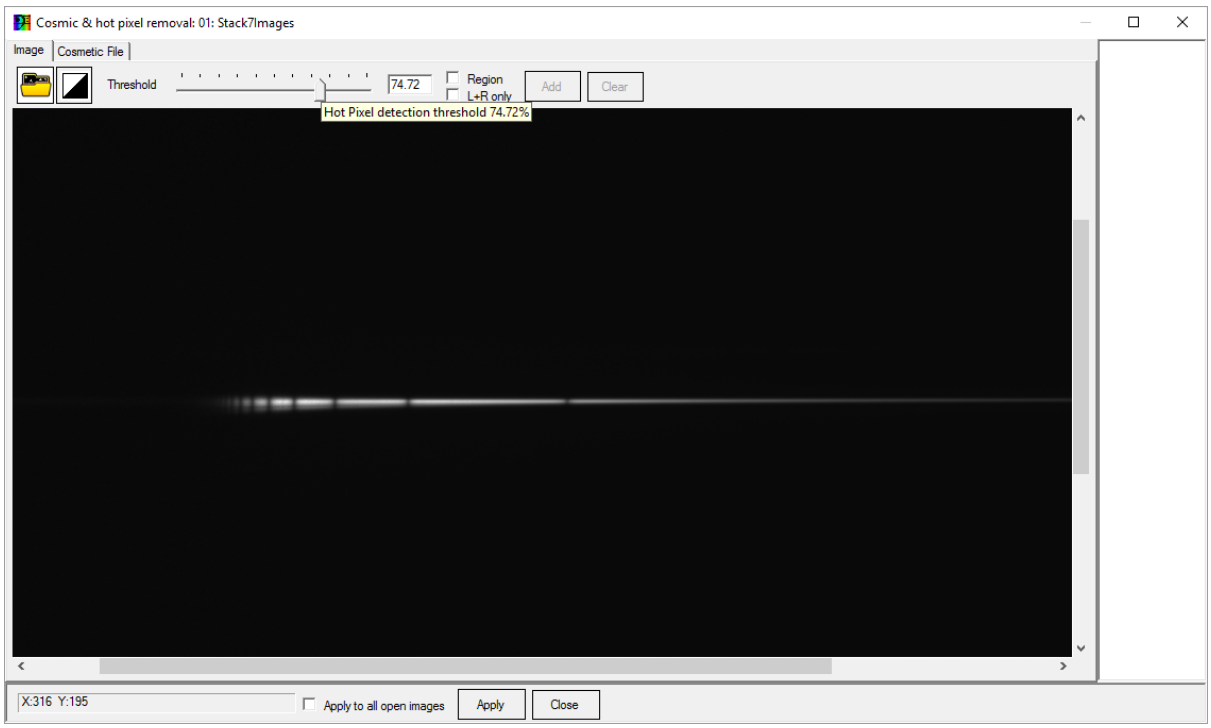
There are 2 approaches that can be used:

- Create a master hot pixel map from your master dark image. This gives a reliable hot pixel removal but will not remove cosmic ray hits from your stacked spectrum image.
- Detect and remove them from your stacked image. This approach is harder since you have to avoid removing the spectrum which can look a bit like hot pixels. This step is needed if you have cosmic ray hits.

The best approach is a mix of the two methods. First apply a master hot pixel map created using your master dark image. If you have any cosmic ray hits, then follow up with a correction to your stacked image to remove the cosmic rays.

To access the screen:

Menu: Image -> Cosmic, Hot & Cold Pixel Removal



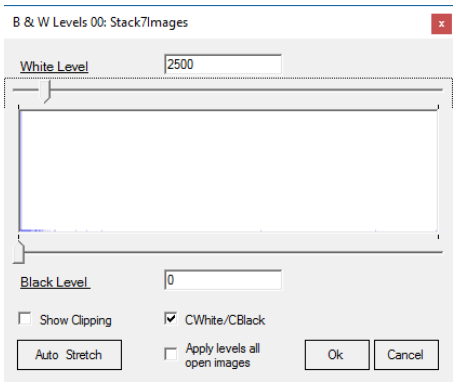
No hot pixels or cosmic rays detected in this image at the 74% threshold.

a. Creating a Hot Pixel Map

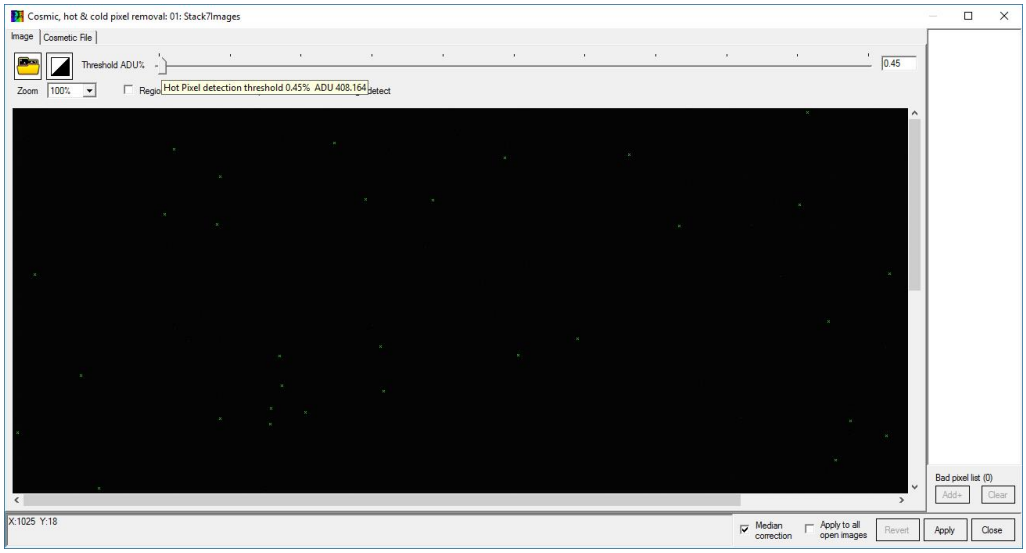
An excellent way to detect hot pixels is to use a master dark image. Such an image will have been automatically created by BASS as long as you left "*Save master images*" ticked in the "*Stack images*" screen. Also, you can typically use the same map for several months.

To help see the hot pixels it is a good idea to amend the black and white levels by clicking the button 

Then adjust the black and white level to low values. Here 0 and 2500. A white level of 2500 means any pixels of 2500 ADU and above will be white, and between 0 and 2500 scaled from black to white.



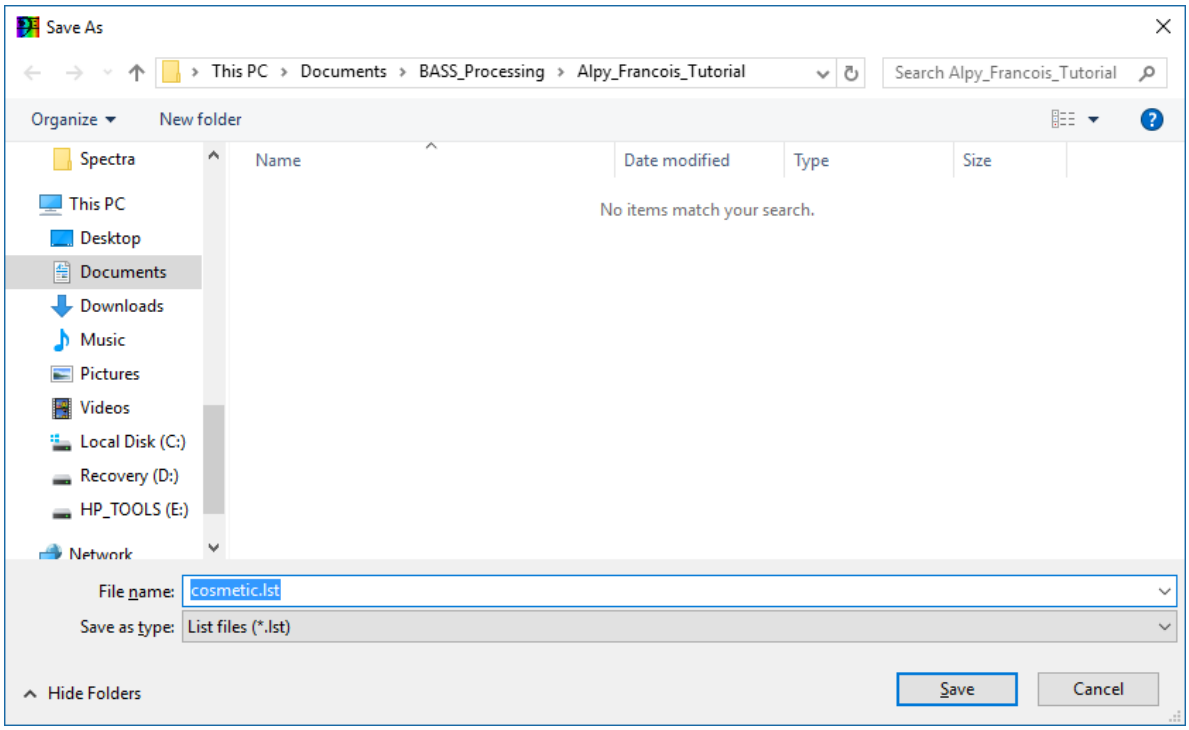
Now you can start on the hot pixel removal. Adjust the threshold percentage until you pick up the majority of the hot pixels. The hot pixels will be indicated by little green crosses. The threshold ADU value will be shown when you move or hover your mouse on the slider.

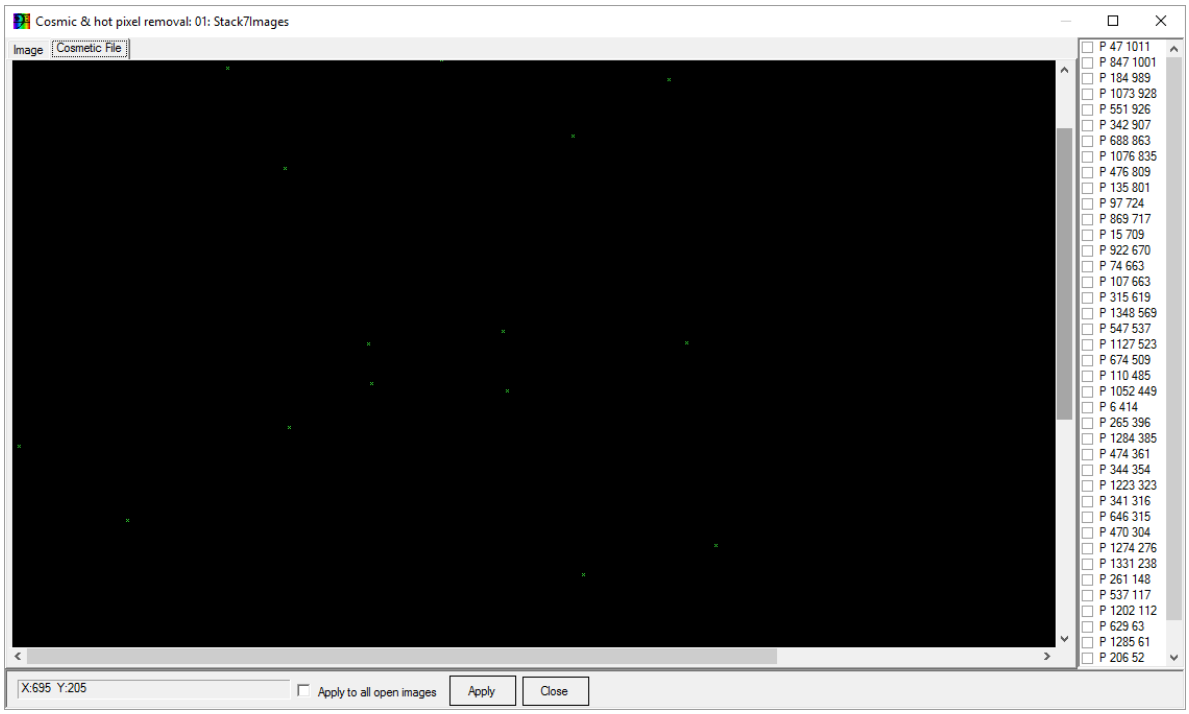


A 0.45% (408 ADU) threshold has been used in the screenshot above as this picked up the hot pixels without saturating the image. If this was a spectrum image then a higher percentage would be needed to avoid removing the brighter parts of the spectrum.

Use the side bars to move around your image to check you have picked up the majority of the hot pixels while leaving most pixels untouched.

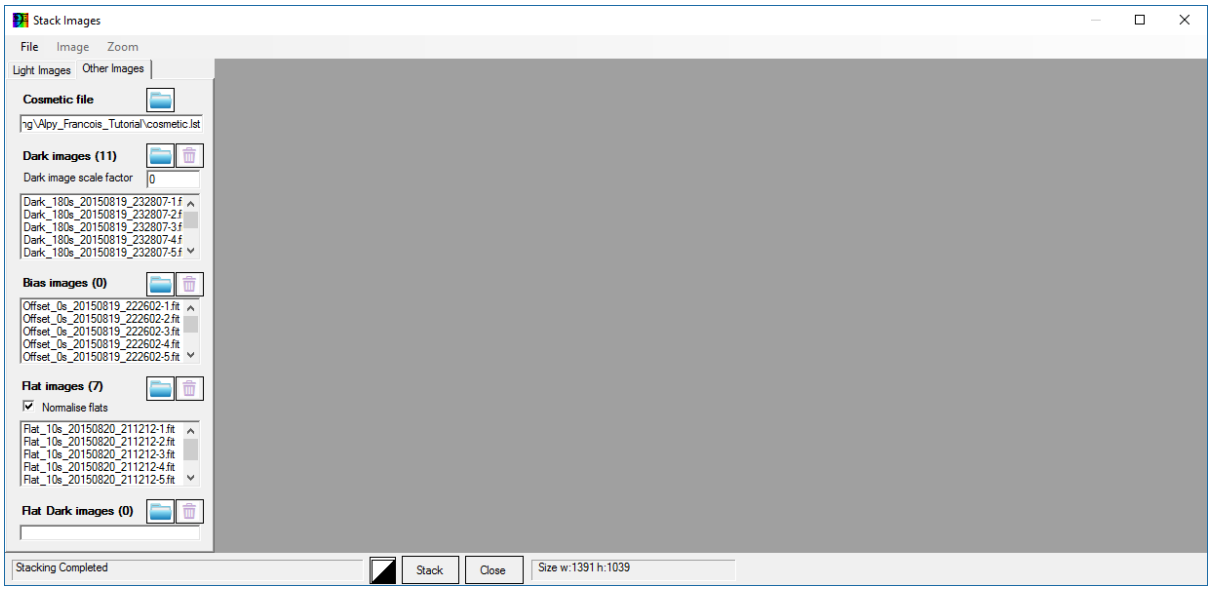
Click the “Cosmetic File” tab and press save to create a master file listing your hot pixels. A good filename would be “cosmetic.lst”.





This hot pixel map can be applied to your stacked image by pressing the Apply button.

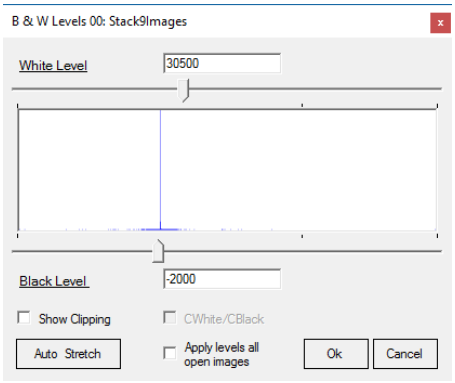
You can also use it in future processing by selecting the "*Cosmetic File*" on the "*Other Images*" tab of the "*Stack Images*" screen.



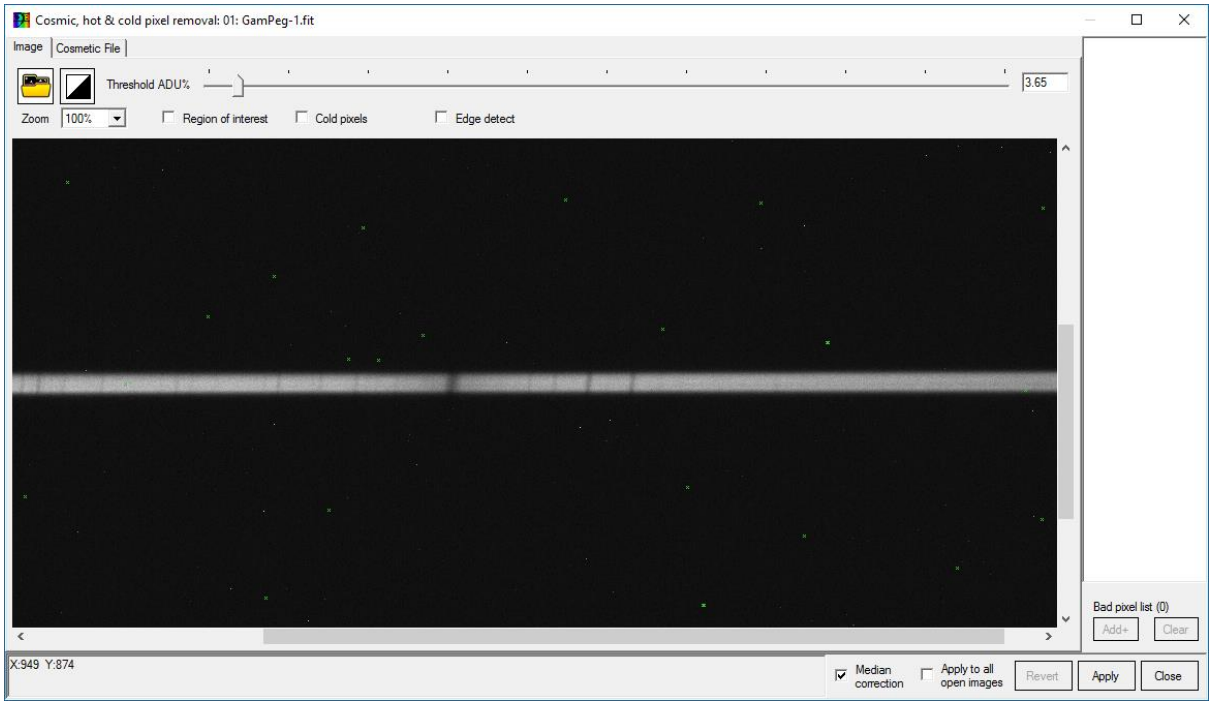
b. Cosmic & Hot Pixel Removal from a Spectrum

Note a hot pixel map would not remove cosmic ray hits as they happen on single images. If you have cosmic ray hits then you must remove them by running the Cosmic, Hot & Cold Pixel Removal.

As before adjust the black and white levels using the button  , so that the spectrum and any cosmic rays and hot pixels look nice and clear.



Adjust the threshold slider until you remove the cosmic ray hits or hot pixels, but without removing any of the spectrum. This can be tricky, so ensure you take your time and be careful. It is very important not to remove any bright parts of the spectrum image when removing hot pixels and cosmic rays.



No clear cosmic ray hits were seen in the sample images for this tutorial. So instead a high resolution spectrum taken with an Lhires III with plenty of hot pixels is shown above.

3 - Geometric Corrections

The geometric corrections must be applied to both your stellar images (stacked) and neon or other emission line calibration images at the same time. Otherwise the geometry of your wavelength calibration image and star images will be out of sync. This will cause your wavelength calibration to vary with vertical position in the image and therefore be wrong.

If you are using a slit spectrograph but are not using a wavelength calibration lamp, then you can use a street light or similar spectrum with emission lines to perform the Smile / Slant correction.

Make sure you have all your different stacked stellar spectrum images and your wavelength calibration image (e.g. Neon line spectrum) open in BASS.

The Image Strip View should be set to “Raw Image ..” at a percentage that enables you to see a good level of detail.

