

Capturing Astronomical Spectra with a Unistellar eVscope

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Unistellar telescopes and software are designed for visual imaging. They're very popular because they're easy to use and they automate an otherwise complicated process.

If you're interested in understanding more of the science behind the stars, then in our opinion, there's no better way than to capture your own spectra. You'll be amazed at how much science you'll learn. It's a bit more work than capturing automated visual images, but it's worth it!

What you need to get started

See www.rspec-astro.com/unistellar for a description of the equipment discussed below.

You're reading version **1.19** of this manual. Check this [link](#) to confirm this is the most recent version.

Are you wondering *why* you'd want to do spectroscopy? See this quick YouTube video: [link](#). For a longer video, see this Zoom presentation on YouTube that Tom Field gave to the iTelescope community: [link](#).

Before you capture spectra, you should be familiar with the standard operation of your telescope. We suggest you get good at capturing visual images with your telescope before capturing spectra.

Questions? You can post questions on the Unistellar Slack channel: #advanced_spectra. You can also contact us directly using [this](#) contact form. We're happy to answer questions.

Capturing spectra with your Unistellar telescope

You can use one of three methods to capture spectra. Below is a summary of each. Further down in this manual, you'll also find more details on each one.

- **Live view** works well on bright stars like Sirius or Vega. We recommend you capture your first spectra in Live view because it works well on stars as dim as magnitude 5. You'll be able to capture the spectra of hundreds or even thousands of stars.

The dimmest magnitude stars that you can observe will depend on your local conditions: how much light pollution is present, the weather, atmospheric conditions, etc. Fortunately, spectroscopy is much less affected by light pollution than visual imaging.

- **Enhanced Vision** is for dimmer stars. You can capture spectral images for durations of up to *a minute* using your eVscope's Enhanced Vision. Start with up to 30-second images. You can experiment with longer images going forward. Note that longer image captures may smear the spectra. This is due to what's called "field rotation," which is caused by the alt-azimuth tracking and software of your telescope's mount. How to avoid the smearing? See the next bullet.
- **Exoplanet transit mode with manual stacking** is for more advanced users. Use Unistellar's Science menu's Exoplanet mode in the same manner to capture longer exposures – up to *five minutes* of data. Unistellar then emails your images to you and you then remove any smearing by manually processing and combining the raw images using third-party stacking software.

In the following pages, we'll describe each of these methods in detail.

How to install your Star Analyser Grating

1. Screw your Star Analyser 100 into your adapter. Thread the grating all the way in. But *don't tighten it down*. Leave it loose. We'll be fine-tuning it shortly.



2. You'll be mounting the Star Analyser and adapter on the eVscope's filter threads that are located behind the vanes. For demonstration purposes, the vanes have been removed in the image below so you can see the interior threads. You should not remove the vanes on your telescope.



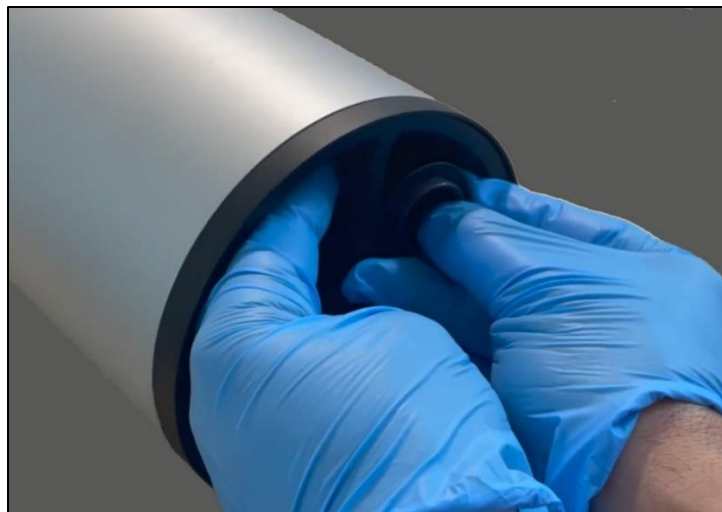
Credit: Franck Marchis

3. First, align your eVscope using the standard Unistellar alignment process. Then, position your telescope tube so that it's level to the ground. This will prevent a dropped adapter from falling onto the telescope mirror.

The photos in this section are from Franck Marchis' excellent video: <https://youtu.be/DyCFjn1MDDQ>. Be sure to watch this important video

4. As shown in the above video, reach through your telescope's vanes to screw the adapter into the Unistellar filter threads. Make sure you tighten the adapter quite well. But leave the Star Analyser a bit loose.

You'll need a bit of manual dexterity, because the telescope's female threads are behind the spider vanes. This process is done "by feel," since you can't see the filter threads.



Credit: Franck Marchis

The first time you install the adapter, it may take you a few tries to get its threads aligned with the Unistellar threads so they engage. After you've done it a few times, it gets easier.

In the next section, we'll show you how to use the Star Analyser that you just installed.

