Star’Ex slit GEN2

Projet Sol’Ex/Star’Ex : http://www.astrosurf.com/solex

Christian Buil, october 2024

1. Introduction

Until mid-2024, the slits used in Star'Ex spectrographs (whether in high or low resolution, or infrared versions) were designed for Shelyak Instruments (https://www.shelyak.com) products, such as the Lhires III and Alpy 600, which preceded the arrival of the "Star Explorer."

From this date forward, you now have the option to use a slit specifically designed for Star'Ex, called the **Generation 2** slit (GEN2). This new model includes enhancements and innovations compared to previous versions, which we detail in this document, which also serves as a user manual.

Figure 1. A set of slits compatible with Star’Ex. On the left, a slit initially designed for the Alpy600 spectrograph. In the center, an arrangement with four slits of varying widths, originally used with the Lhires III and LISA spectrographs from Shelyak. On the right, the new Star’Ex GEN2 slit in its 3D-printed holder.

Please note that the Star’Ex GEN2 slit can be used with other spectrograph models, possibly even those of your own design.

The Star’Ex GEN2 slit is available from Shelyak Instruments:

https://www.shelyak.com/produit/starex-14-20-26-32/?lang=en

2. Overview of the Star'Ex GEN2 Slit System

The Star'Ex GEN2 system consists of a fused silica (synthetic quartz) plate, 16 millimeters square and 2 millimeters thick. One side of the plate is coated with an anti-reflective layer, while the other side is covered with an opaque chrome layer, except for narrow openings corresponding to the slits, which are etched using a high-precision photolithography technique.

On this silica substrate, four independent slits are arranged in a square pattern, with widths of 14, 20, 26, and 32 microns. A central hole, 25 microns in diameter, is also included to facilitate spectrograph alignment.

At the end of each slit, a 0.5 mm-long section widens by a factor of 10 (see Figure 2). This widening serves two purposes: (1) to provide additional information on instrument operating conditions (such as atmospheric turbulence, instrumental efficiency, alignment quality, and instrumental response evaluation); (2) to enable spectrophotometric data acquisition, facilitating the calibration of spectra to absolute flux values.

Additionally, the slit width information is indicated in the corners of the substrate.

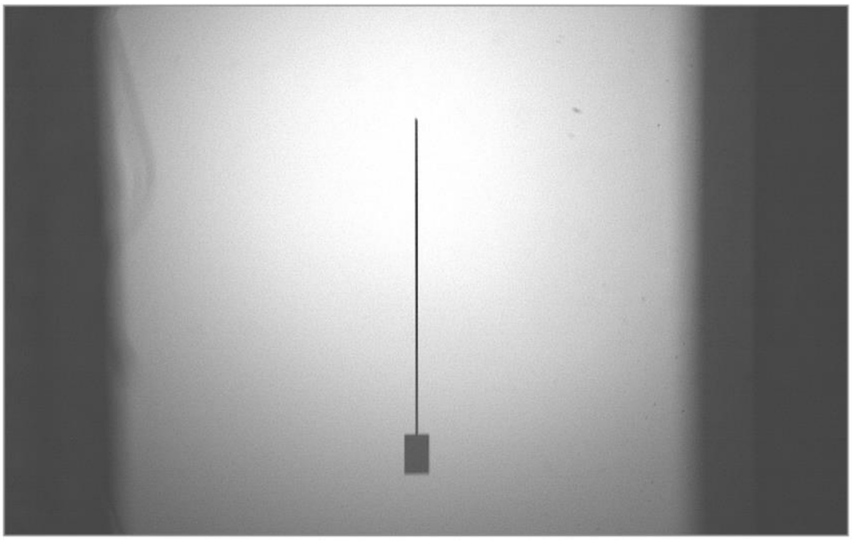


Figure 2. The appearance of the 32-micron-wide slit, as seen from a large-sensor guiding camera (model ZWO ASI174MM Mini).

Figure 3 shows the complete GEN2 system for Star'Ex. It consists of the slit itself (or rather, the slits), along with a specific holder that tilts the slit plane at a 15° angle and a retaining bracket.

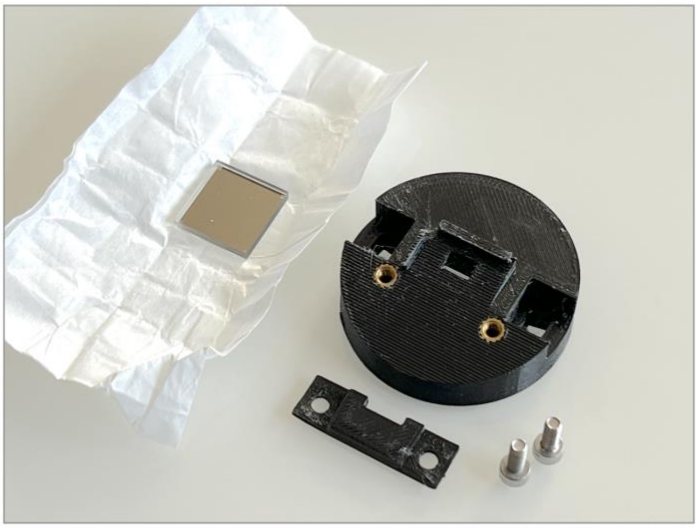


Figure 3. Overview of the GEN2 system.

3. Features of the Star’Ex GEN2 Slit

Here is a list of the benefits provided by the GEN2 slit:

- The variety of slit widths (14, 20, 26, 32 microns) allows for flexibility in many situations. For instance, the 14-micron slit is ideal for very high-resolution spectroscopy with a small telescope. Conversely, the 32-micron slit is better suited for low-resolution spectroscopy with a larger telescope, typically around 300 mm in diameter. Additionally, these slits are long enough to capture spectra of large angular objects, such as nebulae or comets, with good quality.

- The "photometric slit" configuration, with a short 0.5 mm widening at one end of each slit, provides precise instrument diagnostics and allows for absolute calibration of spectra, opening up additional professional applications.

- The inclusion of a discrete 25-micron central hole is a major innovation. This hole enables secure and straightforward spectrograph alignment on a workbench without requiring a telescope or starry sky. It effectively acts as an artificial star. In the next section, we explain how to use it to finely adjust the Star’Ex collimator focus.

