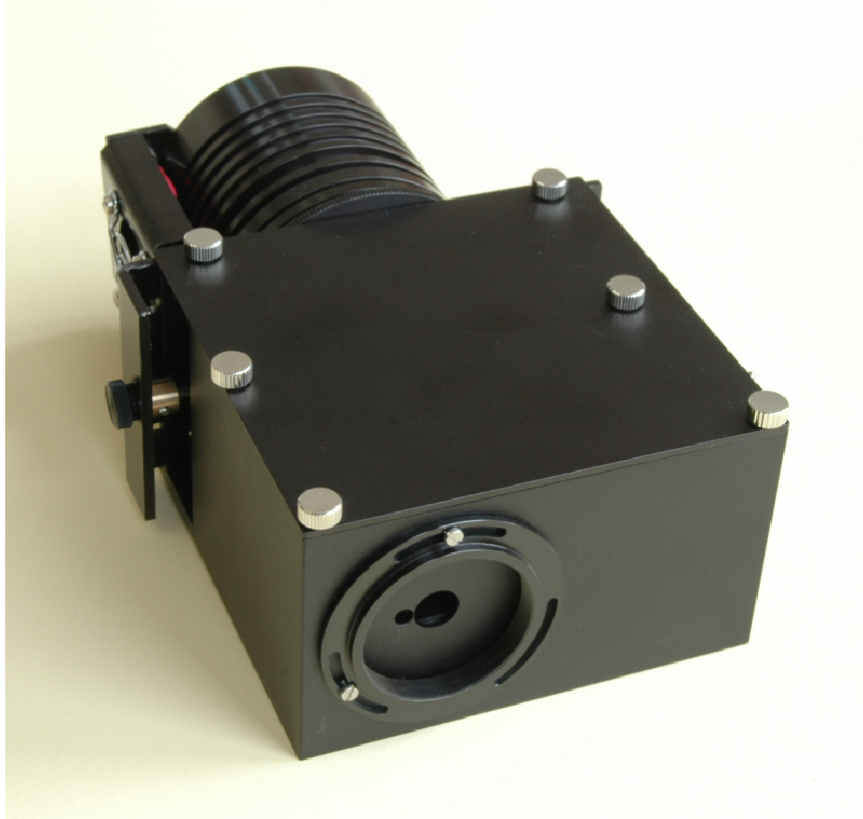




Handbook for the SX Spectrograph



Introduction:

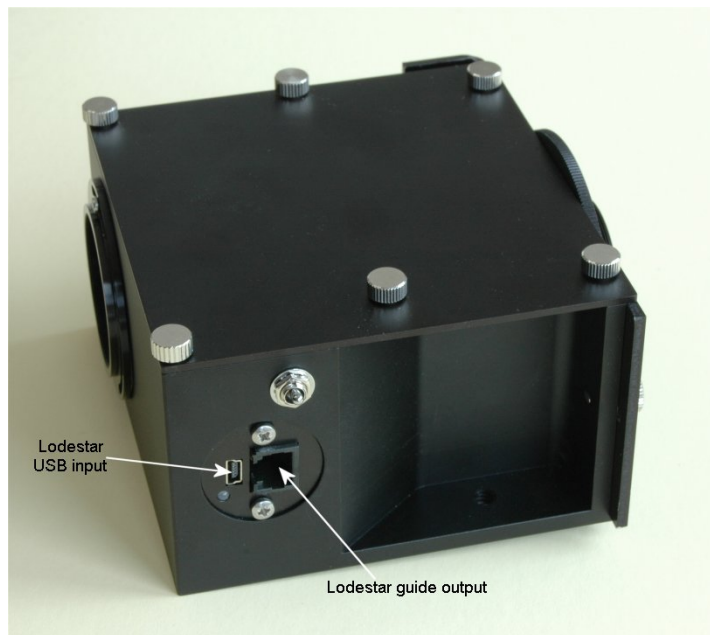
Spectroscopy of astronomical objects is a relatively unexplored field for many amateur observers, as truly compact, inexpensive and effective spectrometers have been unavailable until recently. This situation is now changing and spectrometry is becoming popular as a way to extend the scientific value of amateur observations and to add a new dimension to the hobby. The SX Spectrograph is our answer to the need for a very compact and high performance unit that is easy to use.

General description:

The SX Spectrograph is only 125 x 140 x 75 mm and weighs just over 1 Kg. It is solidly constructed in a machined aluminium enclosure and so will not flex during use. The optical design is based on a highly corrected, 550 groove concave reflecting grating, that provides a spectral length of 31 mm from 340 to 900 nm. The entire spectrum is accessible by adjusting a sliding camera carrier, using a threaded drive screw, but most of the visible spectrum can be seen without adjustment, when using an SX694 imaging camera. A 6 position slit wheel, with various slit widths and lengths, is provided and will allow the sensitivity and resolution to be optimised for the user's project. The resolution R factor when using the smallest slit width (20 microns) is approximately 2000.

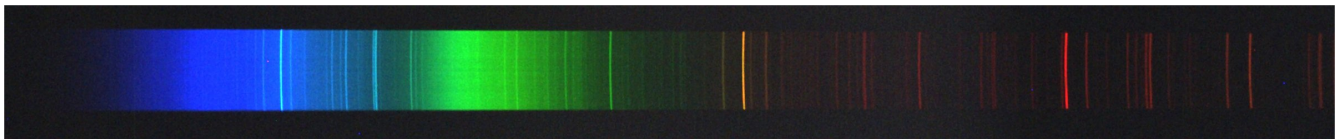


The SX spectrograph design incorporates a Lodestar X2 guide camera, which observes the image field via a 10% / 90% beam splitter cube. The slit is not directly visible in the field, but its position co-ordinates are provided and marked by a cursor box, generated by the PHD2 tracking software. It is therefore quite easy to move the object of interest into the slit cursor



box and then to select any convenient guide star in the Lodestar field for tracking.

The spectrograph also includes a battery powered spectral line source for calibration. This source uses a small gas discharge bulb, which is filled with a mixture of neon and argon. The result is an array of spectral lines that covers the entire visible spectrum and which provides a way to determine the wavelengths of the lines from any external source. The calibrator light is powered by an alkaline PP3 radio battery and may be switched on by operating the small toggle switch, located above the Lodestar sockets.

