Capture and Analysis of Star Spectra Manual

Disclaimer

Almost all the information in the Data Collection and RSpec sections is sourced from the "Getting Started in Astronomical Spectroscopy using RSpec"[1] manual [hereafter referred to as "Getting Started Manual"] by Field Tested Systems, the maker of the Star Analyser SA-100 and RSpec. The value of this manual stems from the amended ordering of information and distillation of facts to suit the equipment configuration available to SPS students.

Data Collection

As the adage goes, "garbage in; garbage out". This is true for any data analysis process, including observational astronomy. Beyond ensuring the best quality data for analysis, optimisation of data collection results in crisp and clear raw images that will impress your peers.

A collection of tips from experience and the Getting Started Manual are as follows:

1. Know the limitations of the diffraction grating (Star Analyser 100 [SA-100])
    a. The SA-100 has grooves that are spaced at 100 lines/mm. Whilst this low density of lines produces a brighter spectrum and allows for shorter exposures, it also limits the resolution. Hence, if you are attempting to identify small spectral shifts, it may not be practical using the SA-100.

2. Screw on the star analyser in an orientation to remove the need for image rotation as a pre-processing step in analysis
    a. There is a line marking on the SA-100 (**Figure 1**). Have this line positioned at approximately the 9'o clock position when the SA-100 is screwed onto the camera. This requires trial and error and hence should be done well in advance of the actual data collection. The ideal orientation of the star and its spectrum is with the spectrum appearing as a horizontal line to the right of the star (**Figure 2**).
    b. Although the captured images can be rotated in RSpec, this may introduce some error or artefacts in the spectrum produced.

[1] Available at https://www.rspec-astro.com/getting-started-pdf/

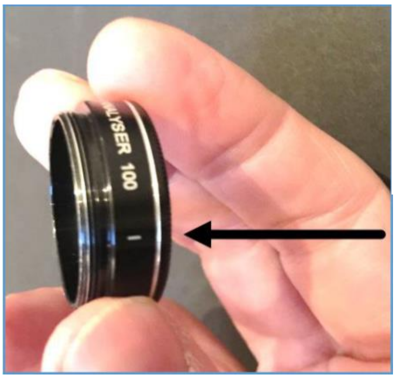

Figure 1 | Orientation line on Star Analyser 100 [SA-100]. Screwing on the SA-100 such that the line is approximately at the 9'o clock position will ensure that rotation of the captured images as a pre-analysis step is not necessary.

Figure 2 | Ideal orientation of star and spectrum. The star and spectrum should lie along a horizontal line with the spectrum to the right. If mono CCD is used, star and spectrum will not have colour.

3. If there are multiple image capturing device options, choose the mono CCD
    a. Whilst the mono CCD does not allow one to take pretty, colourful images, they are often more sensitive and allow for more advanced spectroscopic analysis. Colour cameras rely on Bayer filters[2] to produce the colours which reduces the resolution. In addition, IR/UV filters in the colour CCD limit the spectral range available for analysis.

4. Capture images using the FITS format. If doing so, set RSpec for 32-bit processing which allows the maximum range of pixel values to be used for the Pixel Map tool.
    a. To do this, go to the **Options** panel and mark the **Full 32-bit processing on FITS images** checkbox in the **Advanced** tab (**Figure 3**).

Figure 3 | Steps to set 32-bit processing for FITS cameras. [1] Click on **Options** in the Tools dropdown list. [2] Mark the **Full 32-bit processing on FITS images** checkbox.

[2] A **Bayer filter** mosaic is a colour filter array for arranging RGB colour filters on a square grid of photosensors [source: Wikipedia]

5. Start with bright Type A stars like Vega or Sirius to get a hang of the analysis and to finetune the image/video capture parameters
    a. However, even if bright stars become easy to image, fainter but often more interesting stars tend to still be difficult to finetune image capture for. A quick and dirty method is to capture images with different sets of parameter (e.g. exposure and gain) values so that the best set can be utilised for analysis. It is much faster to screen through images than to find a night with the best imaging conditions.

6. Always capture a bright Type A star for calibration and optimisation of focus at the start of every spectral data collection session.
    a. Type A stars are the easiest to calibrate against and allow for simpler calibration processes for subsequent imaging targets.

7. When imaging, ensure that the first order spectrum is in focus.
    a. The star may have to be slightly out-of-focus (**Figure 4**) but the first order line should be thin and its ends should be sharp points (**Figure 5**).
    b. The best way to achieve the right focus is to start with the star in focus and move it out of focus by small increments, taking an image each time. Analyse these images using RSpec to determine the best focus (**Figure 6**). During each data collection session, assuming you have not changed the equipment configuration, the amount to defocus will be the same for all target stars. Hence, this only needs to be done once per data collection session, preferably on a Type A star.