Method 1: Capturing Spectra with Live Mode (for bright stars: 5th magnitude and brighter)

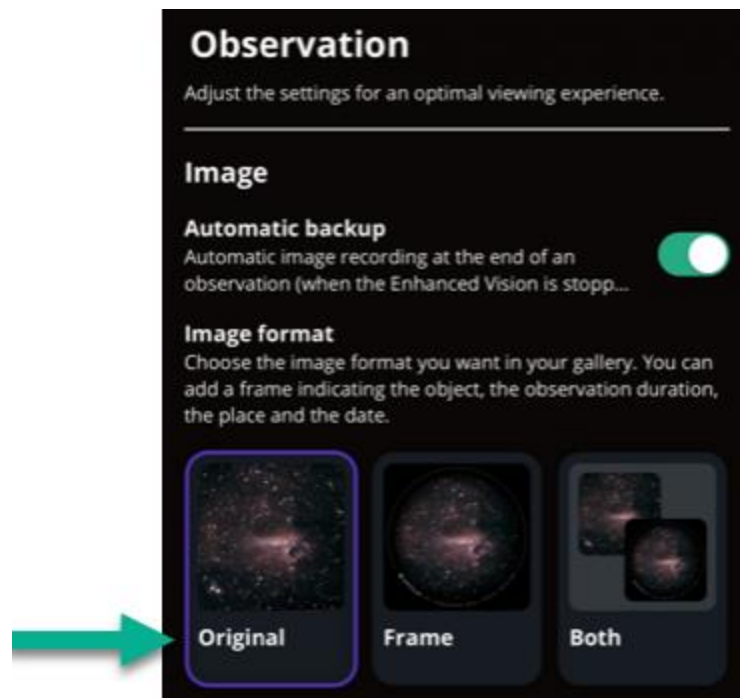
We recommend you capture your first spectra using Unistellar's **Live mode**.

It's very important that your first target is a **bright A-type star** like Vega, Sirius, or Castor. We'll refer to Vega in our example below, but any bright A-type is fine.

For a list of bright, A-type stars, see the *Star Analyser Manual*, Appendix B. You can download the *Star Analyser Manual* from here: ([link](#)).

Steps to capture your first spectrum

1. Set up your eVscope (1, 2, Equinox 1 or 2) according to the usual Unistellar procedures.
2. On the eVscope **Observation** page, set the Image format to **Original** as shown below:



One-time grating alignment

You will need to align your Star Analyser grating once. After you have aligned the grating, you should never have to align it again.

3. In Live mode, point your telescope at Vega, or at another bright A-type star.
4. You should see live images like the one below, which isn't focused yet. You'll see both stars and spectra.



Credit: @Martin Smallen on Unistellar Slack

Because spectra are not as bright as stars, you will need to manually set the gain and exposure in the Unistellar app. The table below shows our suggested settings. Use these as a starting point. They may vary depending on your local sky conditions. (See Appendix A for more details.)

Star Magnitude	Gain (dB)	Exposure time (ms)
-1	10	25
0	10	45
+1	12	80
+2	14	110
+3	18	180
+4	23	220
+5	28	290
+6	35	370
+7	43	450

Figure 2: Suggested Starting Settings

5. A bright star like Vega will have **two spectra**: one to the right and one to the left of the star. You should rotate the grating so that the **brighter** of the two spectra is **to the right of the star**.

To do this, reach into the telescope and rotate the Star Analyser by a small amount (this is why you left it loose when first assembling it). *Do not accidentally loosen the adapter from the telescope filter threads.*

Note: the most you will need to turn the Star Analyser during this procedure is *one revolution*. Turning it multiple revolutions or unscrewing the adapter risks it coming off and falling into your mirror.

6. Rotate the Star Analyser repeatedly, referring to the Live images until the brighter Vega spectrum is to the right of the star and the spectrum is approximately **horizontal**.

Note: You may need to use the telescope's manual pointing controls to move the star toward the left edge of the image so that the spectrum is completely visible.

7. When you have the Star Analyser correctly rotated, to keep it from rotating out of position, reach into the telescope and firmly apply a small piece of tape to secure it to the adapter, as shown below.

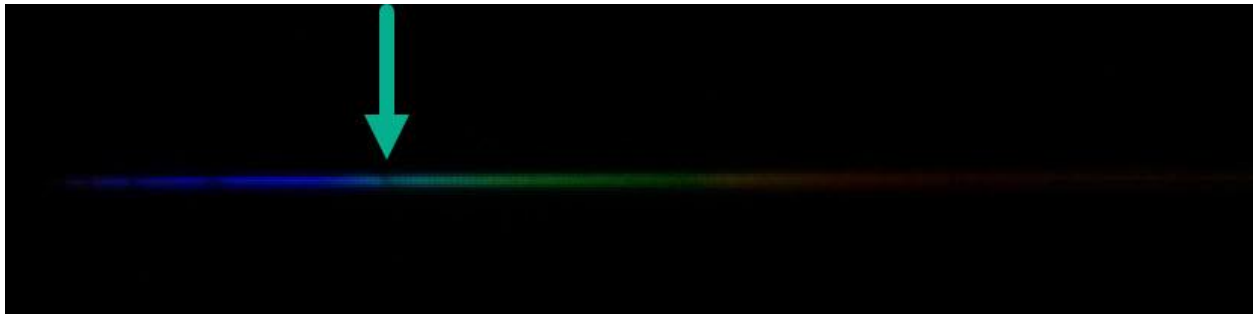


Above: The adapter and Star Analyser taped together.

When you have completed the above steps, you are done aligning your Star Analyser.

Getting a good image

1. Start by focusing on the star. You can use your Bahtinov mask if you wish although it's not critical to use it here since we'll be changing the focus in the next step.
2. Remove the Bahtinov mask if you used it. Now turn the focusing knob **45° clockwise**. With a 10 mm adapter we recommend, that will bring the spectrum into focus.
3. The above step should yield good focus. If you decide you want to manually adjust the focus on your eVscope, adjust it so that the spectrum is sharpest. When the spectrum is focused, the star will be a bit unfocused. That's okay. It's important to get a sharp image of the *spectrum*, because that's where our data is! Zooming can help you visually examine the image to judge the focus.
4. Turn off "Auto" gain and exposure. For a bright star like Vega, start with the gain at 10 dB and exposure at 50 ms (See Appendix A for suggested initial settings if you're not using Vega).
5. By trial and error, adjust the gain and exposure so that the spectrum is as bright as possible without saturating the sensor and over-exposing it. Visually, it should look dull and faded, a bright colorful.
6. Go back and forth a few times with the focus, gain, and exposure controls until you've achieved a well-exposed image that has the best focus you can get.



Above: On a bright A-type star, when you're focused and properly exposed, if you zoom in, you may be able to visibly spot the hydrogen beta absorption, which appears as a gap. (Castor, Credit: @Martin Smallen on Unistellar Slack.)

The amount you must defocus from the star so that the spectrum is properly focused *will be the same for all stars*. If you keep track of how much you changed after focusing on the star, in the future you can simply focus on the star and then "de-tune" the focus the same amount.

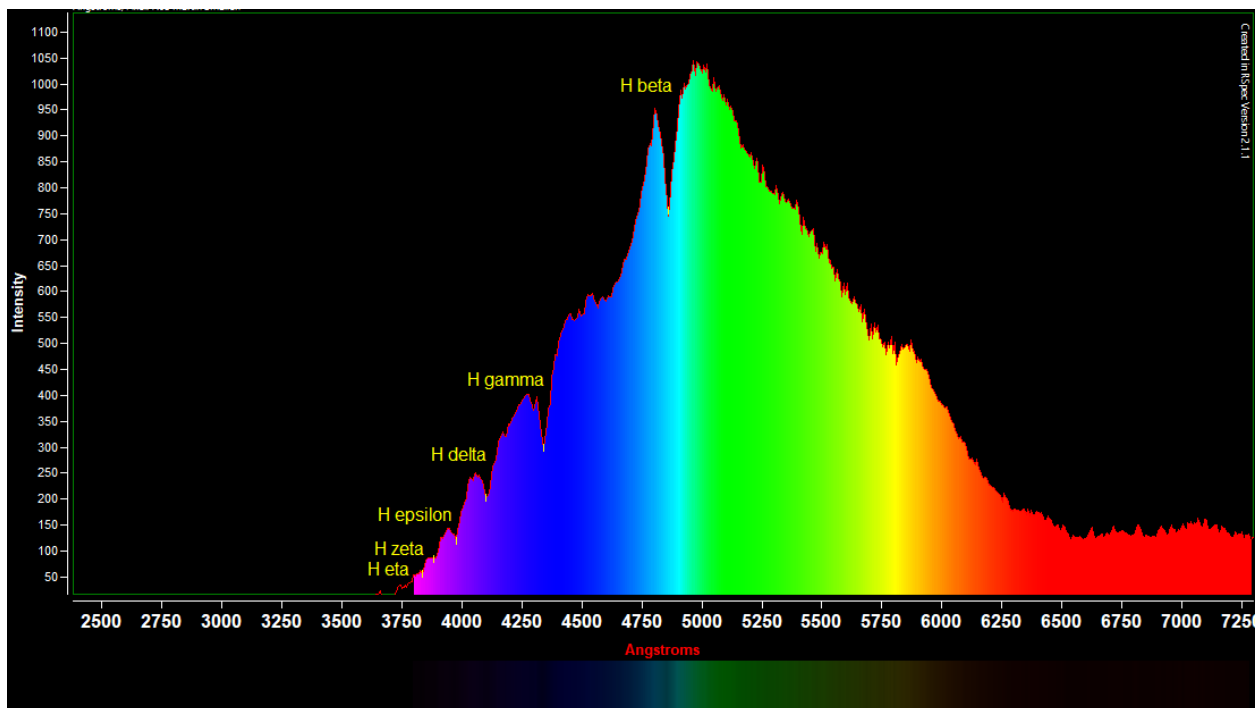
7. Capturing good spectra requires steady skies. The stars shouldn't be "twinkling" to the naked eye. Stars should be round and compact when captured in Live View. If your skies aren't steady, wait for another night to capture spectra.

8. For more details on capturing and processing spectra, see this document: [link](#).

Extracting your spectrum from the image

1. Save the live image using the eVscope controls.
2. Transfer the image to a Windows desktop.
3. Start the RSpec software. A free 30-day trial version is available [here](#).
4. In RSpec, open the spectrum image you saved from the eVscope. Refer to the RSpec User Manual or the “Video Library” (both under the Help menu) for instructions on how to use the software.
5. If the spectrum isn’t almost horizontal, you can use RSpec’s Rotate button to adjust it so that it’s close to horizontal.

Below is the spectrum of Castor in RSpec from an image captured in Live View. The dips are the absorption features created as the starlight leaves the star:



Above: Spectrum of Castor showing the Hydrogen Balmer absorption features
(Credit: @Martin Smalen on Unistellar Slack)

Notes about setting proper exposure and focus

If you look at the image at the top of the previous page, you'll see the rainbow colors in the spectrum. Notice that overall, the spectrum is not very bright. The colors in a properly exposed spectrum look a little faded.

It can be tempting to turn up your camera settings to get a pleasingly bright spectrum. However, a visibly bright spectrum is likely to be over-exposed. Start with the settings in **Figure 2: Suggested Starting Settings** shown previously.

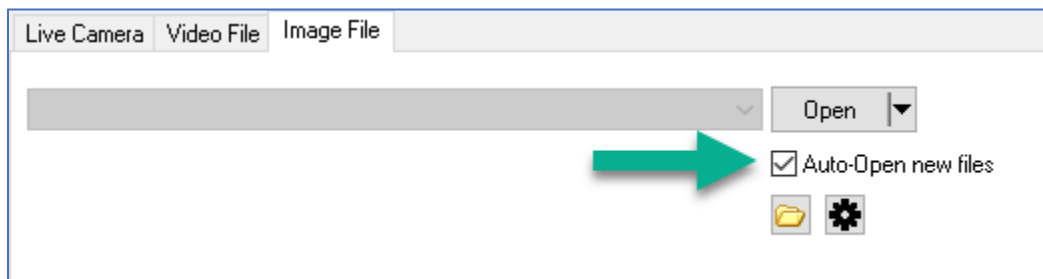
And, as discussed earlier, you should manually focus *on the spectrum*. Set your focus so the spectrum looks the sharpest.

For more details on how to capture spectra, see this document: [link](#).

The best way to determine proper telescope settings is to capture a series of images and view their spectra profile graph in software like RSpec. Use your telescope's "Share image with Contacts" option to send the images to your Windows computer. Open them in RSpec. When the dips (absorption features, as seen in the image on the previous page's graph) are the deepest and most narrow, you have found the best settings for your target.

RSpec also contains some tools to help you determine the quality of your image. See video 50 [here](#).

You can configure RSpec to automatically open any new image that appears on your Windows drive. Configure RSpec's AutoOpen feature to monitor the folder where you'll save your spectra from the telescope. RSpec will open each image immediately when you save it to that folder. The screen capture below shows where you turn this feature on in RSpec. Also, see videos 31 and 50 in the RSpec Video Library for how to use the live 3D pixel map to set proper exposure levels.



RSpec's Auto-Open feature will immediately display any new image that appears in a user-specified folder on your computer.

Method 2: Enhanced Vision (EV) Mode – For less bright stars

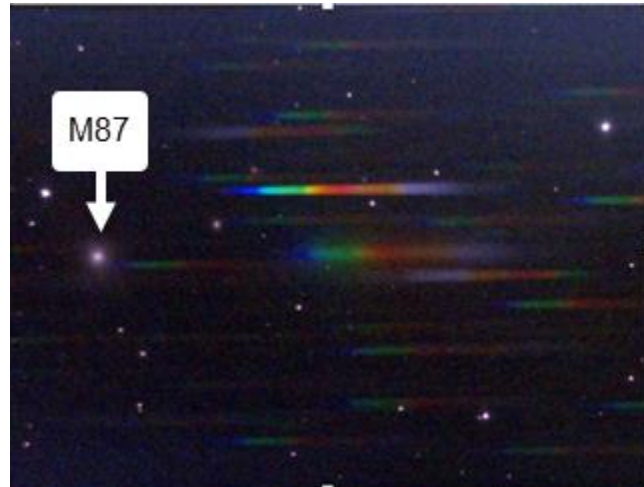
There are hundreds or even thousands of bright stars whose spectra can be captured in Live Mode (as described above).

You can use your telescope's **Enhanced Vision** for less bright stars (magnitudes 6 to 9.5). Urban light pollution (or glow from the Moon, etc.) may prevent you from capturing the spectra of some of the dimmer objects in this range.

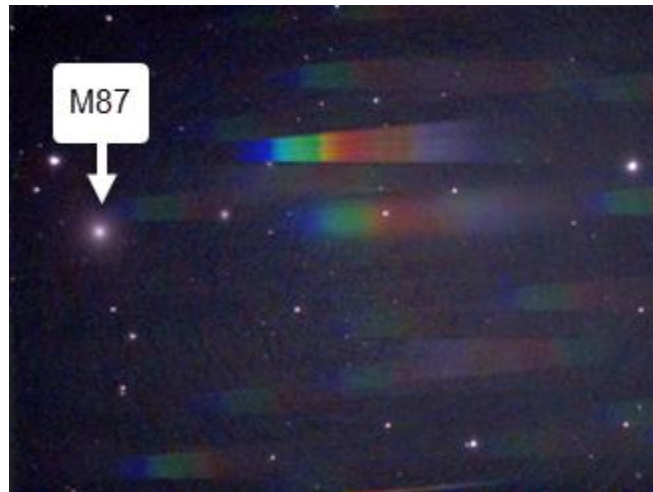
1. Begin by capturing the spectrum of a bright star near your target. Use the **Live Vision** steps previously described. This ensures you have everything set up properly and have good focus.
2. Then capture an image using EV. The longer your exposure, the more it will be degraded by the effects of field rotation correction. Some users of EV have captured good spectra from images that are as long as five minutes or more. We suggest you start with exposures that are just *one or two minutes long*. You can work up to longer, taking note of the effects of field rotation, described below.

What is “Field Rotation?”

Long exposures in Enhanced Vision mode cause the spectrum to fan out or smear. This is due to the unavoidable *field rotation* from the eVscope’s Alt-Az mount. Below are some examples of smeared spectra. These spectra are not usable. You would have to reduce the length of time spent capturing them to produce usable spectroscopic data.



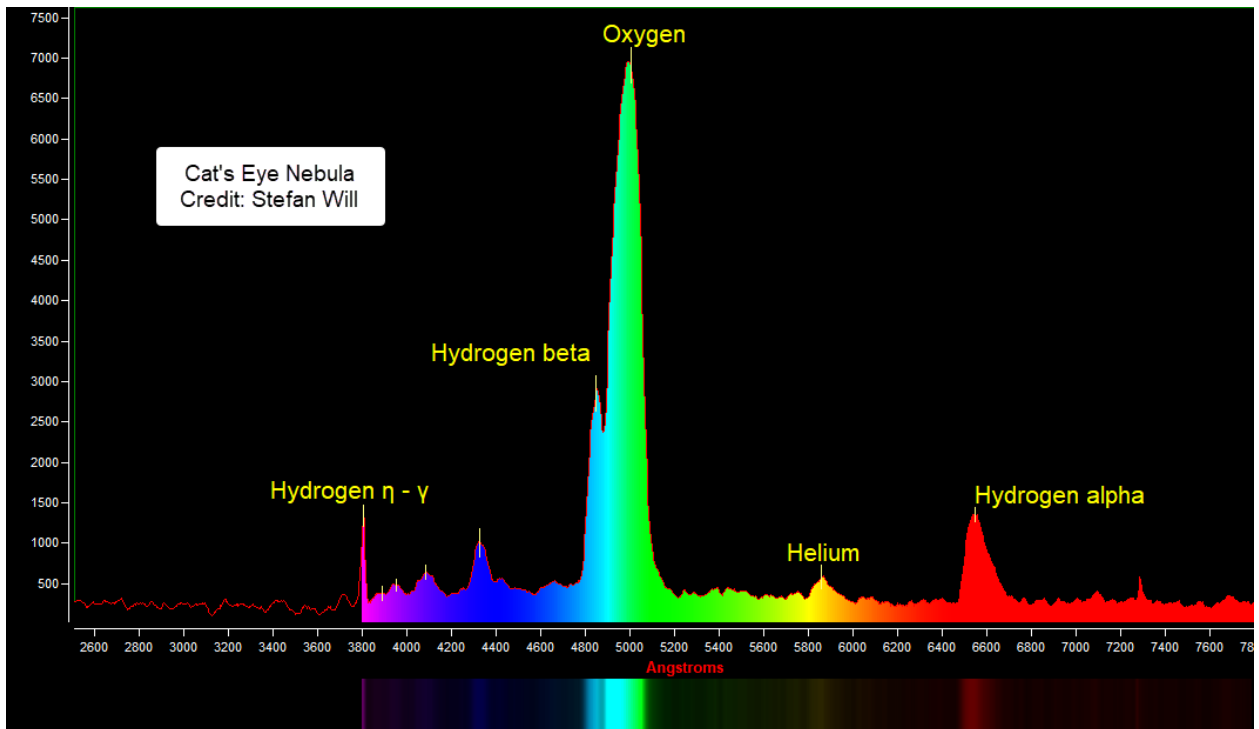
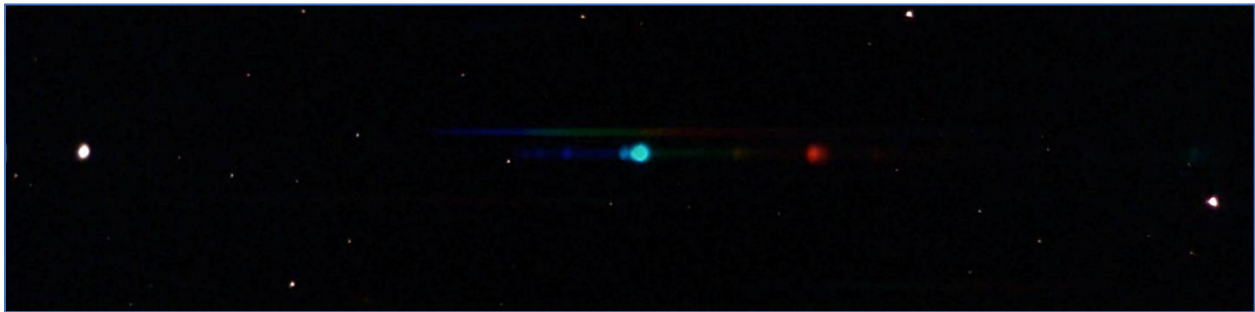
M87 after 6 minutes of exposure showing minor “fanning” of the color spectrum.



M87 after 16 minutes of exposure showing “fanning” of the color spectrum.
Credits: @Martin Smallen on Unistellar Slack

Below is an exciting image of the Cat's Eye Nebula (NGC 6543, magnitude 9.5). It was captured in the **Enhanced Vision** mode. At magnitude 9.5, this is about the dimmest object you'll be able to capture this way. In light-polluted urban areas, your limiting magnitude may be less.

The image below shows the *emission lines* from the glowing gases of this nebula! The profile graph shows the nebula's hydrogen, helium, and oxygen.



Above: Cat's Eye Nebula in Enhanced Vision Mode (NGC 6543)
Credit: @Stefan W. (Raleigh, NC, US) on Unistellar Slack

Note: When capturing dim objects, their colorful spectra may sometimes confuse your eVscope. The Enhanced Vision Mode may not work or may not track properly. This is because spectra are very different from the pinpoint stars that the eVscope software is designed to track. You'll need to select a brighter target object.

In the next section, we'll capture even longer-exposure images with higher-quality results.

Using Method #3: Science menu's Exoplanet transit mode with external stacking

This method is for more advanced users. You should consider this an experimental method. The Unistellar spectroscopy community is still evolving its procedures to produce the best results with this method.

The **Exoplanet transits** mode has better tracking and more flexibility than the other modes. It can capture a multi-minute series of short images that it then uploads to Unistellar's server. You will then download these images from Unistellar and add them together. (This is called "stacking.")

By manually stacking the individual images, you can eliminate the smearing caused by the field rotation correction in your eVscope. This enables you to capture longer exposures with higher-quality results.

The **Exoplanet transits** mode does not show you a preview image on your screen. To confirm your telescope is pointed correctly at your target, you should use **Live** or **Enhanced Vision** mode. You can also use **Live** mode to determine the best Gain and Exposure settings. See Figure 2 and Appendix A for a suggested starting point for your settings.

After you've confirmed your Gain and Exposure settings as described in the paragraph above, you can enter those settings in the Science menu's **Exoplanet transit** mode. Then, you're ready to capture images.

When using the **Exoplanet transit** mode, you do not need to limit the duration of captures. We suggest you start with five- or ten-minute exposures.

How to retrieve the individual science images

You can download all of your FITS sub-images from Unistellar. For details, see this link: <https://help.unistellar.com/hc/en-us/articles/10989728346780-UniData-access-How-to-download-your-RAW-data->

Combining your sub-images

The next step is to combine all the FITS sub-images using a *stacking program* like Registax, Siril, DeepSky Stacker, or Nebulosity, which are all free. You could also use a commercial stacking program like PixInsight. These programs combine and align images to remove the smearing caused by field rotation.

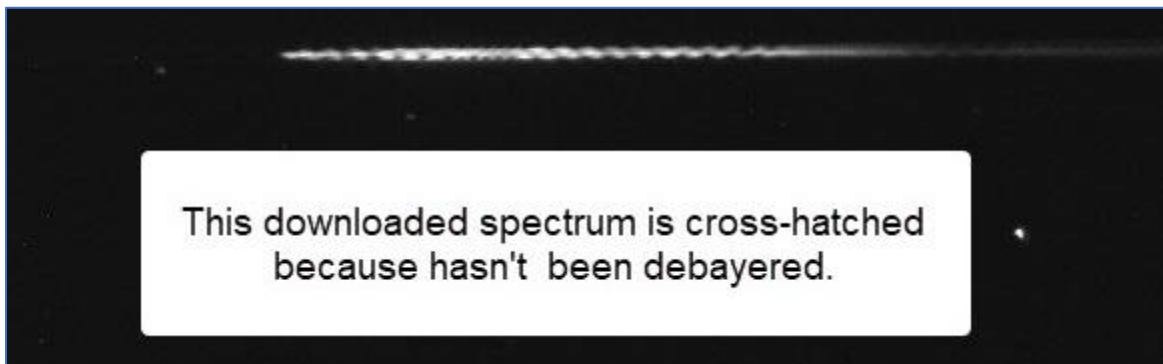
To learn how to stack images with these programs, see their manuals and websites. Stacking images is a common procedure for amateur astronomical imagers. So, you'll find a lot of resources on the web. You can also post questions on the forums of the stacking program you're using. In addition, you can post on forums like the Unistellar Slack channel #advanced_spectra, the RSpec forum <https://groups.io/g/RSpec-Astronomy>, or a CloudyNights forum <https://www.cloudynights.com/index/>.

After you have used a stacking program to combine your individual images into a single image, transfer it to your Windows computer. Save it as a png if it's a color image. If your stacking program converted the image to mono, you can save it as a FITS or png.

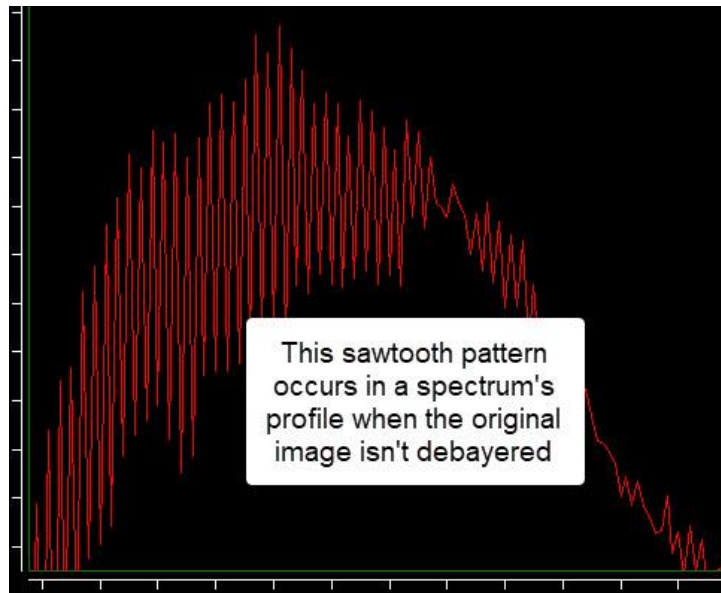
Debayering

The discussion below only applies to images you requested and then receive in an email from Unistellar. This discussion does not apply to single **Live** or **Enhanced Vision** images from the preview window.

The process of converting color to mono images is called *debayering*. The FITS files that Unistellar send you are (appropriately) *raw data*. They are not in color and are not debayered.

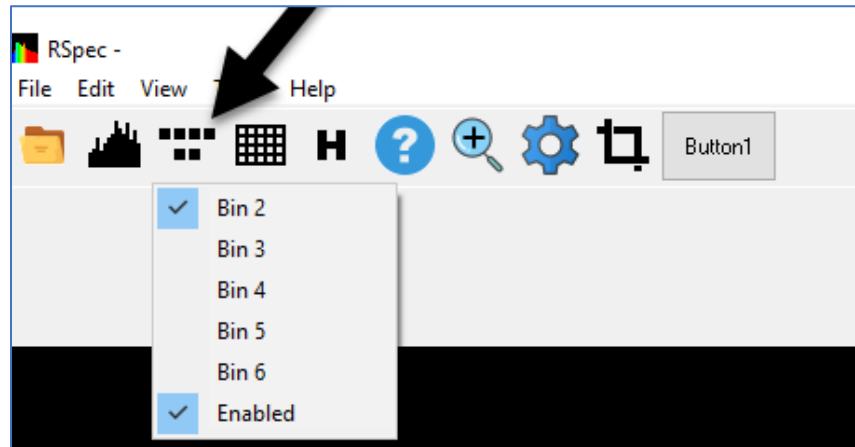


Above: This spectrum image has a periodic cross-hatching due to the Bayer filter on the telescope
Credit: @Stephen Haythornthwaite



Above: Spectrum profile in RSpec of undebugged data
Credit: @Stephen Haythornthwaite

The crosshatched and sawtooth patterns above mean that the image still needs to be debayered. You can pseudo-debayer in RSpec by enabling 2x binning, as shown below.



Here's how RSpec smooths a spectrum:

- **Rows:** When you select "Bin 2" and "Enabled" as shown above, RSpec will average adjacent cells across *horizontal rows*.
- **Columns:** To build the profile graph, RSpec always sums all the pixels in each *vertical column*.

The above will smooth out the Bayer pattern in both rows and columns. Binning in this manner isn't exactly what is usually meant by the term "debayering." That's why we call it "pseudo-debayering".

One reason that professionals seldom use color cameras is that debayering introduces unavoidable inaccuracies. We're using our color eVscopes as an introduction to the field and to do some hands-on learning. So, some minor degradation by pseudo-debayering is acceptable. It's been found to be imperceptible in most cases. To explore more traditional debayering, see the stacking programs mentioned earlier (as well as a program named PIPP).

Some Star Analyser users may want to use a star's Spectral Energy Distribution (SED) and Wien's law to determine star temperatures and types. To do this, the spectrum must be corrected for instrument response. RSpec has the tools and tutorial videos to do this. However, it is difficult to properly correct for instrument response of color cameras – regardless of the software being used. So, star temperatures and types derived from the SED ("Planck" curve) may not be accurate. For additional details, see video 15 [here](#) and the Star Temperature pdf under RSpec's Help menu.

Appendix A – Suggested gain and exposure times using Live view and Exoplanet Transit view

Determining the correct exposure and gain is a trial-and-error process. If you know the magnitude of the object you're capturing, you can use the graph below as a starting point. Your settings may vary, depending on your local conditions.

Capture an image and adjust the exposure and gain up or down depending on the results.

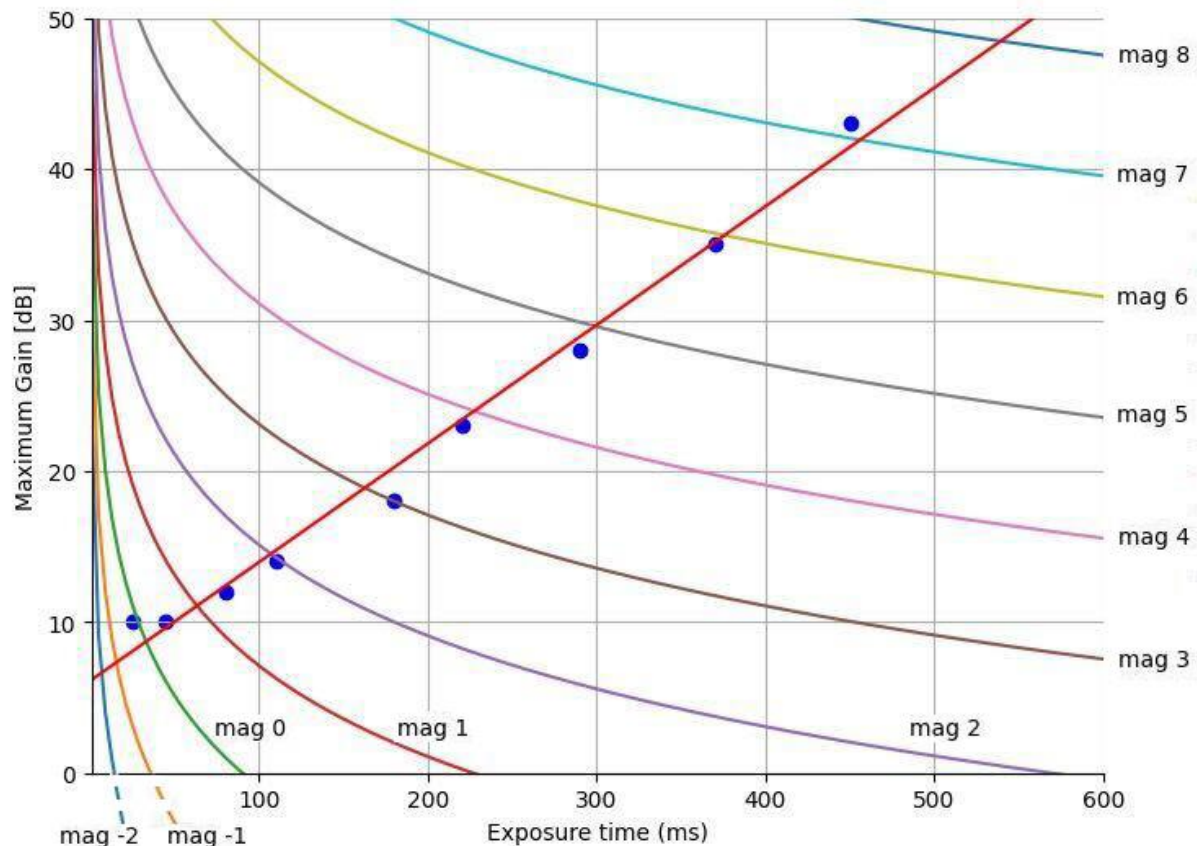


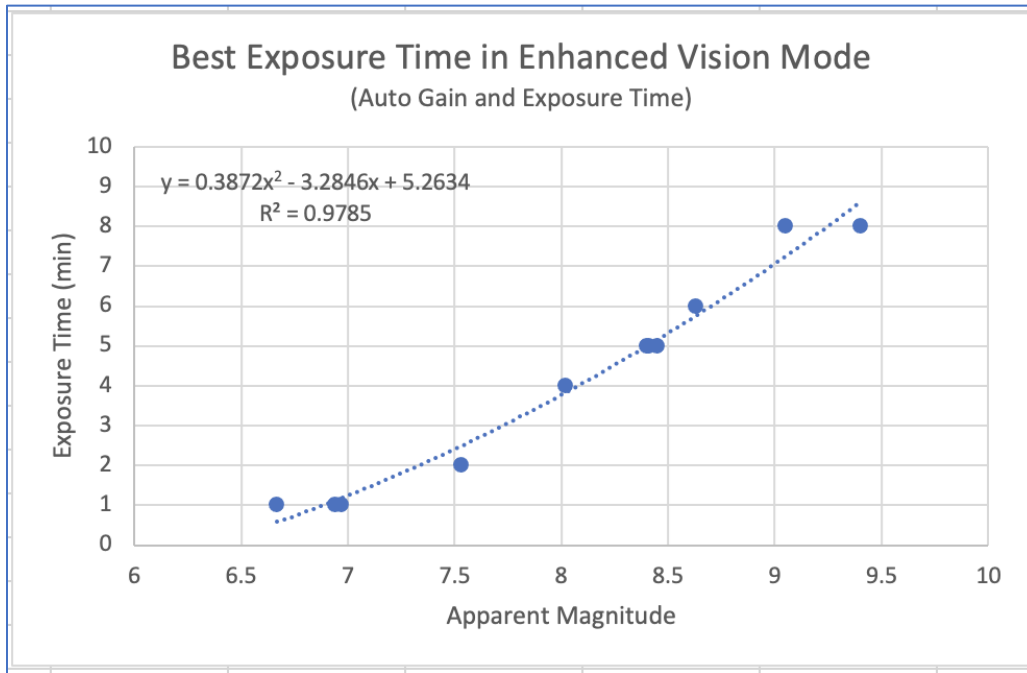
Figure 2: Suggested Live Setting Graph
Credit: Martin Smullen and Stefan Will

Above graph: Using a Unistellar telescope, we captured good spectra of a variety of stars – marked as the blue points. The curves are the theoretical settings for different star types, derived from Unistellar's asteroid documentation and our empirical data. We suggest you start with settings in the region of the straight line.

Appendix B – Suggested exposure times when using Enhanced Vision mode

Determining the correct exposure time is a trial-and-error process. If you know the magnitude of the object you're capturing, you can use the graph below as a starting point. Your settings may vary, depending on your local conditions.

You will need to capture an image and adjust the exposure and gain up or down depending on your results.



Appendix C – Examples of some objects with interesting spectra

Your eVscope is capable of capturing the spectra of many interesting objects.

The spectra of **M-type stars** (like Betelgeuse) are *very different* from the spectra of hotter A-type stars. You'll immediately spot the difference. This is how professionals determine star temperature.

Some **double stars** are composed of one bright star and one cool star. You can see this for yourself by capturing the spectrum of Albireo A and B.

Wolf Rayet stars have fascinating spectra. These stars are enormously hot and have very strong emission lines. (Try WR4 is near the North Pole and is visible year-round from the northern hemisphere.)

Capture the spectrum of a relatively bright **super-giant** like the Saturn Nebula.

You'll enjoy the spectrum of the glowing gas shell around a **planetary nebula** like the Cat's Eye, which we saw earlier in this document. It's magnitude 9.8, so you'll need to use Enhanced Vision and probably stack your images.

Professionals use spectra to detect the **atmospheres of planets** and exoplanets. You can do the same by capturing the spectrum of **Uranus**. To our knowledge, this hasn't yet been done with an eVscope, but at magnitude 5.7, it should be possible. Maybe you'll be the first?

As you capture the above spectra, you'll discover a motivation to read more about what causes them. And you're more likely to understand and remember what you read in this case, because it's **your data** you're reading about.

Note: because it doesn't have a slit, a Star Analyser cannot be used to view the spectra of extended objects like the Moon, Jupiter, or galaxies.

Want to learn more about the interpretation of spectra? See this [link](#) for some great spectroscopy books that are part of the popular Patrick Moore Series.

Questions? You can post your questions on the Unistellar Slack channel: #advanced_spectra. You can also contact us using [this](#) contact form. We're happy to answer any questions you may have.