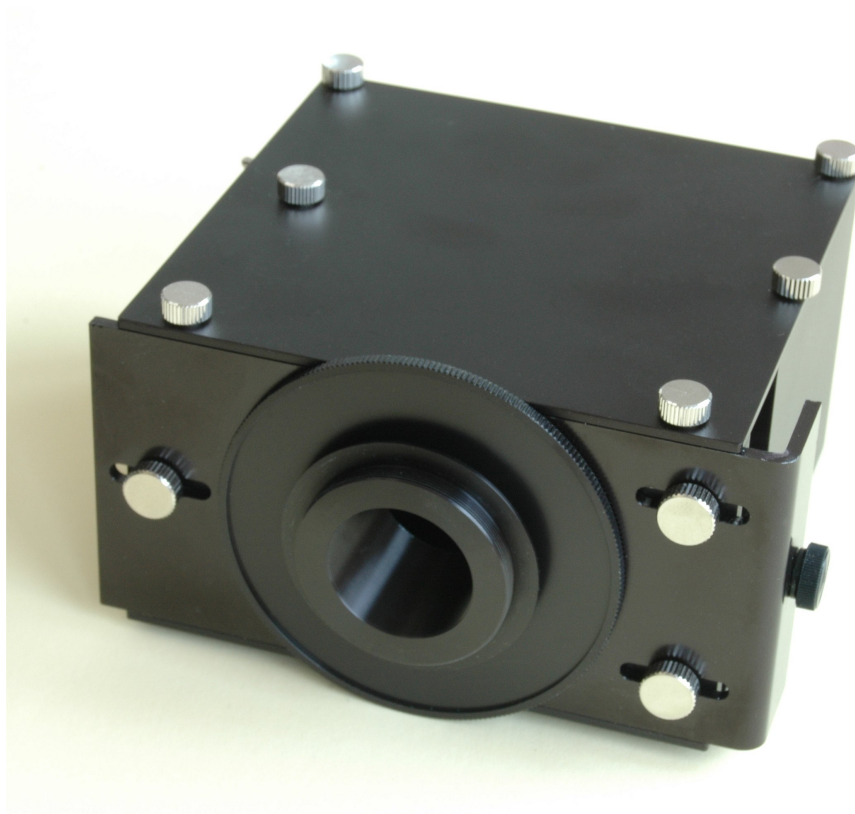


A typical calibration spectrum, imaged with an M25C colour camera.

The optical input to the spectrograph is via a T2 female ring adaptor. There is also a 48 mm female ring option, available on request. The back focal distance from the slit to the front of the T2 ring is approximately 40 mm mechanical (37 mm optical) and the clear aperture is 11 mm. The small hole is for access to the slit wheel lock screw and is not part of the optical path.



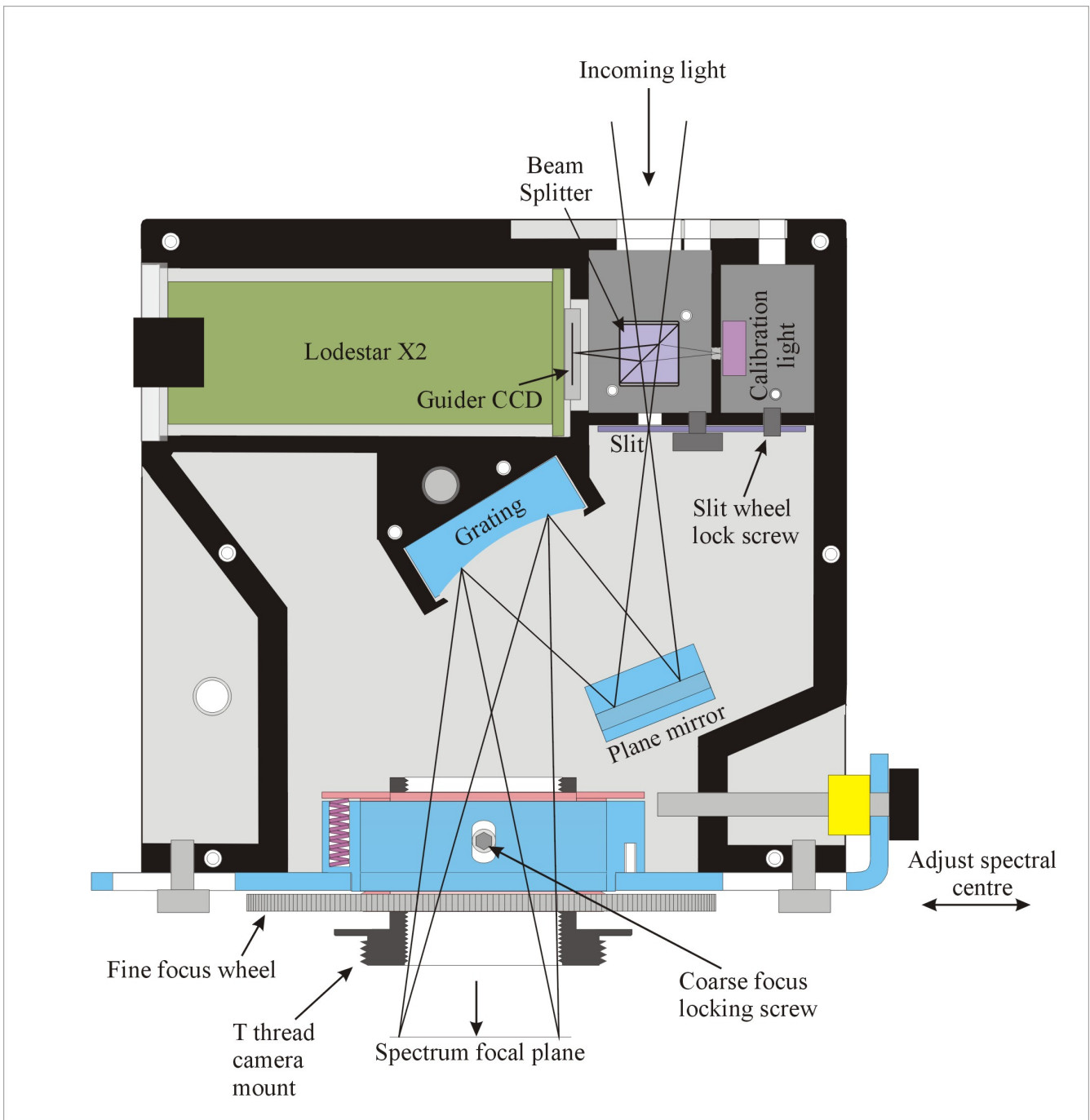
The camera attachment is via a male T2 thread, as shown below:



The T2 thread is part of a removable barrel that is normally locked into a fine-focus sleeve by an M4 setscrew (accessible when the box cover is removed). The fine focus sleeve is itself driven by the large, fine focus ring, which is seen surrounding the T2 adaptor. One rotation of this ring, moves the camera in or out by 0.75 mm, and permits the accurate focussing of the spectrum onto the camera sensor.