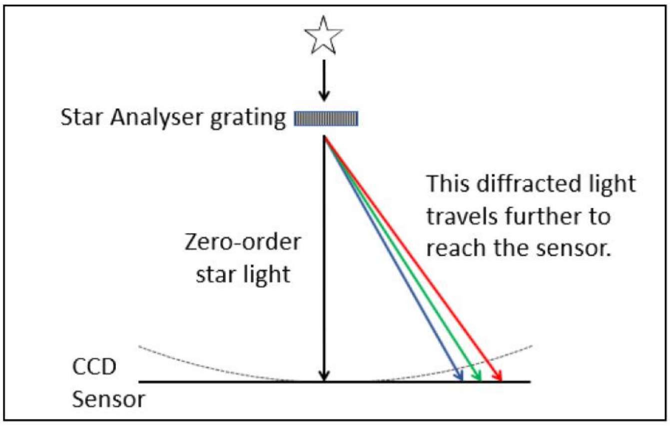

Figure 4 | The first order spectrum requires a different focus from the zeroth order star as the distance that the light travels to reach the CCD sensor differs for the two.

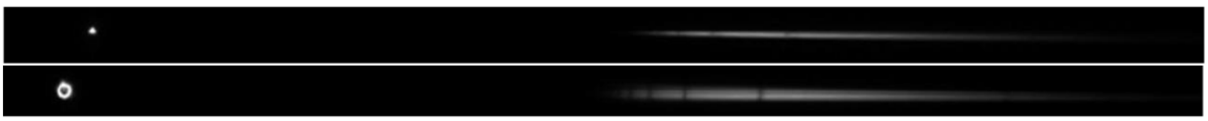

Figure 5 | Examples of focus on zeroth order star (top) and on first order spectrum (bottom). Note it is easier to see the spectrum profile dips (in the form of dark bands) in the bottom spectrum.

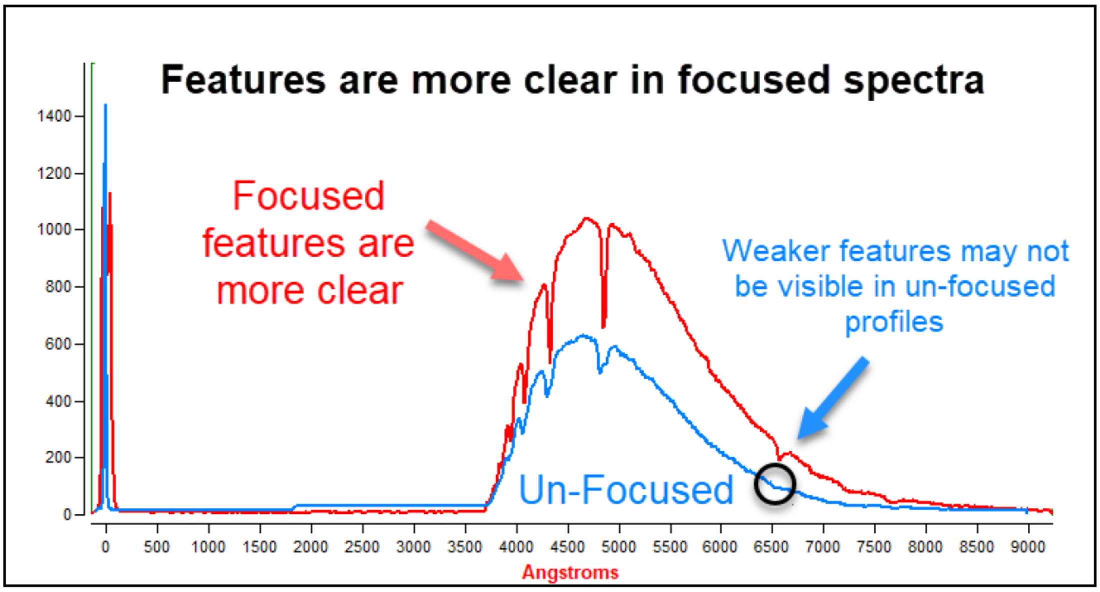

Figure 6 | Difference in clarity of features with differing focus levels on first order spectrum.

8. Check spectrum has appropriate exposure levels
   a. The best exposure is when the maximum values of the spectrum portion of the image (i.e. excluding the zeroth order star) are about 40 to 80% of the full well-depth of the camera. Full well-depth of a FITS camera is 65,535.

9. When imaging, strike a balance between achieving high altitude for the star and lowest background light conditions
   a. A balance must be struck between the factors of timing and star position. The higher the star is, the less atmosphere its light passes through and the light experiences less distortion. However, a potential opposing factor to consider is the amount of ambient light (greater at daybreak or twilight) which makes detecting the star itself difficult.

10. When collecting images of a star over longer exposures, it is important that the star is tracked well by the telescope. This requires the calibration of the tracking function to be done well.
    a. An additional step to better eliminate smearing issues is to position the telescope such that the movement of the star is vertical in the imaging plane. Since RSpec combines pixel values in columns spanning the orange sampling lines, any vertical smearing does not affect the analysis.
    b. However, it may sometimes be difficult to achieve a telescope orientation to ensure only vertical smearing. The Rotate function in RSpec has a De-Slant feature that allows internal rotation of an image when the smearing is not vertical. This is a less preferred option as the background corrections to achieve the de-slanting does degrade the data, affecting subsequent analysis.