- The Star’Ex GEN2 slit is crafted from fused silica. Along with its mechanical strength, this material offers an extremely broad spectral transparency in both the infrared and ultraviolet, extending to very short wavelengths. This allows adapted spectrographs to explore regions of the spectrum that are rarely observed by amateurs but are rich in astrophysical information. Although Star’Ex is not specifically designed for UV observation, using silica offers a modest gain around 375 nanometers (the reasonable blue limit of our instrument’s spectrum).

- The slit has a thickness of 2 millimeters, which is notably thicker than previously used Star’Ex slits. This choice offers a more robust component, less prone to breakage during accidental handling (though care is still required as it’s still glass!). Both sides of the slit are accessible to be cleaned easily. On the guide camera side, this extra thickness doesn’t prevent seeing the standard ghost images in the field as is currently the case; however, these images are wider and less intense.

- As mentioned, the GEN2 slit can also be used on stellar spectrographs other than Star’Ex, as well as in various laboratory setups. By design, this slit is fully compatible with all Star’Ex spectrographs, regardless of configuration. Only a new support piece needs to be fabricated via 3D printing or acquired (see the appendix of this document). You are also free to design a custom mechanical support.

4. Star’Ex Adjustment Assistance

When adjusting a Star’Ex spectrograph, the most delicate yet crucial step is to correctly set the distance between the slit and the collimator lens. We will learn how to make this adjustment using the central hole of the Star’Ex GEN2 slit.

To perform this operation, you’ll need a neon pilot light, which produces clear emission lines around the red region of the Hα line. For example:

https://www.e44.com/eclairage-lampes/lampes-tubes/a-incandescence-miniature/a-fils-avec-resistances/lampe-neon-avec-resistance-220-volts-0.6ma-4x10mm-N76220.html

Ensure safe wiring, as this type of lamp operates at 220 V.

If you don’t have access to this type of lamp, you might find one (see figure 5) in a power strip with a neon-based power indicator (be careful not to confuse it with LED-equipped models; neon lights tend to flicker, unlike LEDs). Place the power strip in front of the Star’Ex input... sometimes, a bit of resourcefulness with whatever is at hand is all you need to achieve a great result!

Figure 5. A neon lamp for adjusting Star’Ex might be right under your feet!

Start by illuminating the entrance of Sol’Ex with the light from this neon lamp, after covering your 31.75 mm or 50 mm eyepiece (already installed) with a layer of tracing paper to serve as a diffuser. A diaphragm simulating the relative aperture of your future telescope can also be used (see figure 6).

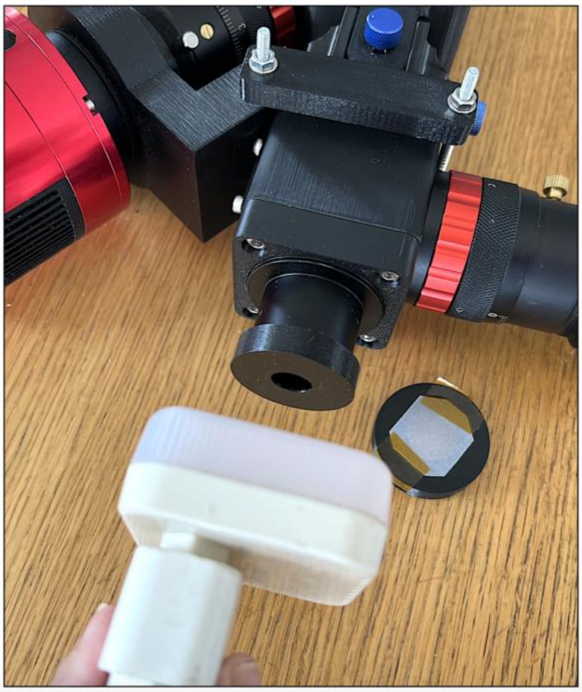


Figure 6. Illumination of the Star’Ex entrance with a neon source.

Let’s go through the procedure, assuming we’re starting with a completely unaligned Star’Ex HR spectrograph.

Step 1: Mount the GEN2 slit onto support #3, which centers the hole in the spectrograph’s field of view (see Figure 7 and the appendix of this document). Then, place the assembly into the designated front slot in Star’Ex.

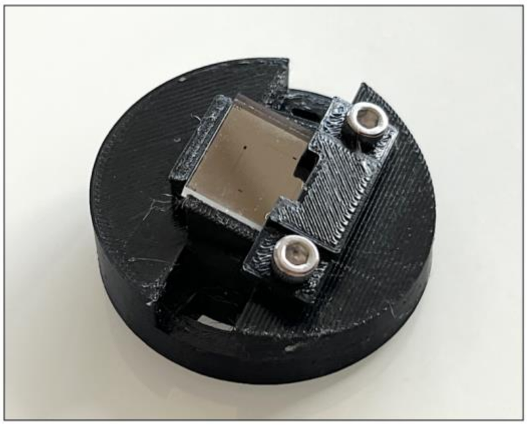


Figure 7. Star’Ex GEN2 slit mounted in adjustment support #3.

Step 2: Orient the grating in the usual way (using the support knob) so that the Hα line is approximately centered on the sensor.

Step 3: Capture an initial spectrum from the neon lamp. The result will likely be disastrous: images of the lines that are completely blurred and very elongated, as illustrated in figure 8 and enlarged in figure 9. In a well-adjusted spectrograph, the image of the point source created by the hole in the GEN2 slit should appear as a point at each spectral line.

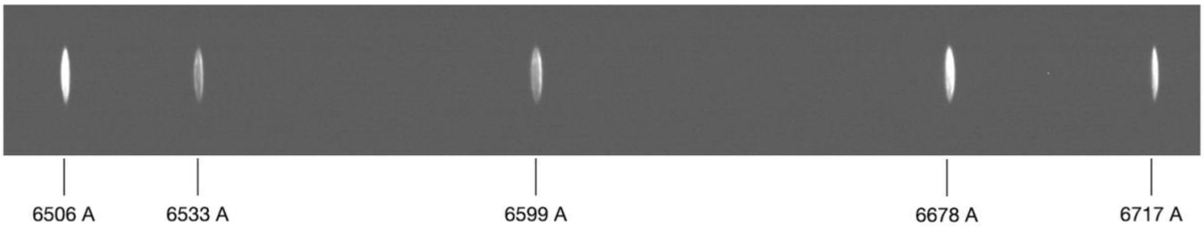


Figure 8. Appearance of the neon spectrum near the Hα line obtained with an uncalibrated spectrograph. The source is the 25-micron hole of the Star’Ex GEN2 slit.