As the spectrum is too long to be completely imaged with a typical CCD sensor, the focus assembly may be moved along the spectrum, by rotating the drive screw that is seen at the right hand end of the cross slide. The three knurled thumb screws are slightly loosened to permit the slide to move, and re-tightened once it is in the correct position.

As the grating is designed for a compact optical system, the available back focal distance for the imaging camera, is somewhat limited. It is typically about 20 mm maximum, and this is sufficient for most compact astronomical CCD cameras, but not for a DSLR. We recommend using either the SX-694 or SX-814 mono cameras for high resolution imaging with good sensitivity. Nice colour spectra may be recorded with an SX-M25C. The camera is screwed onto the T2 adaptor and the correct spectral orientation achieved by loosening the focus lock screw and rotating the T2 adaptor. The approximately correct focal position can also be achieved by setting the T2 adaptor extension with the lock screw.



A general view of the optical and mechanical layout

Quick starting your spectrograph setup:

NB. Your spectrograph contains a delicate replica grating, which is easily damaged by contact with other surfaces, including fingers and cleaning cloths. Avoid coming into contact with this part and keep it free of dust by keeping the spectrograph cover in place when not adjusting the coarse focus.

The spectrograph is supplied with the slit set to the highest resolution position (20 microns wide x 1 mm high). This is generally the best setting for general purpose use, but may be changed by rotating the slit wheel. See the section on advanced settings for further details.

The initial adjustments are most easily made with the spectrograph removed from the telescope. First, set the fine focus ring

at around mid-travel, so that adjustment may be made in either direction. Now attach your camera to the T2 adaptor and remove the 6 thumbscrews from the top cover, so that the cover may be lifted for access to the focus lock screw. Slightly loosen this screw, using a 2 mm hexagon key (supplied), and set the camera orientation so that the long axis of the CCD is horizontal. Drop the cover back into place, but do not screw it down yet. You can now observe the calibrator spectrum to optimise the focus and orientation.

Cover the front aperture of the spectrograph and switch on the calibrator source. Boot up the camera and capture a 1 second exposure of the spectrum. It will probably be somewhat tilted and out of focus - slide and rotate the camera to optimise the image quality and position. When satisfied, lift the spectrograph cover and tighten the focus lock screw. Re-fit the cover and screws to complete this operation.

If the focus is accurate, then you are ready to use the spectrograph on your telescope, but, if necessary, you can refine the focus by turning the fine focus wheel.

The spectrum is pre-set with the green-yellow region (550 nm) close to the centre of the camera image. This will be well suited to most applications, but you can move towards the violet by turning the adjuster screw anti-clockwise, or towards the infra-red by rotating it clockwise.

Setting up the spectrograph on a telescope:

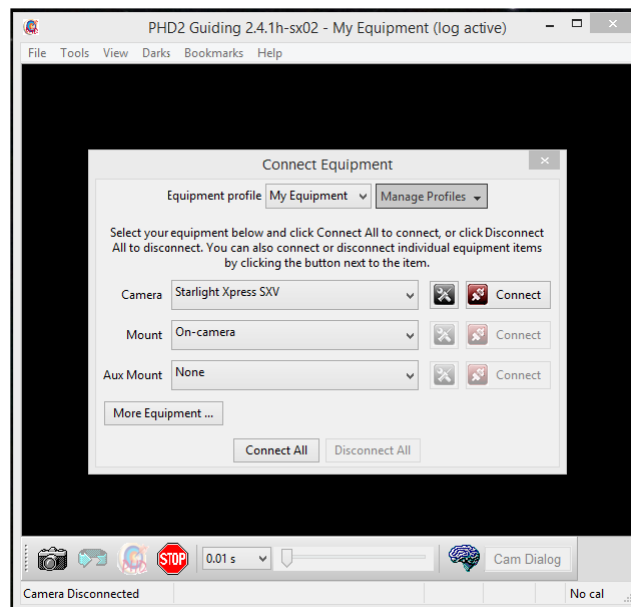
The standard input thread of the spectrograph is a female T2 (42 mm x 0.75 mm), although a 48 mm x 0.75 mm version of the input ring may be substituted. You will need a T2 male adaptor on your 'scope and at least 37 mm of back focal distance to achieve image focus on the slit and Lodestar X2 guider. The spectrograph can accept the full optical beam from systems down to about F3.5, but the best spectral definition will be obtained at F5 and above.

If you do not already have the Lodestar drivers and software installed, please follow these instructions:

To install the Lodestar driver, use the supplied CD to copy the appropriate driver files to a convenient folder on your computer. It is essential to avoid installing directly from the CD, as the wrong drivers are likely to be selected by Windows! Remove the CD from the drive and then double click the 'Setup' file that is in the driver folder. The drivers will now be installed within a few seconds. Connect the Lodestar X2 USB cable to your computer and observe the 'Found new hardware' messages - the drivers should be discovered automatically. You can check for a successful installation by opening 'Device Manager' and looking for a 'Starlight Xpress camera' in the USB devices list.

You now need to install 'PHD2' as the Lodestar control software. PHD2 is available for free download at <http://openphdguiding.org/> and a copy is also provided on the CD. You are now ready to begin using your SX spectrograph!