RSpec

RSpec is a commercial software that allows the spectroscopic analysis of stars using either images or videos as inputs and providing a spectrum profile as an output. This section lists out the basic steps to obtaining a spectrum for further analysis and to optimising the data collection process using tools available on RSpec.

Miscellaneous Features

1. Live monitoring of spectrum quality
    a. Live monitoring of spectrum quality during data collection is possible using the ***Auto-Open new files*** checkbox feature (**Figure 7**). Ticking the checkbox in the file explorer tab at the bottom left of the window instructs RSpec to monitor a folder for new images and it open the most recent image automatically. This is useful for checking the focus is optimised for the first order spectrum. Go to **Options** > **Advanced** (**Figure 8**) to set up the address of the folder to be monitored.

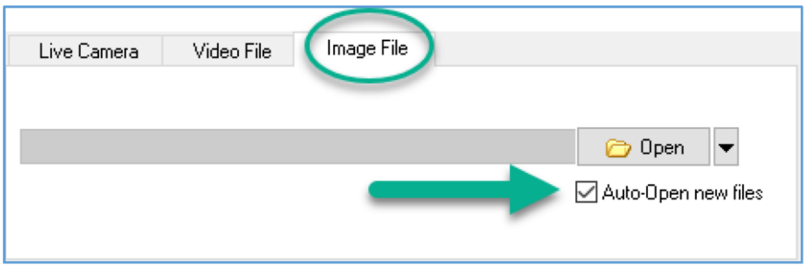

Figure 7 | Checkbox for Auto-Open new files feature.

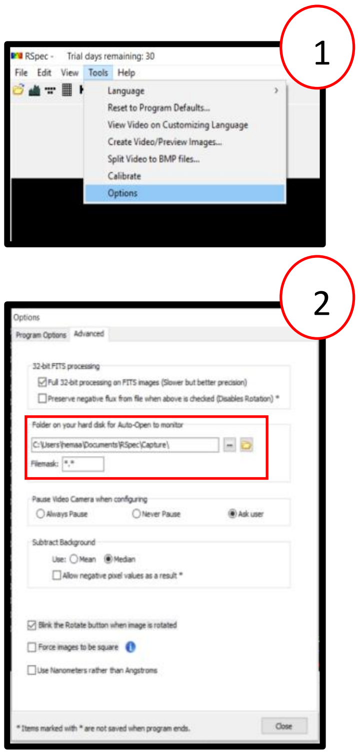

Figure 8 | Steps to set directory for Auto-open new files feature.

2. Check of exposure levels
    a. Check of exposure levels can be done using the Pixel Map tool on RSpec. To use the Pixel Map tool, click the grid-like icon on the toolbar. The Pixel Map panel will be shown. On the image panel, click and drag to select the region-of-interest and the Pixel Map panel will be updated to reflect the values of that region (**Figure 9**)

3. De-slanting of images to correct non-vertical smears
    a. To use the De-slant feature, click the **Rotate** icon which will open the Adjust panel. Check the **Slant** checkbox on the panel to open the Slant slider. Slide the bar to achieve the required de-slanting (**Figure 10**).

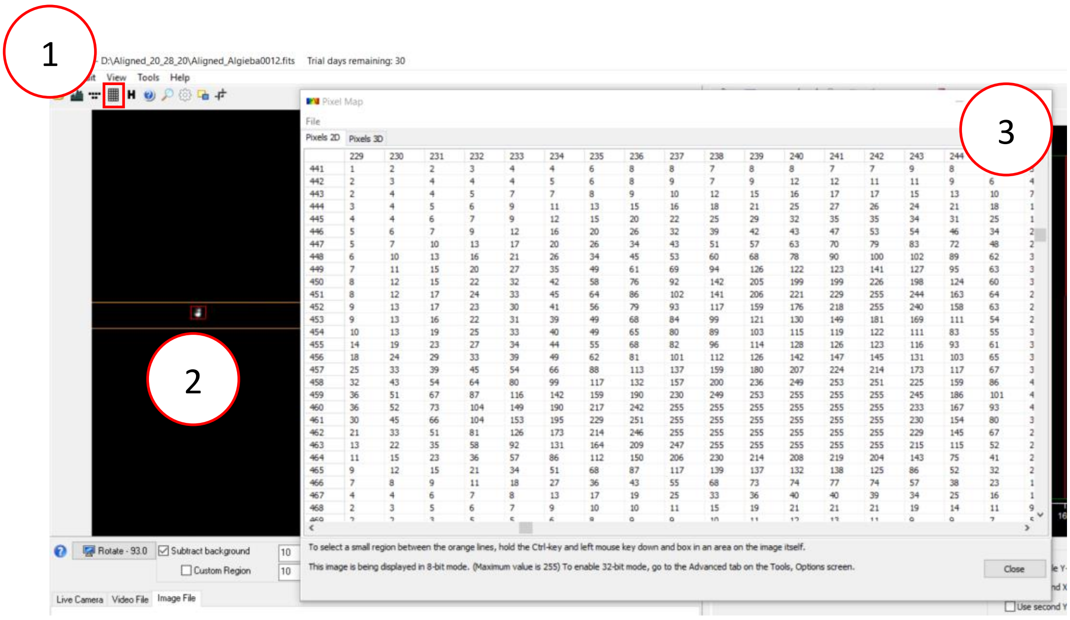

Figure 9 | Steps to utilise Pixel Map tool. [1] Click the Pixel Map icon on the Tools bar. [2] Click and drag to frame a region-of-interest in the image in the left panel. [3] Parse the values of the spectrum portion of the image. Ideally, the value should be about 40 to 80% of the full well-depth for good exposure levels.

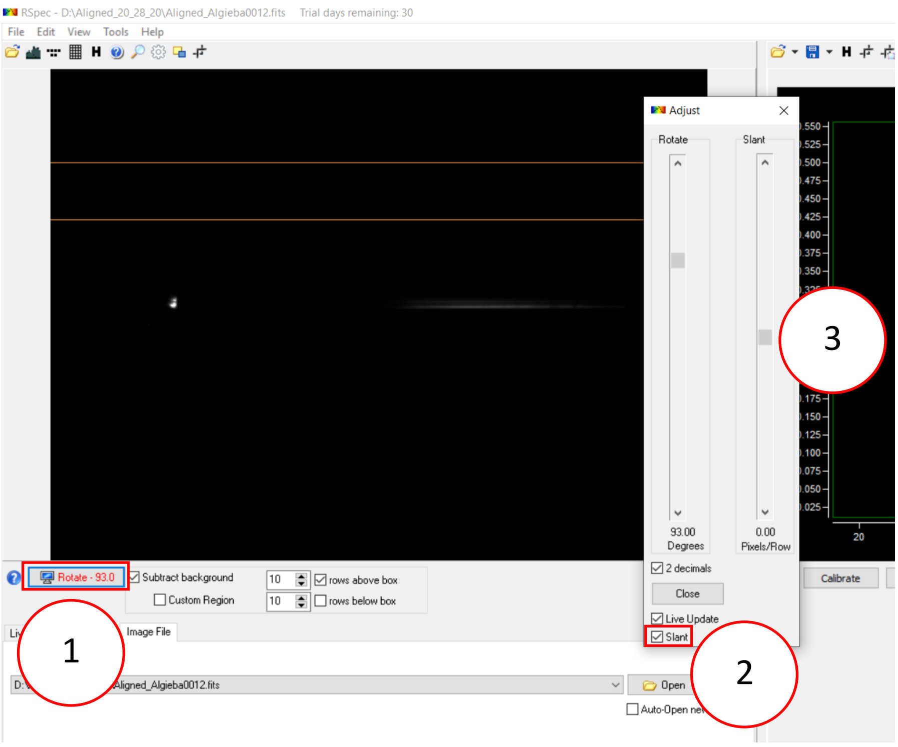

Figure 10 | Steps to de-slant image to ensure smearing is only in vertical direction. [1] Click on the **Rotate** icon below the image display of the left panel. Mark the **Slant** checkbox to open the Slant slider. [3] Move the slider bar accordingly to slant the pixels between the orange sampling lines.

Spectroscopic Analysis

1. Open the captured image or video file using the file explorer tab at the bottom left of the window (**Figure 11**).
    a. Although video files can be used in RSpec as well, image files are recommended as it eliminates the need to stack frames of the video files together separately before analysis to achieve longer exposures.

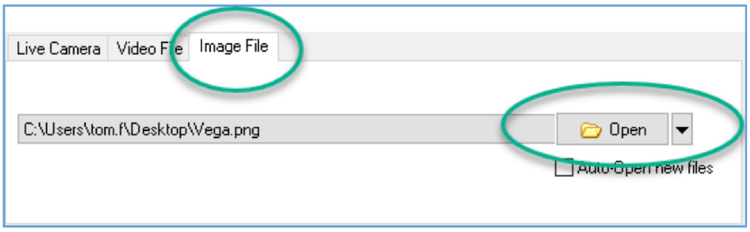

Figure 11 | File explorer tab to open image files.

2. Once the image has opened, the data is presented into two panels (**Figure 12**). The panel on the left shows the image as it was captured with two orange sampling lines. The right panel shows the profile graph of the region-of-interest between the sampling lines.
    a. If the star and spectrum are not visible on the left panel, the Histogram tool can be used to adjust the image contrast (**Figure 13**).
        i. Click the Histogram Tool button on the toolbar.
        ii. In the Histogram Tool panel, check the **Entire Image** option and click the **Auto-Stretch** button. Manual adjustment of the contrast can be done by sliding the blue sliding markers before clicking the **Auto-Stretch** button.
        iii. The stars and spectra previously not visible should be visible now. The tool alters the display of the image but does not modify the original data. Hence, the subsequent analysis on the spectra remains valid.

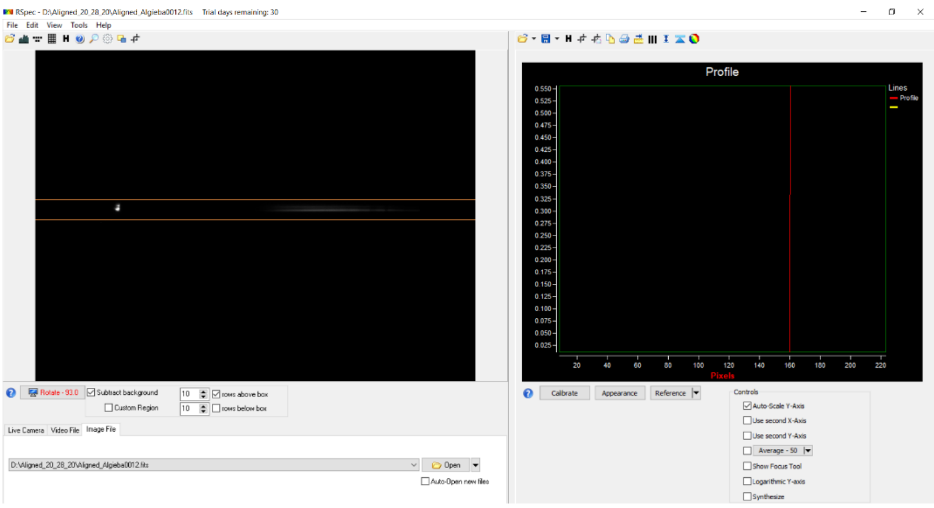

Figure 12 | Image panel on left and profile panel on right following the opening of an image file.

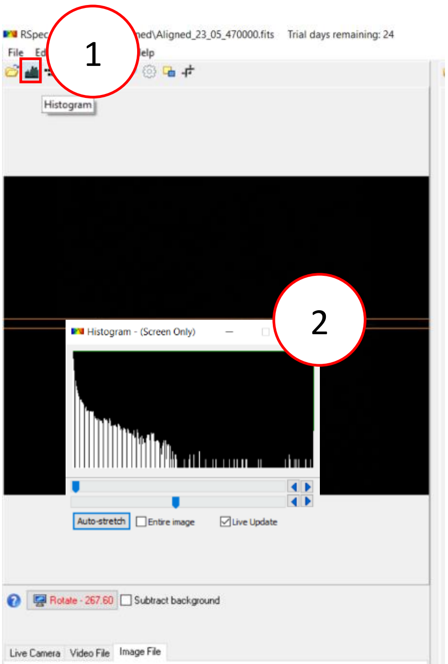

Figure 13 | Steps to adjustment of histogram to few faint spectra and stars. [1] Click on the Histogram Tool button. [2] Check the **Entire Image** option and click the **Auto-Stretch** button.

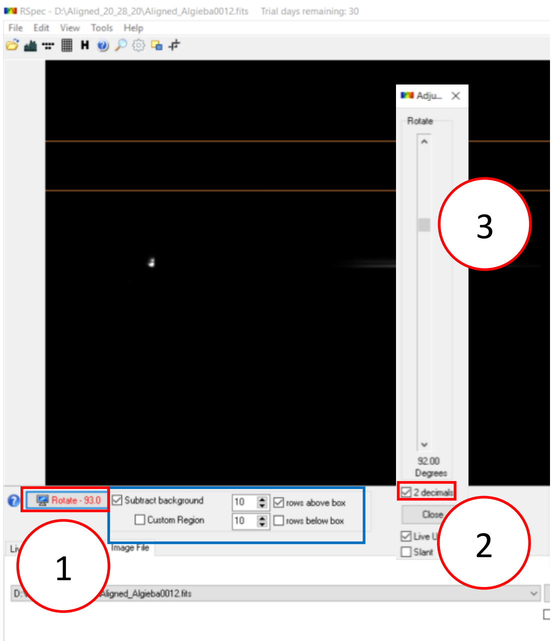

Figure 14 | Steps to rotate the image. Also boxed in blue is the Subtract Background panel. [1] Click on the **Rotate** button. [2] Check the **2 Decimals** option if fine adjustment is desired. [3] Move the slider bar and observe the effects in the image panel on the left.

3. Rotate the image if needed to ensure that the star and spectrum lie on a horizontal line (**Figure 14**).
   a. To utilise the Rotate feature, click the **Rotate** button. Then check the **2 decimals** checkbox on the Adjust panel if finer control is desired. Lastly, move the slider bar to achieve the desired orientation for the image.

4. Adjust the position of the orange sampling lines such that they closely bracket the region containing the star and spectrum.
   a. If the Histogram Tool was used earlier, remove the check from the Entire image option after adjusting the orange sampling lines. This minimises unnecessary calculations to speed up the analysis.

5. If the exposure and focus were appropriate during data collection, the right panel should display a profile graph with a sharp zeroth order peak and a broad first order peak. The first order peak will contain absorption features which are represented as sharp dips in the broad peak. If the broad peak has poorly discernible peaks and/or dips, calibration and further analysis is not possible. One way to slightly improve the data quality may be to utilise the Subtract background feature (**Figure 14**). This can reduce the noise to give a slight improvement in data quality.

6. Check if appropriate dispersion was achieved. The broad peak on the right of the profile graph should be in the range of about 225 to 400 pixels in length. Under-dispersion results in the compression of peaks and dips such that they are no longer visible. Over-dispersion results in the need for longer exposure times to ensure enough light was captured with the side-effect of added noise.

7. Calibration is the conversion of the data in terms of Pixels to Angstroms (x-axis). It involves 2 steps after clicking the **Calibrate** button below the profile graph.
   a. Selection of the pixel column in which the zero-order star appears [is assigned value of 0 angstroms following calibration] (**Figure 15**)
   b. Selection of the pixel column in which the Hydrogen β dip appears (**Figure 16**)

   Finding the Hydrogen β dip may be difficult initially. It is usually but not always the largest, sharpest dip to the left of the broad overall peak. The Angstroms/Pixel value displayed above the profile graph should be approximately between 8 to 15. Values outside this range indicate under- or over-dispersion.

   After calibration of one star, it is not necessary to repeat the two-step calibration for each subsequent star assuming all the stars were imaged during the same session with the same equipment configurations. Instead, a truncated calibration process called One-Step Calibration is sufficient. This involves identification of the zeroth order star's pixel column and the software can apply the previously calculated Angstrom/Pixel value to produce the calibrated profile graph (**Figure 17**).

   a. Check the Use One-Point Alignment checkbox on the Calibration Wizard panel. Select the pixel column in which the zero-order star appears. Then key in the Dispersion factor obtained from previous calibration in the input box above the slider bar.
   b. The One-Point Alignment can also help in the identification of the hydrogen beta line. Activate the hydrogen lines display via the Element Library (see **Step 9**) before opening the calibration wizard. Choose the One-Point Alignment and select the pixel column for the zeroth order star. Then, adjust the slider bar and you will notice the profile scale accordingly. Select a slider bar position which allows the hydrogen lines to coincide with the dips seen in the profile. Be careful when doing this as misinterpretation of the correspondence between the dips/peaks and element lines can result in an incorrect dispersion factor.

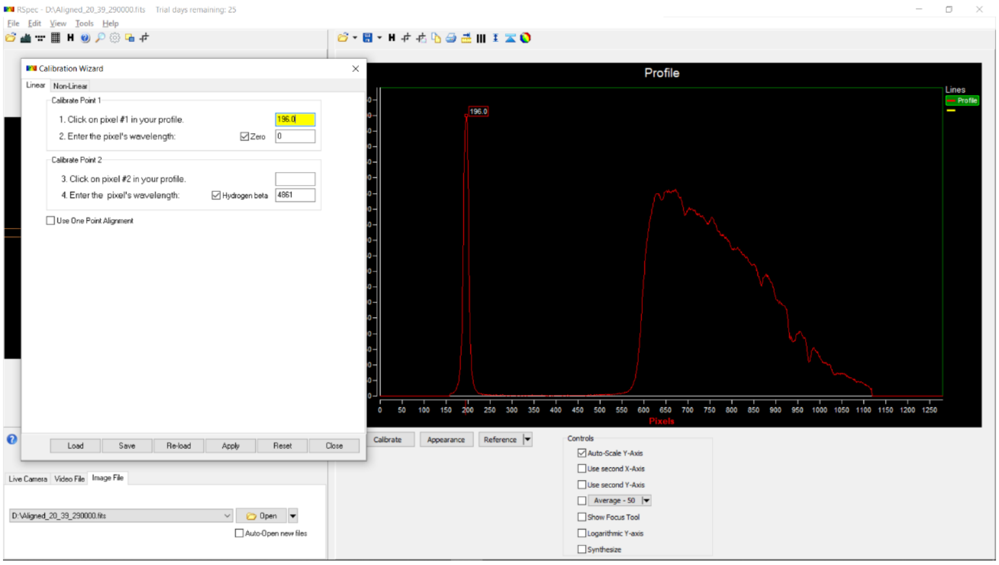

Figure 15 | Zeroth order peak calibration for two-point calibration.

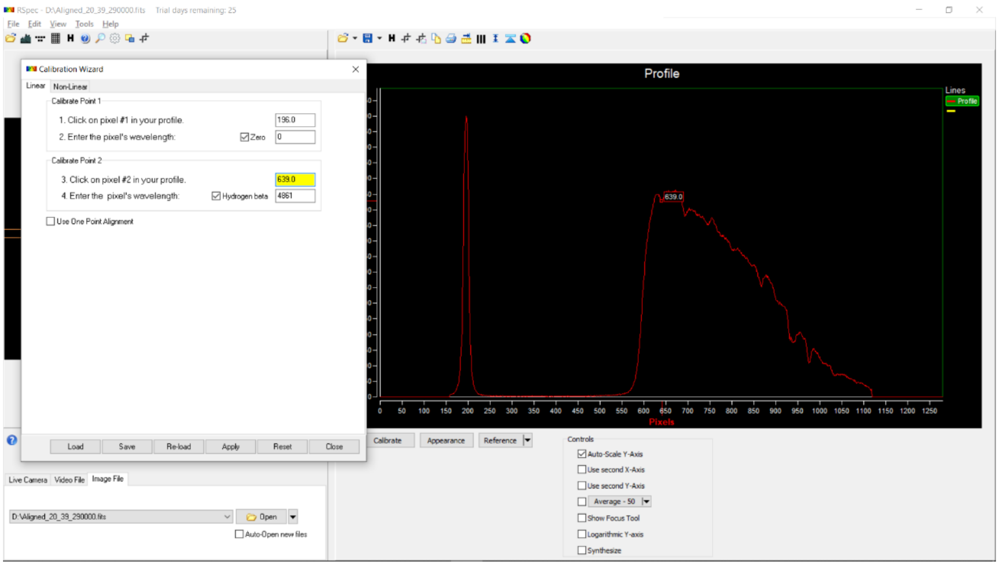

Figure 16 | Hydrogen β dip calibration for two-point calibration.

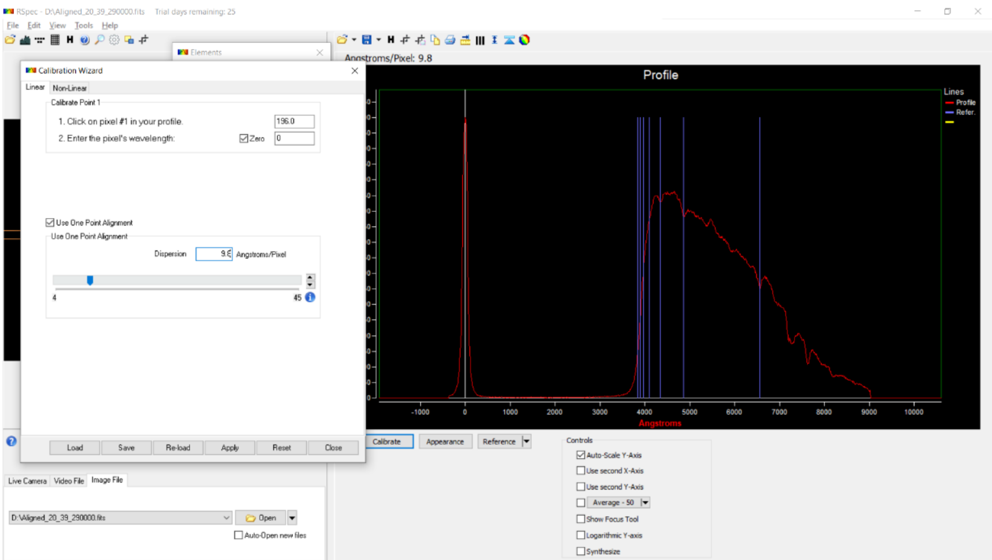

Figure 17 | One-step calibration. The pixel column of the zeroth order star and a previously calculated dispersion factor are used.

8. Before further analysis, it is best to carry out instrument response corrections to the data. The CCD camera does not respond equally to all wavelengths of light as it may be more sensitive to some wavelengths than others (**Figure 18**). The steps for this are as follows:
    a. Creation of instrument response curve.
    $$\text{Instrument Response} = \frac{\text{Raw Spectrum}}{\text{Library Spectrum}}$$
    b. Creation of calibrated profile curve
    $$\text{Calibrated profile} = \frac{\text{Raw Spectrum}}{\text{Instrument Response}}$$
    Since there are several steps to this process, it is much easier to follow along to the official video provided by Rspec and available on YouTube[3] or the RSpec website[4].

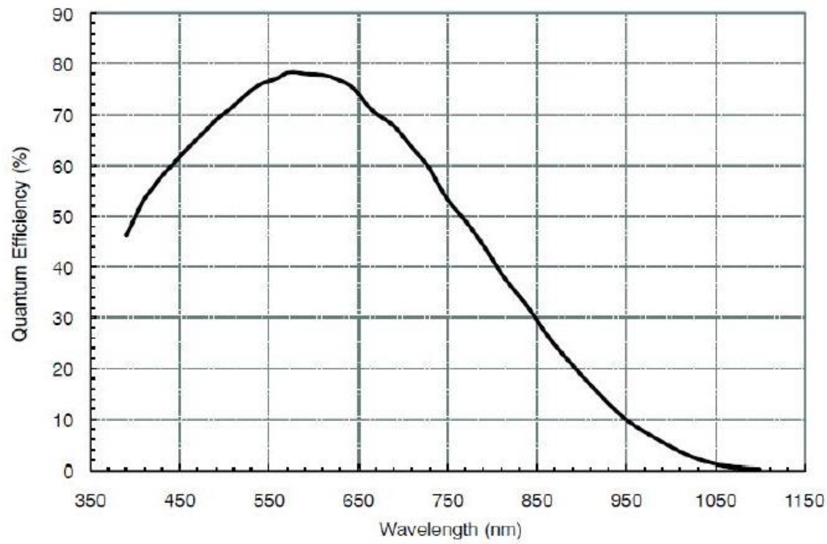

Figure 18 | Quantum efficiency curve for ZWO ASI120MM (taken from https://astronomy-imaging-camera.com/product/asi120mm)

[3] https://www.youtube.com/watch?v=FuEVXfNPgd8
[4] https://www.rspec-astro.com/videos/InstrumentResponse/InstrumentResponse.mp4

9. Confirmation of the calibration and further analysis involves matching the observed dips and peaks in the calibrated profile graph to standards. This is done using the Element Library (**Figure 19**).
    a. To access the Element Library, click on the **Element Library** button and check the spectral lines that you want to compare to.
    b. Verify that the reference lines in blue pass through peaks or dips in the profile graph. Although not all expected features may be present in the profile graph, the features of larger magnitude should be visible. Otherwise, issues may be present in the calibration, exposure, focussing, etc.

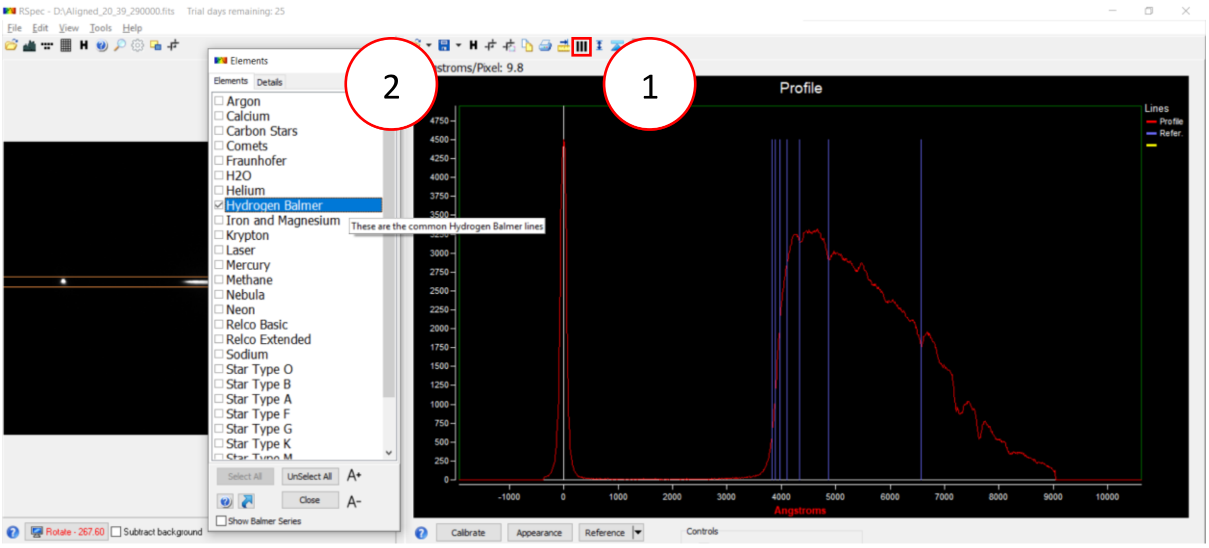

Figure 19 | Steps to access Elements Library. [1] Click on Elements Library icon in Tools bar. [2] Mark the checkboxes of the relevant elements to apply the reference emission/absorption lines.

Getting Help

1. Online forum for RSpec. Link: https://groups.io/g/RSpec-Astronomy
2. Online chat for RSpec. Link: https://www.rspec-astro.com/
3. Email for RSpec, Link: https://www.rspec-astro.com/contact/
4. Seniors

Project ideas

There are many good resources available online to draw inspiration from for project ideas. These include:

1. RSpec website
2. RSpec official user manual
3. The Sky is Your Laboratory: Advanced Astronomy Projects for Amateurs, Robert K Buchheim

There is a great deal of high-level observational astronomy that can be achieved by amateur astronomers, as one will come to discover quickly when exploring the topic online. However, it is important to set reasonable expectations based on the circumstances and resources available. Singapore is a heavily light polluted city whose bright night skies obfuscates all but the brightest stars and planets. Other issues are cloudiness and windiness, which contribute to bad "seeing". A 6" telescope, although very expensive, is at the lower end of the size range used by amateur astronomers doing serious science. For example, a 10" telescope is generally considered the minimum for exoplanet transit observations. Nonetheless, there remains a lot that can be done, particularly for projects dealing with observations of the Sun, Moon, and planets and their moons.