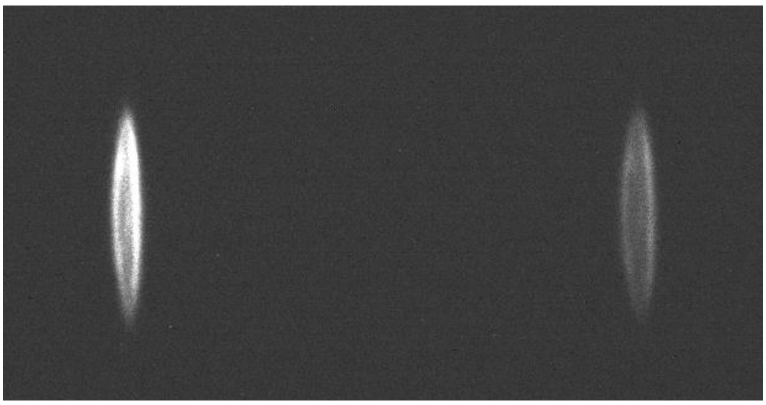


Figure 9. Detail of the neon spectrum when obtained with an uncalibrated spectrograph, showing a mix of astigmatism and defocusing.

Step 4: Adjust the camera focus using the helical system (figure 10) to achieve well-defined narrow lines (figure 11). Don’t worry about the vertical stick shape; the main thing is that our lines are narrow along the spectral axis (the horizontal axis in the images).

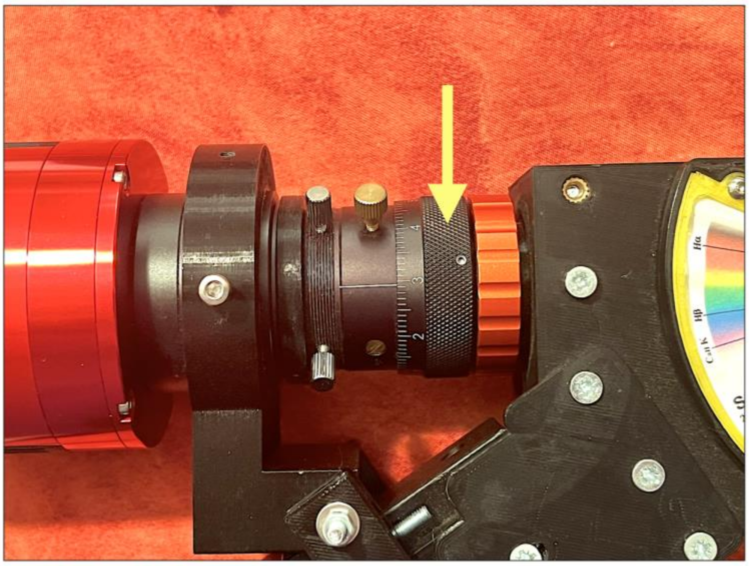


Figure 10. The helical system ring is used to adjust the camera focus.

Figure 11. The spectrum of neon (centered around the Hα line) after the camera has been focused. The lines become narrow, but still elongated, indicating the presence of significant astigmatism.

Step 5: Move the collimator block after loosening the retaining screws (figure 12). The goal of this action is to gradually reduce the vertical elongation of the lines (that is, the astigmatism) – see figure 13.

Figure 12. The adjustment of the distance from the slit to the collimator.

Figure 13. Through successive trials, reduce the height of the astigmatism figure. Of course, choose the correct direction to move the block in order to improve the image.

The use of the fine adjustment system for the collimator block introduced in the latest versions of the Sol’Ex/Star’Ex housings is quite helpful (see figure 14).

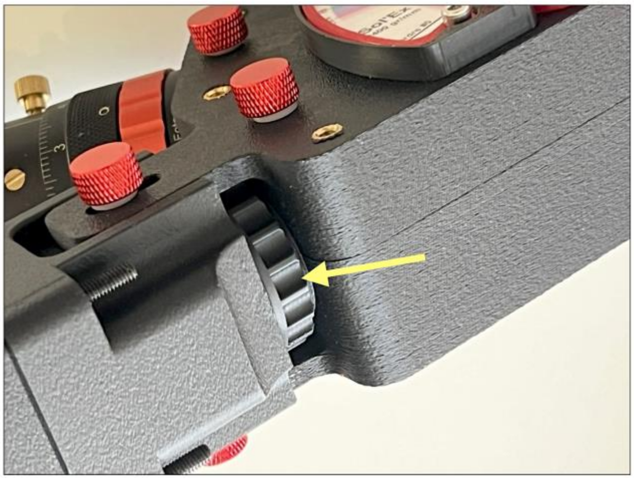


Figure 14. Fine adjustment system for the collimator block (V2 Azur3DPrint housing).

Step 6: As the astigmatism decreases, do not hesitate to also adjust the camera focus. The goal is to achieve the result shown in figure 15. The spectral image of the hole then appears as a spot that tends to be point-like.

Figure 15. Appearance of the neon spectrum when the correct adjustment is considered achieved.

To be honest, we will never obtain a perfect point, partly due to optical aberrations (especially at the wavelength of 6678 Å on the far left), and, more importantly, because the source hole has a finite dimension (25 microns in diameter), which is reflected in the image. Figure 16 shows enlarged views of the neon line at a wavelength of 6533 Å, which will be used for the final adjustment.