It is advisable to apply the geometric corrections in the following order:

1 Rotate / Tilt Correction
2 Smile / Slant Correction

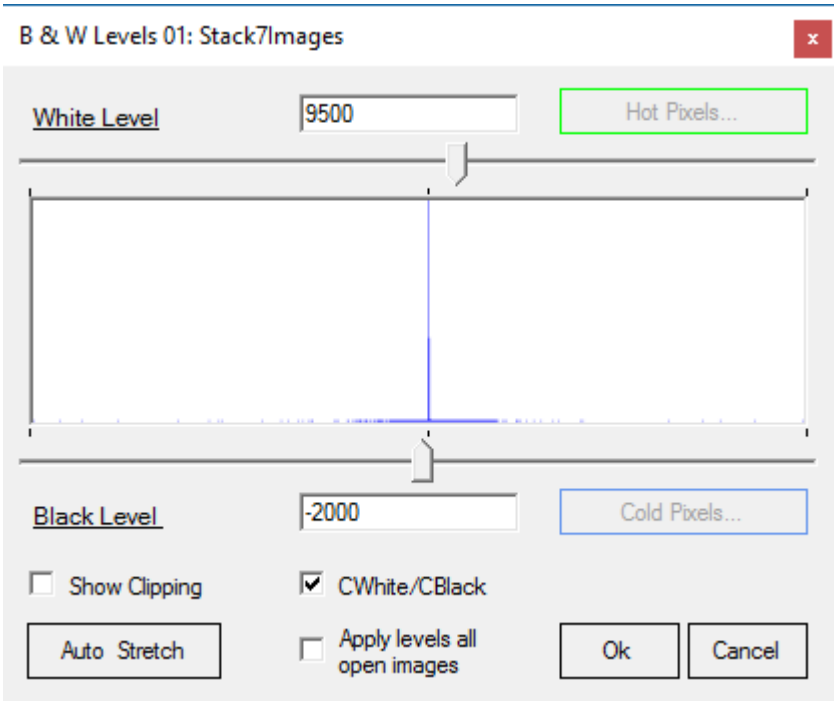
This is because the rotation / tilt adjustment will change the slant angle, but the slant will not change the tilt.

a. Rotate / Tilt Correction

Click on one of your star images so that this image is now selected, border turns yellow.

Make sure that the black and white levels are set such that the spectrum image is clear.

Menu: Image -> Black & White Levels

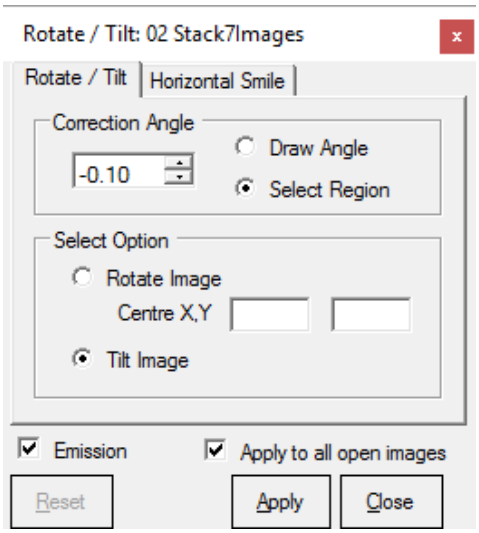


Do not worry if you have some negative pixel values. This is caused by random noise in dark current and bias.

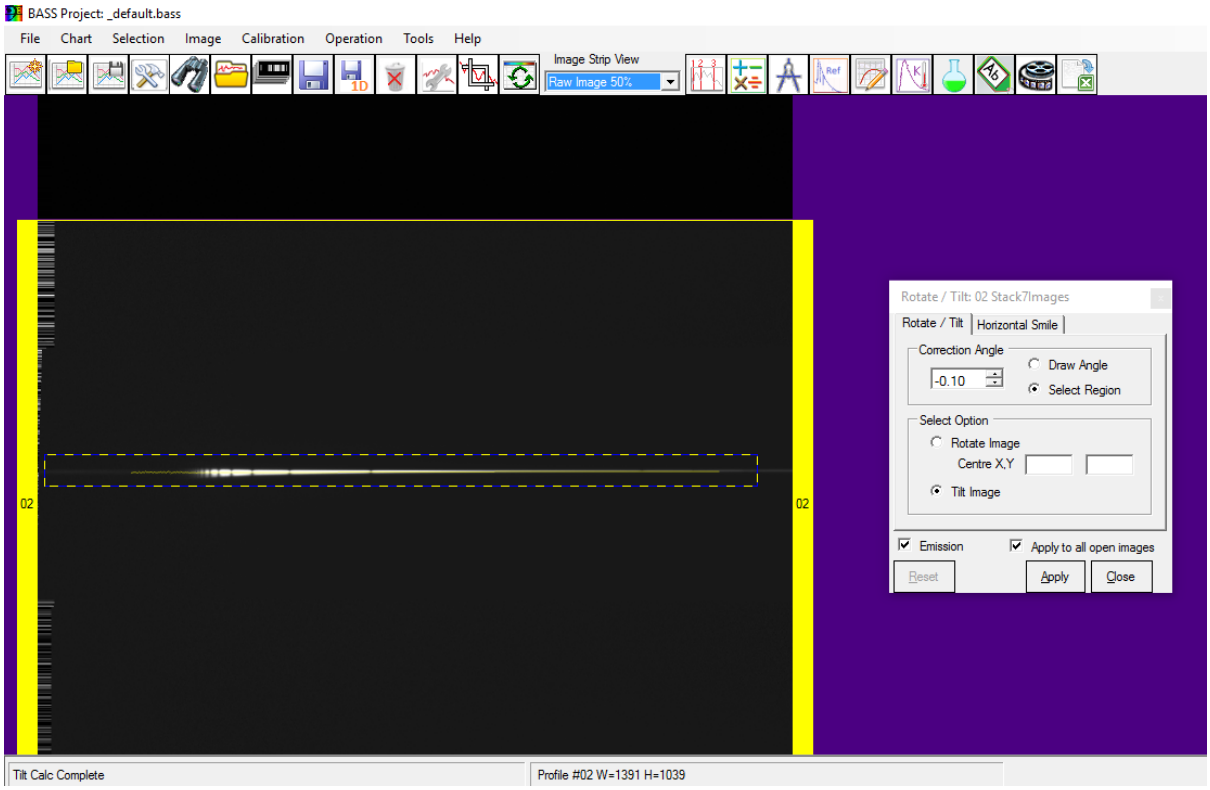
To make your spectrum perfectly horizontal we use the following menu screen.

Menu: Image -> Rotate / Tilt correction

Ensure apply to all open images is ticked



Draw a rectangle around your spectrum image.



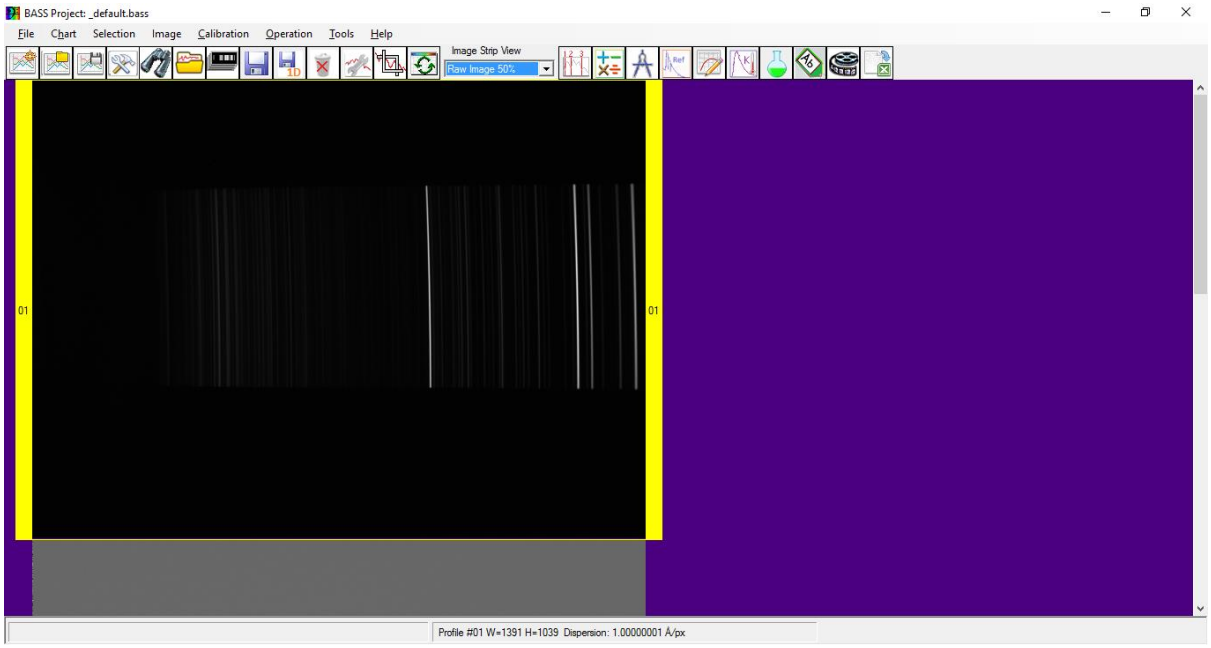
Click Apply.

Check that the correction looks sensible, i.e. you now have a horizontal spectrum.

If it looks wrong then press reset and try again.

b. Smile / Slant Correction

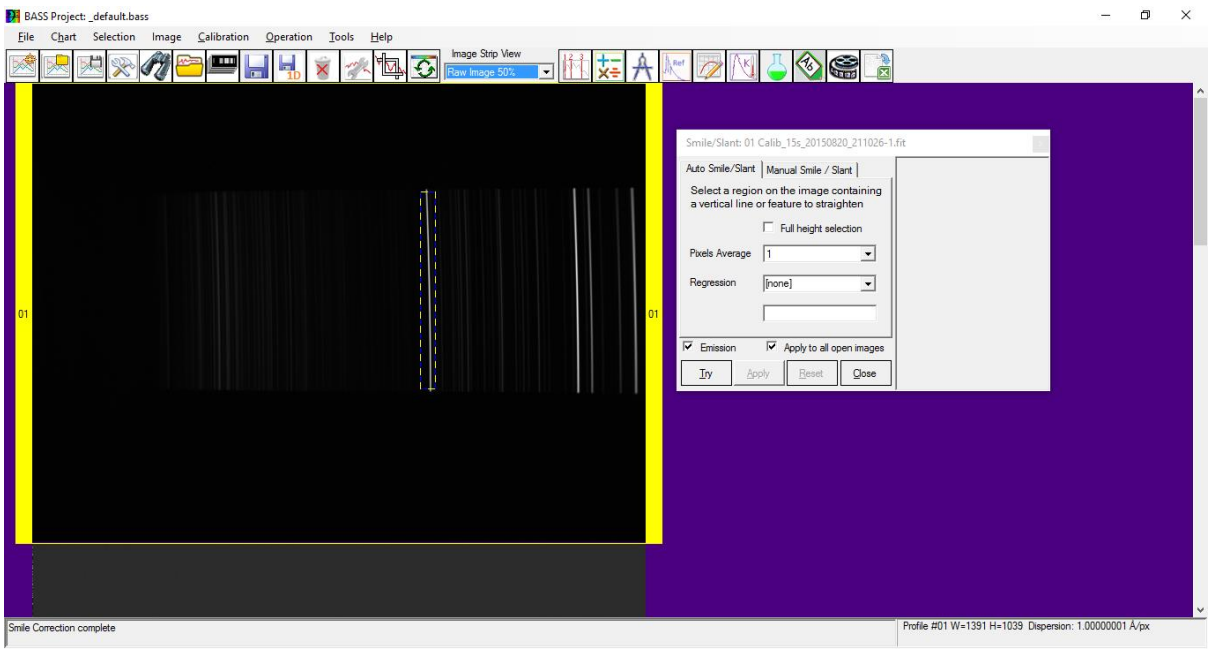
Make the neon image the first image by right clicking the image, select Sequence, then 01.



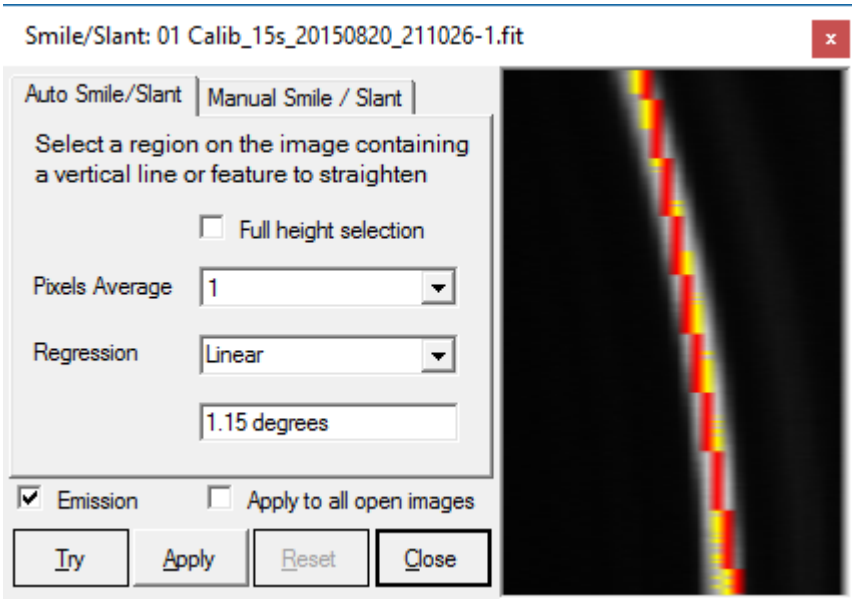
Menu: Image -> Smile / Slant Correction

Make sure the “Apply to all open images” is ticked.

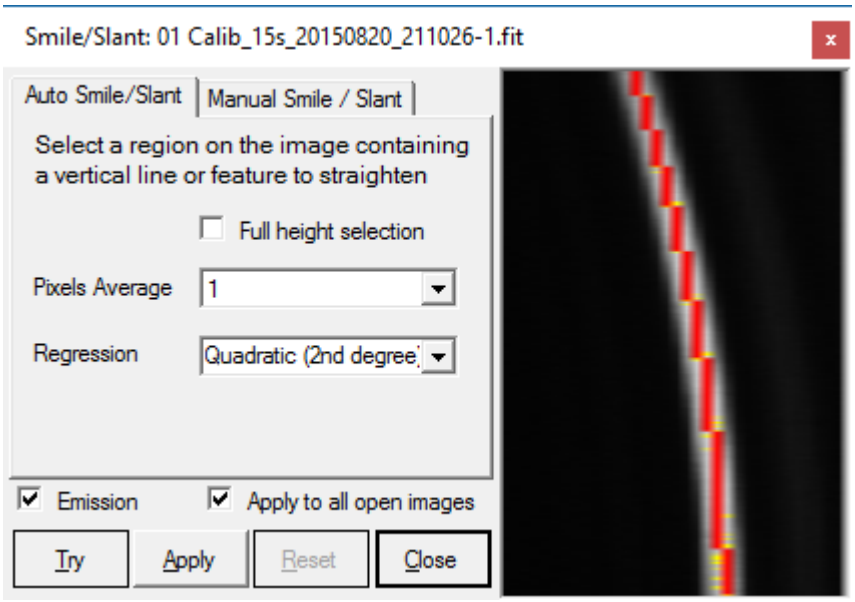
Choose a nice bright calibration line, not too close to any edges, and draw a rectangle around the line. Keep the selection height within the emission line (or the ends will add noise to the calculations).



Set the regression to Linear and then press “Try”.

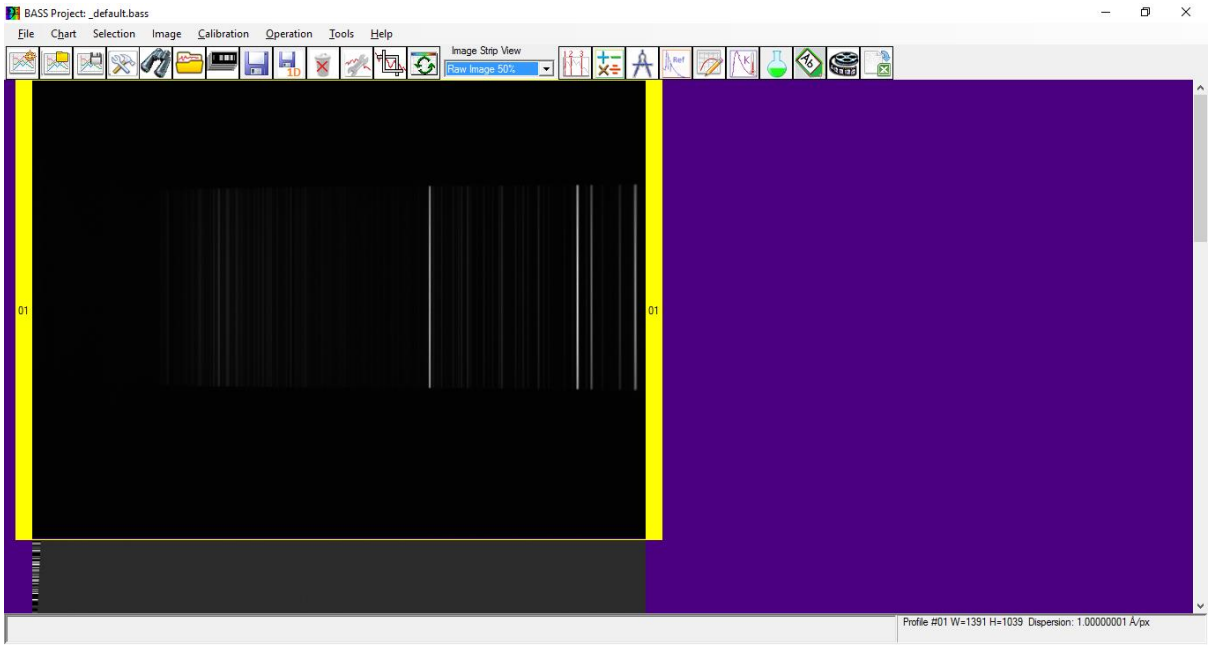


If the bright red line follows your emission line then great. Otherwise try adjusting the Pixel Average and Regression parameters then press “Try” again. Repeat until you have a good fit.



When happy, again make sure the **‘Apply to all open images’** checkbox is ticked, and then press Apply.

You should now have nice straight and vertical emission lines, noting this will also have been applied to your spectrum image.



If you are happy with these results then now save both your neon and stellar images, giving them a different name, e.g. adding "_geo" to the end.

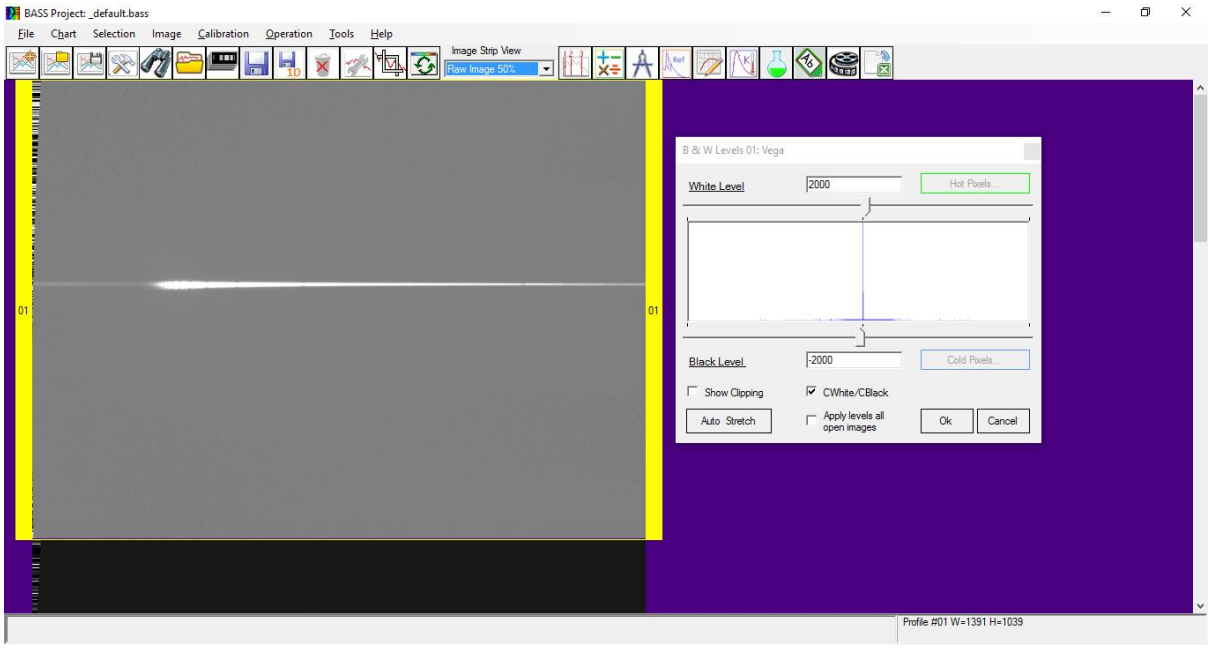
4 - Select Binning Regions

Make sure your star spectrum image is selected, click on it if necessary. A yellow border shows it is selected.