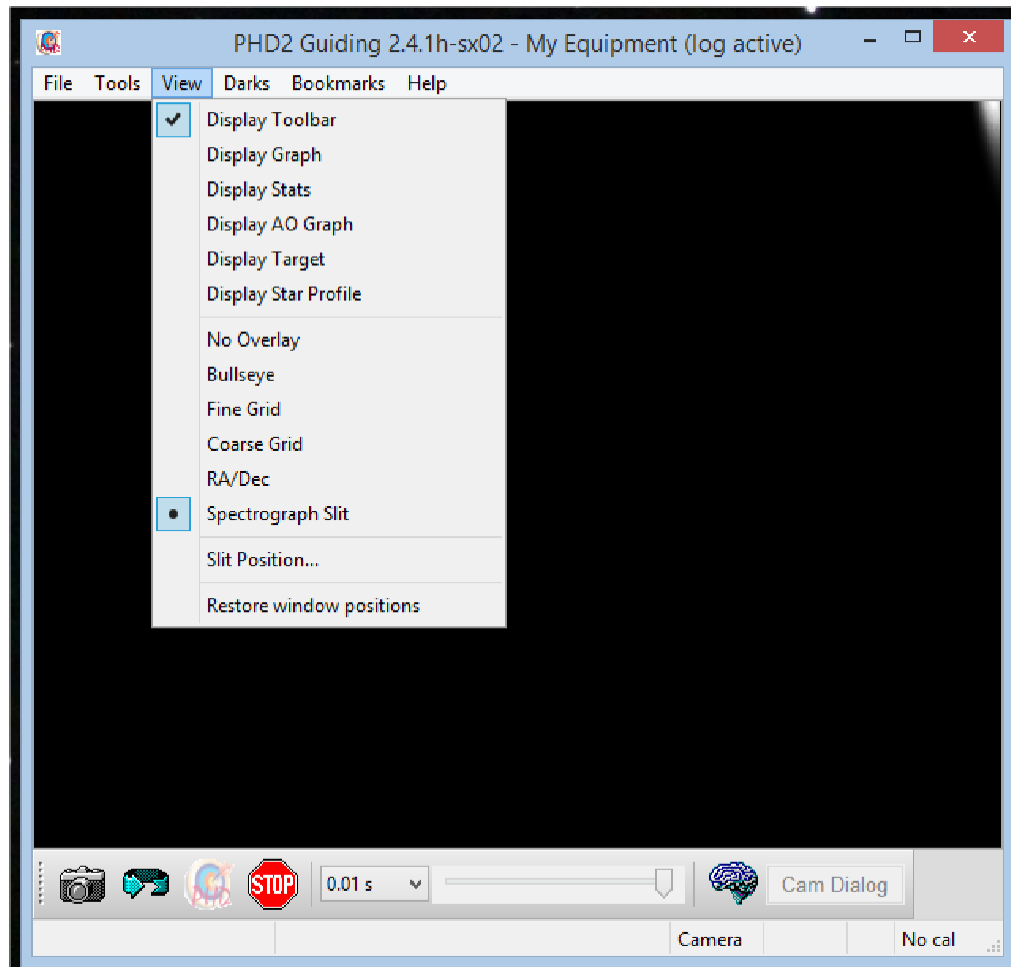
Open PHD2 and click on 'Camera'. Select 'Starlight Xpress SXV'.



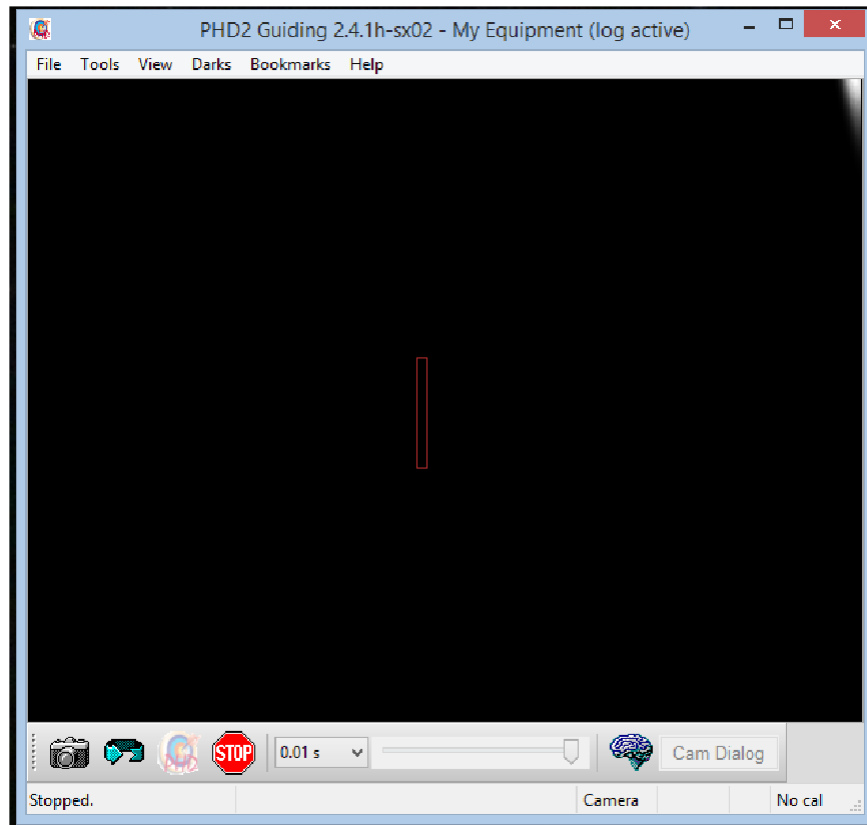
If you are using the Lodestar guider cable, select 'On camera' for the mount connection. Otherwise, select your preferred pulse guiding option from the menu.

Press 'Connect All' and you should see the Lodestar offered as the guide camera, or it will automatically connect. Connect the Lodestar and connect the mount, then shut the connection window.

Now open the 'View' menu. Select 'Spectrograph slit'.



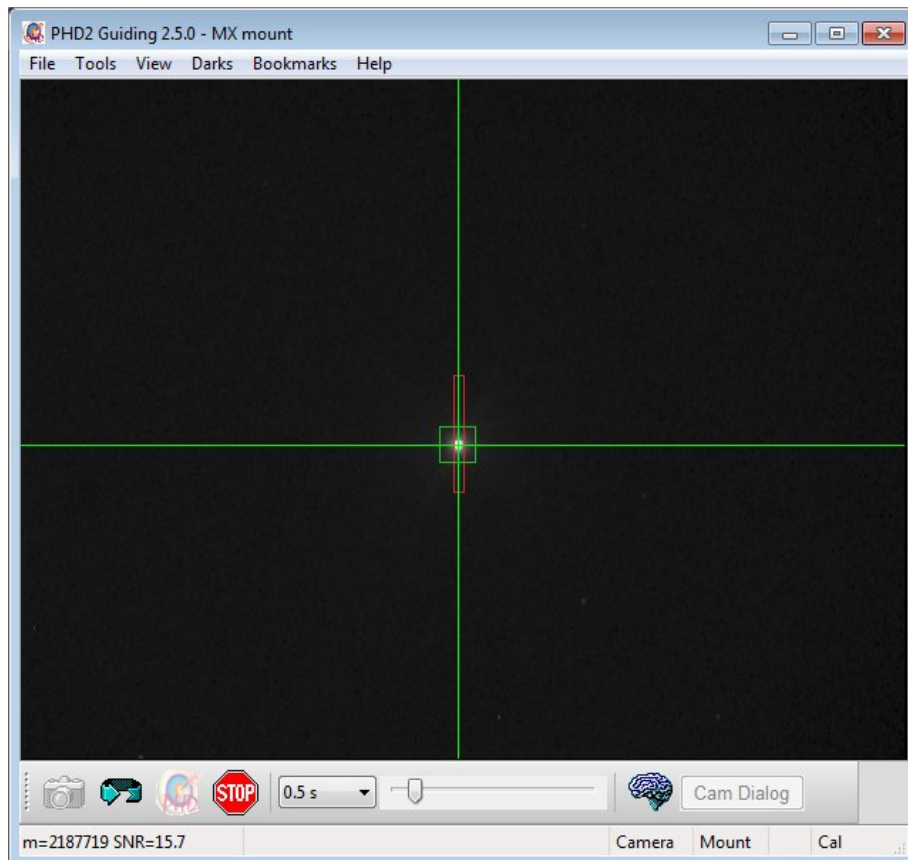
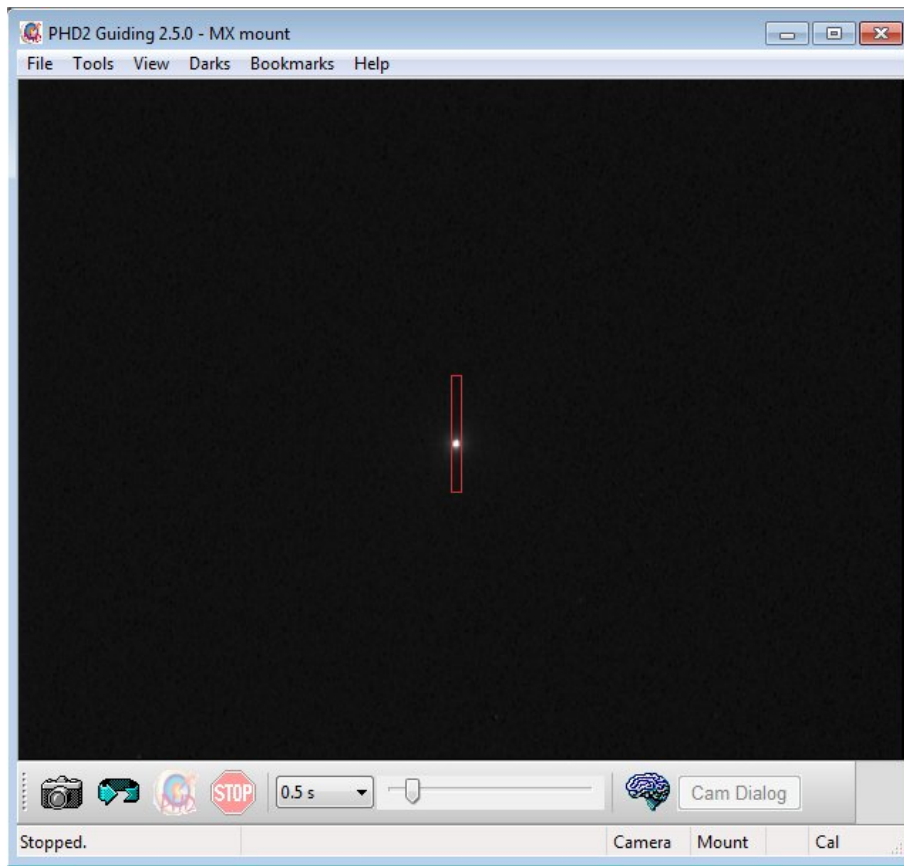
A vertical red rectangle will appear in the centre of the image - this is an approximate representation of the position and size of the spectrograph slit (assuming that the 1 mm x 20 μ m slit is in use). The slit cursor position will probably need adjusting to match your spectrograph. The nominal setting will be provided on the inside of the spectrograph box and can be entered into the 'Slit position' setting for PHD. Any refinements to the size and position can be made once a stellar spectrum is being observed.



You should now be able to start PHD2 on an imaging cycle (use the 'Loop' symbol to start it), and set up the focus on a guide star. Point your 'scope at a dense star field with many bright stars to make this job as easy as possible - open clusters like M44 are good targets. With any luck, you will be able to see several stars when using a 1 or 2 second exposure, and be able to refine the focus until the stars are sharply defined.

If you have a test target in mind, slew to this object and find a good bright guide star in the field, otherwise find any bright star to calibrate PHD2. Use the mouse to click on the guide star and then click on the 'target' icon in PHD2. A green guide box and cursor will appear and centre on the star, PHD2 will then run a calibration sequence to determine the optimum guiding parameters. Once completed, PHD2 will begin to guide on the selected star.

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You can now see if the spectrograph will give a spectrum from an object within the slit cursor of PHD. To test this, switch off guiding in PHD2, set PHD2 to looping images, and then slew a bright star into the spectrograph slit cursor box. The slewing can be done by using the 'Manual guide' option in PHD2, or by operating your telescope controls. Centre the star in the slit cursor and then select it as the guide star, so that PHD2 keeps it in position.

Imaging a test spectrum:

1) Centring the slit:

I will assume that you already have a camera attached to your spectrograph and that the imaging software is connected to this camera. Almost any software can be used - the SX software, Maxim DL, AstroArt, Nebulosity etc., just set an exposure of about 5 seconds and see if a spectrum can be seen on your computer monitor. There is a good chance that something will be visible, but you can try a longer exposure, if necessary. Note the brightness of the spectrum and then try slewing the 'scope slightly East or West before taking another image. If the brightness falls off for both directions, then the slit cursor is correctly positioned, otherwise adjust the cursor co-ordinates to optimise its location.

2) Focusing the spectrum:

Having centred your test star in the slit, take an exposure of a few tens of seconds to examine the quality of the spectrum. If the star is yellow or red (e.g. Arcturus), you should see plenty of dark absorption lines - white or blue stars, such as Vega, will have only a few hydrogen lines on a uniform continuum. If the dark lines are clearly defined, then the camera is in focus, otherwise try adjusting the focus wheel to see if you can improve it. Seriously out of focus spectra may need the lid to be removed and the coarse focus lock screw loosened to allow the T2 adaptor to get closer to the correct focus position. I also recommend that you rotate the camera so that the spectrum is close to parallel to the long axis of the CCD.

3) Centring the spectrum:

The SX spectrograph is supplied with the middle part of the visible spectrum centred on the CCD position, but you might want to change this. If so, slightly loosen the three thumb screws on the rear camera slide and then turn the black thumb-wheel at the right hand end of the slide. Turning this clockwise will move the CCD towards the red/ infra-red part of the spectrum, turning anticlockwise will move it towards the blue/ UV. Once satisfactory, re-tighten the thumbscrews.