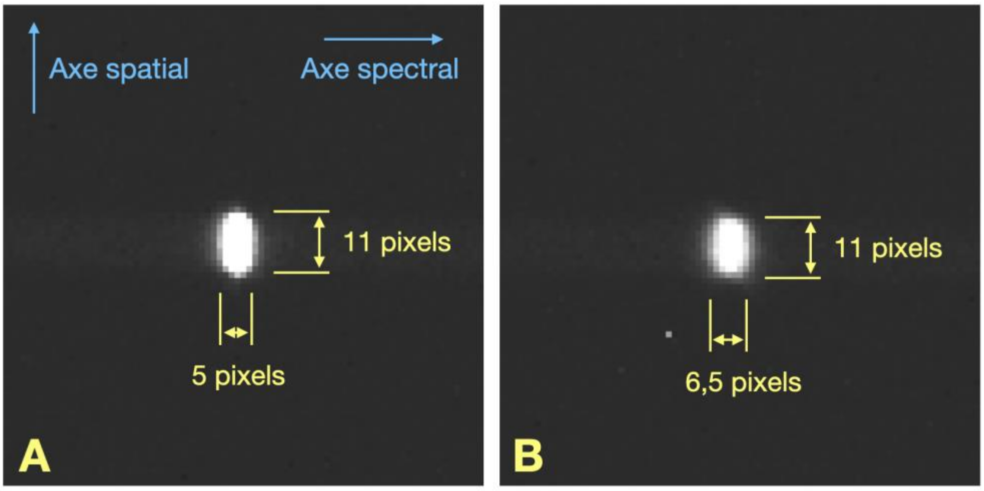


Figure 16. In A, the best spectral image of the source hole for the 6533 Å line. In B, the result of a very slight defocusing of the collimator, now showing a slightly wider image spot.

Given the internal magnification of the Star'Ex HR (the focal ratios of 125 mm for the camera objective and 80 mm for the collimator objective) and the pixel size of the camera used (here an ASI533MM with 3.76-micron pixels), we calculate that the image of the hole should measure 11 pixels along the spatial axis (128 / 80 x 25 / 3.76). This is precisely the value found in the data. Regarding the width of the image spot along the spectral axis, it is necessary to consider the phenomenon of anamorphosis, which tends to elongate this spot (shape factor of 0.386). In image A of Figure 16, which corresponds to our best adjustment, we measure a width of 5 pixels, while calculations, taking anamorphosis into account, yield a theoretical value of approximately 4 pixels.The discrepancy can be explained by the presence of optical aberrations (which always affect the spectral axis more than the spatial axis) and the difficulty of measurement.

It is very important to be aware of the presence of anamorphosis. The ideal image is not a circle but an oval, even if this is not intuitive! It is possible, by adjusting the collimator settings, to converge toward a round image (as seen in B of Figure 16), but be cautious, as this will come at the expense of spectral resolution. The difference between adjustments A and B is actually very small, and the difference in stellar spectra will be minimal. In any case, as soon as one moves significantly away from the reference line, the images naturally change shape due to optical aberrations.
The adjustment is nearly complete. Now, the retaining screws of the collimator block must be tightened.

If you now point the entrance of the Star'Ex towards the sky during the day or towards a wall illuminated by the Sun, while the hole is still in place, you will obtain a spectrum very similar to that which you would obtain at night by pointing at a solar-type star (Figure 17). The hole in the Star'Ex GEN2 slit indeed acts as a star simulator. At this stage, you can orient the camera to align the spectrum horizontally, a task you won't need to perform at night.

Figure 17. Spectrum of daylight passing through a hole 25 microns in diameter. This spectrum trace anticipates what you will obtain when observing stars.

Step 7: All that's left to do is install the slit of your preferred width into support #1 (see the appendix), and your spectrograph will be ready to capture the spectrum of stars in the best possible way. You can still work during the day, for example, by orienting the slit so that the spectral lines are generally vertical, as shown in the image in Figure 18. Here, we are using the 32-micron slit. The dark line is the Hα line, and the entire height of the slit is displayed. The white area at the bottom corresponds to the photometric part of the slit.

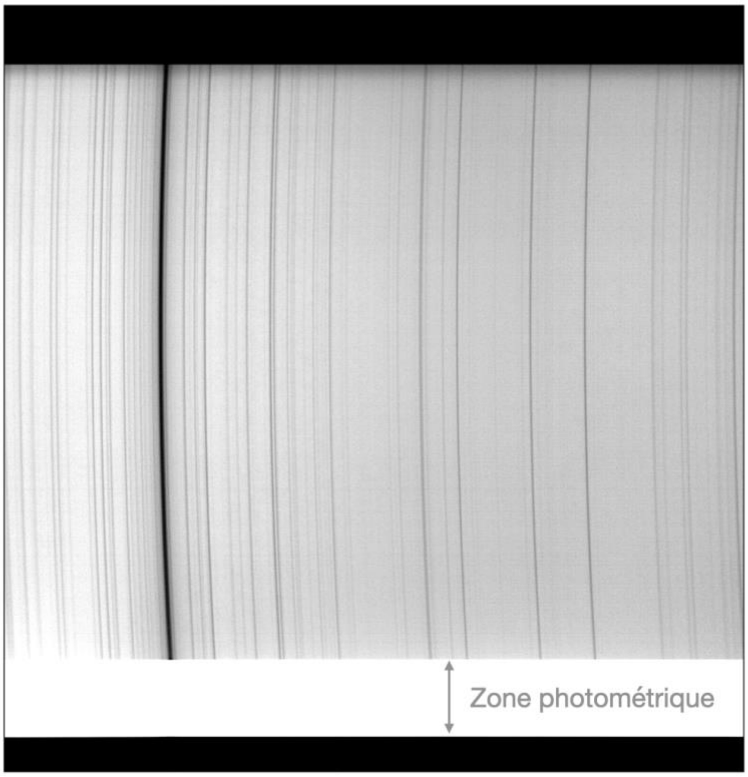


Figure 18. Spectrum of daylight taken with a slit 32 microns wide. Depending on the brightness of the observed scene, it may be necessary to expose for about ten seconds to achieve this result.

Figure 19 shows the same image with a contrast level such that the photometric area is no longer saturated. The solar spectrum appears in this section, but with very poor spectral resolution, as the slit is no longer 32 microns wide but 320 microns.

Figure 19. Le spectre de la lumière du jour en désaturant la zone photométrique de la fente de 32 microns.

The spectrum in Figure 20 is from a neon lamp, while some daylight also enters the slit. The neon line on the far left, with a wavelength of 6717 Å, appears less sharp than the others. We are reaching the limits of the spectral range at high resolution around the Hα line (the result also depends on the F/D ratio at the entrance of Star’Ex).

