

RS-Spectroscope™

User's Manual



Decoding the Message in Starlight

The RS-Spectroscope attaches to an eyepiece to spread light from stars and nebulae into a rainbow of colors – colors that provide a whole new way to enjoy astronomy. Astronomers analyze the rainbows of stars -- analyze the colors present and the colors missing -- to decode the message in starlight, a message that reveals the true nature of stars, nebulae and the universe. Use the RS-Spectroscope to experience what astronomy textbooks only describe. Discover the absorption and emission lines that fingerprint the chemical makeup of stars and nebulae. See the OBAFGKM spectral sequence in living color. Visualize the Hertzsprung-Russell diagram that arranges stars by luminosity, size, temperature, pasts, presents and futures.

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Using the **RS**-Spectroscope for Visual Observation

Overview

The RS-Spectroscope has (1) a grating element that disperses light into a *spectrum* (rainbow) and (2) a widening lens element that widens features in the *spectrum* into *spectral lines*.



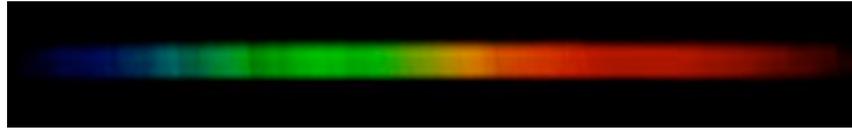
(1) Grating Element (2) Widening Lens Element

Use both elements together for stars. Below is the *spectrum* of Betelgeuse *unwidened*, just as it comes out of the RS-Spectroscope grating element (photographed with a coolpix-995 digital camera). Some spectral features created by molecules in the star's atmosphere can be made out (bands of color with slight dimming between them) in the blue/green, but that's about it.



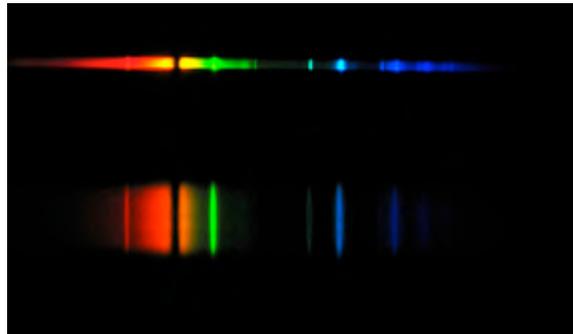


Add the widening lens element and much, much more is revealed. Below is the spectrum of Betelgeuse widened to show many more spectral features. The *molecular bands* are clearly shown in the blue and green, and individual *absorption lines* (dark lines running across the width of the spectrum) throughout the whole spectrum.



By the way, you now know why astronomers speak of spectral features as spectral *lines*, not spectral *dots*. It is the widening of the width of the spectrum that stretches spectral *dots* into spectral *lines*. Lines are much easier to see because, well because they are (that's how the eye works).

Attachment the widening element is easy. Push it into the hole on top of the grating element with the white line aligned with the white line on the spectroscopy. Fine tune alignment by rotating it in the hole to make sure spectrum is widened correctly. Test drive it on a distant sodium vapor street light to make sure the lines are at right angles to the spectrum. Below is the bright line spectrum of a distant sodium vapor street lamp without (top) and with (bottom) the widening lens. Note that the length of the spectrum is about 10x the width of the spectrum. This will give you a feeling for how wide the spectrum should appear with the widening lens. Bright line spectra are much easier to see than dark line (stellar) spectra.



like planetary nebulae, have rainbows that consist of a few widely spaced colors with the colors in between missing. These are called *emission line* spectra. That's why nebular filters make viewing nebulae easier, they let through the colors nebulae emit, and block the other colors which are just skylight from city lights. Through the RS-Spectroscope, planetary nebulae can appear as single or multiple images, one in each of the brighter emission lines, while nearby stars will appear as streaks.

We recommend using eyepieces with long eye relief, as the RS-Spectroscope will place your eye about an inch back from the eyepiece. Small, sharp star images is important, as it is the sharpness of the star image that defines the sharpness of the lines in a star's spectrum, as seen through the RS-Spectroscope.

Attaching the RS-Spectroscope to an eyepiece

Remove the rubber eyeguard from the eyepiece (1). Loosen the three red thumb knobs, mate the RS-Spectroscope to the eyepiece, tighten the three red thumb knobs into the rubber eyeguard groove (2). Attach the rubber eyeguard to the RS-Spectroscope camera adaptor groove if you prefer. For smaller diameter eyepieces, use the 3 long thumb screws.



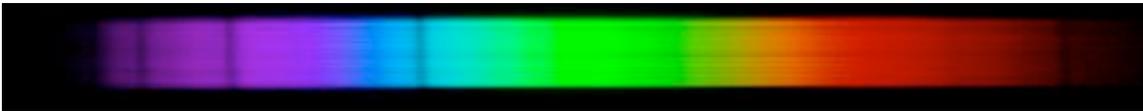
(1) Remove rubber eyeguard



(2) Attach RS-Spectroscope

Acquiring, Focusing and Viewing a Star's Spectrum

Acquire, center, and focus either **Sirius or Vega** as you normally would before attaching the RS-Spectroscope to the eyepiece. Focus the telescope for normal vision (with your glasses on) then attach the RS-Spectroscope to see the spectrum. Sirius and Vega are bright and have strong, easy to see *spectral lines* (the dark, absorption lines are the spectral fingerprint of the element Hydrogen in the star's atmosphere) and are great for focusing. Sirius' spectrum, photographed with a coolpix-995 digital camera and an RS-Spectroscope looks like this.