Using the spectrograph

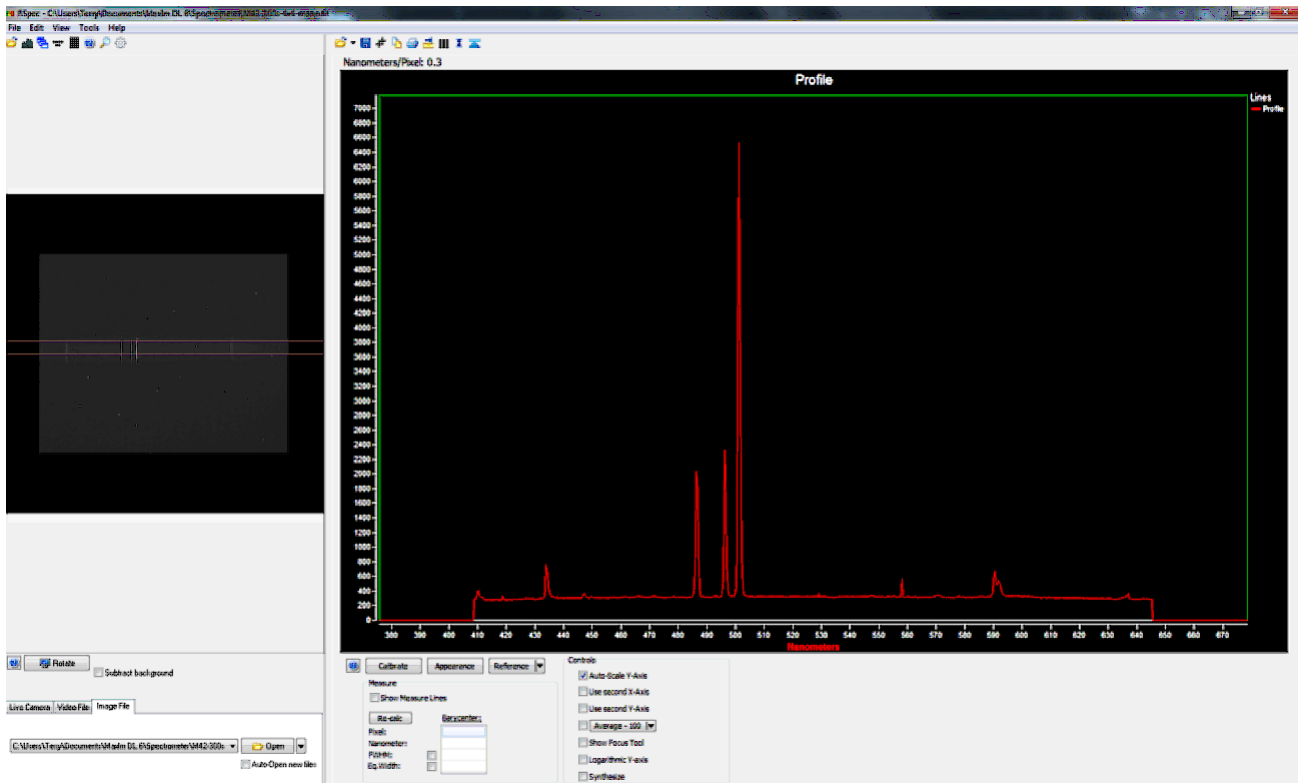
Your spectrograph is now ready for general use. The basic sequence of operations might be as follows:

- 1) Locate the field of your subject star or nebula and centre the subject in the slit cursor of PHD2.
- 2) Find a suitable guide star in the field and click the mouse cursor on it. Click the PHD2 target button to start guiding.
- 3) Start an exposure with your imaging camera software. The exposure time required will depend on the subject brightness, but 5 or 10 minutes will suffice for many fairly bright objects. Adjust as necessary.
- 4) Save your spectrum image as a FITS file. You might also like to 'stretch' the image contrast and save the result as a jpeg or Tiff for easy import into other software (such as RSpec - see below).

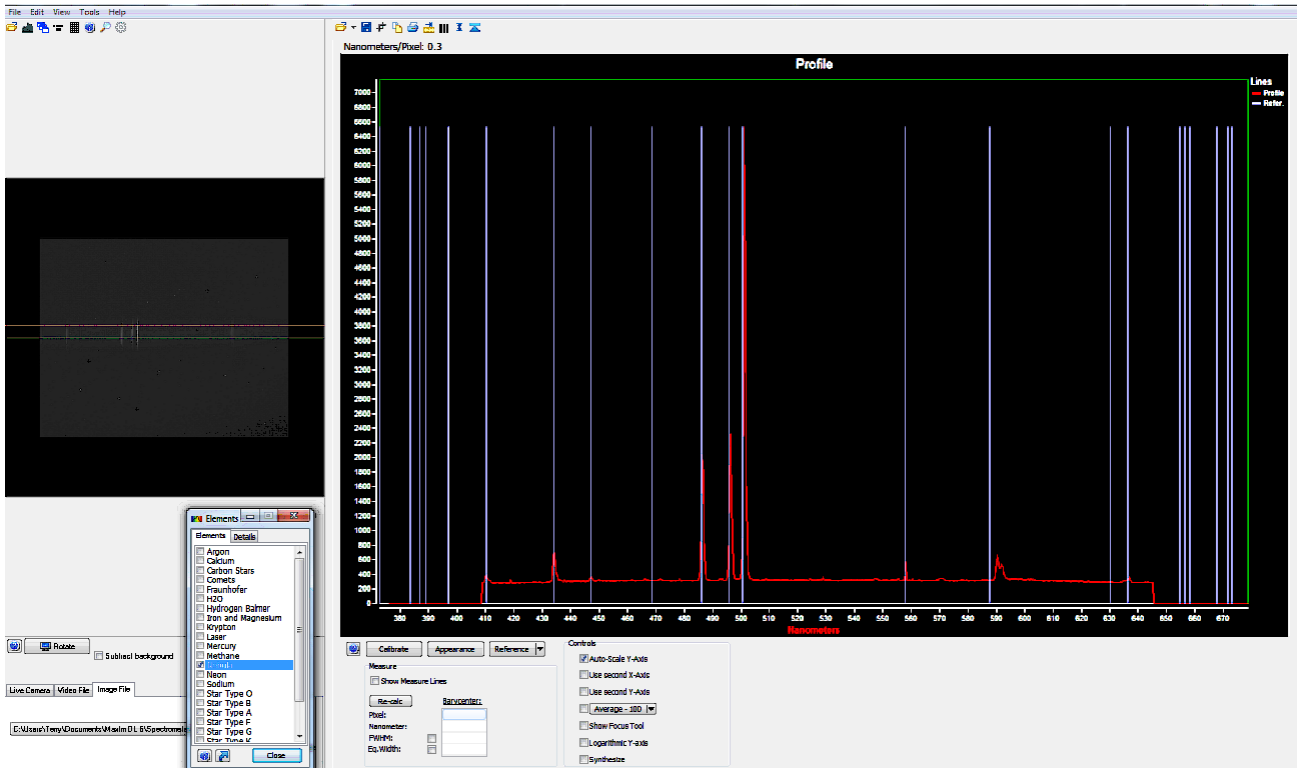
These simple instructions are sufficient for capturing a spectrum, but you will probably want to identify spectral lines and, perhaps, perform further analysis of the data. To this end, we recommend using the third party program 'RSpec'. RSpec is an easy to use spectral analysis software that can show a graphical plot of your spectrum and will allow you to calibrate the wavelengths of the visible spectral lines. The current full price is a very reasonable \$99, but we have included in your purchase price of the Starlight Xpress spectrograph, a license for this software. You can begin using the software immediately by downloading a 30-day trial version from their website: www.rspec-astro.com/download. To remove the 30-day restriction on the downloaded version, contact them at info@fieldtestedsystems.com, providing the serial number of your spectrograph, the date of purchase and the dealer from whom you purchased the spectrograph."

Once RSpec is installed on your computer, start the program and click on 'Open' at the lower left side of the screen. Find your jpeg or Tiff image and open it. RSpec will show your spectrum in the small image box at the left hand side of the screen. Now drag the upper and lower cursors so that the spectrum is neatly boxed between the cursors - the large window

will display a plot of the line profiles in the spectrum. The following image shows a spectrum of the Orion nebula (M42) and you can see the strong oxygen lines etc. very clearly.



The line wavelengths may now be calibrated by superimposing one of the RSpec reference spectra onto the display. Here is the result of superimposing the 'Nebula' reference and then matching the strong emission lines by using the 'Calibrate' option in RSpec. You can see that the hydrogen and oxygen lines match up well with the calibration chart. The small 'double peak' at the right is caused by sodium light pollution and is not in the calibration chart. You can see that the spectrum is quite linear and matches the reference very well.

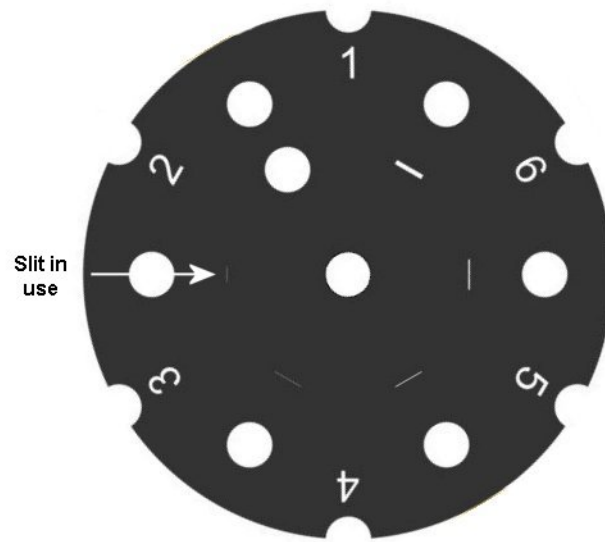


Bright nebulae, such as M42, give excellent calibration spectra, with very well defined emission lines. White or blue bright stars, such as Vega, can also be used, as their spectra show strong hydrogen absorption features that are easy to identify. You can, of course, also use the internal calibrator light source. This provides bright spectral lines from a mix of argon and neon, so there are lines from near infrared to near UV. Once calibrated, the spectra should be stable and not need further calibration, unless the spectrometer optics are adjusted in some way.

Selecting a slit width:

The standard 20 μm x 1 mm slit (position 1) is best for high resolution spectra, but restricts the light input from extended objects to a low level and so limits the sensitivity of the spectrograph. You can use wider slit settings to increase the sensitivity at the expense of resolution - this will be acceptable for many examples of faint nebulae etc.

Remove the spectrograph cover and locate the slit wheel with its central silver thumbscrew. The slit wheel is locked in place by a 3 mm setscrew (on the right hand side), which can be accessed with a 1.5 mm hex key via the hole near the edge of the input aperture. However, it is generally unnecessary to do this, as the slit wheel centre thumb screw can be loosened to the point where the wheel can be lifted clear of the lock screw and rotated to a new slit position. The selected slit number is shown at the top of the wheel. Re-tighten the centre thumbscrew when ready, ensuring that the slit locating hole is over the lock screw.

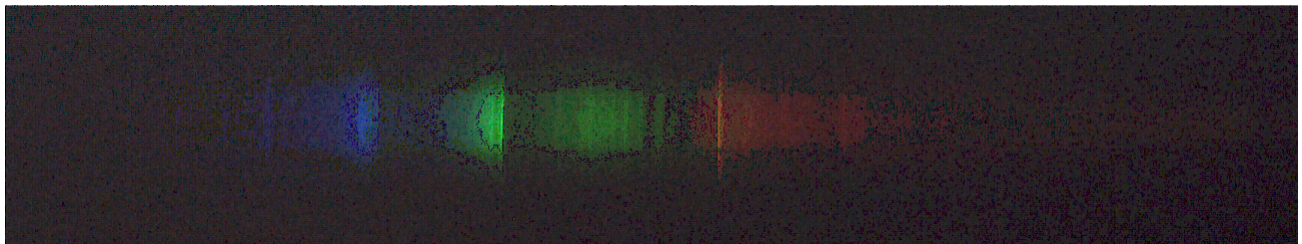


The slit wheel, showing the slits and locating holes

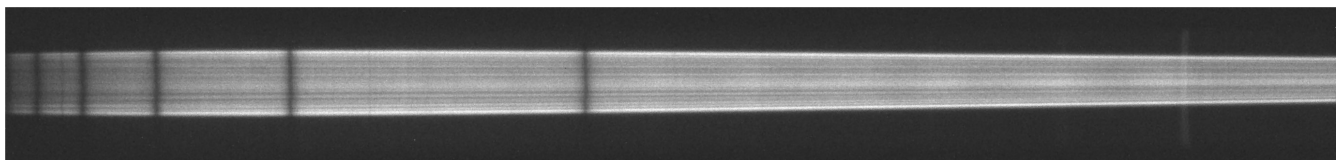
For maximum light input with point sources (stars or small nebulae), select slit position 6. This will open up a 3 mm circular aperture and your spectrum will become an overlapping streak of images of the object. This can be very effective on planetary nebulae and extremely faint stars.

Be careful to keep the slits as clean as possible - very small particles will cast strong dark streaks along the full length of the spectrum. An air cannon, or soft photographic lens brush, will generally work quite well.

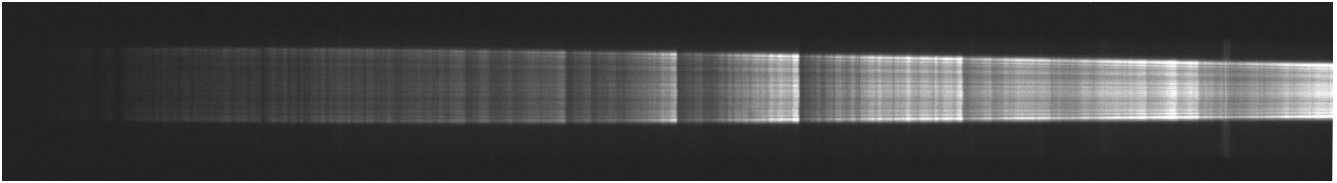
Here are some sample test spectra of various objects, taken with the spectrograph attached to a Takahashi FSQ106:



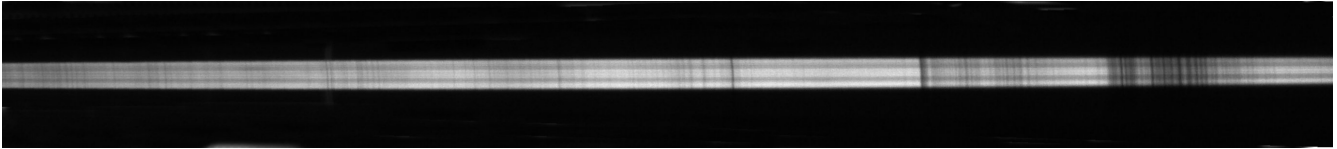
Comet Lovejoy 2014C/2 - showing ionised carbon emissions



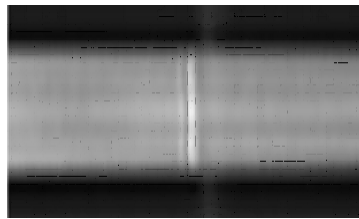
Alpha Corona Borealis - showing hydrogen absorption lines



Rasalgethi (Alpha Herculis) showing 'fluted' lines, typical of red supergiant stars



Methane absorption lines in the near-infrared spectrum of Saturn



Hydrogen line doubling from the orbital Doppler shifts in Beta Lyrae

Because the spectrograph uses a concave grating at a steep angle, there is a small amount of residual astigmatism in the spectral image. Although astigmatism is normally undesirable, it can be quite useful for expanding the height of the spectrum from point sources. This makes the emission and absorption lines more readily visible, without the need to de-focus the star image at the slit. As the astigmatism is somewhat variable with wavelength, the spectral height is at a maximum in the blue and steadily reduces towards the infrared. This is clearly visible in the spectrum of Alpha Corona Borealis above. For most practical purposes, this is of little importance, but many image processing programs include geometric correction options that can be used to make the spectrum more uniform. A horizontal perspective correction in 'Paint Shop Pro' was used to correct the Methane spectrum above.

Advanced adjustments for experienced users:

The height and resolution of the spectrum are both strongly affected by the angle of the small flat mirror in the spectrograph. We try to optimise this setting to give best results, but you might want to experiment with the angle to achieve a different spectral width or line shape. The theoretical 'best angle' is marked by a groove in the floor of the spectrograph, but a variation of two or three degrees in either direction, will change the spectrum in subtle ways. To make a change, slightly loosen the countersunk M4 screw that is visible on the underside of the spectrograph. You can now slew the mirror holder slightly to change its angle and then observe the results. Note that the focus of the spectrum will also change as the mirror is twisted, so be careful to check that the camera is accurately in focus when checking the result of your adjustment. Multiple changes to the spectrum will be seen, as follows: (1) The apparent height and taper of the spectrum (2) The curvature of the emission and absorption lines (3) The definition of the lines (4) The start and end positions of the overall spectrum (5) The position of the focal plane of the spectrograph. Clearly, you need to thoroughly check that all of these parameters are acceptable, before re-tightening the mirror fixing screw.

Calibrator lamp battery replacement:

The calibration light source is powered by a 9 volt PP3 or MN1604A alkaline battery. This battery will last about 10 hours in continuous operation. The battery is easily accessible by removing the spectrograph cover and lifting the battery out of the top compartment. Unclip the connector and snap a new battery into place. Take care that the clip and wires are not projecting so far that the spectrograph cover will not fit.

Spectrograph specifications:

Basic design:

Self-collimating concave reflective grating spectrograph with a highly corrected flat field toroidal grating. Minimal attenuation of near UV, due to mostly reflecting optics. Built-in guide camera and calibration source.

Grating specifications:

Groove pitch - 550 grooves per mm at centre of grating.

Blaze wavelength - 400 nm.

Spectral efficiency at 400 nm - Greater than 50%.

Useful spectral range - 340 to 900 nm

Useful grating aperture - 26 x 26 mm.

Slits:

Rotary slit wheel with 6 slit positions:

Position 1 - 20 μ m x 1 mm

Position 2 - 20 μ m x 2 mm

Position 3 - 50 μ m x 2 mm

Position 4 - 100 μ m x 2 mm

Position 5 - 300 μ m x 2 mm

Position 6 - 3mm x 3 mm circular

Input / Output:

Female T2 thread (42 x 0.75 mm) input

Male T2 thread output

Input back focal distance - approximately 37 mm

Output back focal distance - nominally 17 mm, adjustable between approximately 10 and 20 mm

Size:

Box size - 120 x 115 x 70 mm

Weight - 1.17 kg

Dear Observer,

Thank you for purchasing a Starlight Xpress CCD Imaging System. We are confident that you will gain much satisfaction from this equipment, but please read carefully the accompanying instruction manual to ensure that you achieve the best performance that is capable of providing.

As with most sophisticated equipment a certain amount of routine maintenance is necessary to keep the equipment operating at its optimum performance. The maintenance has been kept to a minimum, and is fully described in the manual.

In the unfortunate instance when the equipment does not perform as expected might we recommend that you first study the fault finding information supplied. If this does not remedy the problem, then contact Starlight Xpress for further advice. Our message board service on the Starlight Xpress web site will often provide solutions to any problems.

The equipment is covered by a 12-month guarantee covering faulty design, material or workmanship in addition to any statutory Consumer Rights of Purchasers.

CONDITIONS OF GUARANTEE

- 1) The equipment shall only be used for normal purposes described in the standard operating instructions, and within the relevant safety standards of the country where the equipment is used.
- 2) Repairs under guarantee will be free of charge providing proof of purchase is produced, and that the equipment is returned to the Service Agent at the Purchaser's expense and risk, and that the equipment proves to be defective.
- 3) The guarantee shall not apply to equipment damaged by fire, accident, wear and tear, misuse, unauthorised repairs, or modified in any way whatsoever, or damage suffered in transit to or from the Purchaser.
- 4) The Purchaser's sole and exclusive rights under this guarantee is for repair, or at our discretion the replacement of the equipment or any part thereof, and no remedy to consequential loss or damage whatsoever.
- 5) This guarantee shall not apply to components that have a naturally limited life.
- 6) Starlight Xpress's decision in all matters is final, and any faulty component which has been replaced will become the property of Starlight Xpress Ltd.

For further info. or advice, please call:

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