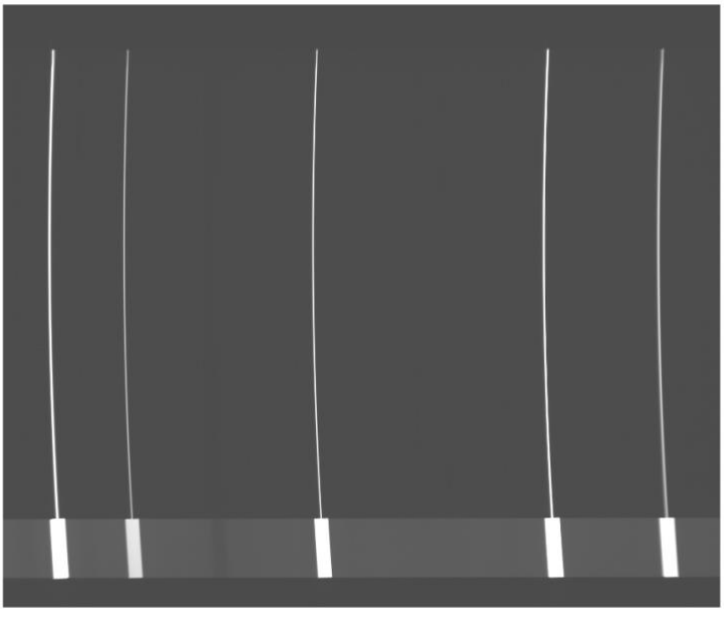


Figure 20. Emission line spectrum of a neon lamp while a faint daylight also passes through the slit.

It should be noted that the adjustment procedure described can be completed in less than an hour, without leaving your table and chair.

The procedure is very similar for the Star'Ex LR (Low Resolution) spectrograph, but here the phenomenon of anamorphosis is absent. The correct adjustment will produce round monochromatic images that are as small as possible (see Figure 21).

Figure 21. Spectrum of the neon lamp taken through the 25-micron slit after the adjustment was made.

5. Results

It remains to verify on actual stars, rather than artificial ones, that our adjustment holds up to its promises. To evaluate the result, in the following example, we attach Sol'Ex HR and LR to an Askar 107PHQ telescope (D=107 mm, F=740 mm, F/D=6.9).

Figure 22. Askar 107PHQ telescope to which Star'Ex is attached, all mounted on a ZWO AM5 mount.

The instrument is used in an urban environment, which allows the slit to be clearly seen against the background sky with the guiding camera, as shown in the screenshot of Figure 22, which features the bright star Vega on the 20-micron slit of the GEN2 assembly. One can immediately notice the presence of ghost images related to reflections on the slit plate, as the star is very bright and the exposure is deliberately extended (the guiding camera is an ASI290MM Mini). The ghost images are visible here because the exposure time is intentionally exaggerated. In most situations, these stray images are invisible.

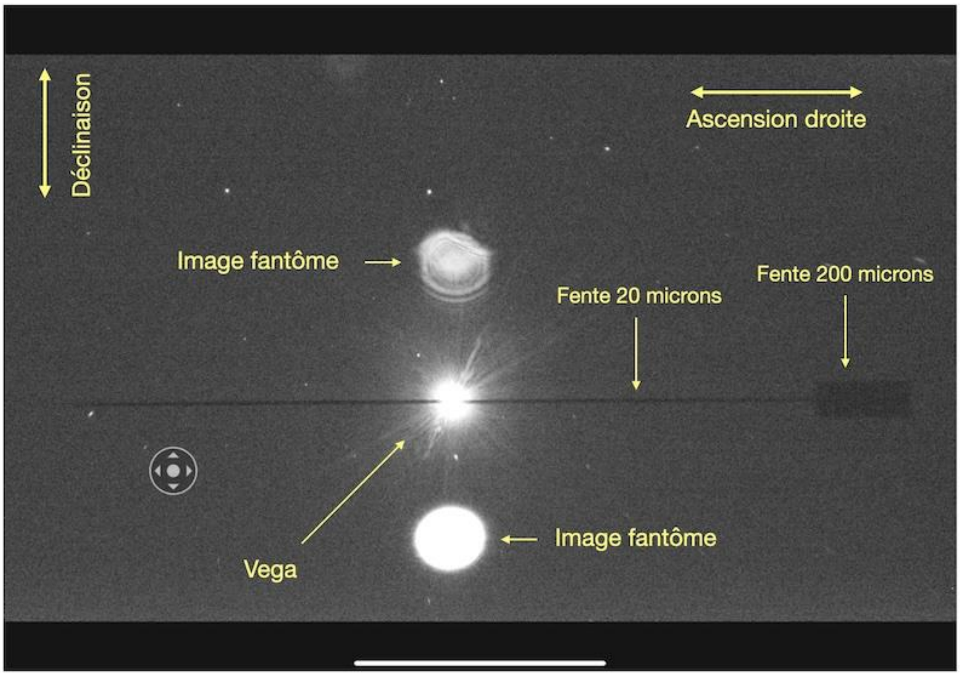


Figure 22. Appearance of the guiding image when pointing at a bright star. Note the choice of declination guiding and the orientation of the long axis of the slit along the long side of the sensor (Sony IMX290).

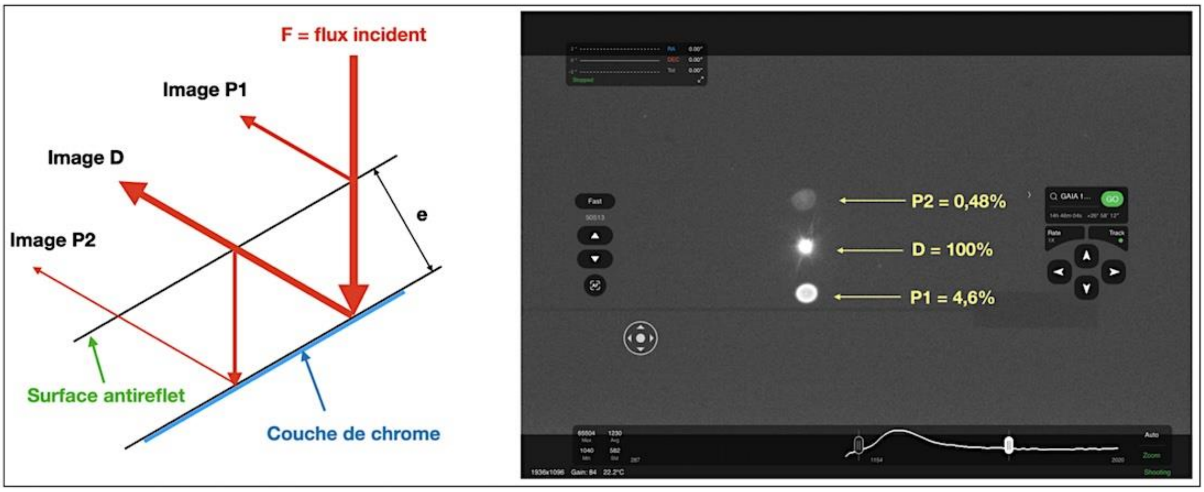


Figure 23. On the left, the path of the rays explaining the origin of the ghost images, which frame the nominal image (D). On the right, the relative intensity of the images (here with a Lhires III slit of 4 positions, 0.5 mm thick, but the result is quite similar with the Star’Ex GEN2 slit, except that the ghost images are more spread out).