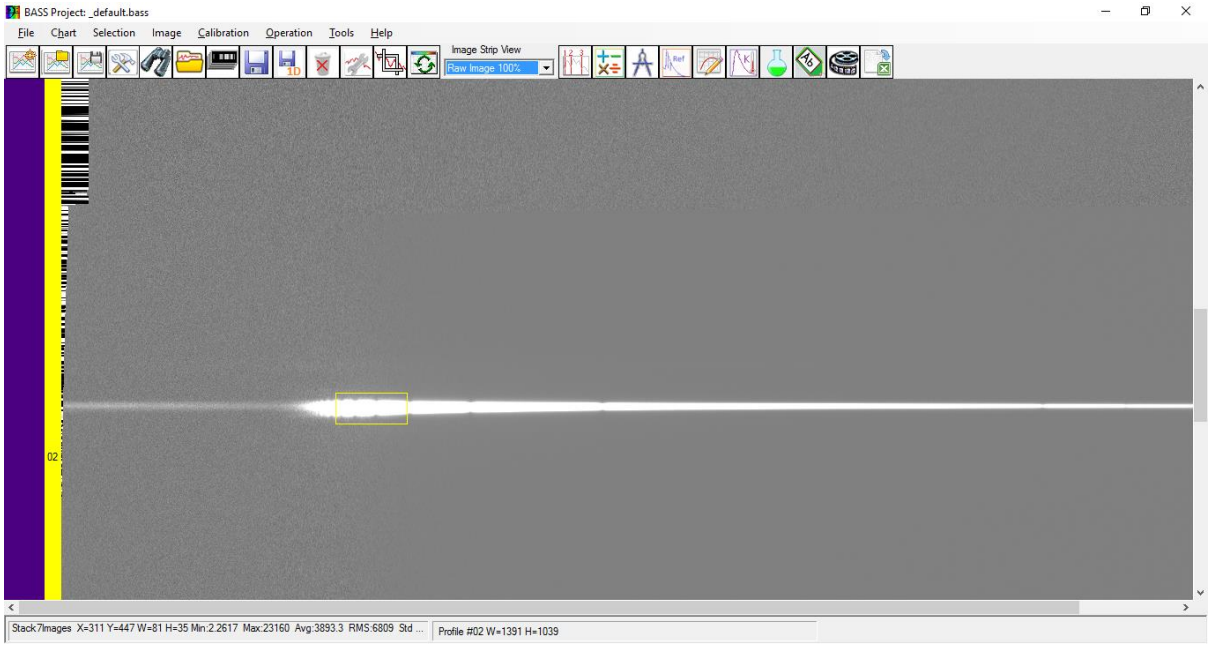
Enlarge the image so you have a clear and detailed view of a good part of your star spectrum image. The zoom level is changed in the “Image Strip View” in the top centre of the screen.

Adjust the black and white levels so that the spectrum image appears bright and you can see the faintest parts of the spectrum image easily. Do not worry above the spectrum looking over exposed.

Menu: Image -> Black & White Levels

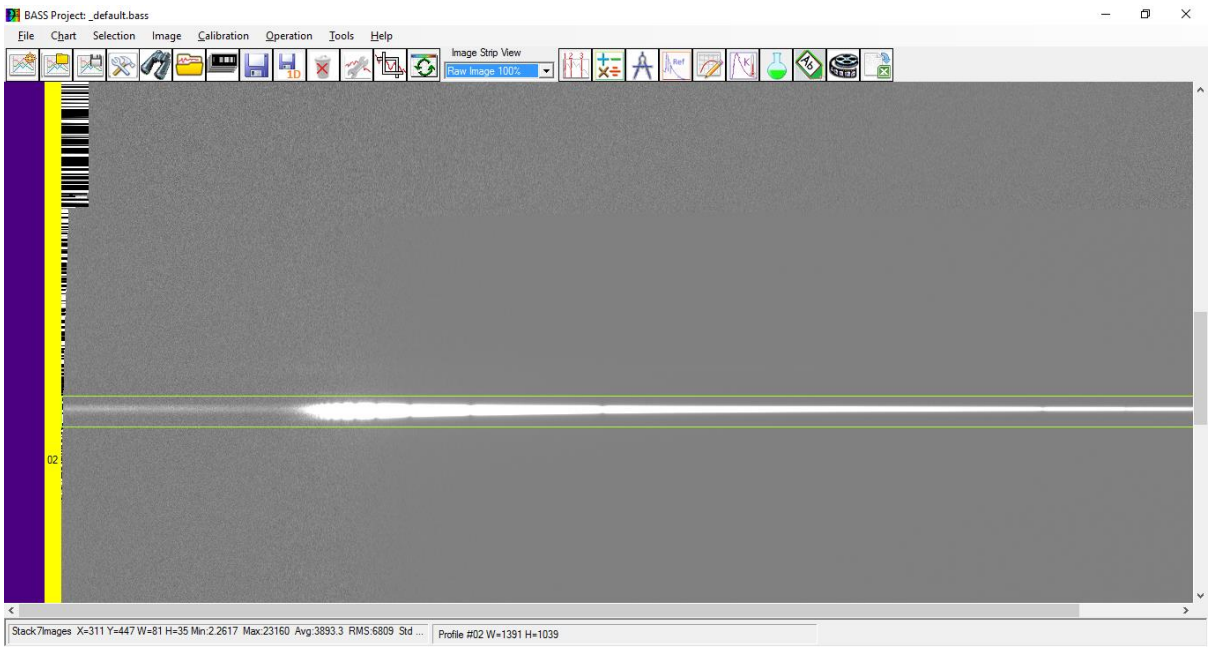


Draw a rectangle around part of the spectrum. It does not need to be wide. What matters is that the top and bottom parts of the spectrum are fully enclosed, and as little background as possible is included. Note that your spectrum will often contain faint tails above and below the main bright horizontal line. It is important to include these tails.



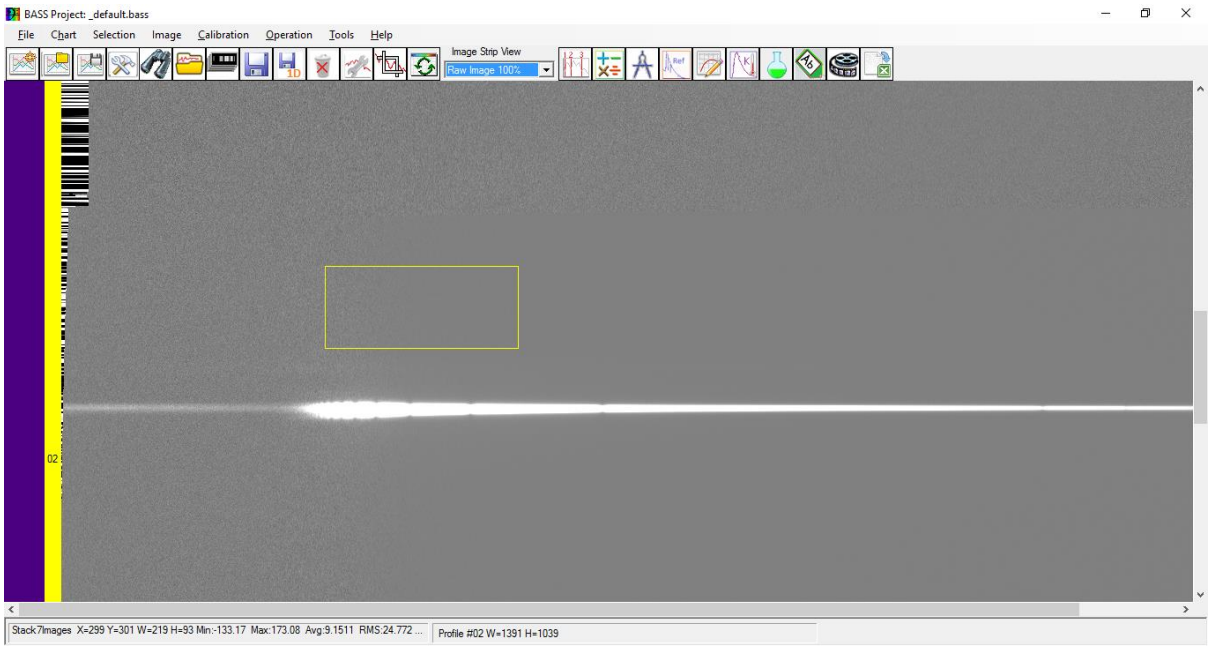
Then select the following menu item.

Menu: Selection -> Select Active Binning Region

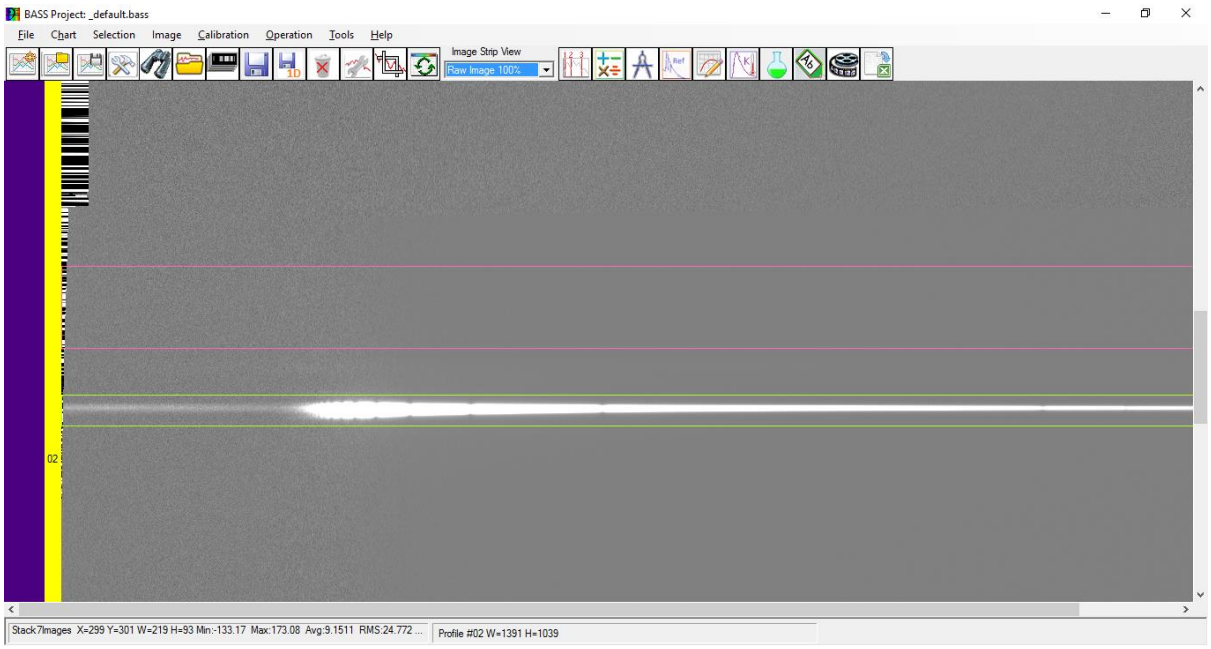


Green lines will now appear above and below the spectrum. The region between these lines will be used to sum up the pixels and give you your spectrum.

Now select a rectangular region above your spectrum for the sky background. This should be away from your stellar spectrum and avoid any other obvious feature so you are just picking up sky emission.

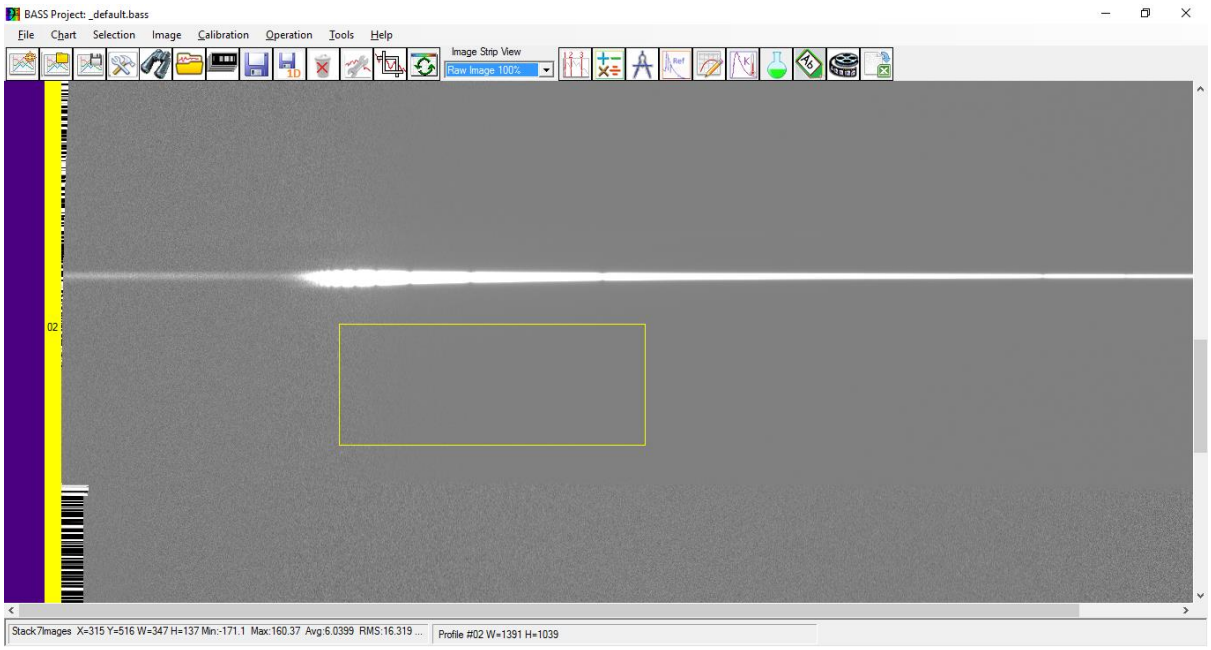


Menu: Selection -> Set Active Subtraction Region 1

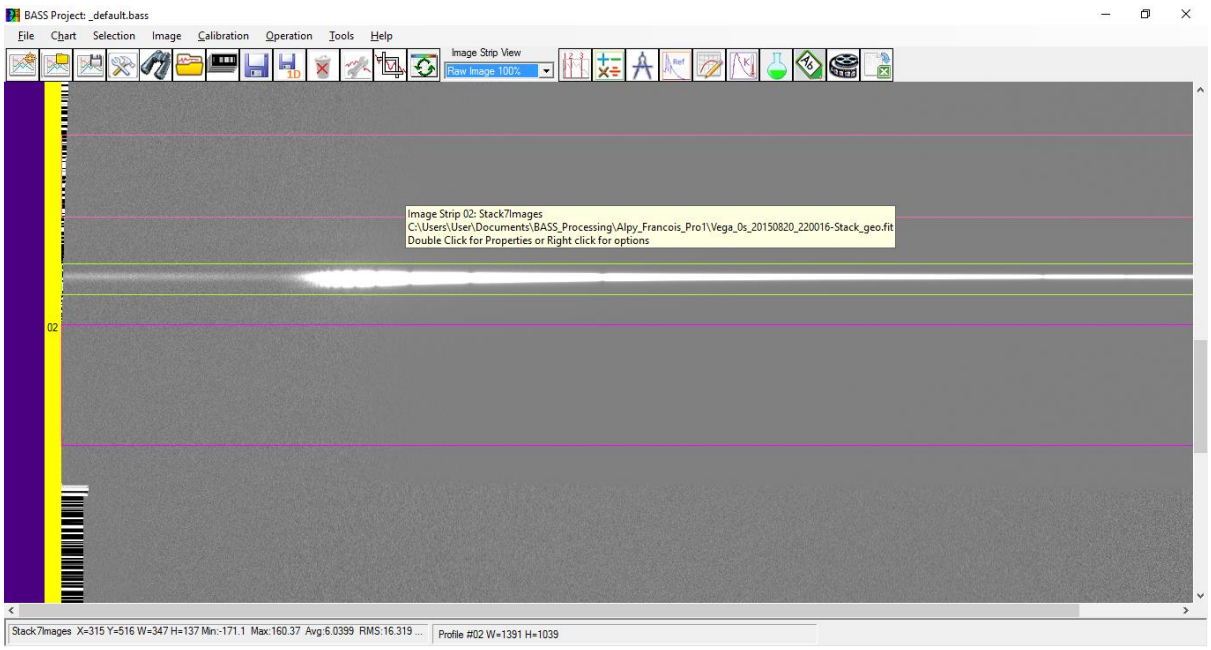


2 pink lines will now appear above the spectrum. Pixels between these lines will be used for the sky background subtraction.

We need to do the same below the spectrum. So select a rectangle below your spectrum image.

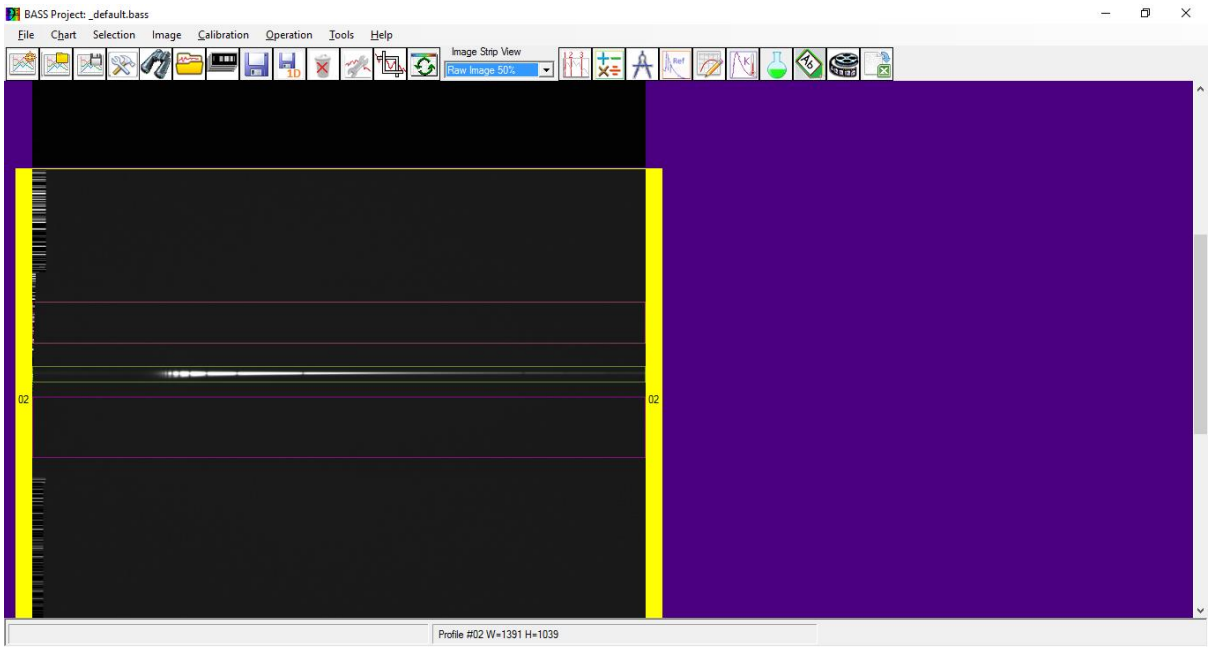


Menu: Selection -> Set Active Subtraction Region 2



Now 2 pink lines will appear below your spectrum.

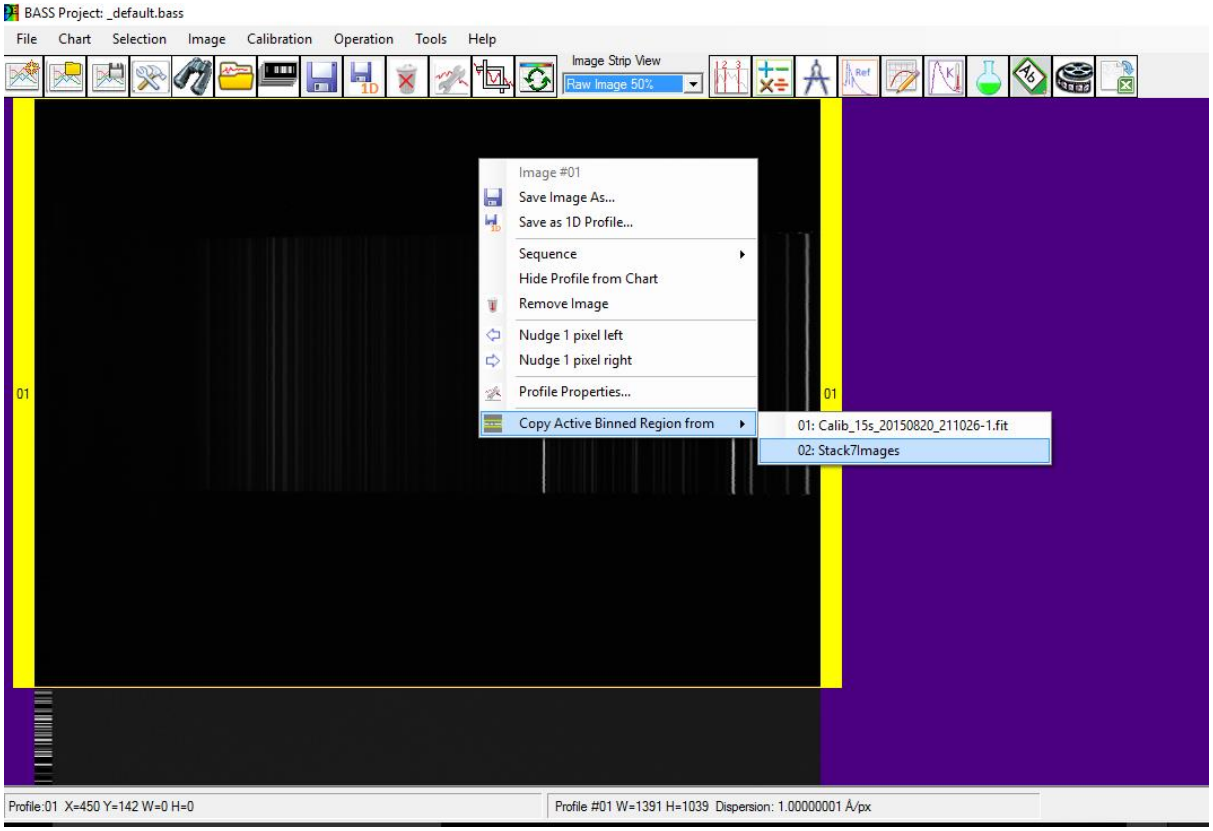
You can now reset the zoom and black and white levels.



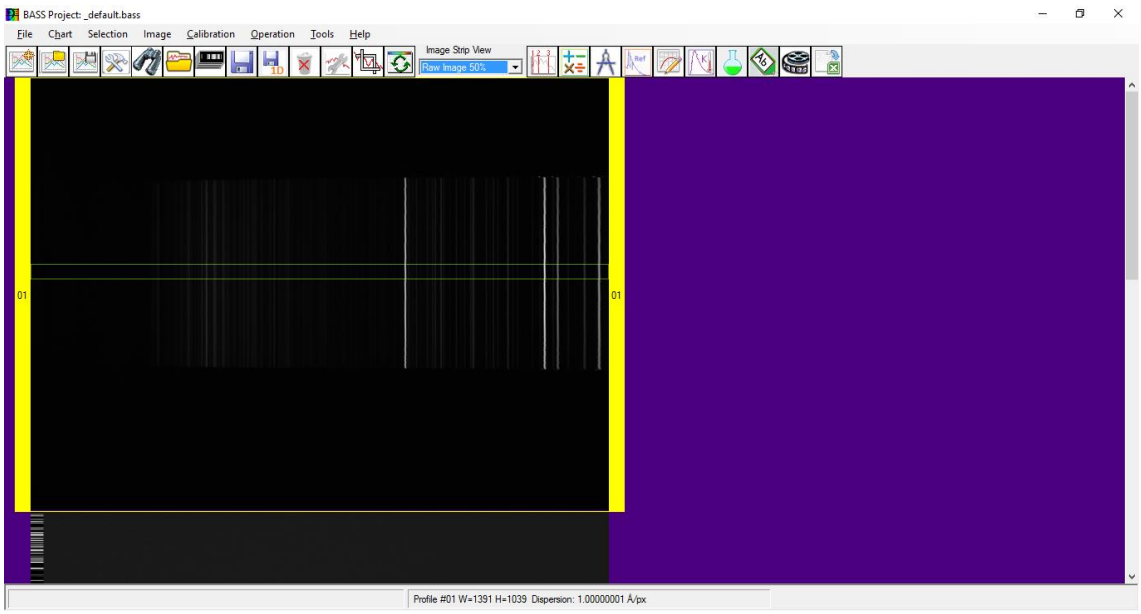
We need to copy the same binning regions to the neon calibration image.

Select your neon calibration image so it is highlighted with a yellow border.

Right click the image and select copy active binning region from and then the star spectrum image on which you set the active binning region.



The green lines will appear on your neon spectrum matching the active binning region from your star image.



5 - Wavelength Calibration

This can be surprisingly difficult at low resolution due to the large number of lines that may be shown in your neon or other wavelength calibration spectrum. For example the Alpy module may contain lines from neon, argon and hydrogen.

The first subsection below provides some sample low resolution spectra. These should help you to identify lines for wavelength calibration, and some suggested lines are given for Alpy users.

Then then next subsection explains how to do perform wavelength using a Neon or similar emission line calibration lamp spectrum.

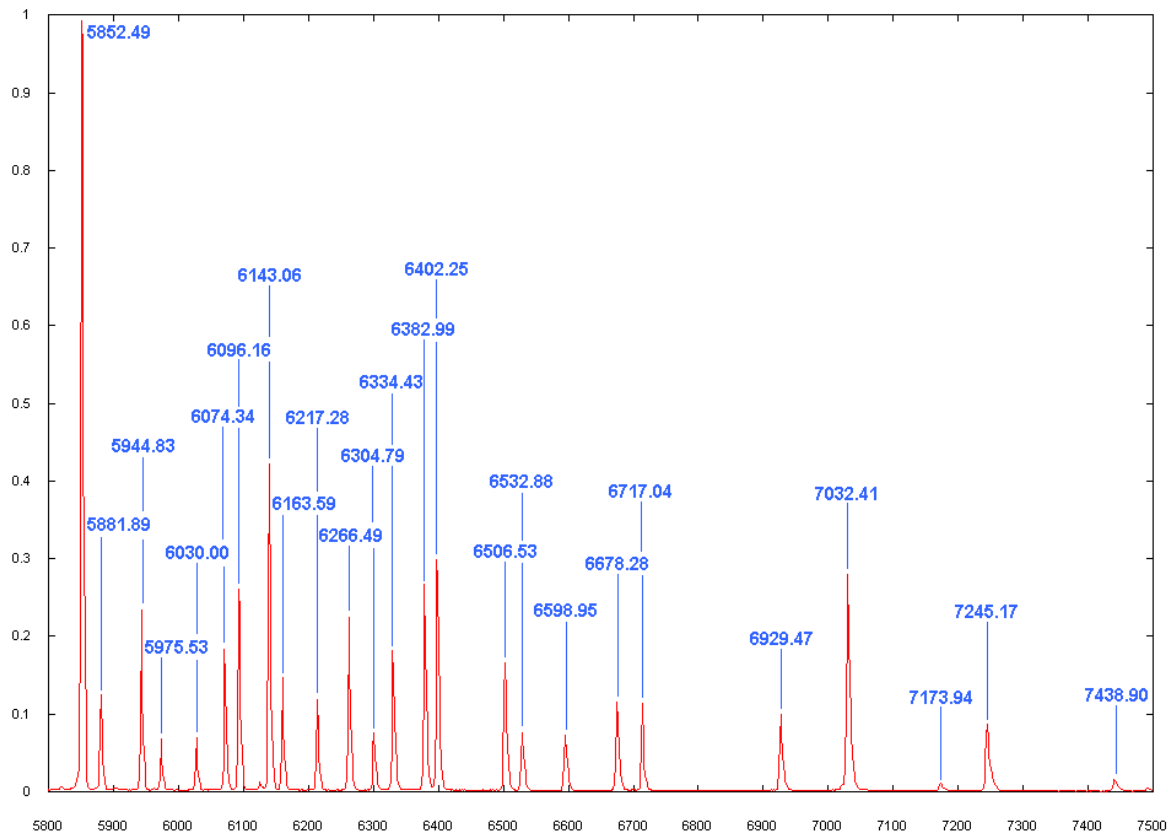
For those who do not have a calibration lamp, the final subsection explains how to perform wavelength calibration using an A or B-type star.

a. Sample Calibration Spectra

Below are a few sample spectra from various websites which may help to identify the lines in your calibration spectrum.

Neon spectrum from Christian Buil's website:

http://www.astrosurf.com/buil/us/spe2/hresol4.htm



From the Alpy user guide.

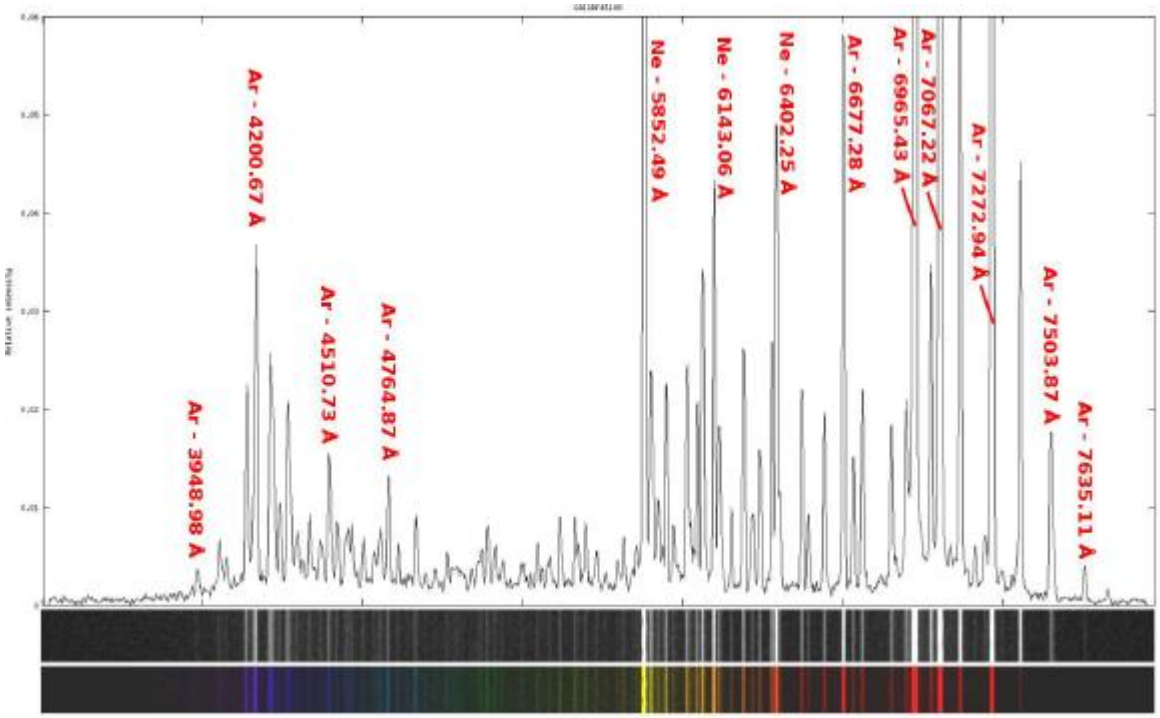
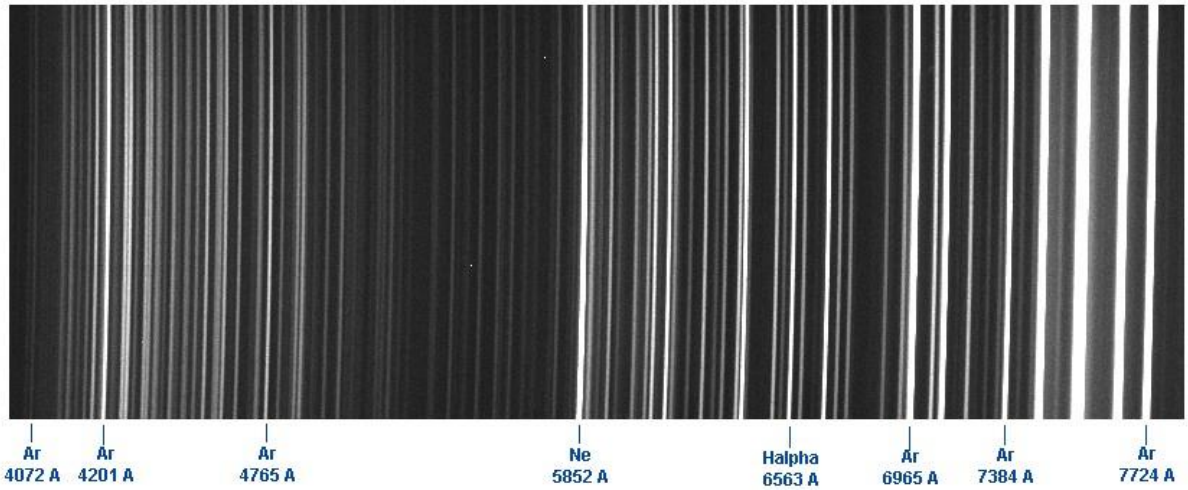


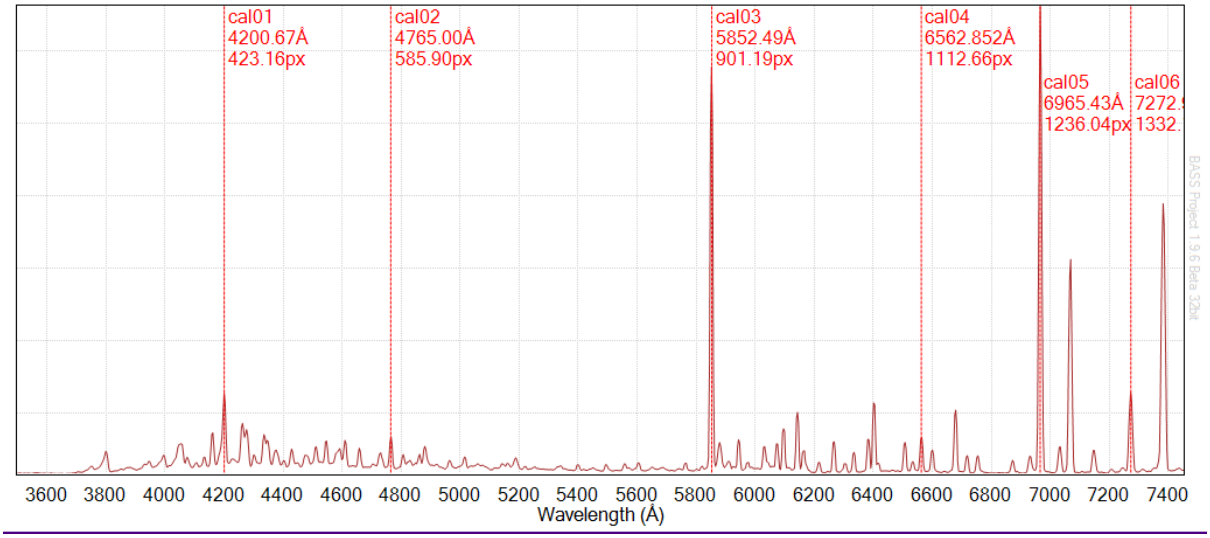
Image from Christian Buil's website.

http://www.astrosurf.com/buil/alpy600/first_light.htm



I found the following lines worked well for the Alpy calibration spectrum from François Cochard. Note that calibration lamps may vary so find what works best for your setup.

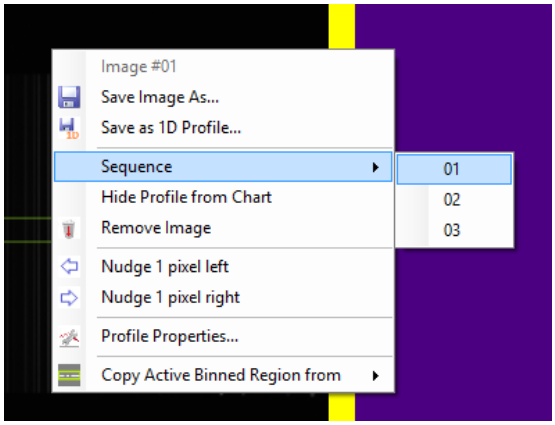
- 4200.67 Ar
- 4764.87 Ar
- 5852.49 Ne
- 6562.85 Hα
- 6965.43 Ar
- 7272.94 Ar



b. Wavelength Calibration Process

Make sure your neon calibration image is selected.

The calibration image needs to be the first image. If it is not then right click the image, select Sequence and then 01.

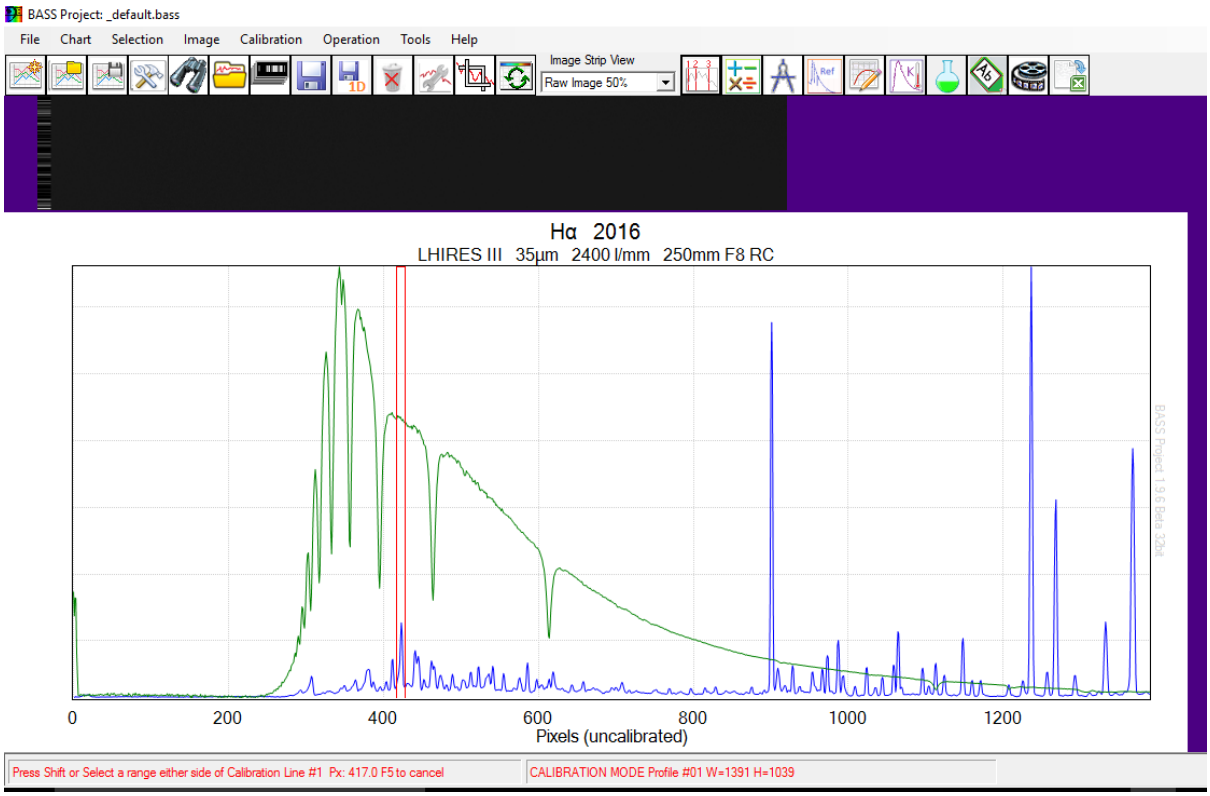


Scroll down to the graph area of the screen, as all selections will be done on the lines on the graph.

To enter calibration mode select the following menu item.

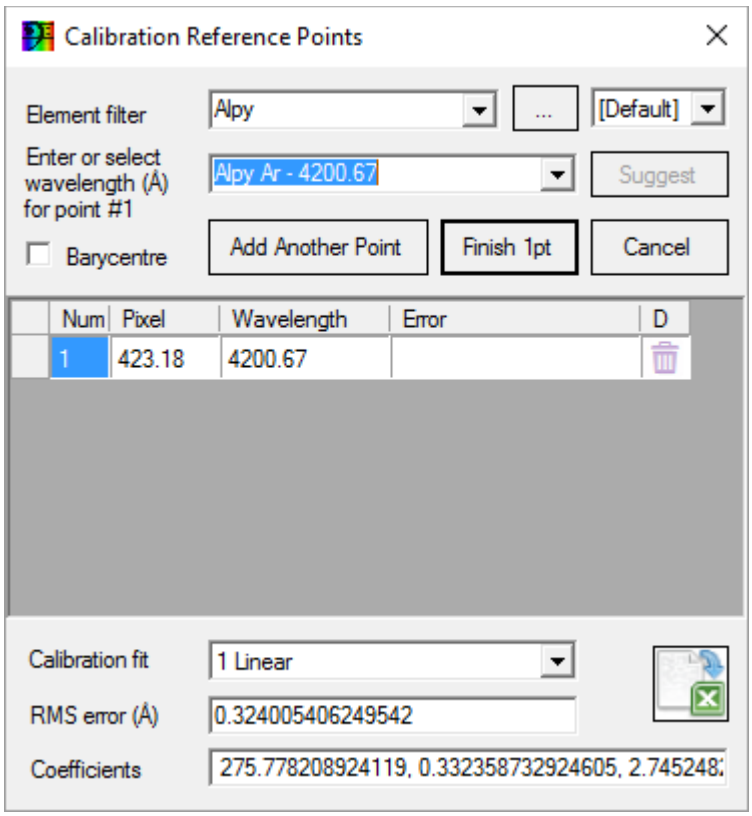
Menu: Calibration -> Create/Edit Calibration

Now select a nice bright neon line on the left of the screen.



Then either select an element filter or type in the wavelength for the line.

Note that for convenience I've added the list of 6 Alpy lines I am use to the CalibLines.dat file. This file can be found in the ..\BASS Project\Reference folder.

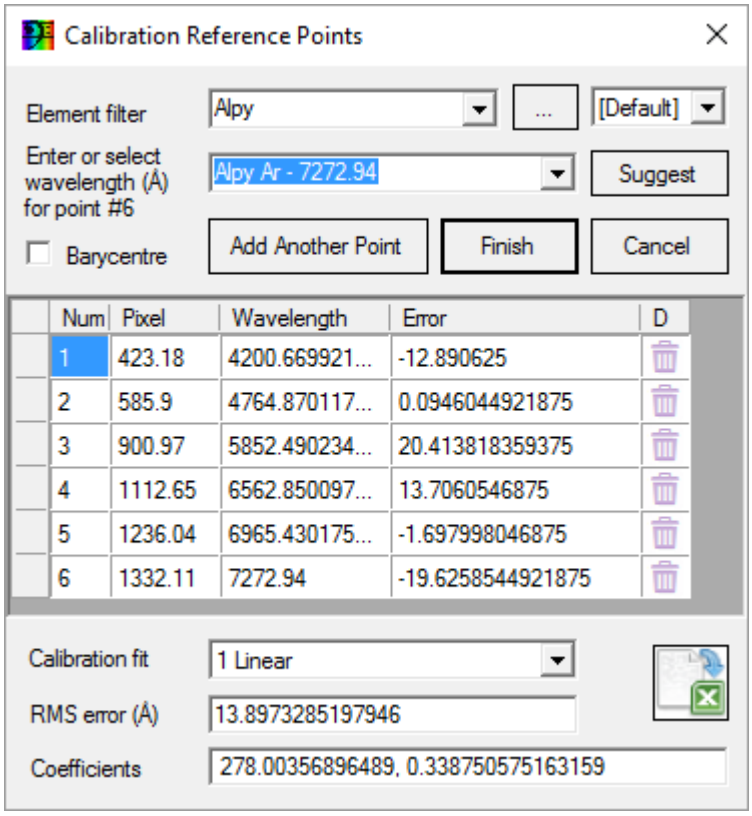


Click Add Another Point.

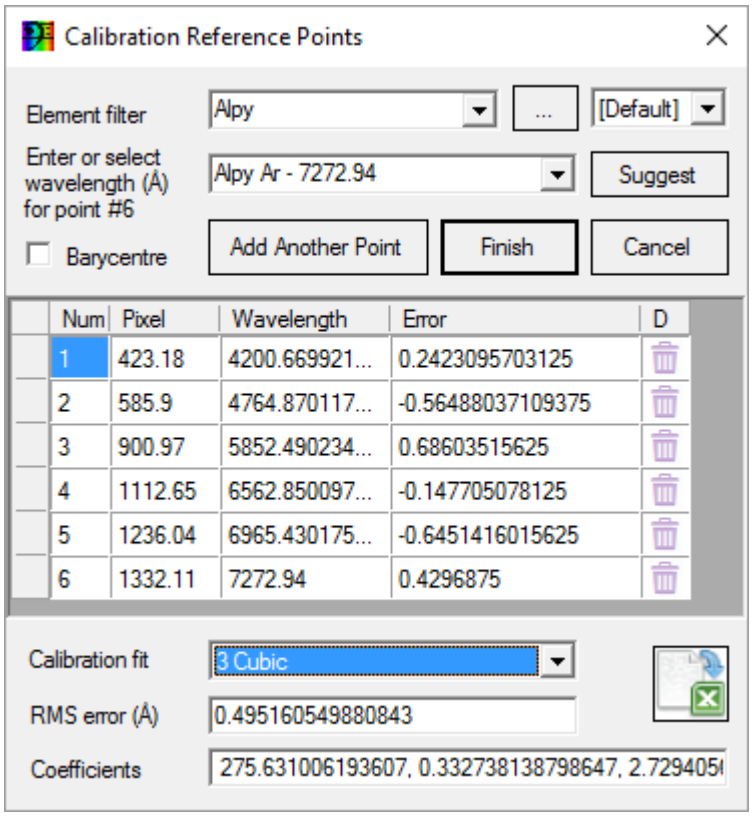
Select another bright line which you can identify.

Continue until you have 5-7 lines, checking that the error remains small for each new line. A very large error on one line may indicate that it has been mis-identified.

The below screenshot illustrates the error I was getting with 6 lines and a linear fit.

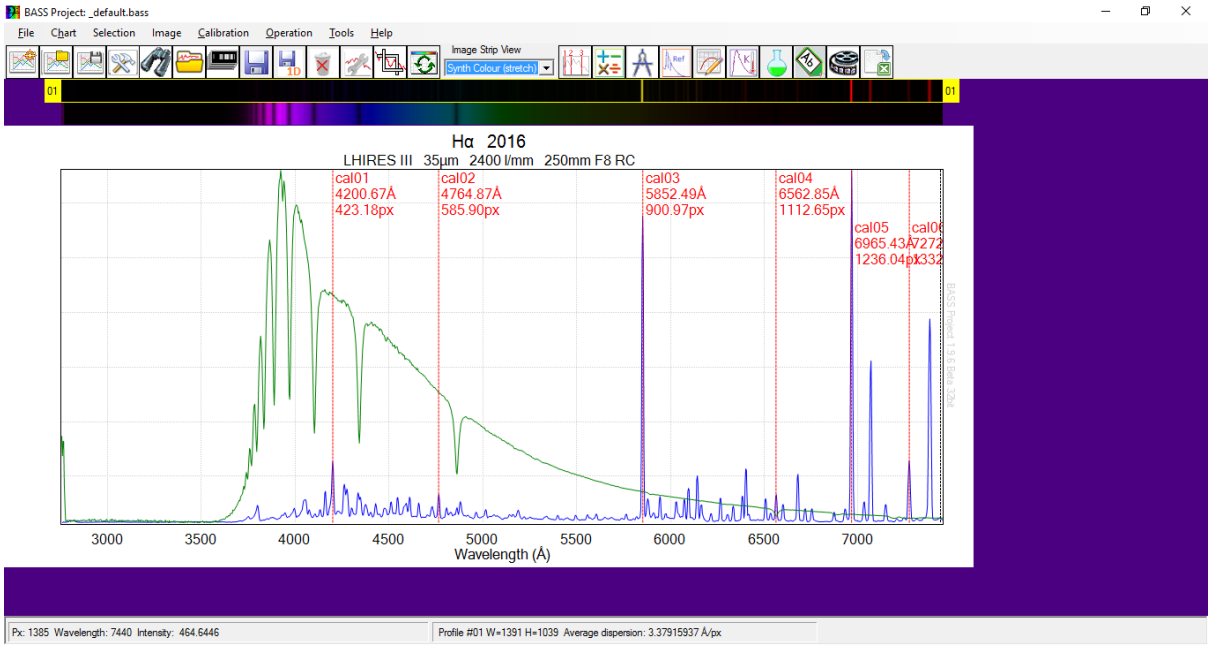


Adjusting the calibration fit to “3 Cubic” gives a much better fit.



It may be possible to improve on the fit by choosing more or better lines, or by increasing the polynomial of the calibration fit. However be careful. Choosing a high order polynomial of 1 below your number of calibration points or higher will always give a perfect fit. This is misleading as you are simply fitting the number of free parameters in the polynomial to your number of data points. Even if you pick a completely wrong line the fit will remain perfect. Therefore avoid very high order polynomials unless you have good reason to believe they give a true fit to your wavelength calibration.

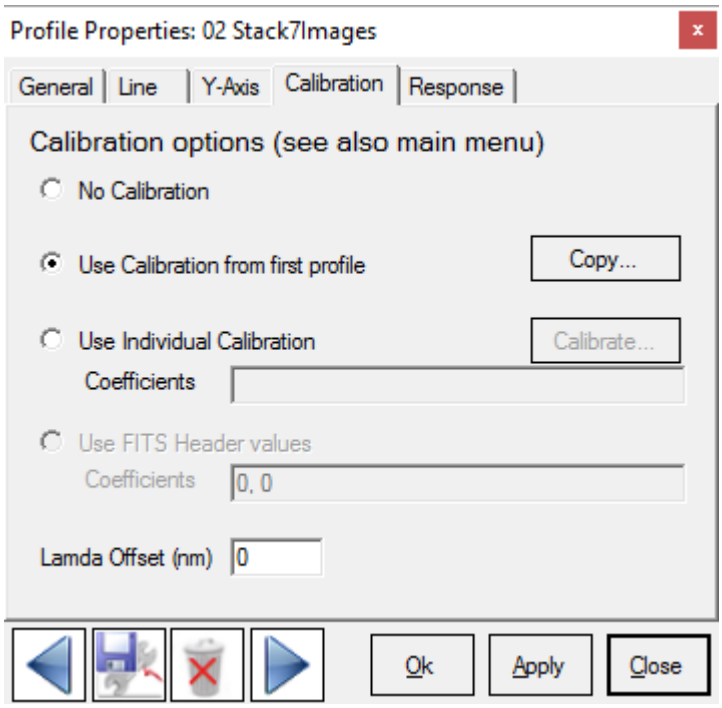
You can then set the Image Strip View to Synth Colour (Stretch) to show your spectra in colour.

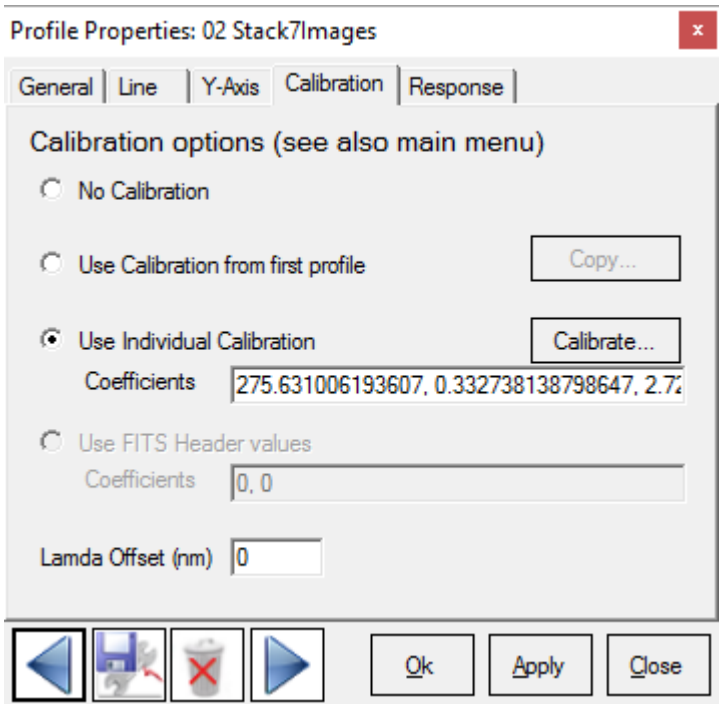


To copy the calibration parameters onto the target spectrum, double click the target star image.

Select the Calibration tab.

Then press Copy.





Save your images.

c. Wavelength Calibration with an A or B-Type Star

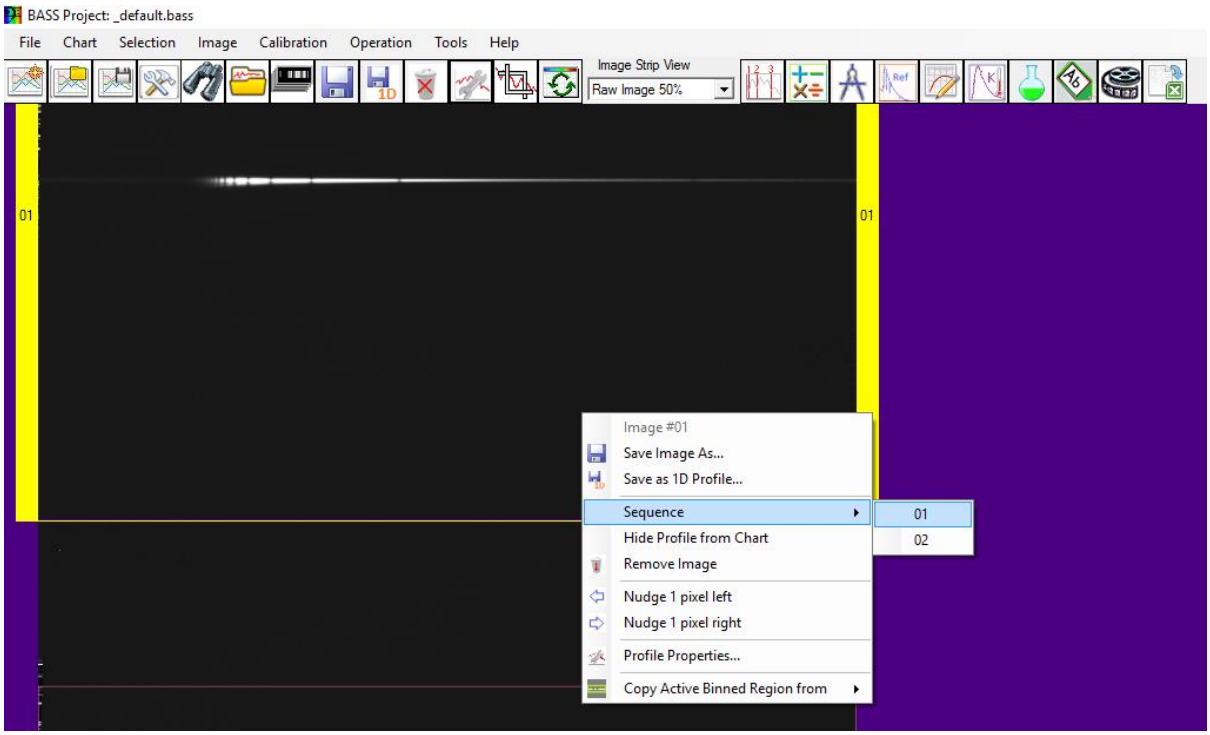
If you do not have a calibration lamp to wavelength calibrate your spectrum, then it is possible to use the hydrogen lines from an A or a B-type star.

To do this you will need to have taken an image of the spectrum of an A or a B-type star, with your equipment in exactly the same configuration as when you took all of your target star spectra on the same night. You should pick a bright A or B-type star with clear hydrogen absorption lines. So you want an ordinary star. Vega is ideal when it is visible. You will need to easily see absorption lines from H-alpha to at least H-delta or further.

Note the basic process is the same as if you were using a calibration lamp.

Make sure your A or B-type star image is the first image.

Right click image -> Sequence



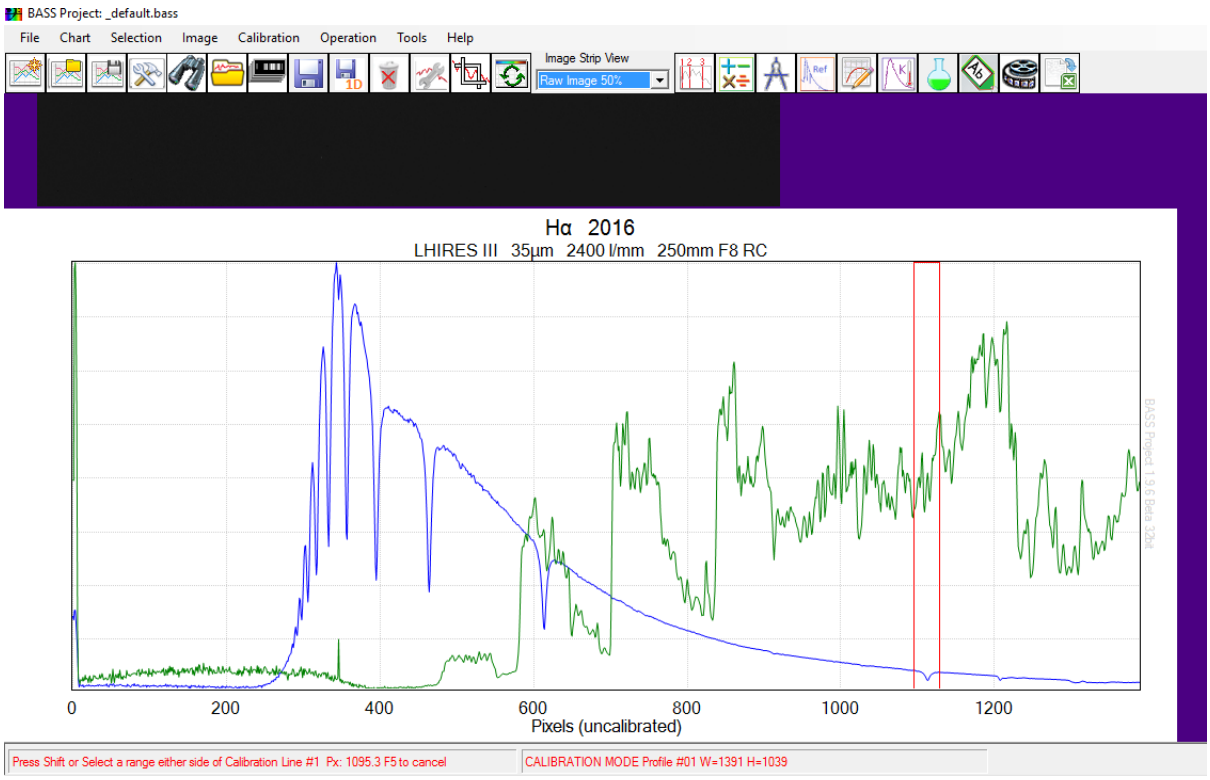
Also make sure that your A or B-type star image is selected.

Scroll down to the graph area of the screen, as all selections will be done on the lines on the graph.

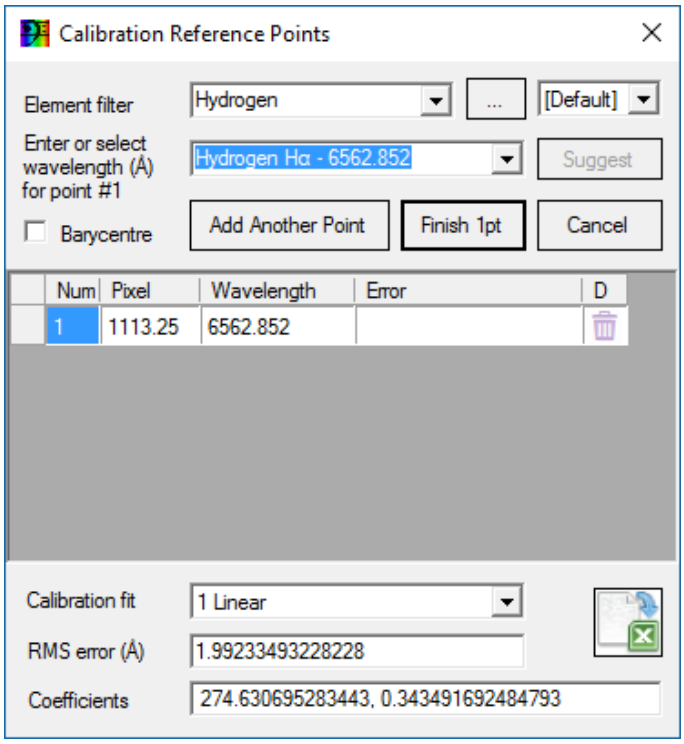
To enter calibration mode select the following menu item.

Menu: Calibration -> Create/Edit Calibration

It is easiest to start by selecting H-alpha, the rightmost hydrogen line. This is done by placing the cursor just left of the line on the graph, dragging over to the right of the line and then releasing.

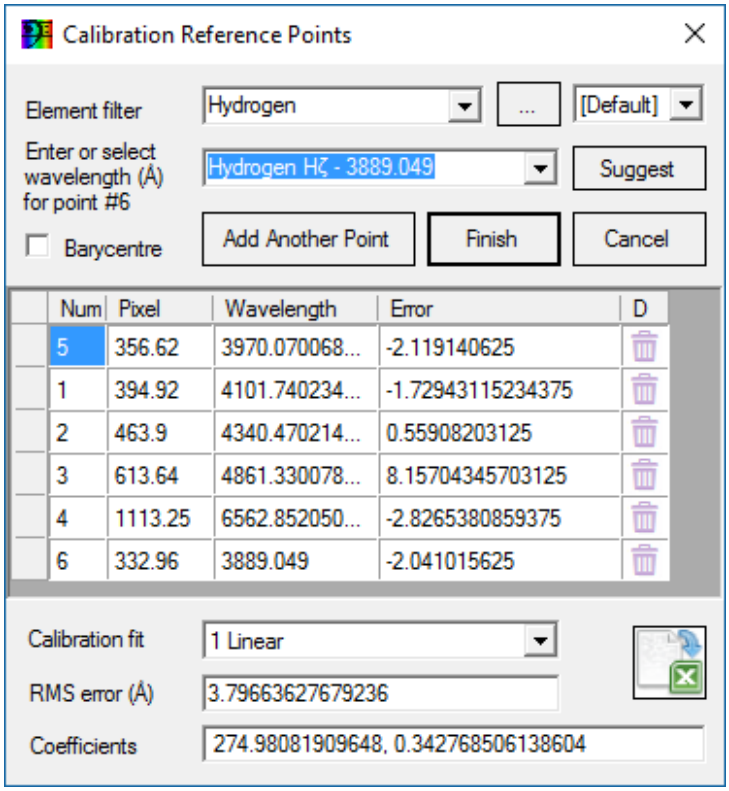


Select Hydrogen from the Element filter and Hα from the wavelength drop down.

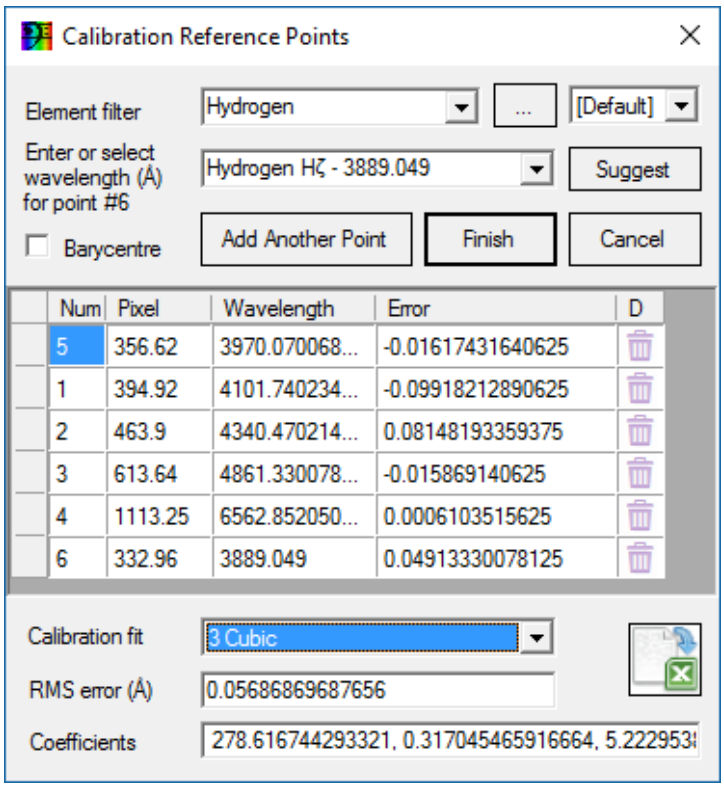


The click Add Another Point and repeat for as many clear hydrogen lines are visible.

At first with a linear fit the errors will be large.

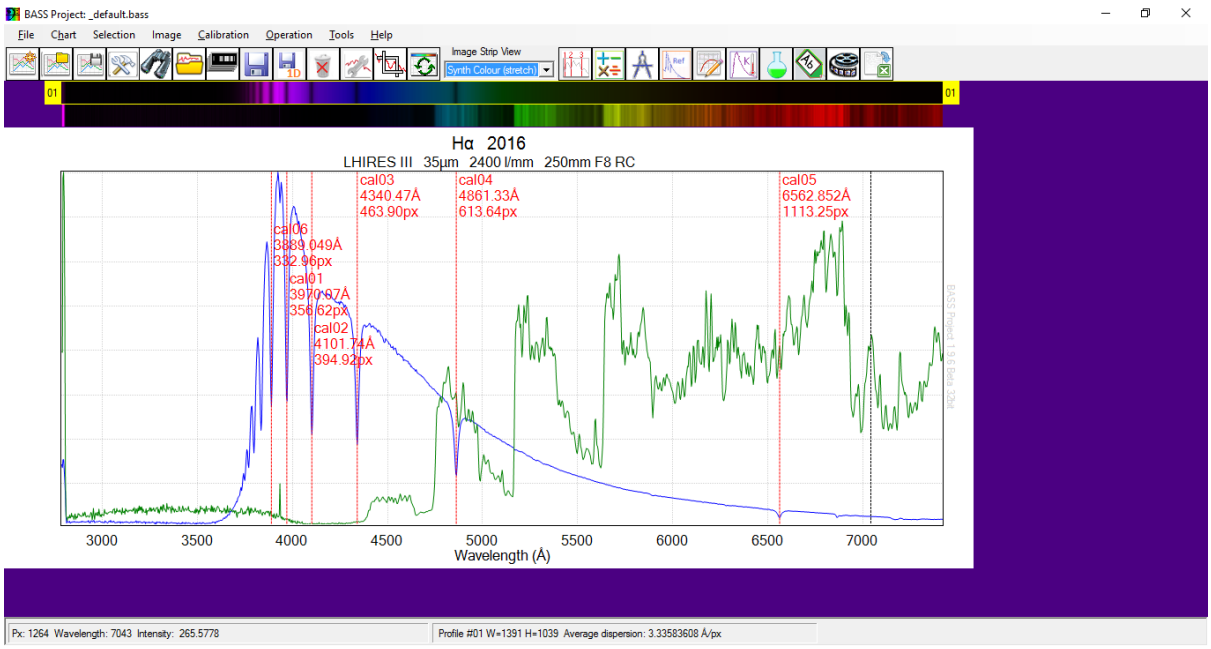


Changing to a Quadratic or Cubic will give a better result.



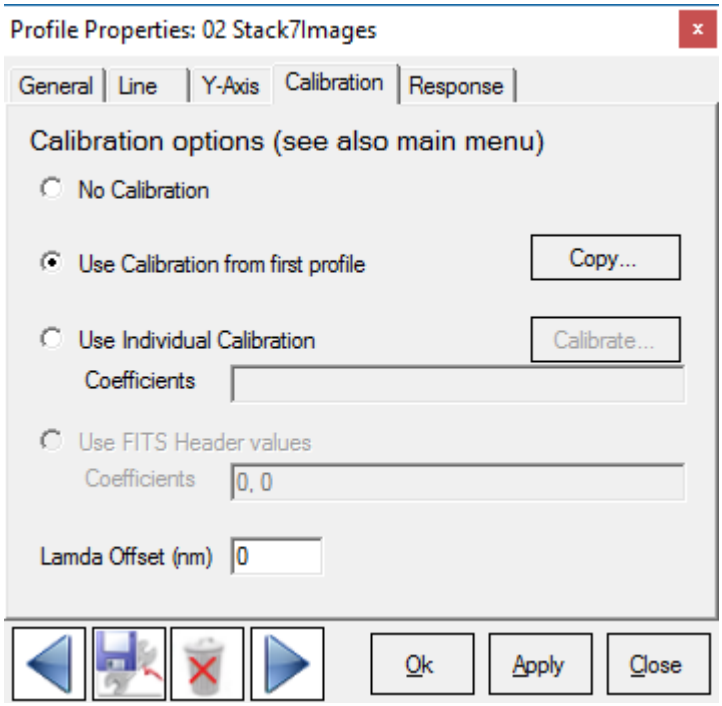
You will now have a well calibrated spectrum, though you should be cautious of the wavelengths below the shortest calibration point and above the longest wavelength calibration point.

You can get now get a colour view of your spectrum image strips by changing the Image Strip View to Synth Colour (stretch).

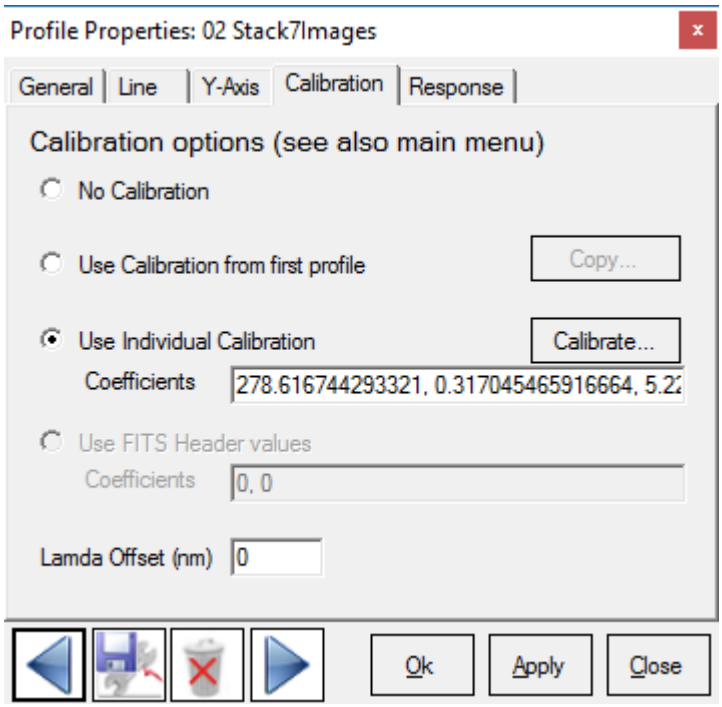


To copy the calibration to another star, then double click the image strip for that star.

Select the Calibration tab.



Then press Copy to copy the calibration from the first profile.



6 - Response Correction (Advanced)

Normally an A or a B type star is used to obtain the response correction as they are very simple spectra dominated by absorption due to the hydrogen Balmer lines. This response correction curve can then be applied to other stars at a similar altitude on the same night.

What we are after is a curve that will correct for the effects of your instrumentation and the Earth's atmosphere. By applying this curve your spectrum will be corrected to show the actual stellar spectrum, noting this will often differ from the perfect spectral type.

You should avoid response correcting each target star spectrum separately using a template spectrum that matches its spectral type. This is because you would always get a perfect fit that matches the spectral type as you would be going in a processing circle forcing the spectrum to match whatever template you started with. This would also mean that if the star was not a perfect match for its spectral type, a common occurrence, then your corrected spectrum would make it look as though it were a perfect match.

The below process uses the A0V star Vega to create a response curve, and then confirm this has worked by comparing it back to an A0V template. In scientific work this would be the first step. Next this response curve would be applied to your target stars other than Vega.

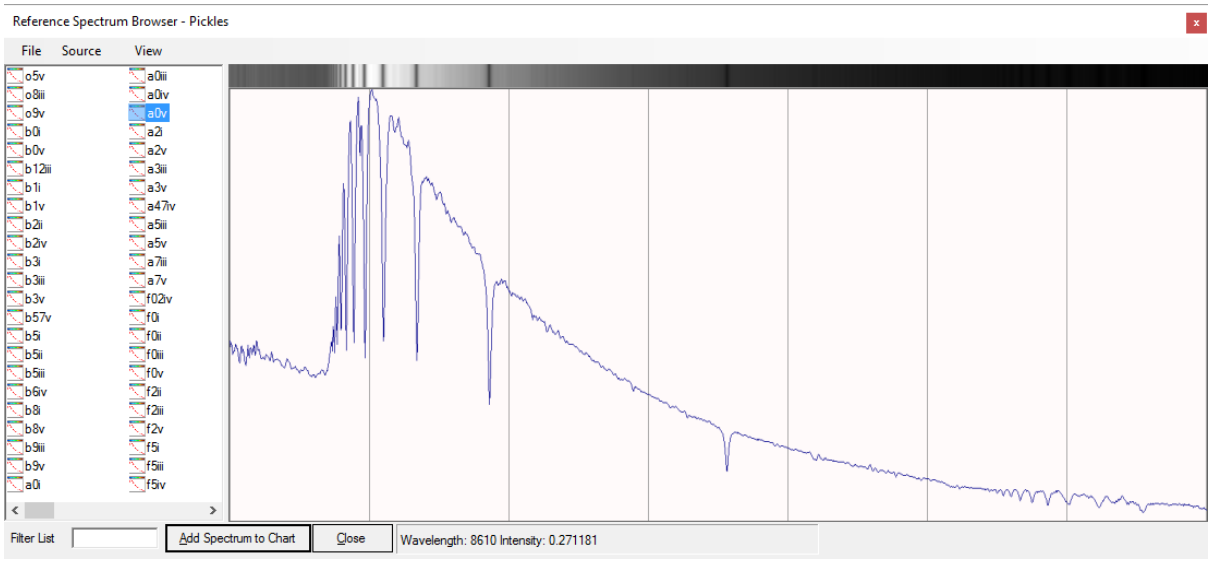
First load an appropriate standard spectrum to match the one you are working on. The ideal would be a Miles spectrum of the exact star but otherwise a Pickles spectrum for the spectral type.

Note, if you use a Miles star then you must not use the spectra labelled “dered”. These are spectra which have been corrected for interstellar extinction and would invalidate your response curve.

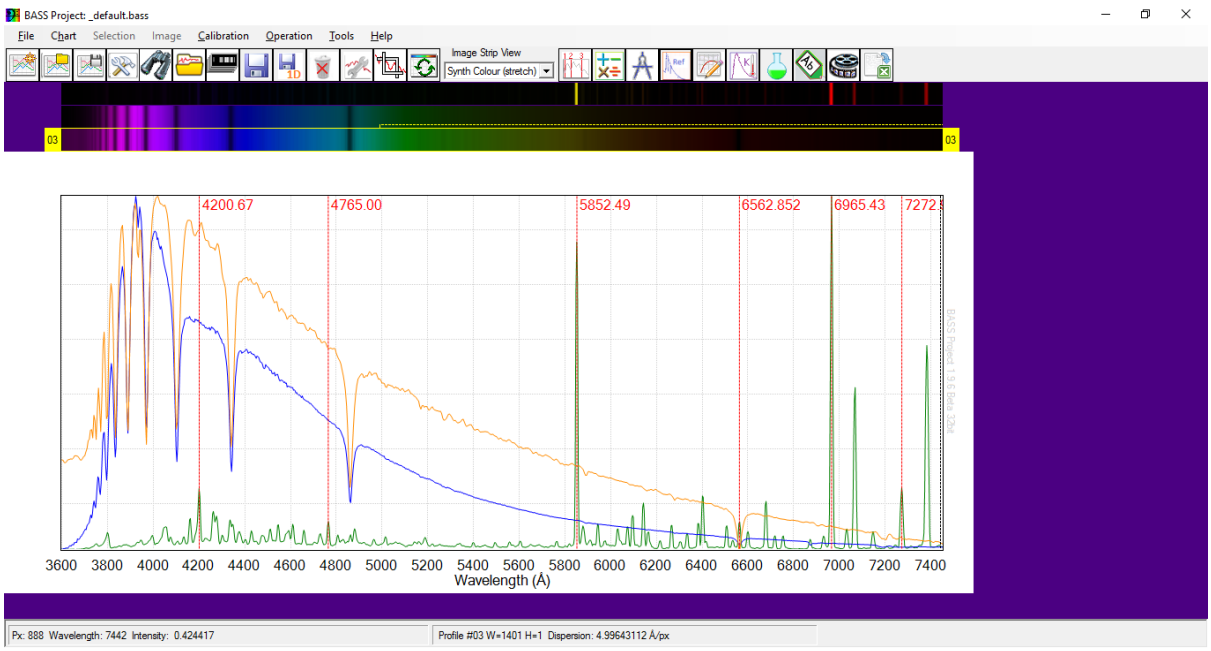
Menu: Tools -> Reference Spectrum

If using a Miles star, then click Source and Miles. Then search for the HD number of the star.

This example is Vega, which is not in the Miles database. So we shall select the Pickles A0V spectrum.



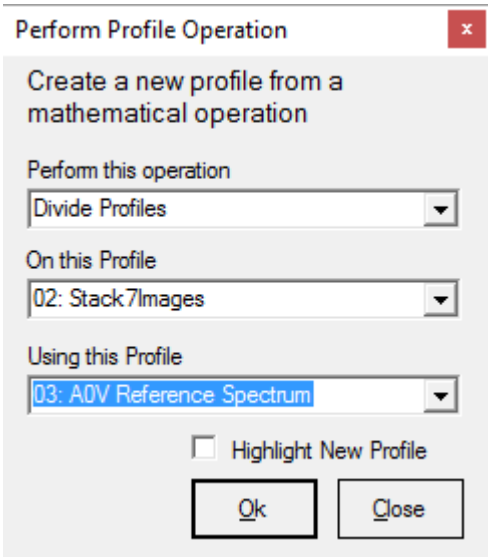
Click “Add Spectrum to Chart” then close.



This has added the Pickles A0V spectrum as a third profile.

The next step is to divide your spectrum by the standard spectrum.

Menu: Operation -> Divide one profile by another



Your spectrum is the first profile, and the standard spectrum is the second profile.

Now we need to smooth out the bumps and spikes. Only large scale features are part of the response profile. The smaller scale features are due to different resolutions and other small scale effects which cannot be corrected for.

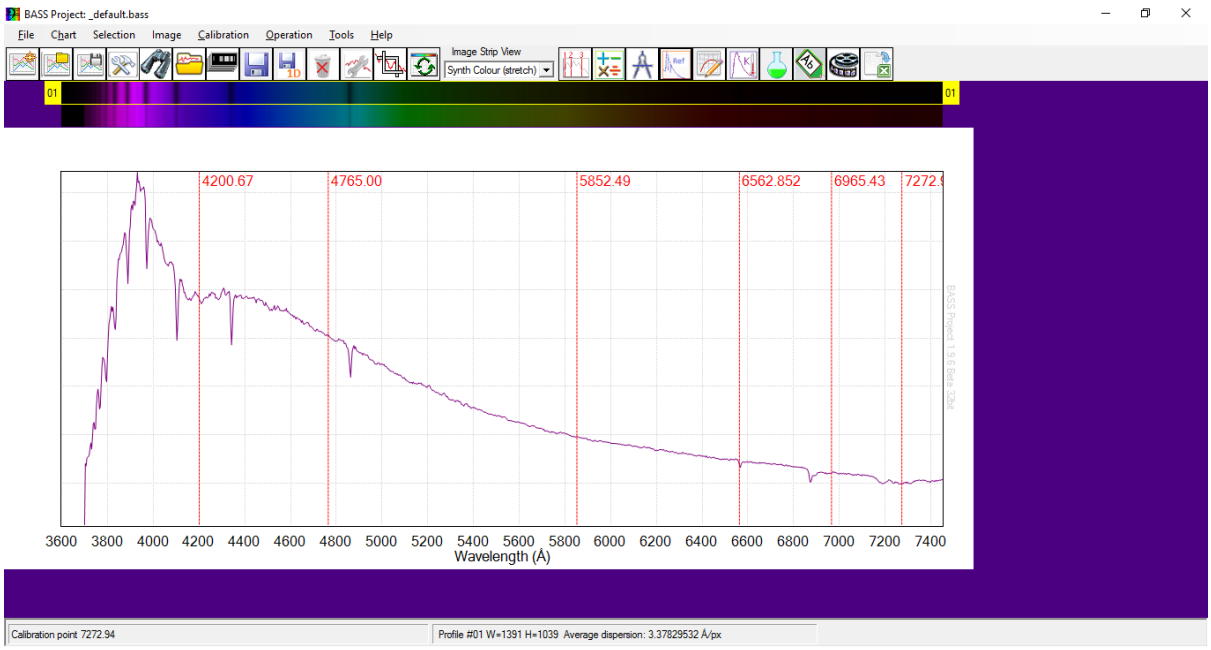
To make this process easier, we shall first remove and hide the other spectra.

Remove the neon spectrum by selecting it, then right clicking and pressing Remove image.

Remove the Pickles A0V spectrum by selecting it, then right clicking and pressing Remove image.

Hide your image/spectrum by selecting it, then right clicking and pressing Hide Profile from Chart.

You should now only see the division profile as follows.

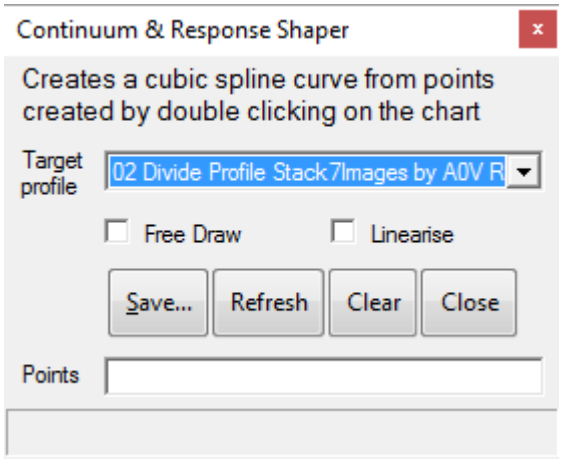


Make sure the division profile is selected.

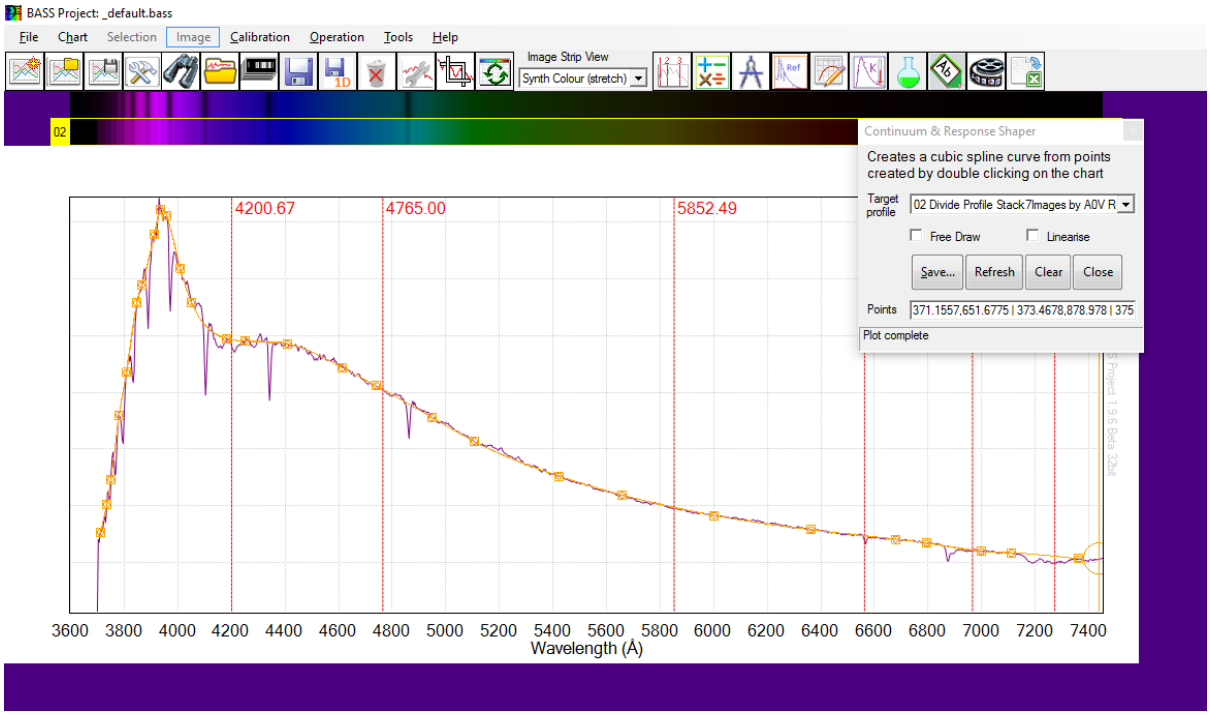
We are now ready to create the smooth response curve.

Menu: Tools -> Continuum Shaper

Select the division profile as the target profile.



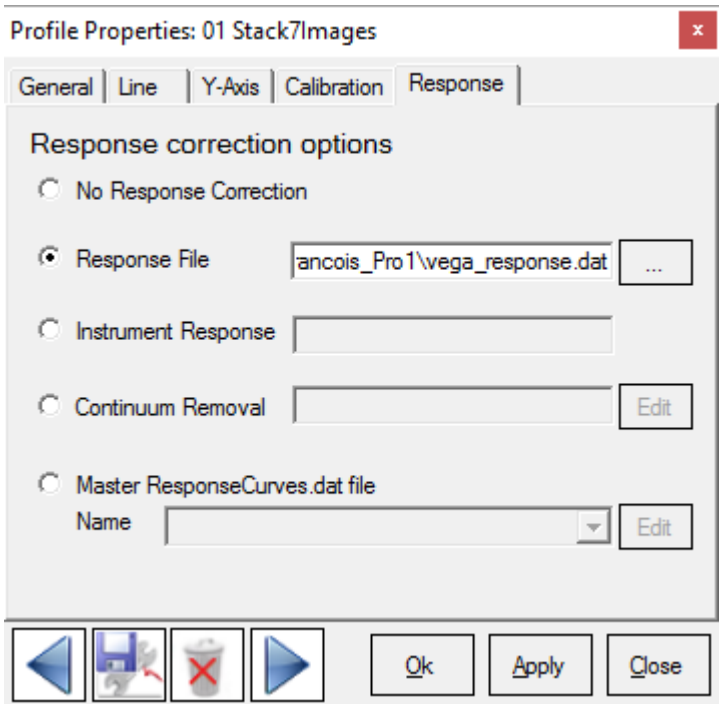
Then double click at points along the profile from left to right, skipping over troughs and peaks.



You can correct any errors by double clicking a point for a second time to remove it.

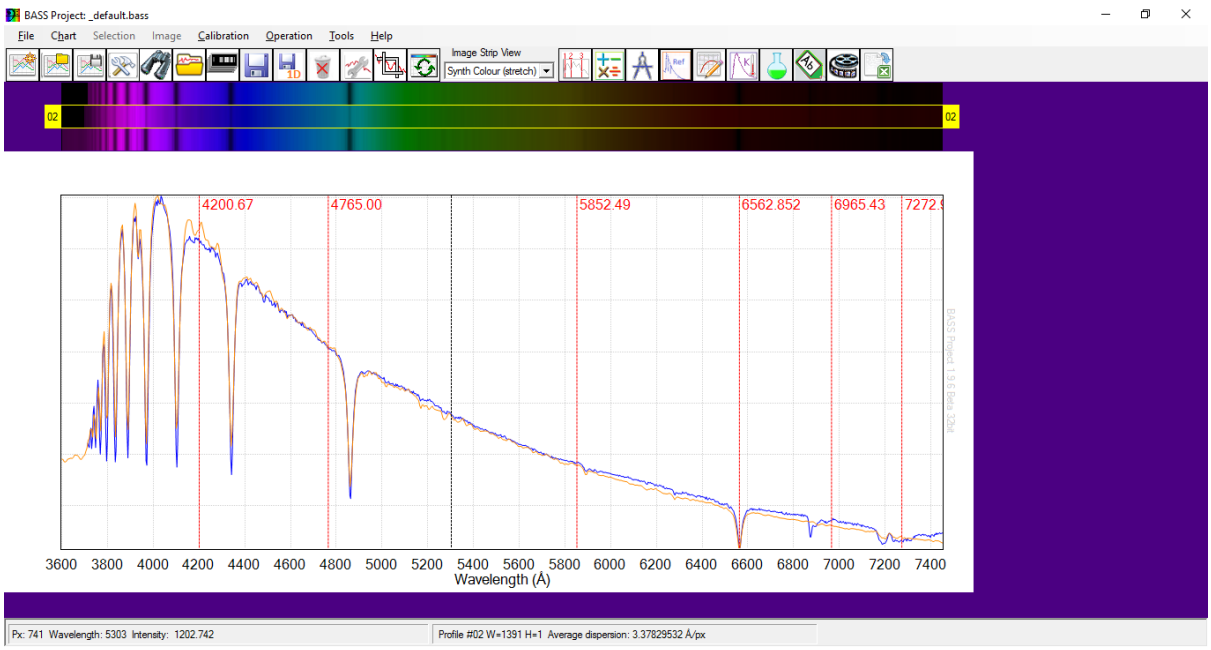
Now click save. There are several options here, I suggest save as a response DAT file in the folder where you are working, calling it something sensible. In this case I called it vega_response.dat. Then it is available to be used for all your spectra on that night.

Now double click your profile and select the Response tab. Then select the file you just created in the Response File box.



Here is your response corrected spectrum.

You can compare it to the Pickles A0V to check how well it has worked. You can use this knowledge to refine your technique.

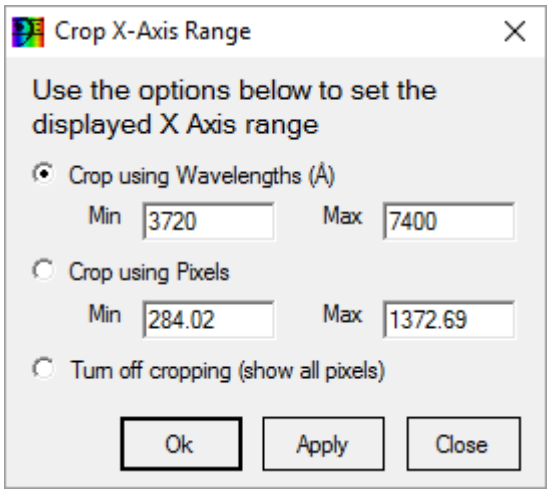


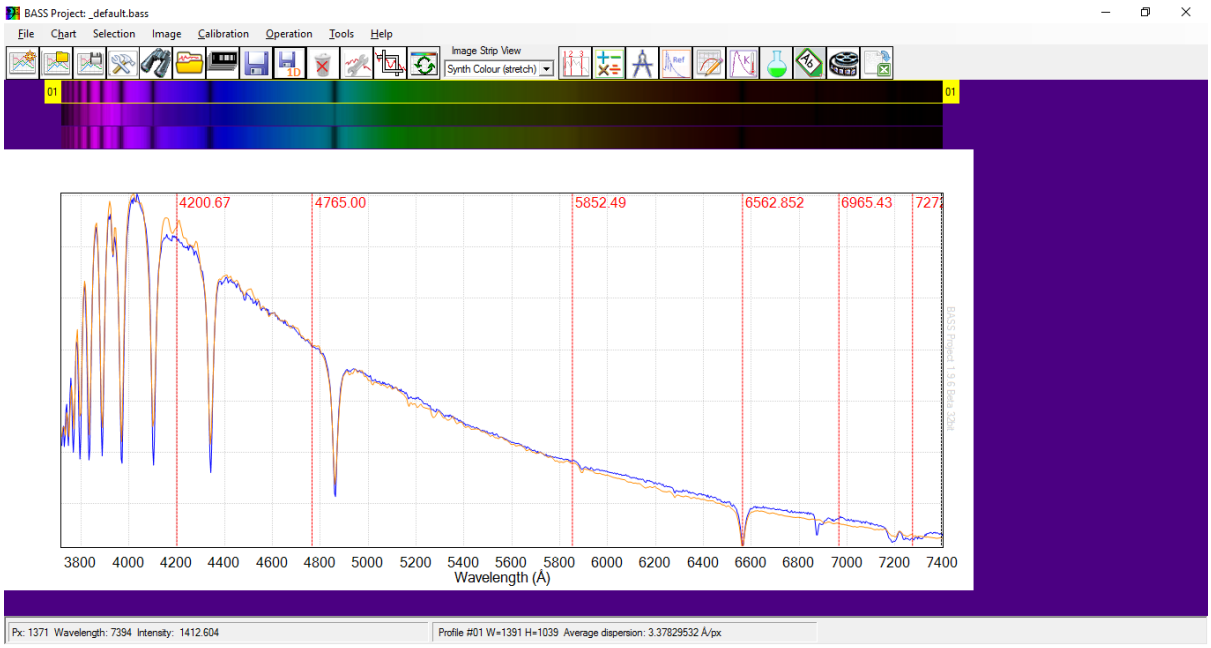
7 - Crop Spectrum

By default your spectrum will include regions which are not accurate due to the limitations of your telescope, spectrograph, detector and the atmosphere. Hence it is good practice to crop your spectrum to the wavelength region where you are confident in the processing.

Menu: Chart -> Crop X-Axis range

Manually populate the crop range.

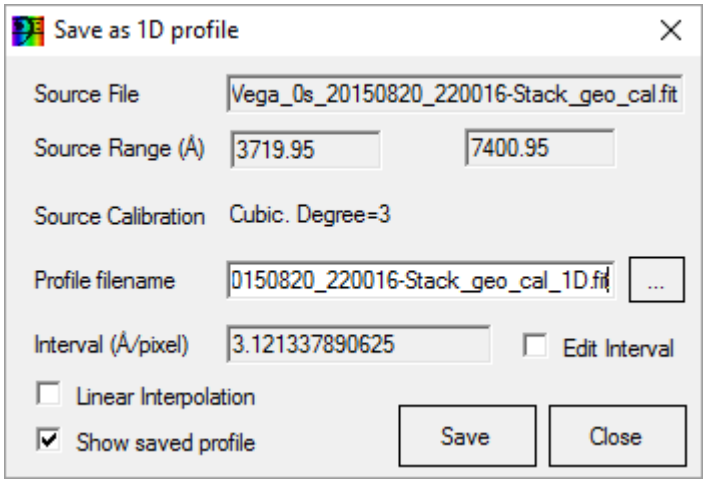




8 - Saving Your Spectrum

It is standard practice to save your finished spectrum as either a 1D fits file, or a 1D dat file. The spectrum is simply composed of wavelength and intensity values, so you do not need the 2D image of your spectrum once you have processed it. This will allow you to share your spectrum with others and to open it in other spectroscopy packages.

Menu: File -> Save as 1D profile



9 - BeSS Settings / BAA

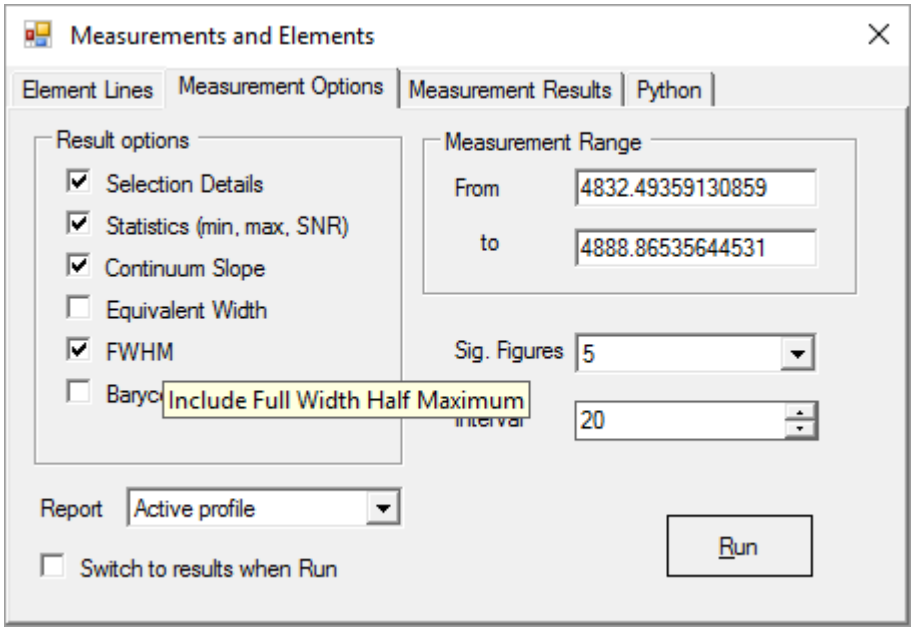
Good quality spectrum files can be submitted to databases like the BAA, BeSS and ARAS. These all need spectra to be saved as files of the same format. This format is 1D fits files compliant with the BeSS standard, which basically means certain fits header fields are populated. BASS has a menu for populating these fields to make it straight forward to create compliant files.

a. Working out the resolution

Before proceeding you will need to know the resolution of your spectrum. The easiest way to calculate this is to open your wavelength calibrated neon spectrum. To measure the resolution click on the following menu item:

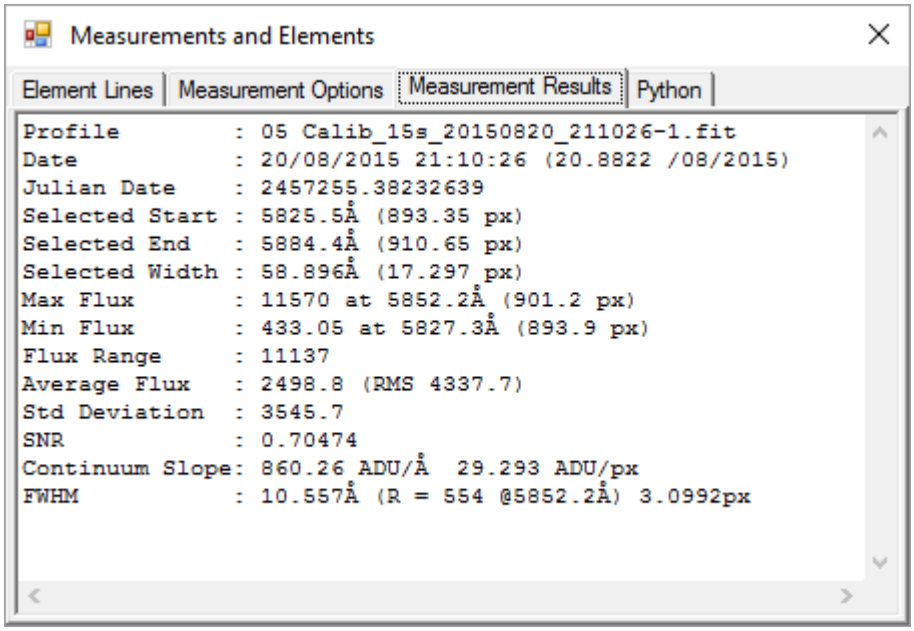
Menu: Tools -> Measurements and Elements

In the Measurement Options tick FWHM. This means full width at half maximum, a measure of a spectral line's width.



Choose a bright clean line near the middle of the neon spectrum. Press and drag the cursor from left to right across the spectral line.

Then look at the measurement results window.



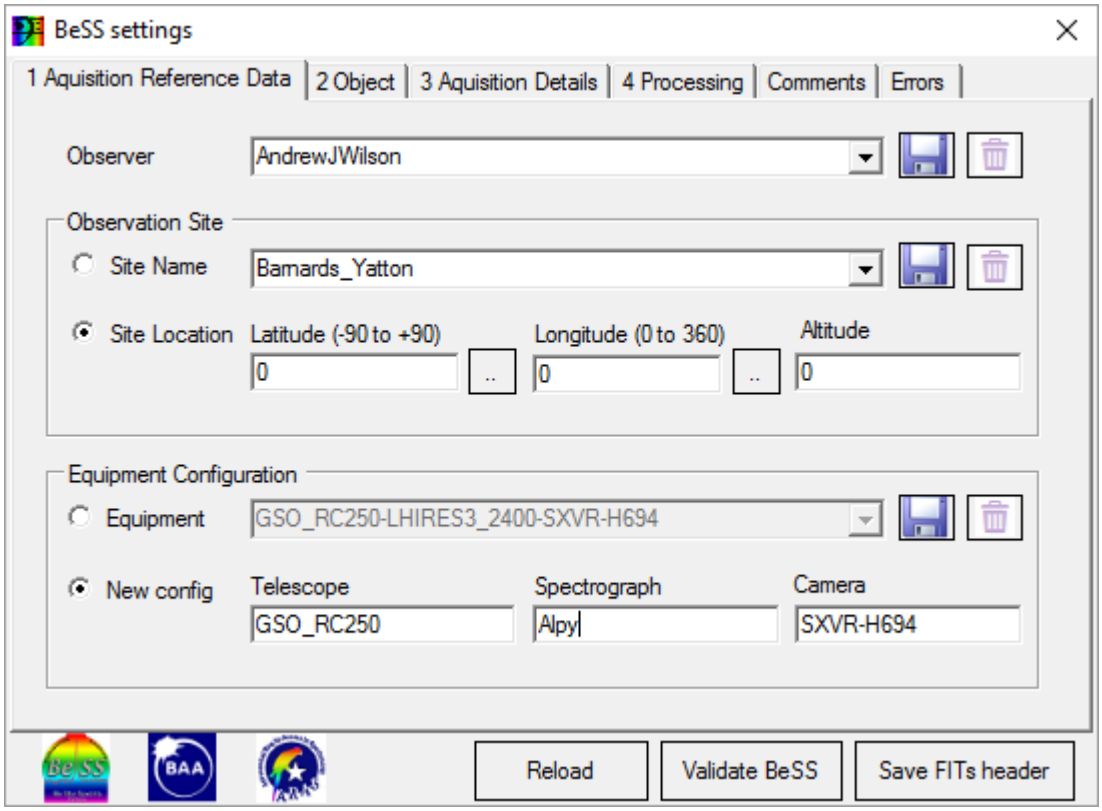
The FWHM gives you the numbers you need, they are the R value and the wavelength, so 554 and 5852.2.

b. Populating the BeSS Settings

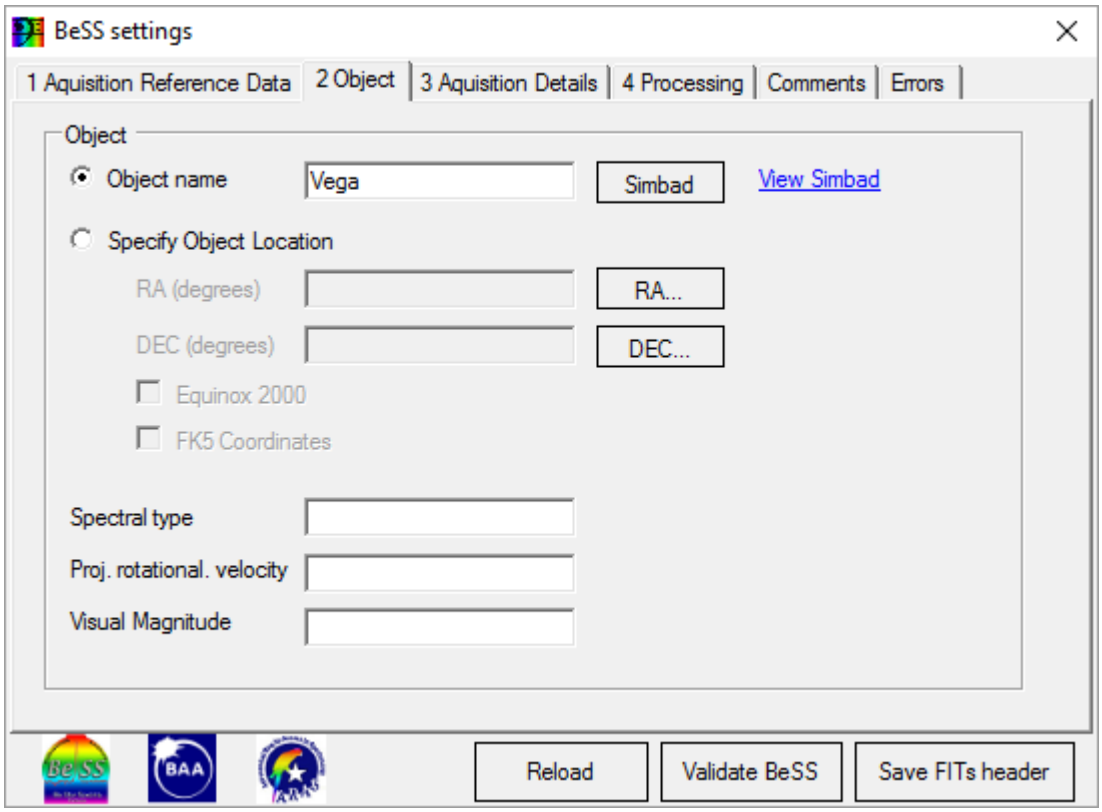
Make sure your 1D spectrum file is selected then use the menu.

Menu: Image -> BeSS Settings

The first tab can be populated as follows with your details:



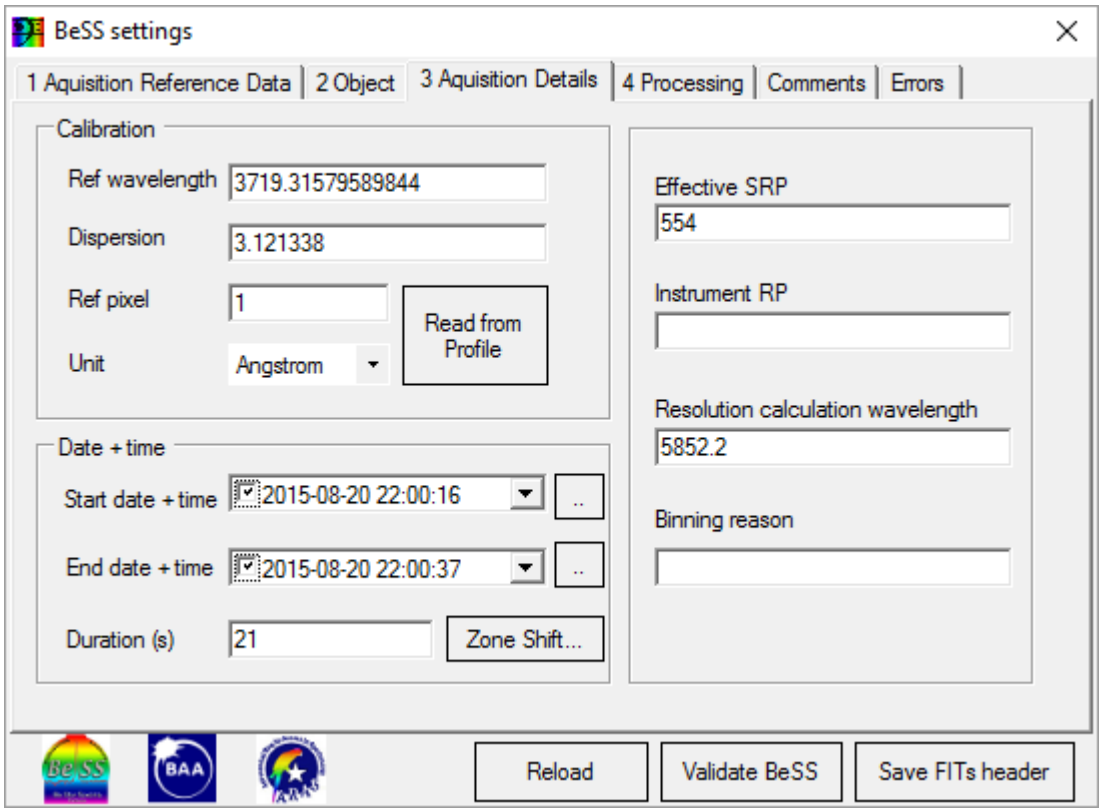
The next tab only needs the object name. Other detail can be useful but is not required for the BeSS, BAA or ARAS databases.



The 3rd tab needs the Acquisition Details.

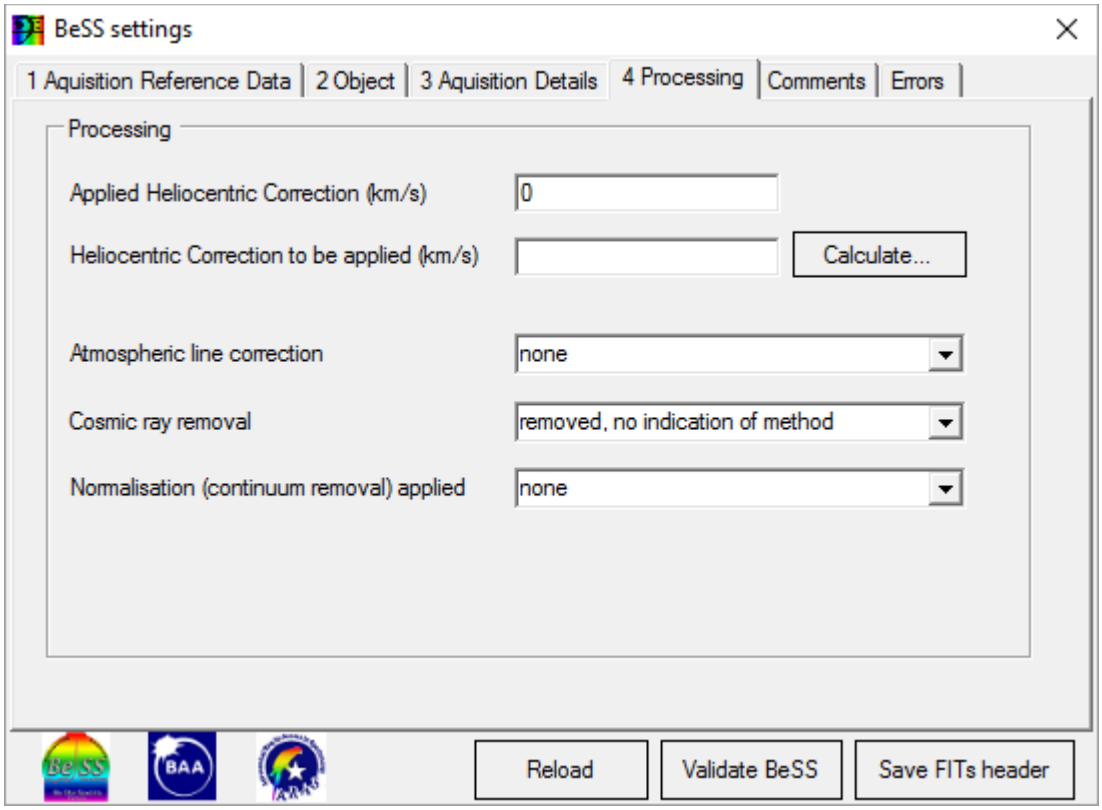
You can use the “Read from Profile” button to populate the calibration data.

Then enter “Effective SRP” and “Resolution calculation wavelength” from the resolution calculation above.



The 4th tab called “Processing” can normally be populated as follows.

Note that no heliocentric correction should be applied when submitting to databases unless this has been specifically requested.



Press the “Validate BeSS” button.

Assuming there are no problems indicated by the validation then press “Save FITs header”. The Save FITS header updates the 1D fits file so there is no need to resave the file.

The BeSS settings window can now be closed.

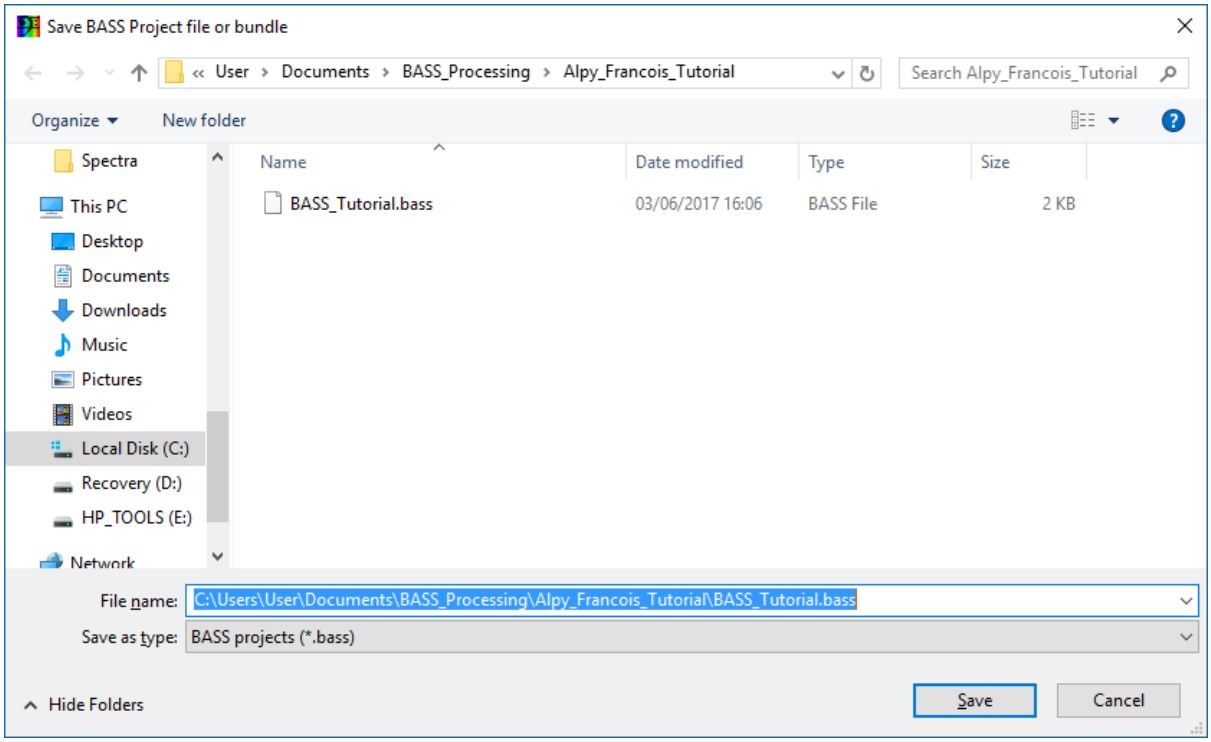
You can then submit this file to a database such as the BAA Spectroscopy Database, BeSS and ARAS. Note that not all databases are interested in all objects, for example BeSS is for Be and Herbig Ae/Be stars only. You should also ensure that your processed spectrum is of good quality.

10 - Creating .bass and .bun Files of your Session

BASS has a very useful feature which allows you to create a Project or Bundle file containing all of your images, spectra and settings. The Bundle files are especially useful if something is going wrong with your reduction process, as it can be used to share your BASS session with other users so they can provide help.

To save your BASS session:

Menu: File -> Save Project



This screen has the option to save as 2 files types:

- .bass
- .bun

.bass

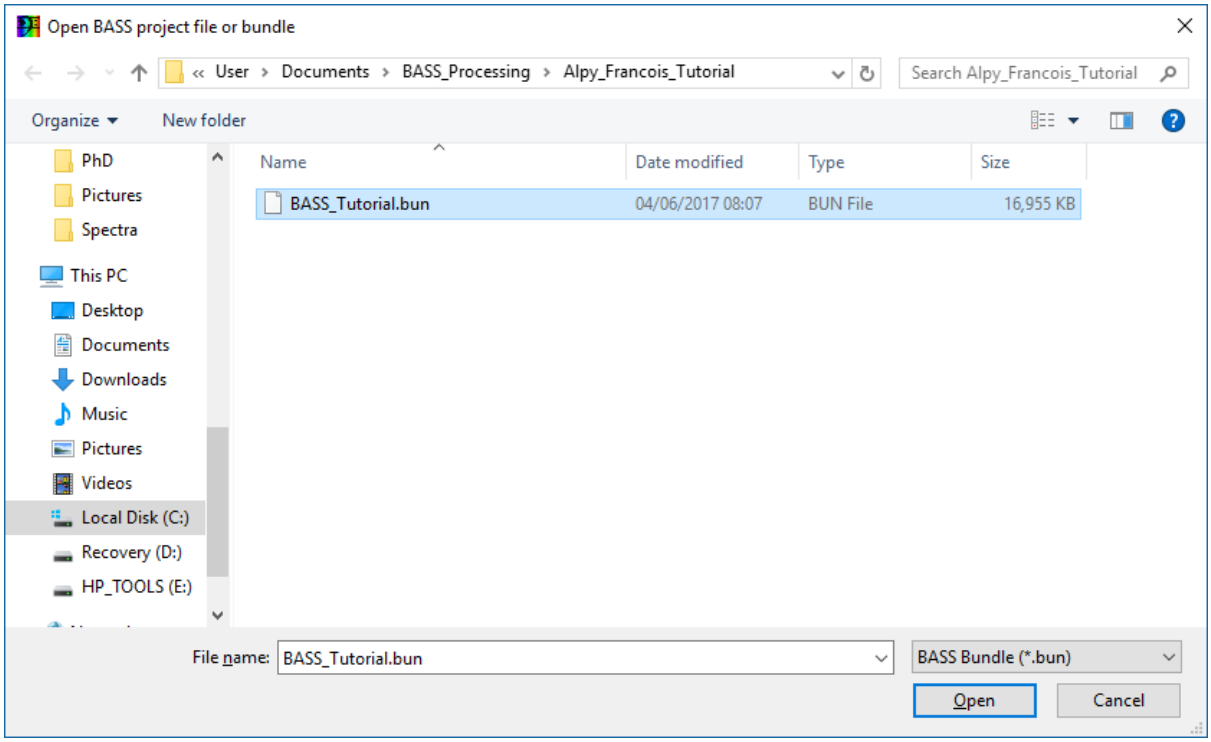
This saves a project file for your session containing your settings and links to the images and spectrum profiles stored on your computer. So when you re-open a .bass file it will re-open all of the images and spectra from their original location on your computer. This is good for personal use as it does not duplicate the files, and any changes you make will update those same files

.bun

This creates a bundle file which contains all of your images and spectrum profiles in the .bun file, as well as all of your settings. When you open a .bun file it will extract the images and spectrum profiles into a new folder of your choosing. It is a good idea to save a .bass file before creating a .bun file.

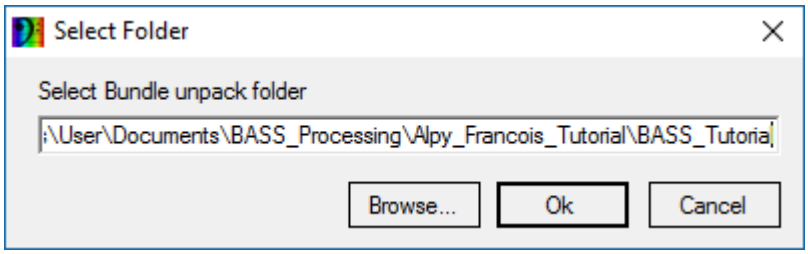
To re-open a project:

Menu: File -> Open Project



The drop down in the bottom left allows you to choose between a Project (.bass) or a Bundle (.bun) file.

If you select a Bundle file then it will ask you where you want to unpack the bundle. This will create copies of all of your images, spectra and settings in that folder. By default the folder will be the name of the bun file, but you can choose a different folder using the browse button.



Once unpacked, BASS will open all of the images and spectrum profiles from the new folder. So this will not link back to the original copies of your images and spectra.

Below is an example of an unpacked Bundle.