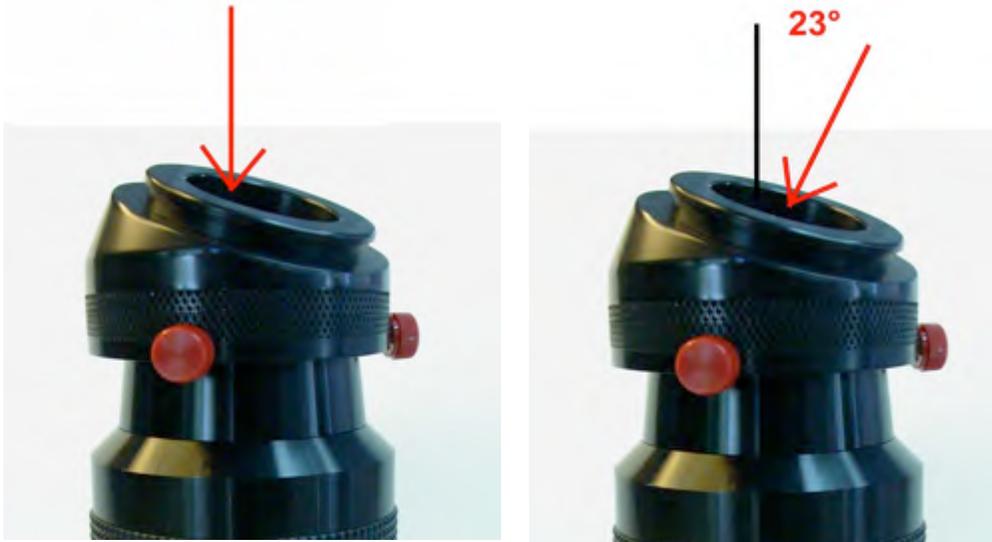


You may see dark lines that run left/right *along* the length of the spectrum, these are due to the star twinkling so **ignore them**. The dark lines that run up/down *across* the width of the spectrum are the *spectral lines*. **Adjust telescope focus to make these sharp**. Once you've focused Sirius or Vega then you should not have to readjust focus again. If you do adjust focus on another star remember to make the *spectral lines* that run *across* the width of the spectrum sharp.

If your spectrum looks like a sharp streak (below), then you're not focused. The spectrum should have a width approximately 1/10th the length of the spectrum (above) with dark lines running across it. Adjust the focus from the sharp streak (below) so the blue end of the spectrum widens first followed the red end of the spectrum (because the widening lens bends blue light more than red light). Continue to adjust the focus in that direction until you see the dark lines like above.



You don't have to remove the RS-Spectroscope from the eyepiece to acquire subsequent stars. The RS-Spectroscope spreads about 60% of a star's light into a *first order* spectrum which exits the RS-Spectroscope grating element at about a 23 degree angle (that's why the back of the grating element is tilted over at 23 degrees).

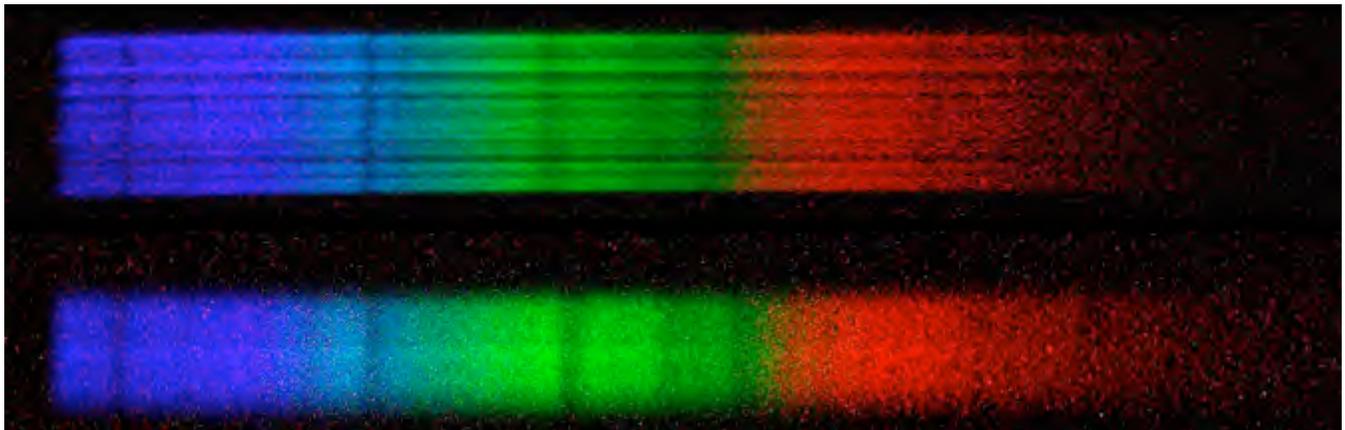


(1) Acquiring a star using zero order (2) Viewing the first order spectrum

Another 20% of the star's light comes straight out the back in what is called the zero order. The zero order looks like a normal but fainter image of the starfield with the stars appearing as small dashes of light (due to the RS-Spectroscope widening lens element). View the zero order to acquire a star and center it by looking through the RS-Spectroscope, straight-on into the eyepiece (1), then lean over at 23 degrees to view the star's spectrum (2).

Seeing Does Matter

The **astronomical seeing** (how sharp a star appears in the eyepiece appear, depending upon how wiggly the air) can make a big difference on the visibility of spectral lines. Below is a comparison of Spica on a good night (top) with steady air and good seeing and a poor night (bottom) with wiggly air and poor seeing. The effects of astronomical seeing can be mitigated by picking a night of good seeing



Using the RS-Spectroscope With a Digital Camera

Attach the RS-Spectroscope to an eyepiece, acquiring a star to view, focusing and viewing the spectrum the same as described for visual observation. The RS-Spectroscope is compatible with digital camera adapters like the QuikAdapt shown below with a consumer digicam (left) and a Digital SLR (right).



Size Does Matter

The techniques that follow describe use with a Digital SLR camera, but also work for a digicam. The advantages of the Digital SLR over a digicam are:

- 1) Brighter spectrum: The bigger the camera lens, the brighter the spectrum.
- 2) Sharper spectrum: The bigger the camera lens, the better the resolution of the spectrum.

Using the RS-Spectroscope With a Digital SLR

Prime focus technique is normally used for astrophotography with a DSLR: The camera lens is removed from the DSLR and the objective of the telescope images directly onto the sensor chip. This can be done with the QuikAdapt by attaching the 2" SLR adapter (essentially a hollow 2" outside diameter tube) to the QuikAdapt and the DSLR (with its camera lens removed).



For spectroscopy, the eyepiece is needed to parallelize the light from the star image into the grating. The camera lens then focuses the light exiting the grating into a spectrum on the DSLR sensor. Since DSLR lenses are pretty long and zoomable, we've engineered an extension to the QuikAdapt riser (see photo below). The camera attaches to the extension using the tripod mounting hole on the base of the camera. The extension can be raised and lowered about 1/2 inch to adjust eye relief for different camera lens zoom selections (e.g., 28, 35, 50, 70, 90). To "square" the optical axis with the QuikAdapt, zoom the camera all the way out till it touches the flat plate with the oblong hole and tilt the camera the lens is flat on the plate, tighten the black camera mounting knob.



Below is the optical stack – eyepiece + RS-Spectroscopy + DSLR. Notice the orientation of the RS-Spectroscopy and the DSLR lets the RS-Spectroscopy disperse the spectrum along the long dimension of the DSLR sensor



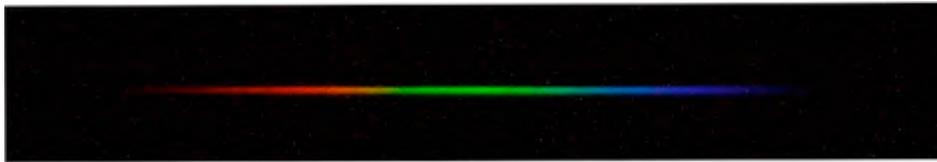


Attach this stack directly into the focuser. If you use a diagonal be careful, it may rotate due to the combined weight of the stack. Since you'll be using your laptop to remotely control the DSLR, you'll only need to look through the camera viewfinder for initial focusing and alignment.

Initial Alignment and Focusing

Center and focus a bright star in the eyepiece alone then adjust the finder crosshairs. You'll be using the finder to realign the telescope, not the eyepiece or camera. Remove the eyepiece, reassemble the optical stack, reinsert the stack the RS-Grating tilting NORTH and cinch the eyepiece set screw snugly, so the stack doesn't rotate or fall out. Using the stack with the RS-Spectroscope angling north lets you widen the spectrum by turning the clock drive off. The additional benefit is any clock drive tracking errors will widen the spectrum, not blur it.

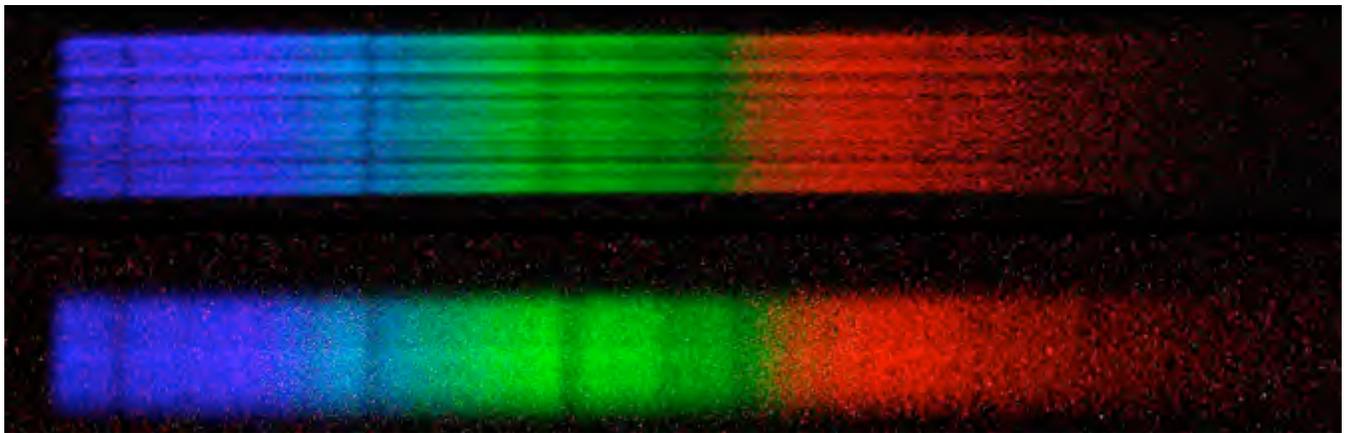
Center on a bright star (using the finder telescope) and set the camera manual focus at infinity, and to a mild zoom (e.g., 70mm). Pick a bright A spectral type star as they have broad Hydrogen lines which will make fine focusing easier. Set the camera focus to infinity and zoom to 70mm. Looking through the camera viewfinder you should see a faint rainbow streak (the spectrum) which you can focus into a sharp gray streak by adjusting the telescope focus.



Center the rainbow streak in the camera viewfinder (if you half press the shutter button, a green ruler will appear soon the bottom of the camera viewfinder that will help you with this alignment).

Seeing Does Matter (Part 2)

The **astronomical seeing** (how sharp a star appears in the eyepiece appear, depending upon how wiggly the air) can make a big difference on the sharpness of spectral lines. Below is a comparison of Spica on a good night (top) with steady air and good seeing and a poor night (bottom) with wiggly air and poor seeing.



The effects of astronomical seeing also show up in the top (good night) as the wiggling back in forth of the spectral line from top to bottom, as the spectrum of the star drifted across the eyepiece (drift spectrum). This wiggling shows up in a **drift spectrum** as sharp spectral lines wiggling back in forth, in a **streak spectrum** the effect of seeing will show up as blurry spectral lines.

The effects of poor seeing and wiggling air can be minimized with a slit in front of the eyepiece, which is how spectroscopes are usually equipped. The star may bloom, shrink and wiggle but the slit doesn't. The only light that gets into the spectrum is the light that gets through the slit. The trade off is the loss of the light that doesn't make it through the slit, cost and complexity. The effects of seeing of can be mitigated for the RS-Spectroscope by picking a night of good seeing and by using a telecompressor to make the star images and the wiggles smaller.

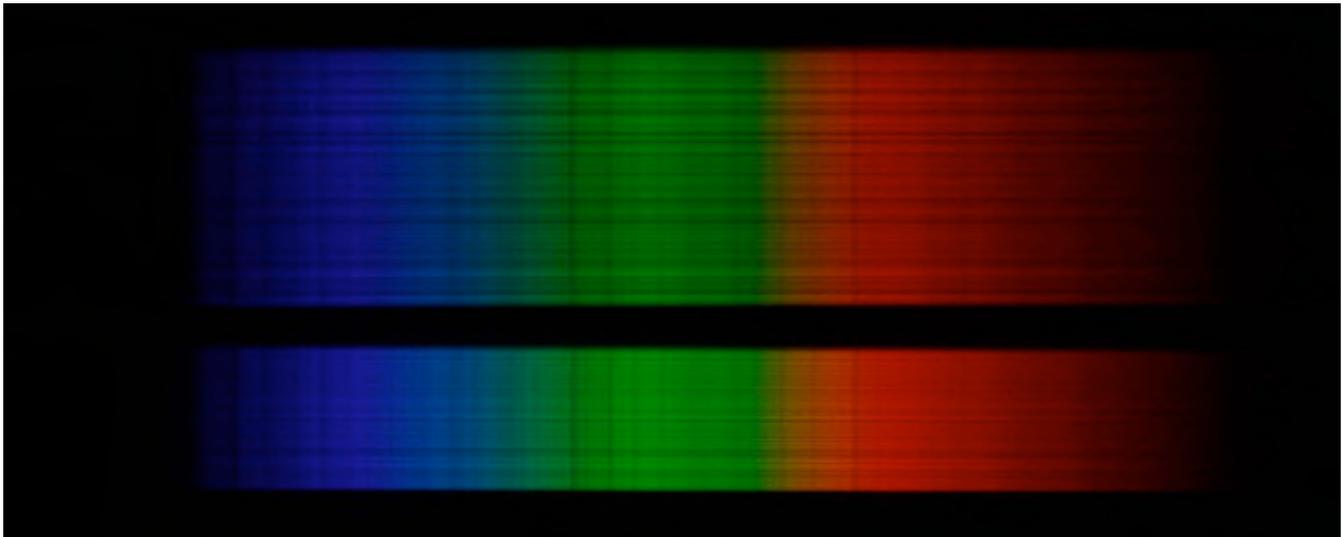
Size Does Matter (Part 2)

The spacing of the telecompressor lens from the eyepiece focal plane (usually found by looking into the end of the eyepiece for the aperture stop using this equation. Sample inputs for **F**, **s**, **f** produce a resulting magnification reduction of 0.51. This required attaching the telecompressor lens to the front of the diagonal, not to the eyepiece.

Telecompressor

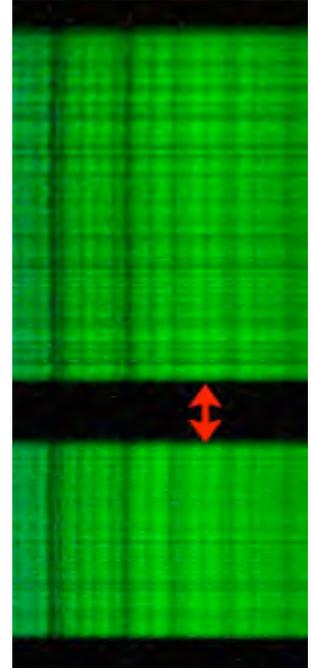
1.00	theta	deg		beam angle used for the calculation
2032.00	F	mm		focal length of telescope
35.47	D	mm	$D = F \cdot \tan(\theta)$	distance of beam from centerline at focal plane
150.00	s	mm		TC lens to focal plane spacing
34.85	r	mm	$r = (F - s) \cdot \tan(\theta)$	distance of beam from centerline at TC lens
300.00	f	mm		focal length of TC lens
6.63	phi	deg	$\phi = 90 - \arctan(f/r)$	angle beam bent back towards centerline by TC lens
17.42	z	mm	$z = s \cdot \tan(\phi)$	distance beam bent back towards centerline at focal plane
18.04	d	mm	$d = D - z$	distance of bent beam from centerline at focal plane
0.51	M		$M = d/D$	magnification

Here's the result for Arcturus. The top spectrum is without a telecompressor, the bottom spectrum is with a telecompressor spaced at the correct distance from the focal plane of the eyepiece.



The compressed spectrum is about half the width, as expected from the magnification reduction, plus it is also brighter and less noisy (most obvious in red end of spectrum), as the spectrum stays on each row of pixels twice as long – another advantage of the telecompressor for obtaining spectra of fainter stars.

Now what about sharpness and wiggle? Here's a closeup in the green part of the spectra for Arcturus. Note some of the fine detail is lost in a jpeg image (see discussion below regarding jpeg vs raw). In the bottom spectrum (with telecompressor) the sharp, faint line is more distinct. Also note the visibility of faint lines between the two broad lines on the left are also more distinct, especially the one on the right next to the broad dark line. Wiggles and focus/defocus due to atmosphere in the lines from top to bottom are less in the telecompressed spectrum (bottom). So the telecompressor offers a number of advantages. This also plays over into aperture – a 5" scope will have about the same performance as an 8" scope of the same f-ratio.



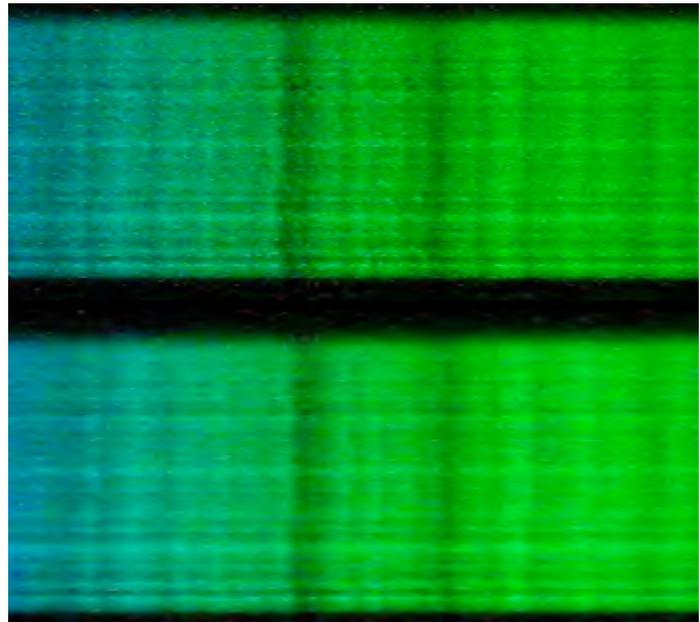
Remote Camera Operation

Follow the directions in your camera manual. The Canon EOS utility controls everything except zoom. Turn your camera on and set the camera mode (round knob on top) to manual (M). The quality of the spectrum image depends on the magnitude of the star and these parameters you can adjust

- 1) F ratio (set to 5.0 and leave it there)
- 2) Image quality (use L+RAW)
- 3) Exposure time (up to 30 seconds)
- 4) iso (100, 200, 400, 800, 1600)

Raw data is better than JPEG images. The image here compares a RAW (top) vs JPEG (bottom) for Arcturus. The JPEG 8x8 coding block noticeably degrades resolution. This will be especially obvious on shorter zooms (28, 35) and fainter stars (noisier images).

The Canon camera will do automatic dark frame subtraction if set up to do so. Automatic dark frame subtraction will double the effective exposure time as the camera will take two exposures, the spectrum frame and the dark frame.

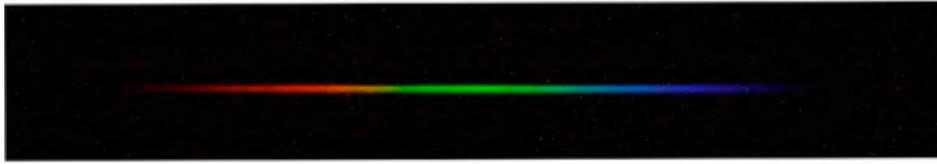


Fine Alignment and Focusing

Take a one second exposure. Based on position of the spectral streak in the camera frame, use the telescope RA & DEC fine adjustment controls to park it in the center. Use more short exposures to

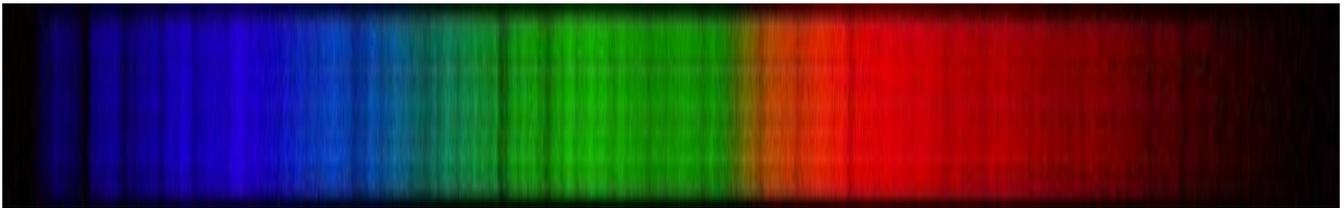


confirm after each adjustment. When it's centered, check your finder to see where the star is on the crosshairs. You could adjust the finder to put it back on the crosshair but I do not recommend that since because of the weight of the optical stack, it will change as you move around the sky. It's best just to remember where it the star is in the finder when it's centered in the camera.



Drift Spectrum

Exposure time sets the width of the spectrum while iso and zoom adjust the quality of the spectrum image. Using Arcturus as an example, a C8 telescope, with zoom at 70mm and iso at 800 and some processing produces pretty spectacular results.



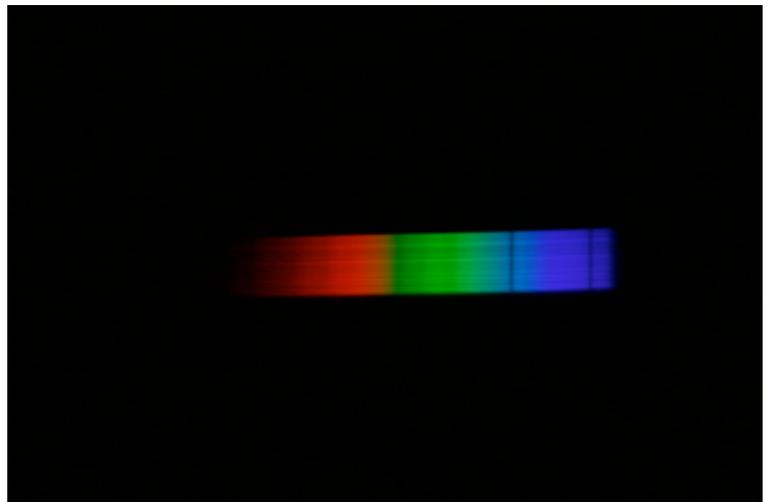
For **fainter stars** adjust **iso up** and/or **zoom down**. For **brighter stars** adjust **iso down** and/or **zoom up**. For example, Vega is too bright for iso 800, so use iso 400 or 200. For Regulus try iso 800 or 600 and zoom 70 or 50.

To collect a drift spectrum like the above for Arcturus, Set the camera to

- 1) Zoom = 70mm
- 2) iso = 800
- 3) Exposure = 8 sec

Turn the clock drive off and start the exposure. When you hear the camera finish the exposure, turn the clock drive back on. Examine the spectrum on your computer. You should see two broad Hydrogen lines in the blue end of the spectrum, like this, for Vega. If the lines aren't sharp, adjust the focus about 1:20th of a turn one way and take another exposure.

If the spectral lines got blurrier, adjust focus the other way and take another exposure. You get the idea. Stop when the lines are sharp! I've found that the focusing is very forgiving with a long focal length eyepiece, like the 40 or 55 mm televue plossls.





Adjusting Skew and Rotation

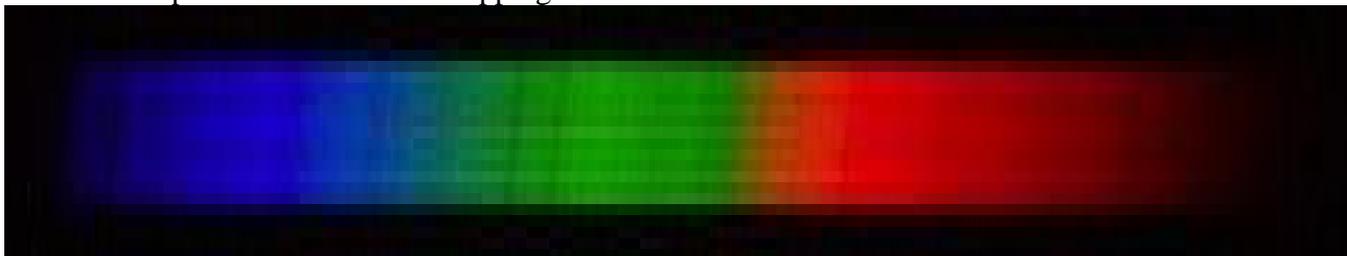
Ideally, the spectral lines should be at right angles to the spectrum and the spectrum nice and square in the camera frame. You can adjust skew by loosening the eyepiece set screw, rotate the entire stack, retighten the eyepiece set screw. Try a few more exposures to check. Any residual skew can be corrected in Photoshop (distort : skewing). You can adjust rotation by loosening the QuikAdapt attachment screw (the long one) and rotating the camera slightly. Half press the shutter button to get the green ruler which will help. Any residual rotation can be corrected in Photoshop (image : rotate canvas).

Processing

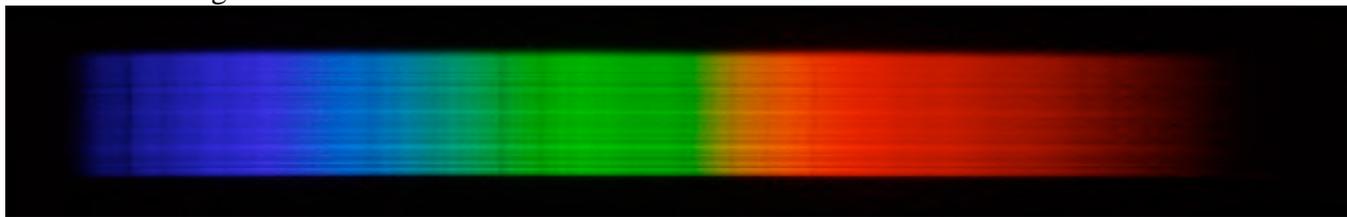
I use three applications for processing the raw image files:

- 1) **Digital Photo Professional** (comes with the Canon camera). Use to convert RAW images from Canon's CR2 format to 8-bit TIFF (File : Convert and Save : 8-bit TIFF).
- 2) **Photoshop** (expensive). Cropping (Image : Crop), rotation (Image : Rotate Canvas) and skewing (Distort : Skew) of the spectrum image. Also use to generation the spectrum continuum image (Blur : Motion Blur : 0 degrees, 50 pixels).
- 3) **ImageJ** (freeware). Scale the spectrum continuum image (Process : Math : Multiply by 0.7) and then subtract (Process : Image Math : Subtract) from the cropped/rotated/skewed spectral image to enhance the spectral lines.
- 4) **Photoshop** (one more time) Tweak the contrast (Image : Auto Contrast) of the final spectrum image.

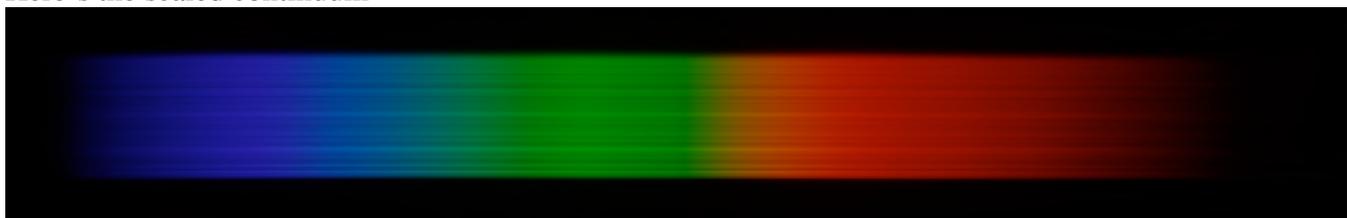
Here's a sample of Arcturus after cropping and rotation



After de-skewing

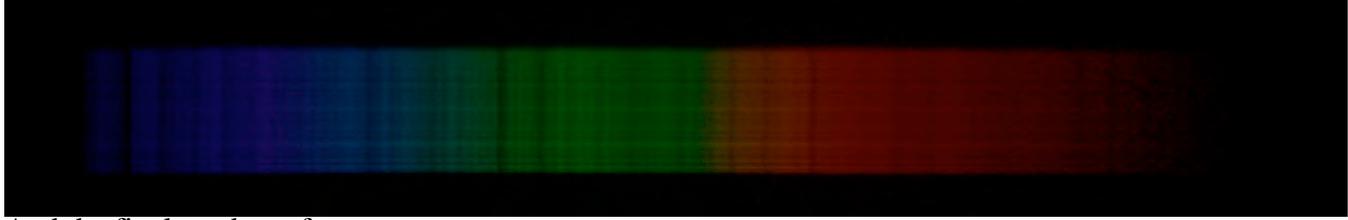


Here's the scaled continuum

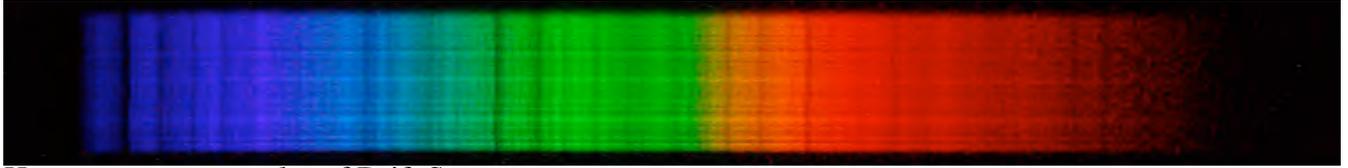




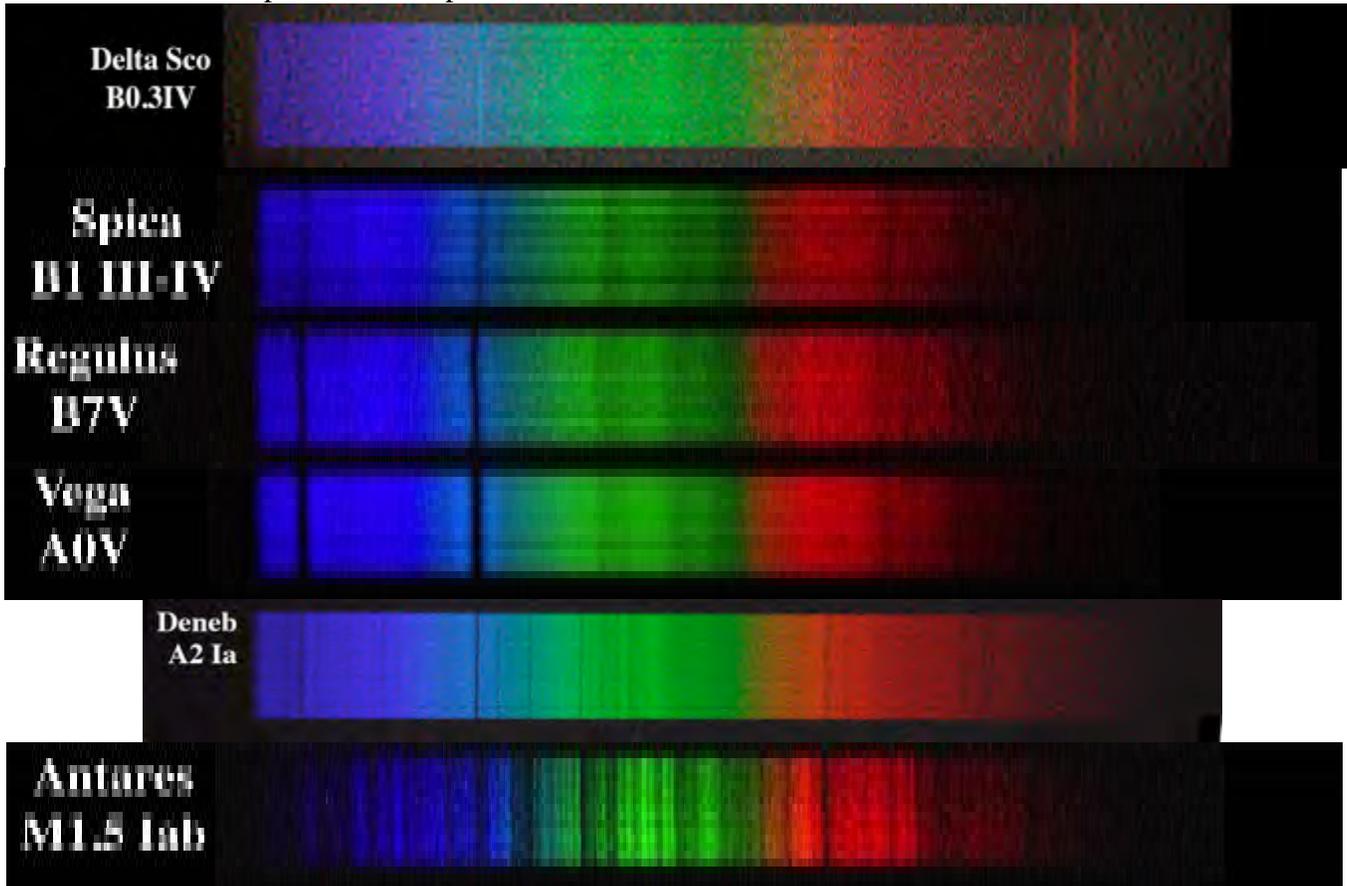
Here's the spectrum after subtraction of the scaled continuum



And the final product after auto-contrast



Here are more examples of Drift Spectra



Streak Spectrum

Streak Spectrum is for fainter stars or non-stellar objects. Leave the clock drive on while collecting the spectrum and the spectrum is collected as an unwidened streak. This concentrates more photons into each pixel and produces a brighter spectrum than the drift method but resolving spectral lines (lines being an artifact of widening the spectrum by techniques like turning the clock drive off) is much more difficult. Here, for example is the streak spectrum of Arcturus, processed as described above for a 1/4th second exposure at iso 1600, zoom 70,mm.

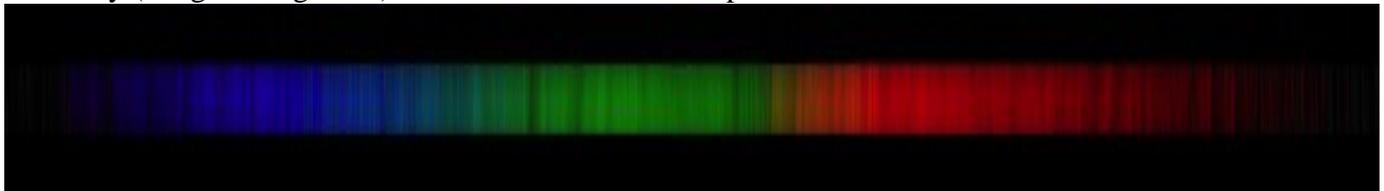




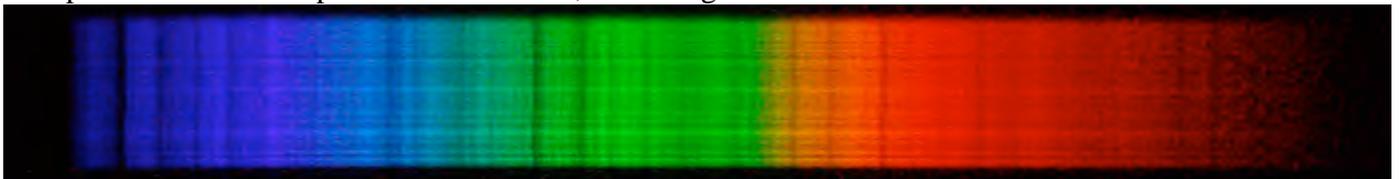
Some of the broad dark spectral features are visible. To make them more visible, the height of the spectrum can be stretched in Photoshop (image : image size) to stretch the spectral features into lines.



Apply a little vertical smoothing (blur : motion blur : 90 deg), cut out the middle of the streak, stretch it vertically (image : image size) to further “enhance” the spectral lines and voila! But...



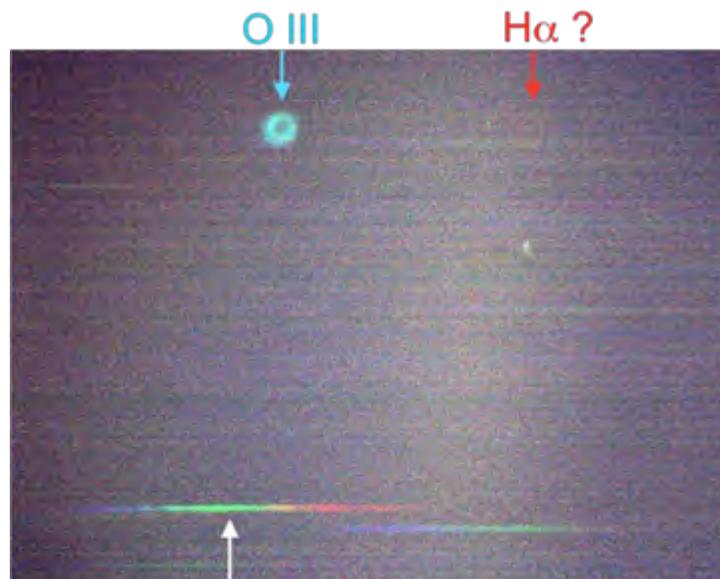
Compare it to this drift spectrum of Arcturus, the strong lines are real but the weak are “artificial”.



Streak Spectrum works for the broader, darker, spectral features but for faint stars with noisy spectra, be suspicious of spurious weak lines.

Nebula Spectra

Here is a stack of eight 30 sec spectra of 9th magnitude M57 (the Ring Nebula). Note, that as a bright line (emission line) object, it shows up as an image in each color emitted. In in this case the O III image is readily visible while the H α image is not because the internal camera filter doesn't extend far enough into the red. At the bottom is the spectrum of HD 175577, an 8.7 magnitude, M spectral type as confirmed by the molecular band structures in the spectrum.





Care of the **RS-Spectroscope**

Treat the optical surfaces as you would any optical surface, blow or dislodge dust with a soft brush. Be especially careful of the microglass window on the top side of the RS-Spectroscope grating element that protects the ruled surface of the grating. Do not impact it.

Links to Other Information on Spectroscopy

Visit our website at www.rigelsys.com for links to more information on astronomical spectroscopy both professional and amateur, and listings of interesting objects to enjoy with your RS-Spectroscope!

1 Year limited Warranty

1 Year limited warranty: Rigel Systems, 26850 Basswood Ave, Rancho Palos Verdes CA, 90275 warrants to the original consumer purchaser of its product that the product will be free of defects in material or workmanship 1 year from the date of purchase under normal use. During this warranty period, **Rigel Systems** will, at its option, repair or replace the product without charge for parts or labor when delivered to **Rigel Systems** with proof of the date of purchase and a statement of the problem with the product. Shipping and handling charges to **Rigel Systems** are your responsibility. This warranty does not apply if the product has been altered or repaired by anyone other than **Rigel Systems** or has been subjected to purchaser abuse, accident, negligence or damage subsequent to purchase including battery damage to product. This warranty excludes incidental or consequential damages resulting from the product or use of the product. The product is not a toy. Keep away from children.