Now we arrive at the most important moment, the one that validates all our efforts. First, we carefully focus the target star in the plane of the slit (here 20 microns wide). Note the use of the ASIAir system. The sign that we are well-focused is the visibility of the core of the stellar image at the center of the slit (see Figure 24). This core is apparent even though the light from the star enters Star’Ex because part of it is reflected by a glassy reflection at the opening of the slit (about 5% of the incident flux). The targeted star is beta Lyrae (Shelyak).

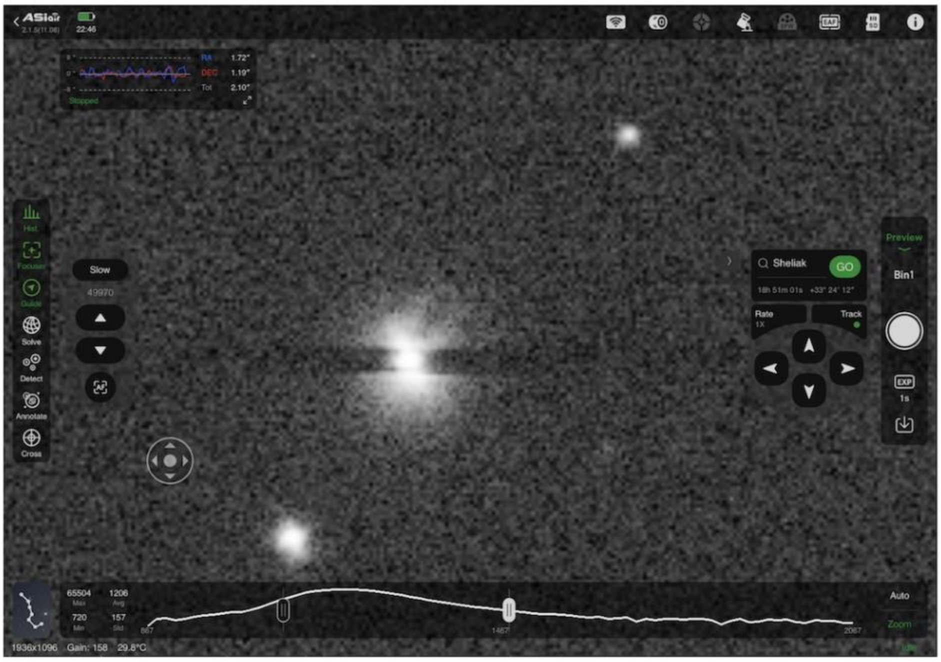


Figure 24. Enlarged view of the star beta Lyrae, centered on the opening of the slit measuring 20 microns wide.

The peacekeeper is to observe a sharp and fine spectrum of this star in the science camera simultaneously with sharpness in the guiding camera. This is indeed the case, as shown in Figures 25 and 26. The adjustment is a success!

Figure 25. Image du spectre de l’étoile beta Lyrae (une étoile Be) en haute résolution, allant de la raie d’émission Hα à gauche à la raie rouge de l’hélium à droite, toutes deux en émission.

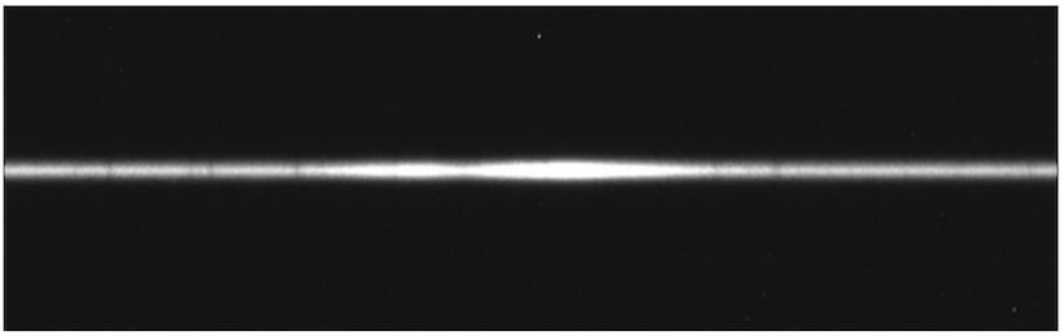


Figure 26. Details from figure 25. The spectrum appears very fine, with no trace of astigmatism that would result from a poor adjustment.

We can also verify that the photometric function of the Star’Ex GEN2 slit is functional. Here, for example, in Figure 27, is the image of the star Vega centered on the wide part of the slit. We are working far from the center of the field, and the image is poor in the guiding camera. But that is not the important part. Figure 28 shows that the spectrum of Vega is almost as sharp, whether the star is positioned on the narrow or wide part of the slit.

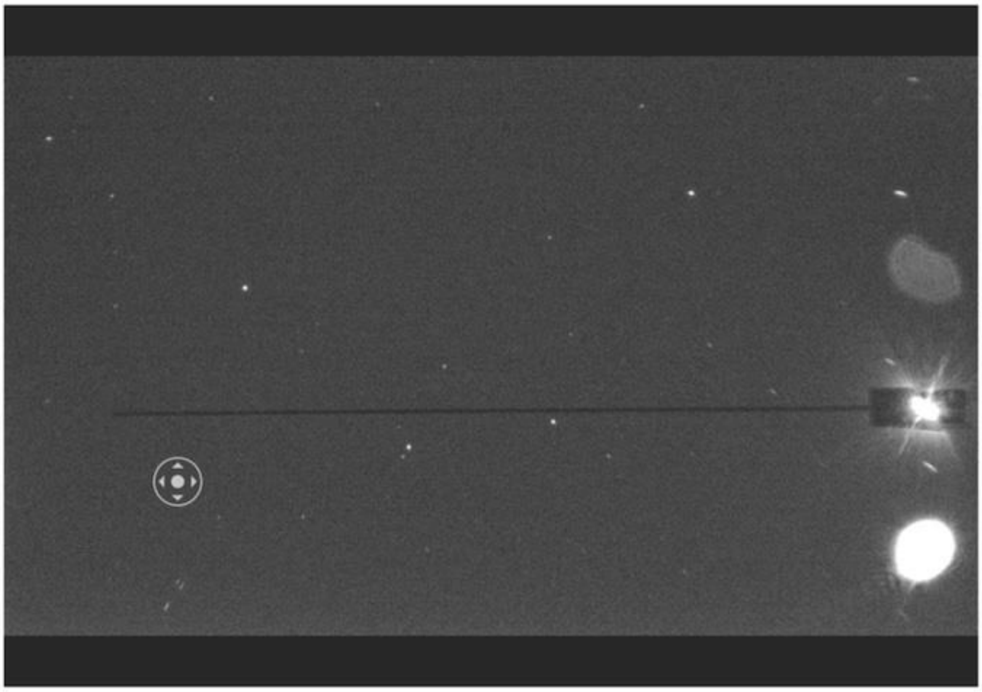


Figure 27. Positioning of the image of the star Vega in the photometric area.

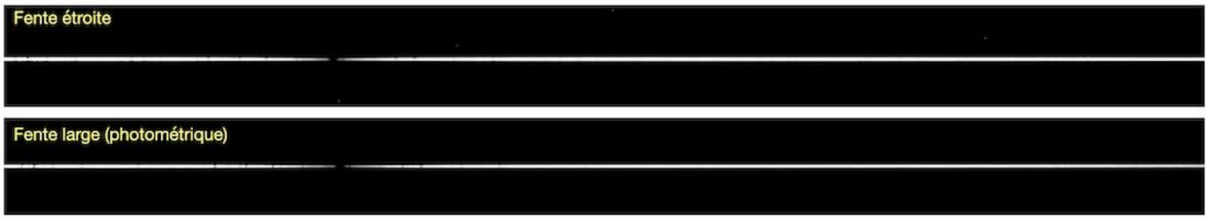


Figure 28. Appearance of the spectrum trace of Vega, whether using a narrow slit (here 20 microns) or a wide slit (here 200 microns).

The screenshots in Figure 29 illustrate the use of the GEN2 slit on a Star’Ex LR ("Low Resolution") with support #2 (see in the annex), which positions the photometric area towards the center of the guiding image to facilitate its use.

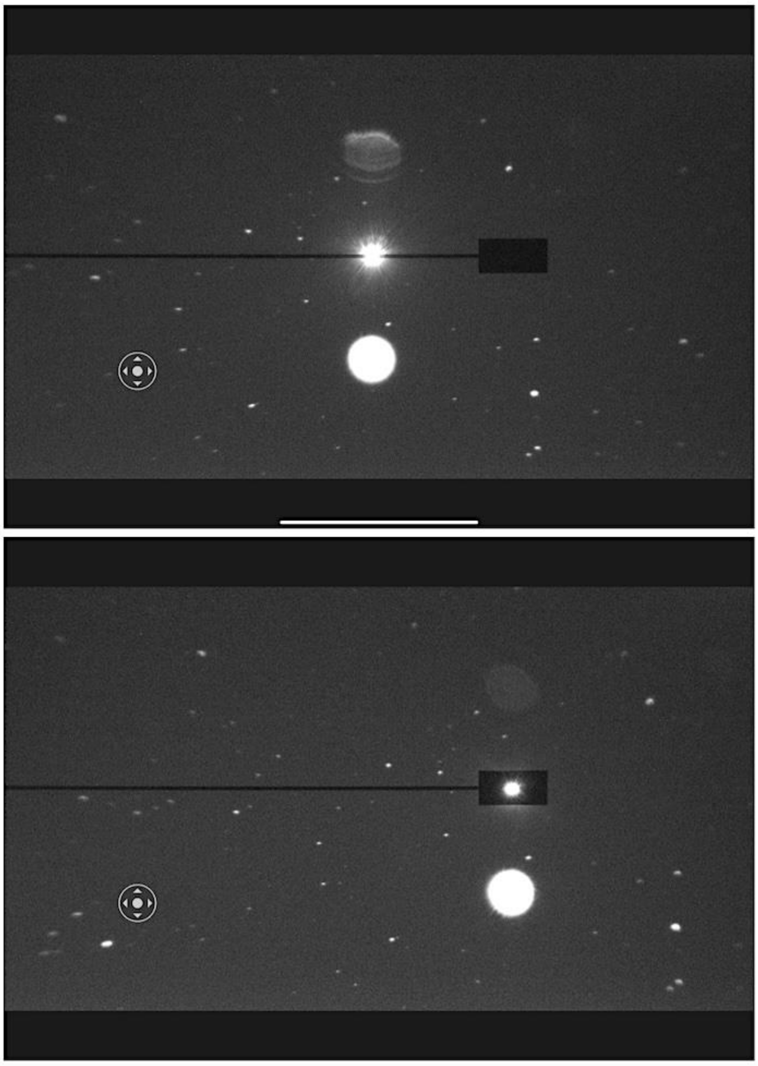


Figure 29. At the top and bottom, the star gamma Cyg positioned in the narrow and wide areas of the slit, respectively. We use the slit support #3, which recenters the photometric area relative to support #1.

Figure 30 shows the image of the spectrum of the star gamma Cyg in low resolution. Once again, the adjustment procedure described in this note works perfectly. The spectrum is clear, as suggested by the observation of the GEN2 star, and this is achieved on the first attempt.

Figure 30. Image of the visible spectrum of the star gamma Cyg (single exposure of 3 seconds).

ANNEX

STL Files for Slit Supports

Three types of slit supports are proposed for specific functions:

- **Support #1:** This support positions the slit to center its narrow part on the optical axis of the instrument. It is the standard support, the one that will be most used for the classic observation of stars and nebulae.

- **Support #2:** This support positions the adjustment hole on the optical axis of Star’Ex. It is used only briefly during the adjustment phase.

- **Support #3:** This support recenters the photometric area of 1 mm on the optical axis. It is intended for those who wish to perform spectrophotometric measurements and accurately calibrate the instrumental response curve routinely (support #1 also allows this operation but with lower optical quality, as the photometric area is further from the center of the field).

A retaining bracket, common to all supports, completes the set.

The corresponding STL files can be downloaded if you wish to print these supports yourself. You will need a 3D printer, some PET-G filament, two M3 inserts, and approximately one to two hours of time.

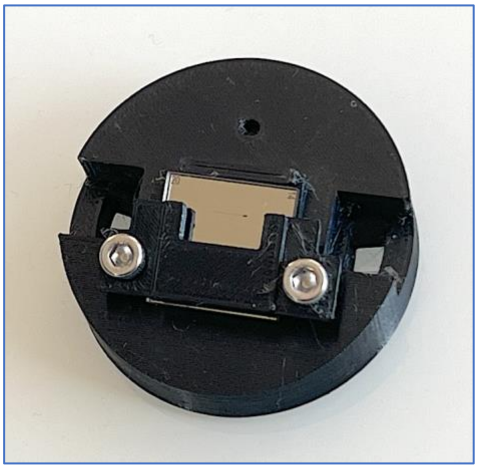


Figure 8. Appearance of the slit in its support #1 made using 3D printing.

The Star’Ex GEN2 slit system consists of 3 supports and a bracket. The supports can be identified by the dots on their upper surface: 1 dot = standard support, 2 dots = photometric support, 3 dots = support for adjustment with the artificial star at the center of the field.

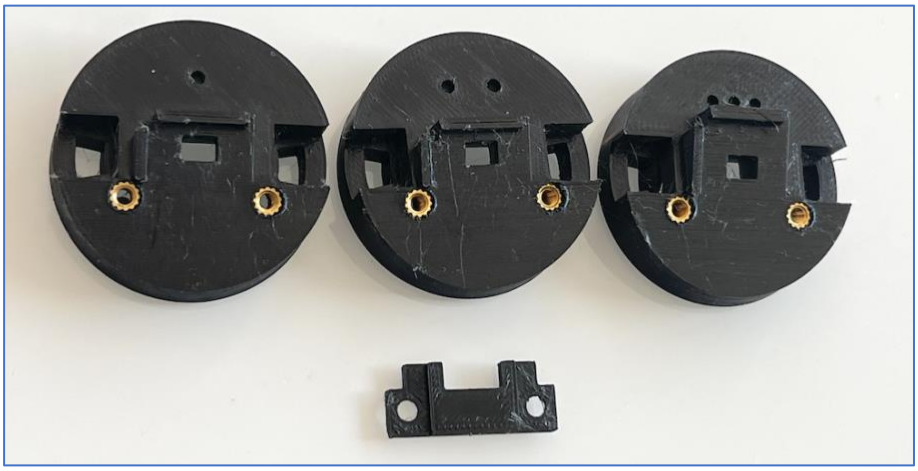
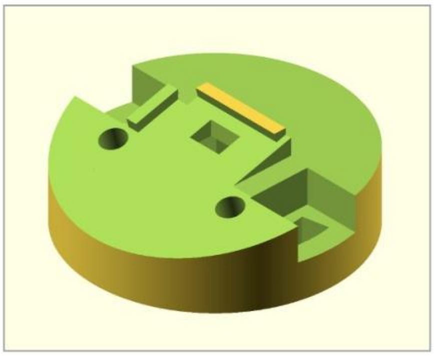


Figure 9. The supports and the bracket of the GEN2 system.

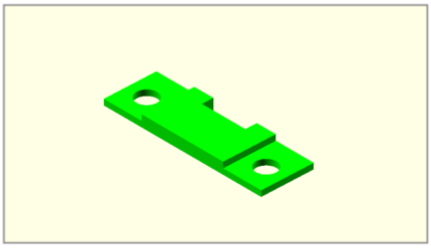
STL file for support #1 (1 dot) can be downloaded here:
http://www.astrosurf.com/buil/starex/slit_starex_gen2_1.stl

STL file for support #2 (2 dot) can be downloaded here:
http://www.astrosurf.com/buil/starex/slit_starex_gen2_2.stl

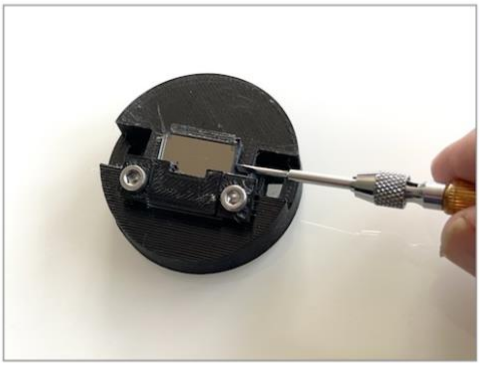
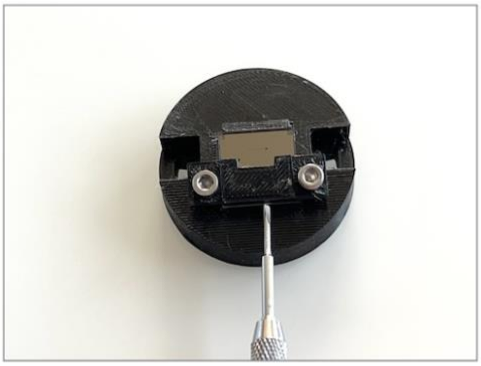


STL file for support #3 (3 dot) can be downloaded here:
http://www.astrosurf.com/buil/starex/slit_starex_gen2_3.stl

STL file for the flange can be downloaded here:
http://www.astrosurf.com/buil/starex/flange_starex_gen2.stl



Finally, a few mounting recommendations. First, before tightening the bracket, ensure that the edges of the slit are flush against the shoulders:

The Star’Ex GEN2 slit is significantly more robust than the previously used models, thanks to its 2 mm thick glass. However, the bracket should be tightened moderately, as it is designed to be flexible. The tightening of the M3 screws can be done by hand, applying only a small amount of torque, as the slit will already be adequately secured. A very slight tightening with an Allen key can be done for reassurance, as shown in the following photographs:


Below is a photograph of the GEN2 slit in place within the Star’Ex spectrograph: