Alpy 600
User Guide

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Welcome to the world of spectroscopy !

Alpy is a modular product line, allowing you to start in spectroscopy in a very easy way, and progress up to producing high quality spectra on astronomical objects. Alpy 600 is the main module in this family. It has several operating modes. You can use it visually, on different light sources as well as on stars with a telescope. You can also take pictures to share what you see, and make scientific measurements : you'll be surprised how far you can go in astrophysics with such a basic instrument. For instance, you'll be able to measure the temperature of a star, define its spectral class, measure the expansion velocity of a nova, observe the emission line of a Be star[1], measure the expansion of the universe, and so on.

The Alpy 600 design meets several objectives:
– To offer an instrument which is easy to start with and fun to use, but which is also powerful enough for people who want to go deeper into the science. There is no compromise on the spectrum quality: the optics are specially designed for this spectroscope.
– To provide an affordable and scalable instrument. Several additional modules are available. You can use the Alpy 600 module alone to produce high quality spectra, but adding the guiding and/or calibration modules will make your astronomical observations much easier and more productive.
– To be easily adaptable to your own setup (telescope, camera...). the mechanical interfaces are standard, and allow many different usages.
– In spectroscopy, there are different kinds of instrument : slitless, with slit, or with fiber optics. All of them have advantages and drawbacks: It is the type of observation which defines the optimal configuration. The Alpy 600 allows all of them! Then, you can decide for yourself what is best in your case.

Prerequisites

Spectroscopy is a very large subject. Some parts are very easy. For instance, looking visually at a spectrum, during daylight or with a star, requires no experience.

However, if you want to take images or make scientific measurements, it is highly recommended to have some experience with your instrument - telescope and camera. In this document, we assume that you're new to spectroscopy, but that you're already familiar with the basics of astrophotography. Specifically, we'll not cover here the following points:
– Setting up and tuning your telescope. You must be able to point and track a star. Ideally, you should have autoguiding (with external parallel optics, off-axis or with the Alpy guiding module).
– Installing, starting and using most common software. You should have a PC available, running under Windows (we use MS Windows 7 in this document).
– Astronomical imaging. You should know what is a dark, an offset, a flat field and classical image processing.

💡 If you've already made some deep sky images, with long exposure and good processing, moving to spectroscopy will be easy for you - a new adventure which gives access to a new dimension.

Recommended learning path

Here is a proposed learning path to guide you step by step through the discovery of your Alpy 600:
– First, use the Alpy 600 in slit mode (as it is configured in our factory), during daylight.
– start by looking at some lamps and daylight spectra - the Sun spectrum, in fact.
– record images and reduce data.
– Secondly, change to slitless configuration, and install the Alpy 600 on your telescope.
– start first with visual observation of some bright stars,
– then record & process star spectra images.
– Lastly, take star and extended object spectra in slit mode.
This document follows this path.

Software

The Alpy 600 is shipped with a CD-ROM containing all the software tools you need to observe and process your data. These software are free - you can find their latest versions on the web. Of course, you can use your own software if you prefer. In this document,

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1. http://arasbeam.free.fr/

we use AudeLA [2] for acquisition and ISIS [3] for data reduction.

Equipment configuration

The Alpy 600 can be used in many configurations, but we cannot document all of them ! This documentation is based on a specific configuration (which fits Alpy requirements perfectly). It will be easy for you to adapt the instructions to your own equipment & software.

– A Goto telescope, able to point and track a star in autoguiding mode.
– A C8 telescope with F/6.3 reducer.
– A CCD camera Atik 314L+. It has a 8.9 x 6.7mm CCD chip, with 6.45μm pixels. It covers the full Alpy 600 spectrum.
– A PC running under Windows 7.

💡 A CCD camera is the optimal choice for astronomical observations. However, Alpy 600 can also be used with a DSLR camera. Because the backfocus (distance between camera mount and sensor chip) of a DSLR camera is much higher than in a CCD camera, we've designed an optical adapter for DSLR cameras. Refer to Appendix for accessory descriptions.

Alpy modules

Alpy is a scalable instrument. This a family of modules, to best fit your own needs & observations. These are the main modules :

– The Alpy 600 is the main module. It is the spectroscope itself. It can be used in different configurations, to cover most applications in astronomy & the lab.
– The Guiding module : For astronomical applications, it is difficult to ensure that all the light from the object you're observing goes into the spectroscope. This module will help you to observe & control the spectroscope entrance.
– The Calibration module: For accurate results, a spectrum must be properly calibrated, in wavelength and intensity. The calibration module simplifies this operation by providing both a calibration and white light. It can be used manually or remotely.
– Accessories : DSLR camera adapter, C-mount camera adapter, fiber optics connector.

Astronomical sectroscopy is a never ending story. We have thought about a lot of applications (you can find some ideas on the Shelyak Instruments website [4]).

However, we know that you'll invent new ones. We'll be very happy to take your experiences into account to continuously improve this product : do not hesitate to contact us if you have any comments !

We invite you to join the growing Shelyak Instruments users and amateur spectroscopist community on the Spectro-L Yahoo group [5] and the Aras forum [6] to share your own experiences and ask questions to the community. We are really interested to see your results there.

It is now time to enter in this wonderful world... Are you ready ? Enjoy Spectroscopy !

Olivier Thizy [7]   *François Cochard* [8]

2. http://www.audela.org/
3. http://www.astrosurf.com/buil/isis/isis.htm
4. http://www.shelyak.com
5. http://groups.yahoo.com/group/spectro-l/
6. http://www.spectro-aras.com/forum/
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Discover your Alpy 600

1.1 Out of the box

When you receive your Alpy 600, it is assembled in slit configuration, ready for mounting on a telescope and for imaging with a CCD camera. The package contains the Alpy 600, as well as a tool set and a CD.

1.2 Technical specifications

The Alpy 600 specifications are given in table 1.1, and dimensions are given in figure 1.1. In addition, the table 1.2 gives the wavelength covered depending on the CCD length.

1.3 Alpy 600 elements

Remove the external body from the big ring:

CCD Sensor	CCD length	λ min	λ max
	4 mm	4560Å	6055 Å
	5 mm	4293Å	6322 Å
1/2"	6.4 mm	3920 Å	6695 Å
KAF400	6.9 mm	3790 Å	6825 Å
	9 mm	3650 Å	7380 Å
	10 mm	3650 Å	7656 Å
	11 mm	3650 Å	7923 Å
	12 mm	3650 Å	8190 Å
ICX694	12.5 mm	3650 Å	8319 Å
	13 mm	3650 Å	8457 Å
KAF1600	13.8 mm	3650 Å	8500 Å
	15 mm	3650 Å	8500 Å
	16 mm	3650 Å	8500 Å

Table 1.2: Covered bandwidth vs CCD size. Note that above 7500 Å, the 2nd order may recover the 1st order.

Look at the slit, at the end of the spectroscope:

| Description	Value	Unit	Comment
Dimension Alpy 600		mm	See drawing below
Weight	200	g	with 1,25" nosepiece & without CCD camera
Resolution Power (R) @ 650nm	~600	-	with 25μm slit
Resolution Power (R) @ 450nm	~400	-	with 25μm slit
Spectral domain	370 - 750	nm	
CCD min length	8.5	mm	if smaller, only a partial spectrum is visible
Optical dispersing element	Grism	-	grating + prism
Grating density	600	l/mm	
Typical spectral dispersion	480	Å/mm	
Input beam F-ratio	F/4	-	Telescope beam can be from F/4 to F/10 (optimal luminosity performance is at F/5)
Slit width (standard)	25	μm	also included : hole 3mm, slit 300μm, 100μm 50μm, hole 25μm
Slit length	3	mm	except for hole 25μm
Mechanical interface	M42 x 0.75 thread	-	Standard T-mount (or T2)

Table 1.1: Alpy 600 specifications
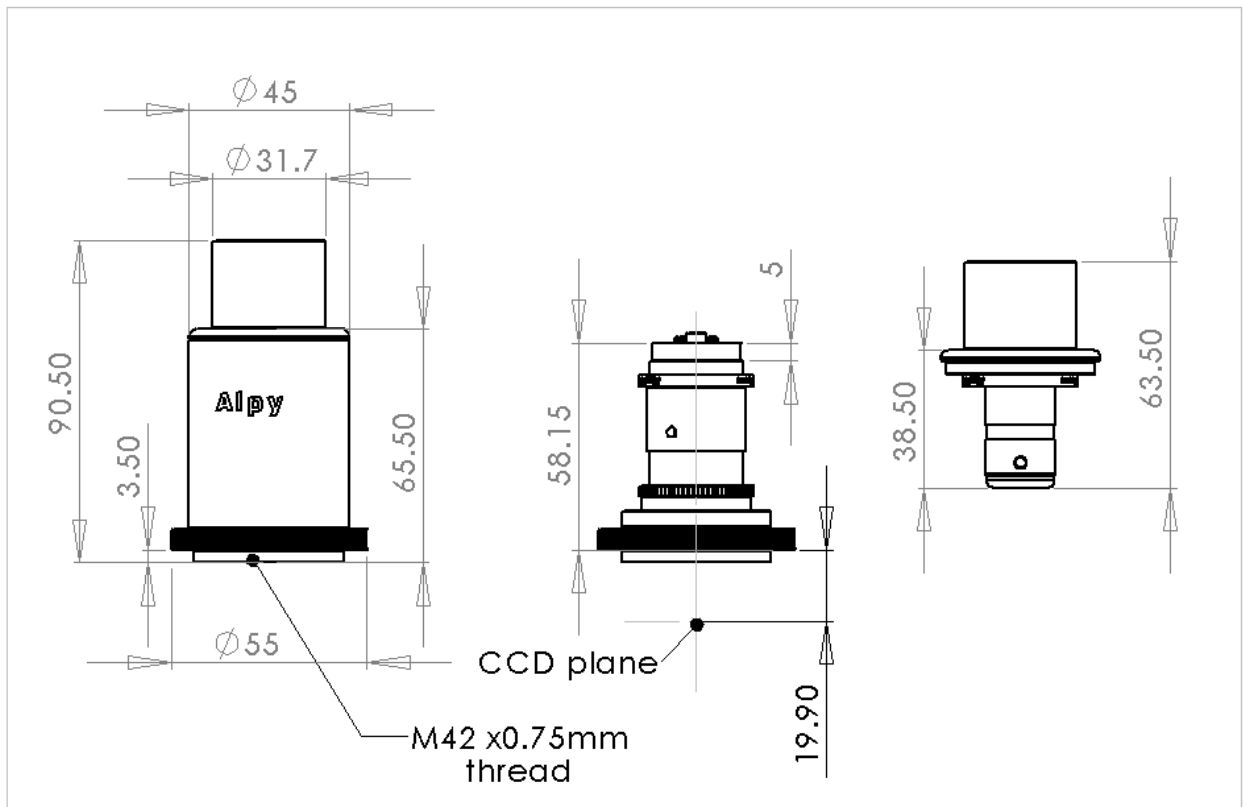
Figure 1.1: Alpy 600 dimensions (in mm)

Loosen the three small screws around the spectroscope body, and remove the Alpy 600 core element :


You have now a view of all the elements of the Alpy 600: Core element, Objective lens, external body and nosepiece 1,25".
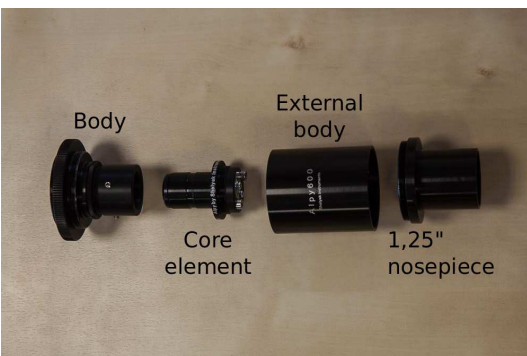
💡 As far as possible, standard threads have been used on the Alpy 600 parts, to allow you maximum flexibility with your own equipment. For instance, the external body is made with standard M42x0,75mm threads : you can use a 2" eyepiece holder instead of the 1,25" one.

Several slits are available. We'll see in the next chapters how to change it and under which conditions to use each of them.
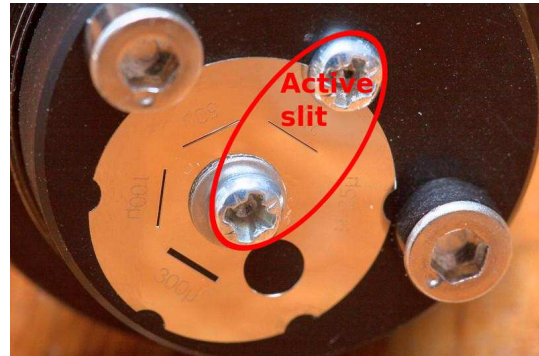
1.4 Mechanical interfaces

The Alpy 600 uses several standard threads for mechanical interfaces, to adapt the instrument to your own setup.

The CCD camera interface is a standard T-mount thread (M42 x 0.75mm)

The same thread is used on both ends of the external body. For instance, you can replace the 1,25" nosepiece by a 2", using a common 2" to T-mount adapter.

The thread around the slit is of SM1 type: external diameter 1,035" (26,29mm), 40 threads/inch (pitch = 0.635mm).

The standard 1,25" nosepiece includes a standard filter thread (M28.5 x 0.6mm): you can easily measure the response curve of any filter mounted in a standard ring.


1.5   Visual observation

Now, take the core element and look at any light source: classical lamp, or spectral lamp, or even the sky, cloudy or not (do not look directly at the sun, it is far too bright).
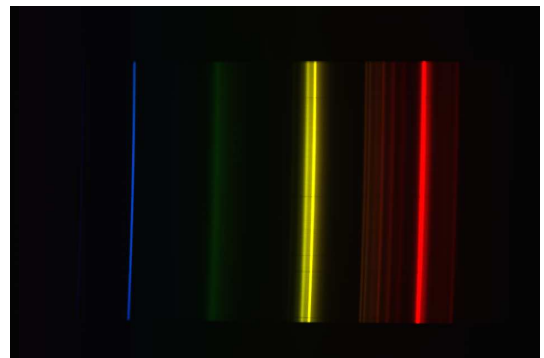
💡 Do not look directly at the Sun, with or even without a telescope !

You'll see your first spectrum. Look at different sources, to see the different spectra types :
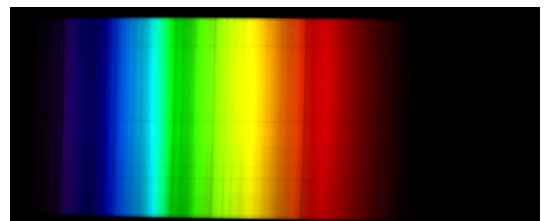
A tungsten lamp has a continuous spectrum:
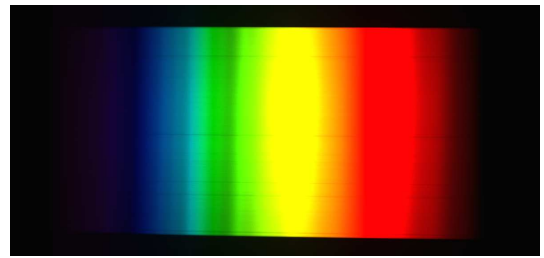
A power saving lamp has several bright emission lines and some bands:

The Sun shows a continuous spectrum, with a huge number of Fraunhofer absorption lines:

This shows that each source of light has it own spectrum, and the spectrum reveals a lot of scentific information about its origin.

This will be the same for stars and any astronomical object : each one has its own spectrum, which reveals many physical parameters of the star.

💡 This document follows the standard convention for presenting astronomical spectra. The blue end of the spectrum corresponds to the highest frequencies, or lower wavelength. The red end is for lower frequencies or higher wavelength. Usually, in Astronomy, we show the spectra from lower to higher wavelength. From now on, get into the habit of putting blue on the left, and red on the right.
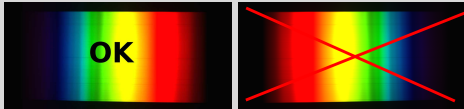
1.6 Alpy 600 principle

The principle of the Alpy 600 is as follows. A point light source is sent to a collimator lens which makes the beam parallel. This parallel beam goes through a dispersing element (usually a prism or a grating): all outcoming rays of the same wavelength (or color) go in the same direction, but the output angle differs for other wavelengths. Then, an objective lens collects all these beams and focuses them on the focal plane, where we put the sensor.
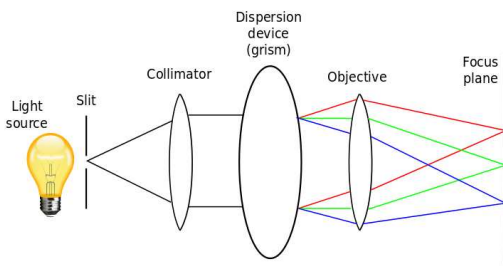
To make the source point-like, we usually use a narrow slit: only the light which goes through the slit is spread out. The narrower the slit, the higher resolution the spectrum is, but the less light goes through: there is a compromise to find for each case.
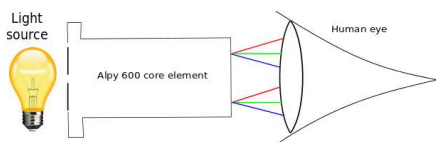
In Astronomy, we're lucky : stars themselve are point-like. So, when looking at stars, we can afford to remove the slit:
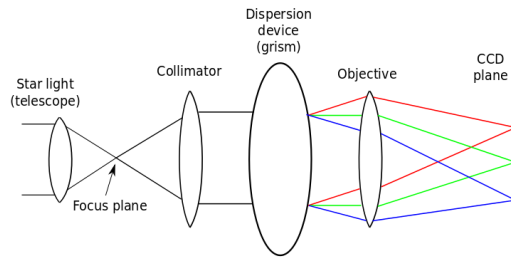
The Alpy 600 is designed in a modular way. The core element consists of the the slit, the collimator lens, and a grism. A grism is a combination of a grating and a prism. The grating spreads out the light, but also deviates the beam by a significant angle. Using a prism brings the beam back onto the axis of the input light. In this way we have an on-axis instrument.
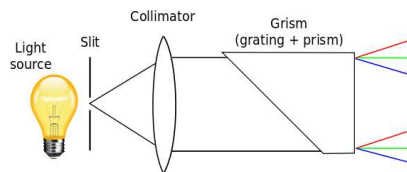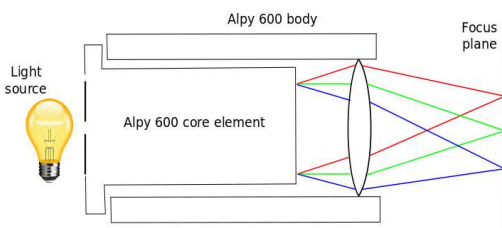
The light coming out the core element is then a set of parallel beams. This is exactly what the eye needs : a parallel beam is comparable to a beam coming from infinity. Then, if you put your eye behind the core element, you'll see the spectrum.

If you want to take an image with a camera, you need to add the objective lens, to focus the parallel beams onto the CCD sensor. This is built into the Alpy 600 body:

On the next picture, you can see the objective lens, part of the Alpy 600 body:

💡 The eye contains its own objective lens - the crystalline lens. Then, it accomodates any beam coming from the infinite !

1.7 Different slits

The Alpy 600 is a versatile instrument. As described in section1.6, a spectroscope requires a point light source to properly work - the smaller the source, the better is the resolution. Alpy 600 contains several slits, to fit to several usages. Table 1.3 shows some of them.

To work with an extended source (which is the case in most everyday situations), use the standard slit - 25μm wide. It is optimized for visual usage, and for bench measurements. The resulting spectrum is a wide band (top line of table 1.3).

In some conditions, it is better to only have a small hole : this way, the spectrum is always at the same position in the image - but it is more difficult to see visually. To a certain extent, this is a way to reproduce in the lab what will be seen with stars (second line).

There is another useful case : working in slitess mode. This is applicable to stars, which are point-like. The advantage is that you'll see a bigger star field, and you'll be able to find easily the star you're looking for. To do that, you can totally remove the slit from the Alpy 600, but it is better to keep in position the "3mm hole" : this way, you'll limit the optical aberrations at the field edges - and you'll not lose the slit (third line).

Sometimes a wide slit is useful. For instance, when you have no guiding module but want to eliminate most of the sky background, or when you want to collect the full star light if the star image is bigger than 25μm. In this case, you can use the 300μm slit (last line).

The Alpy 600 also includes 50μm and 100μm slits.
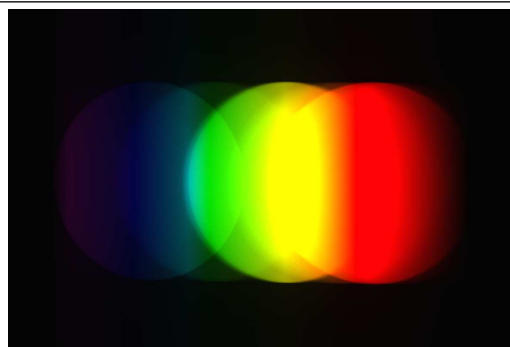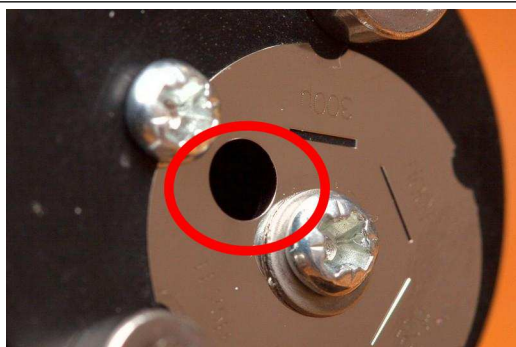
Changing the slit position

The slit position is easy to change. It is mounted with two screws. Remove the outer one, and just loosen the central one. Choose the slit you want, and put its notch in front of the outer screw's hole. Put back the
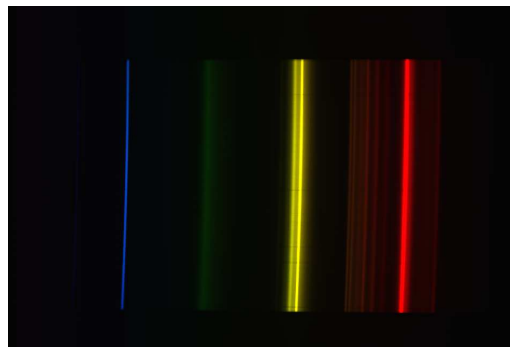
Standard slit : 25μm

Hole 25μm

Hole 3mm
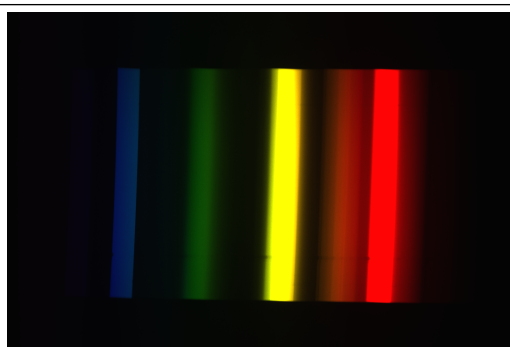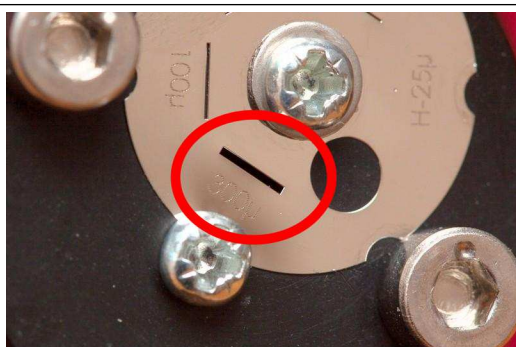
Wide slit 300μm

Table 1.3: Alpy 600 slits

outer screw, and tighten carefully the two screws.
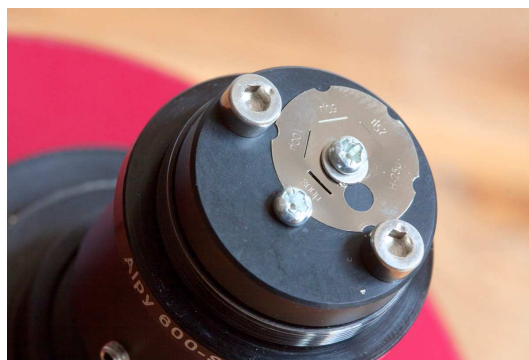
💡 The slit is a fragile component - take extra care when changing its position, and make sure that you can move it freely, before turning it.

Cleaning the slit

Over the time, there can be some dust on the slit. A dust particle in the slit is seen in the image as a dark line along the dispersion axis. You can clean-up the slit with a soft, dry cloth, or gently blow away loose particles.

Alpy 600 - Spectroscopy in slit mode

In the previous chapter, you've looked at lamp spectra using the Alpy 600. Now, you probably want to take a picture of what you've seen, either to share it with others, or to make measurements. This is the purpose of this chapter. Here you will work in slit mode, with everyday light, working on a bench.

2.1 Configuration for imaging

As explained in section 1.6, compared to visual observation, we need to add more optics behind the grating, to create an image at the focal plane (the CCD surface). These optics are contained in the Alpy 600 body:

The body is threaded, for tuning the distance between the optics and CCD when it is mounted in the CCD camera adapter. (The nominal distance is about 19,5mm) . A threaded ring is used to lock the body in the focused position.

💡 Watch out that the optics do not touch or damage your camera sensor.

Assemble the CCD camera adapter to your camera:

The camera used here has a T-mount (M42x0,75mm thread). If you are using a C-mount camera, an optional C-mount adapter is available (see appendix 7.1.4).

Put the Alpy 600 core element in the body. It can turn freely : this will be used to put the spectrum horizontally.

There are three small screws around the body, to lock it in the right position:

Now, put the camera in a stable position, and point the slit towards a daylight source (sky or window). Start your acquisition software. Setup the CCD camera cooling at -5°C for instance. Take a first image of the spectrum. You may have something like this:
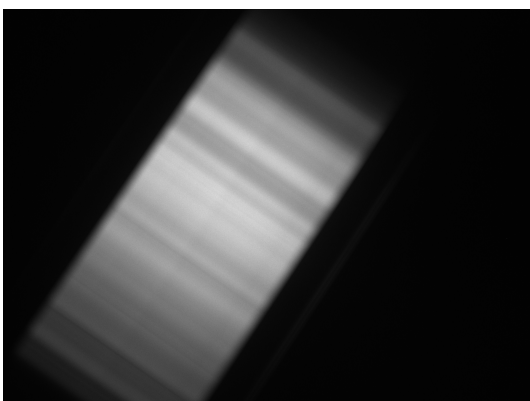

💡 Even if the weather is cloudy, the daylight is always the Sun light. You don't need to wait for good weather when taking a solar spectrum.

The first point to check is that the image is not saturated. The CCD camera has a capability of recording a certain level of light (this is the dynamic range specification). If the source exceeds this level, the camera considers it is like a "maximum light", and cannot see any details in it. The Atik 314L+ camera has a dynamic range of 65535 ADU. If a pixel in the image is above this value, it means that image is saturated. To solve this problem, you must reduce the exposure time, or reduce the source intensity if it is possible.

At the opposite end, if the maximum level of the image is at the bottom end of the dynamic range of the camera, you lose the capability to see details in your images. You can then increase the exposure time. The optimal level is about 80% of the camera max level.

💡 If the image is totally black or white, it can be due to the image visualization threshold settings in the software. Move the cursor in the image and check the pixel level (bottom right). Or change the thresholds by clicking on "Auto" button (bottom left).
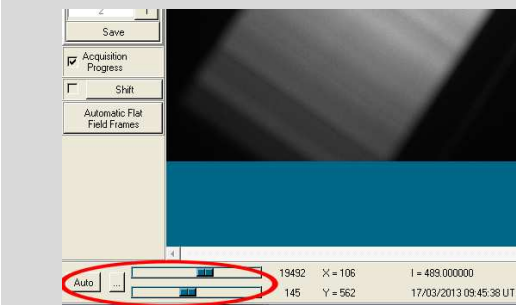
The spectrum is probably unfocused, and in any direction. To put it horizontally, simply rotate the Alpy 600 core element in the body:
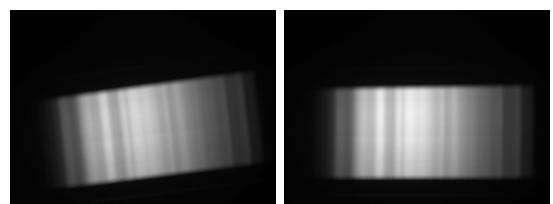
To focus the spectrum, turn the body in the CCD camera adapter. Proceed step by step, taking continuous images.


💡 When you turn the body in the CCD camera adapter, you change the spectrum focus, but also its orientation. To see the focus improvement, it is better to keep the spectrum with the same orientation. To do that, fix the the CCD camera firmly (we often use a small hand-vice), take the Alpy 600 core element in one hand to keep it in place, and turn the body with the other hand.


When the spectrum image is correct, tighten the threaded ring around the body, and the three screws to lock the Alpy 600 core element.

You should have something like this:
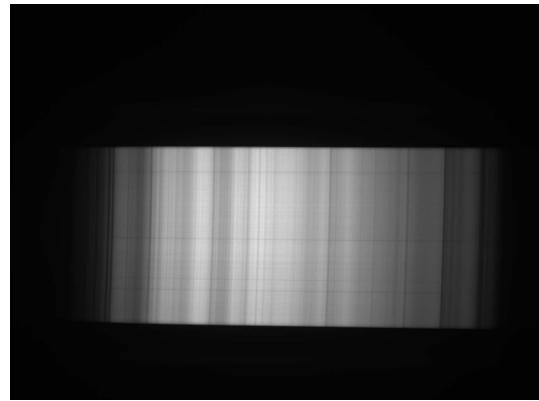
The spectrum must be orientated with blue on the left, and red on the right... It is not obvious to see in a black & white image ! With experience, you will immediately recognize the Sun spectrum. Refer to this image to put it in the right position:
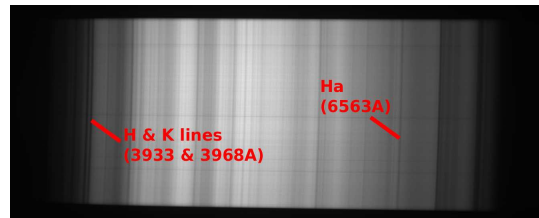
You've completed the most complex part of spectroscopy with Alpy !

At this stage, your camera is equiped with the spectroscope, and any image you take will be a focused and horizontal spectrum of the light coming into the slit.

💡 When The Alpy 600 is focused, you can remove the core element and put it back quickly : the focus is not lost. You'll have only to tune the rotation angle, to put the spectrum horizontal in the image.

Test now different kinds of lamps: tungsten, power saving lamps, neon lamp, Alpy calibration lamp... each source has its own spectrum. The table 2.1 shows some examples.

For the next step, record at least one image of the Sun spectrum in FITS format.

💡 FITS format is the *image file format* for Astronomy. This is a format which keeps the whole information in the image (no compression), and adds some key data in a file header, such as date, image size, observer, observing site, object coordinates, and so on.
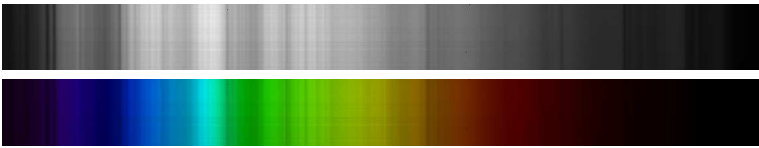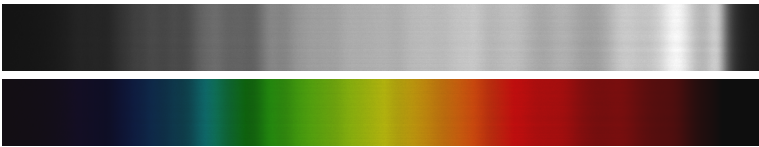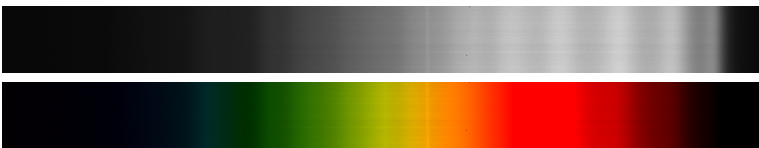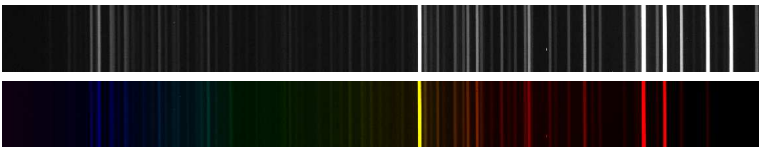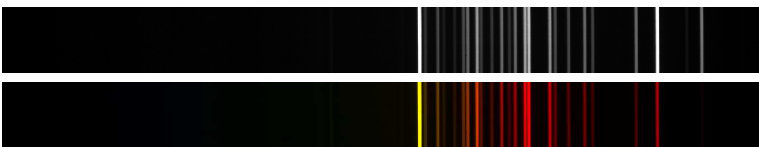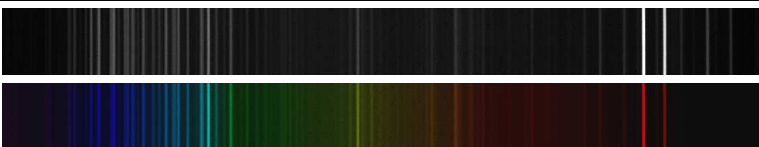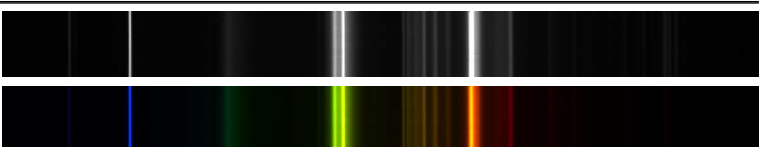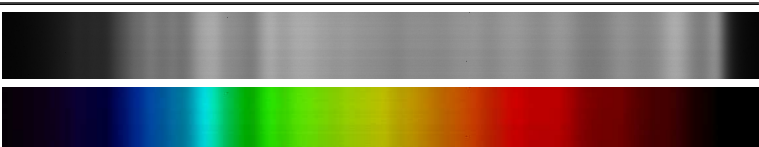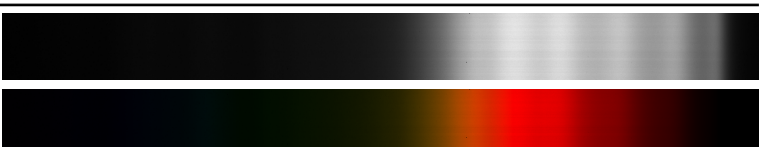
Description	Images
Sun light	
Halogen lamp (flat field lamp of the Alpy calibration module)	
Candle light	
Argon / Neon (Alpy calibration module)	
Neon lamp	
Argon (Habitat lamp)	
White LED	
Power saving lamp	
Blue paper, illuminated by a halogen lamp	
Red paper, illuminated by a halogen lamp	

Table 2.1: Some examples of common light sources. The color version of each spectrum is colorized by software.

2.2 Color or black & white ?

When you look visually at the spectrum, you see a rainbow, with beautiful colors. Using most CCD cameras, you get only a black & white image. This is normal, because the CCD camera is not color-sensitive. If you had used a color camera (or a DSLR camera), you would have a colored spectrum like this one:
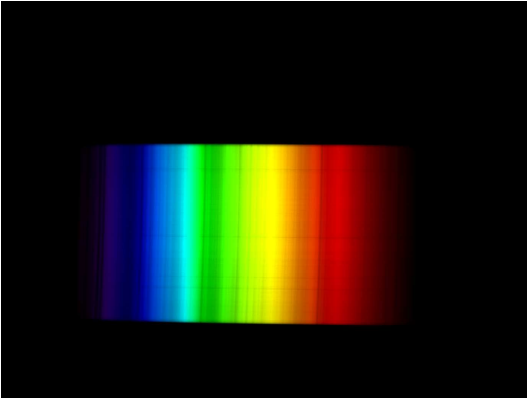
You might think it is better to have the color... it depends ! If this is only for sharing what a spectrum is, this is true. But if you want to make measurements on your spectrum, a black & white camera is preferable : its surface is uniformly sensitive, and there is no effect of the colored pixels (Bayer matrix effect).

Anyway, keep in mind that color or black & white only depends on the camera : the spectroscope itself works in color.

2.3 Preview of your spectrum

You've recorded your first spectrum image. That's great, but not very useful in this format. Usually, a spectrum is presented as a profile, giving the light intensity vs the wavelength. To make the conversion from image to profile, you must use spectral data reduction software. Alpy 600 is provided with ISIS software, which is one recommended tool. This document isn't a tutorial of ISIS (refer to the ISIS documentation[1], and specially the Alpy tutorial[2]), but shows very quickly the basics for this first experience.

Here is how to proceed with your Sun spectrum.

Run ISIS, ang go to the "Settings" tab. Select "ALPY 600 (without calibration module)" in the spectrograph model, and specify the working directory where you've storedyour images (FITS files):
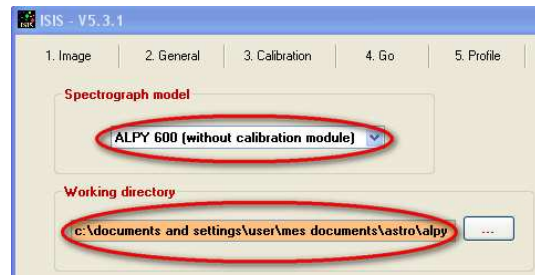
Go in the tab "Image". Select your Sun image (Sun-1.fit), and display it :
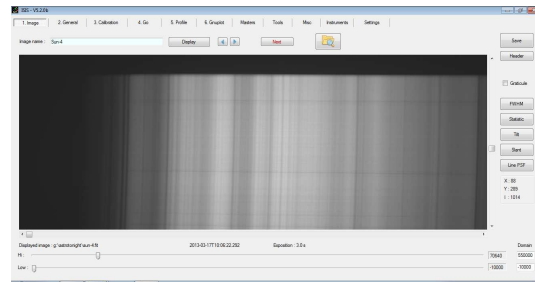
If you don't see the spectrum, it is probably because it is outside of the displayed zone. You can move in the image using the scrollbars

Select the checkbutton "Reticule".

It will display the area of the image which will be selected for profile extraction. If the area is not in the spectrum, double click in the middle of the spectrum : it will put the reticule there.
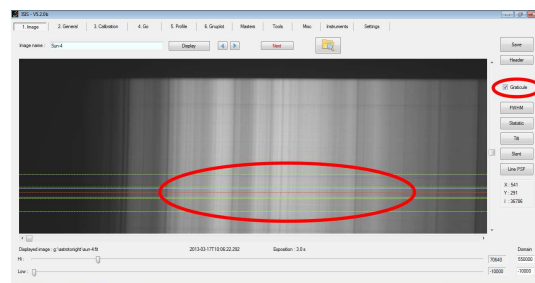
Then, click the button "Next"; ISIS switches to the "2.General" tab, and updates automatically several fields. Put "Sun" in the object name. In the options area, select the "don't remove background" checkbutton. This is to tell ISIS that your spectrum is from an extended object (the spectrum is not a single line in the image). Unselect "wavelength calibration", because at this stage, we've no data for calibration.

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1. http://www.astrosurf.com/buil/isis/isis.htm
2. http://www.astrosurf.com/buil/isis/guide_alpy/tuto_en.htm
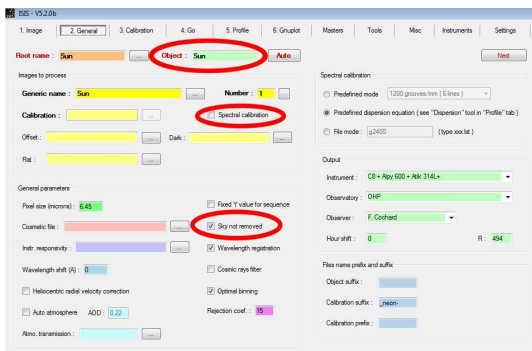
Click on the "Next" button. Isis switches to the "3. Calibration" tab. Check that "Tilt angle", "Smile Y", "X coordinate of line at wavelength" and "A =" have the value zero. Put 10.000 in the "Radius" value. Uncheck the "Auto" after "vertical coordinate":
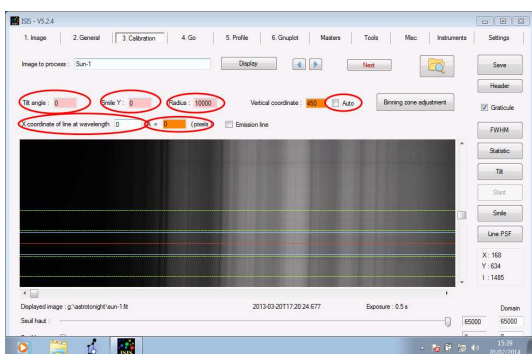
Click on the "Next" button. Isis switches to the "4. Go" tab. Click on the GO button; ISIS runs the data reduction:
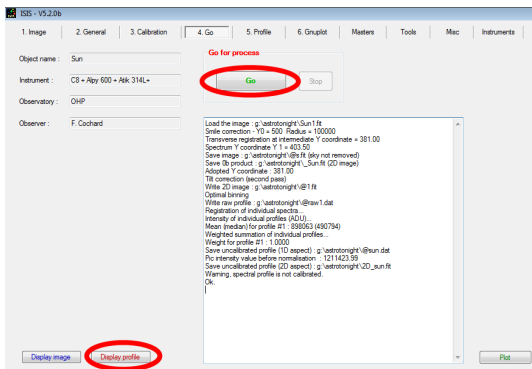
After a few seconds, the process is done. Click on "Display profile". You should have this kind of image:
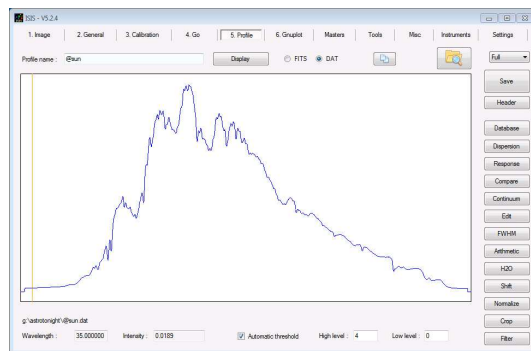
This is your first Sun spectrum profile ! There are a lot of absorption lines - each of them is the signature of a chemical element in the external layers of the Sun's atmosphere (photosphere).

However, at this stage, your profile is still not of a high scientific interest. For three reasons, at least :

– The 2D image has not been pre-processed,
– The spectrum is not calibrated in wavelength,
– The profile is not corrected for the Instrumental Response.

In the next sections, you'll learn how to proceed to make these corrections and calibrations.

2.4 Reference images

Digital imaging is affected by several instrumental effects, such as offset, thermal signal, read-out noise, hot pixels, and so on. These effects are quite easy to correct, using reference images : offset, dark, flat fields.

The pre-processing can be highly automated, once you have made the proper reference images. These images are "offset", "dark frames", "flat field" and "calibration".

It is always better to take a series of images instead of a single image. From the series, you can make either an average or a median. This way, you'll be able to eliminate any accidental events (such as cosmic rays in images), and improve the image quality. ISIS software can manage series of images for all type of reference images.
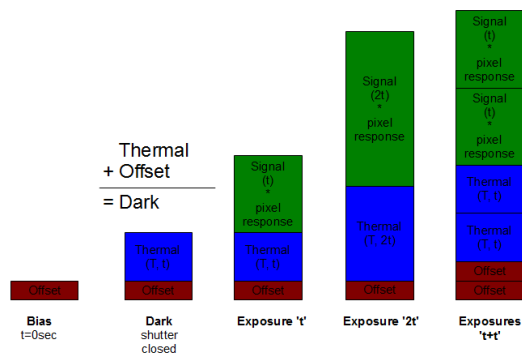
2.4.1 Offset image

To avoid negative signal digital conversion, CCD cameras have a fixed offset on the analog signal which is called Offset. Any data readout from the CCD chip includes this offset.

💡 Offset images are also called Bias in some documents. In this User Guide, we made the choice to use Offset, but consider it is equivalent to Bias.

This offset is fairly stable and once you have a master offset frame, you can keep it for long time. You can make one again once per year approximately. It is also not too much temperature dependant. Because it is very stable, you can improve your data by taking a long series of offset frame (around 100 exposures) and perform a median average to create a smooth master offset frame for your camera. A median average is better than a simple average as it will totally remove out of the ordinary defects on some of your images, such as cosmic rays for example.

To get an offset image, put a cap on the Alpy 600 light entrance to ensure that no light comes in. Take an exposure of 0 second, binning 1x1.
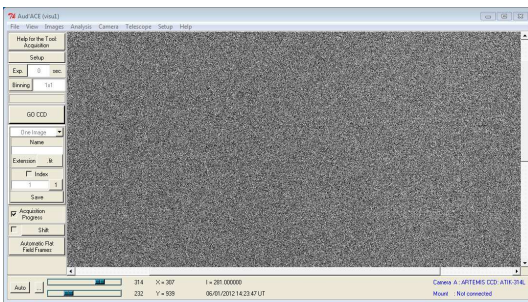
💡 Offset images are sometime called Bias images.

You can measure the average level in the image (draw a rectangle, and right-click to get the statistics in the window):
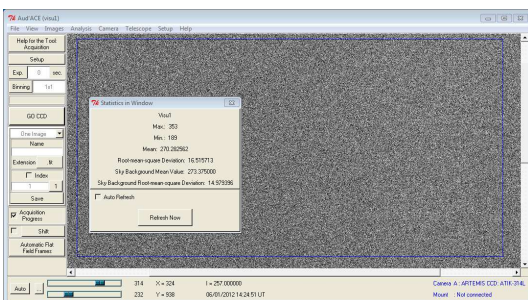
2.4.2 Dark frames

CCD chips have a tendency to build up electrons over time, particularly at high temperature. This temperature dependant effect is called « thermal noise ». The thermal noise is included in dark frames which are exposures taken with the camera shutter closed; the offset is also included in dark frames.

Hot pixels are individual cells that are particularly sensitive to this thermal noise and tend to saturate quickly during long exposure. These hot pixels have to be processed separately (usually replaced by the average of the surrounding pixels). An interesting property of thermal noise is that it is linear with exposure time. For example, the thermal noise in a 2sec exposure is twice the thermal noise in a 1 sec exposure. This means that you can extrapolate any shorter thermal noise frame from a master thermal noise frame with long exposure – assuming you have mapped the hot pixels properly. This is done by doing a median average of a long exposure dark frame series (at least 7 frames, if possible more). Most astronomical software require both offset and dark frames to pre-process your image. The thermal noise is of course embeded in the dark frame. Be very careful as the thermal noise (thus the dark frame) is very sensitive to temperature. Make sure to use a dark frame taken at the same temperature as your spectra. If your camera doesn't have temperature regulation, you should take dark frames close to the time you expose your spectra. Some software can still extrapolate a proper thermal noise map based on the area of your chip with no signal, which is very easy in the case of Alpy 600 spectra. You do not have to rebuild your dark frame every night; you can create your library of dark frames taken at different temperatures and use it for several months.

A dark frame is taken with the same conditions as the target spectrum (exposure time, temperature), but with no light coming into the spectroscope.

For instance, if your star spectra are made with 300s exposure, dark frames must be taken with the same duration.

Here is a typical dark frame of 300s (binnng 1x1, of course):
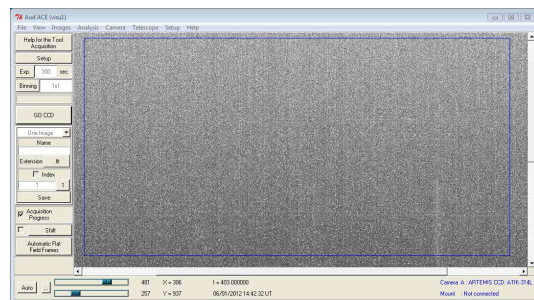
2.4.3 Flat field spectrum

A flat field spectrum is obtained by illuminating the spectroscope with a continuous spectrum of white light. Ideally, it should be a lamp that has the same energy level in each wavelength. It doesn't exist in real life... As a compromise, we use tungsten or halogen lamps (but not power saving, calibration lamps, or sunlight !). The exposure time must be choosen to give 80% ot the max level of the camera.

This image is mainly used to determine low frequency non uniformities, caused by dust on the CCD front glass for example or overall instrumentation vigneting. Make sure to take a series (at least 5 exposures) of flats. The signal has to be as high as possible without any saturation.
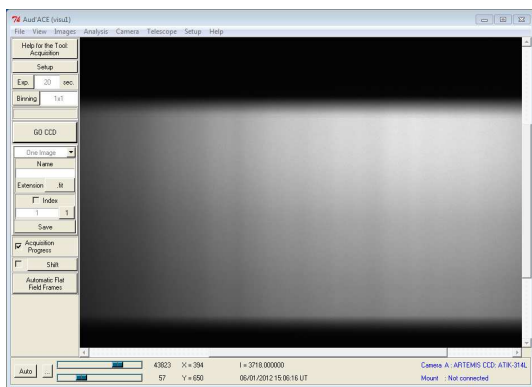
> 💡 The Alpy calibration module contains a halogen lamp which gives a perfect flat field spectrum.

2.4.4 calibration spectrum

As explained in section 2.5.3, you will process your Sun spectrum using the calibration information contained within itself. But you can also use a calibration lamp - if you are working in slit mode. For instance, below is a neon spectrum

> 💡 The Alpy calibration module contains a calibration lamp made of neon, argon and hydrogen which makes it very easy to calibrate in slit mode.
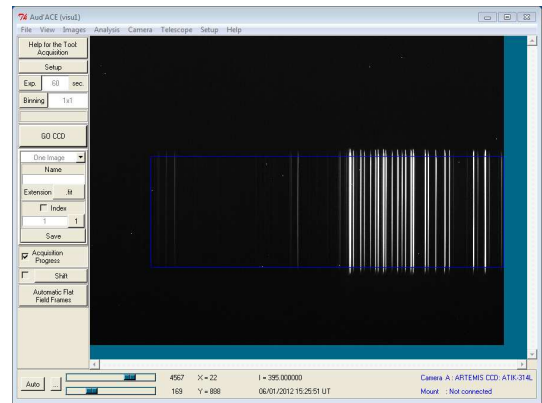
2.4.5 Typical observation

To get all the data you need for a high quality observation, here is a suggested list of all the images that you should have before switching off the equipment. This is applicable for your Sun observation, but is also valid for night observations:
  – 7 offset images (or more)
  – 7 dark images (or more)
  – 7 flat field spectrum images (or more)
  – 1 calibration spectrum image
  – 5 reference star spectrum images (or more)
  – and of course all the images of your object !
For each image, you must check that there is no saturation.

> 💡 A scientific measurement on an astronomical object spectrum requires not only a single spectrum of this object, but a whole set of images. If you make sure you have all these images during an observing session, data reduction will be easy and fast.

2.5 Data reduction

You've now acquired all images for a full data reduction of the Sun observation. In this section, you will see how to proceed with ISIS software. You will proceed with these images as if they were from any star.

2.5.1 Prepare master files

This step is to convert the series of reference images into single images, called master files. It is done very quickly in ISIS. Go to the "Masters" tab, and select each series of images (offset, dark, flat), to create a master. Click on "Go" for each series:
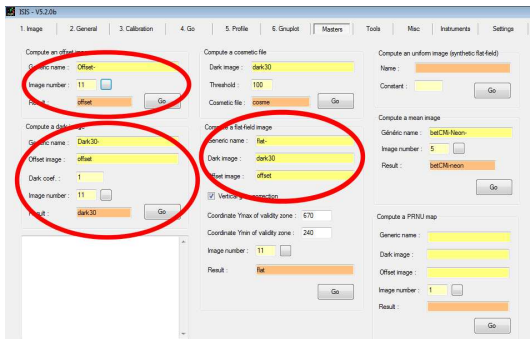
Also create a cosmetic file, which records all the hot pixels in your camera. Hot pixels are pixels that react differently from the others; we consider they are defective and the processing will replace their value by the average of the surroundig pixels. The cosmetic file is made from the dark image (set up the threshold in such a way that you get around 200-300 hot pixels - this is a reasonable value):
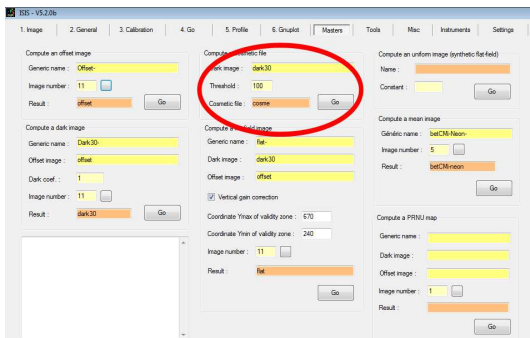
2.5.2 First pass : raw profile

The first pass is very similar to your first spectrum preview (section 2.3), but you can now include the master files for pre-processing. In the "2. General" tab, select offset, dark, flat and cosmetic master files:
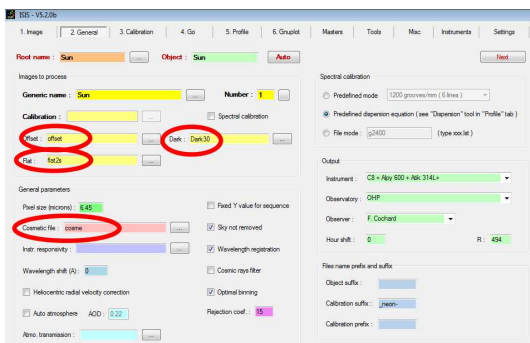
Then, switch to the "4. Go" tab, and click on Go. Display the resulting profile:
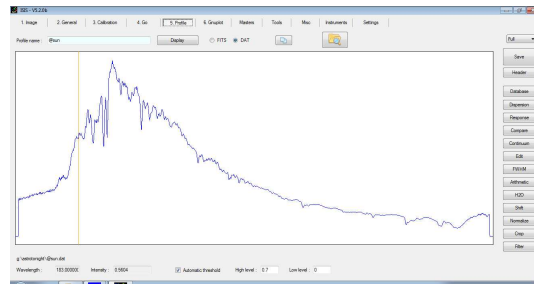
The profile is significantly different from the initial one made with no reference images at all. This difference is mainly due to the flat field correction.

2.5.3 Second pass : wavelength calibration

You now have to establish the calibration law (the relationship between pixel position and wavelength), to display the spectrum in wavelength units. The more lines you have, the more precise is the calibration. The dispersion law is usually a 3rd order polynomial. To reduce the Sun spectrum, you will proceed in a special mode : in the Sun spectrum itself, there is a list of known absorption lines that can be used for the calibration. It is not the simplest way (some lines can be quite difficult to identify), but this is a reference spectrum that you can use without any additional measurements. Of course, if you have access to a calibration lamp, you can use it in preference.

wavelength	Line
3933 Å	Calcium K line
3968 Å	Calcium H line
4307 Å	G band (molecular)
4861 Å	$H\beta$ (balmer line)
5167 Å	Magnesium triplet
5270 Å	Iron (Fe) line
5893 Å	Sodium doublet
6563 Å	$H\alpha$ (balmer line)
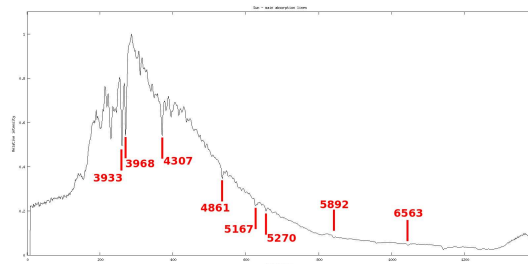
Click on the button "Dispersion", in the right side of the screen. The dispersion panel appears. Fill in all

the wavelengths above, select "absorption line" and click on the first radio button (matching 3933 Å):
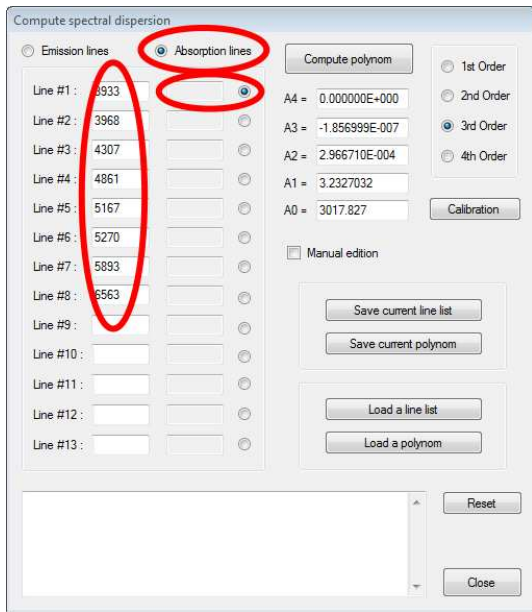
Now, **double click** in the profile, on each side of the absorption line at 6563A. This will measure precisely the center of the line (in pixels). The next line will be automatically selected.
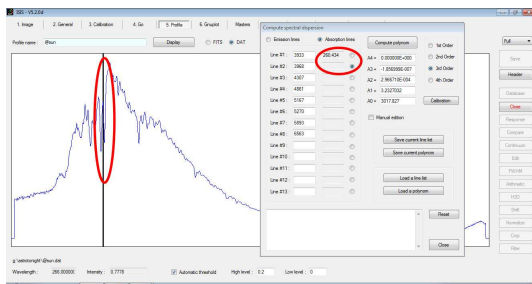
Repeat the same operation for each recorded line.

When it is done, select "3rd order" option, and click on button "Compute polynomial". Based on the lines you've selected, it calculates the dispersion polynomial law.
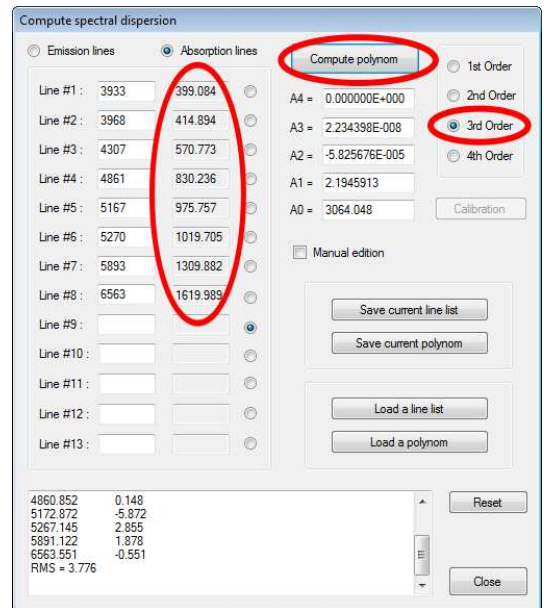
In the bottom area, you have the RMS error resulting from the calibration. It should be around few Å(here, the error is of 3,7 Å)

Now re-run the reduction process, but selecting the "Spectral calibration" button in the "2. General" tab. You also have to select "Predefined dispersion equation" in the "spectral calibration" panel:
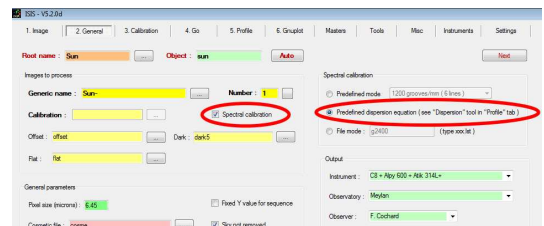
Display the spectrum: you can see that it is now calibrated in wavelength:
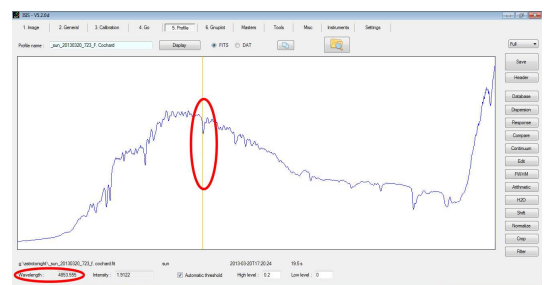
> 💡 The calibration law can be established from any spectrum containing several known features. It is highly recommended to use a calibration light to do this when working in slit mode: the more lines you can identify, the more precise the calibration law will be.

2.5.4 Third pass : Response curve correction

The whole instrument, including telescope (if any), spectroscope, and CCD camera, has its own response to the light. It is called Instrumental Resonse Curve. For instance, a CCD is much more sensitive to red than to blue light. If you want to get the true spectral profile of the source (the Sun in your case), you must correct for this very important effect. The best way to do this is to record the spectrum of a known star (a reference star), and compare it to its "theoretical" spectrum found in the literature.

In the current case, you're observing the Sun... and the Sun is a very well known G2V type star ! So, we'll make the correction from a G2V spectrum.

When you observe astronomical targets, it is necessary to observe a reference star, generally a hot star (A-type, with few absorption lines), close to your own target to prevent atmospheric effects.

A reference star is required for both calibration and response curve correction. Of course, the same star can be used for both needs.

💡 Each observing session must start by observing a known hot reference star, to allow the correction of any instrumental effect.

ISIS includes a database of spectra recorded at different resolutions. Here is how to get a G2V star reference spectrum. In the "4. Profile" tab, click on the database button. The database panel appears:
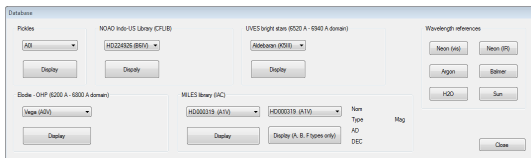
At the top left, you can select an G2V star from the Pickles list:
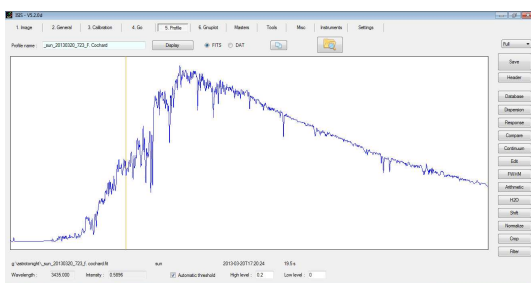
This profile is different from yours. This is due to the Instrumental Response curve and the wavelength range covered.

Click on the "Display" button for reloading the sun profile. Then click on the "Response" button. A response panel appears : select the G2V profile as reference. Click on the "Response" button (red).
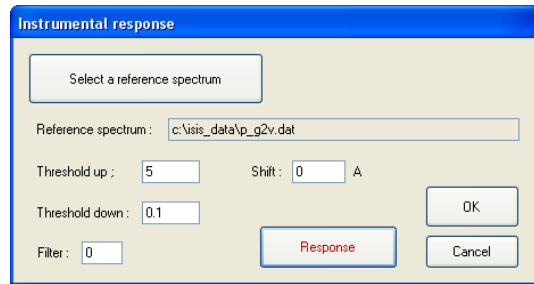
In the main window, you now have 3 profiles: your Sun spectrum, the G2V theoretical profile, and the division of both - which is indeed the raw response curve.
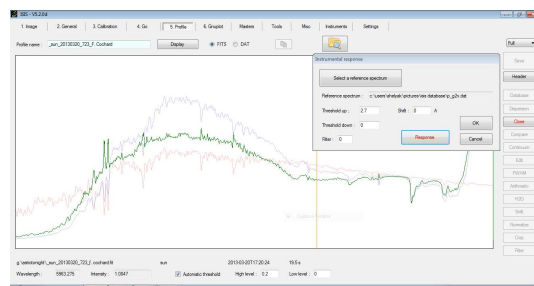
Click on the OK button: only the response curve remains. As you can see, this profile is very noisy, and there are some "emission lines". This is a side effect of the division between the profiles, because the Alpy 600 and reference profiles do not have the same resolution.

To get the effective response curve, you need to remove these lines, and smooth the profile. This can be done with the "continuum button":
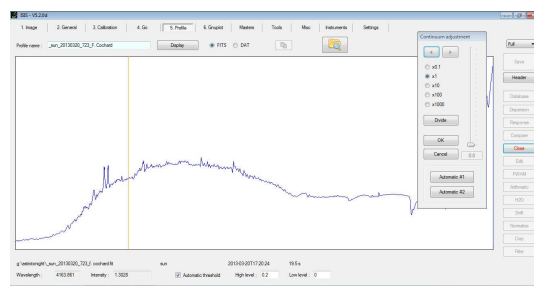
To remove the emission lines, double click on both sides of each line. The line is replaced by a straight line:
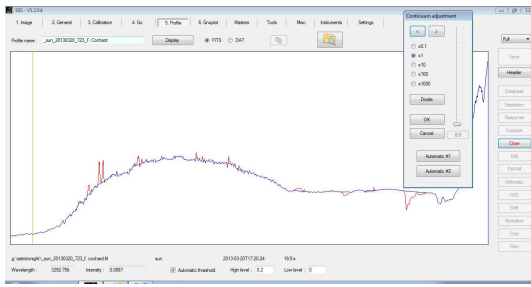
Now, move the cursor in the continuum panel to smooth the profile, and remove all the noise in the profile:

Click on OK, and save this response curve.

Now go back to the "2. General" tab, and fill in the "response curve" field.

You can then re-run, for the third and last time:
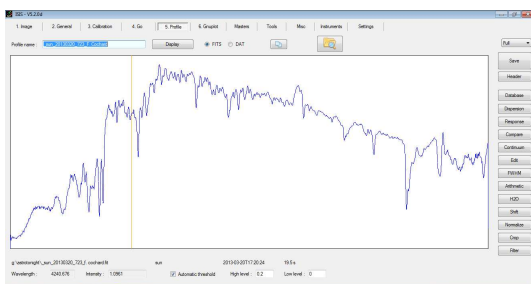
This is the actual spectrum of the Sun !

You can compare it with the G2V theoretical spectrum (click on the "compare" button):

You can see that the result is excellent - much of the detail that we could suspect to be noise is in fact the sunlight signal.

Summary

The spectrum of the Sun is now fully processed. To do it, you've run the data reduction process three times: the first time to get the raw profile, the second one to include the wavelength calibration, and the last one to correct for the instrumental response curve. This process needs to be done only once per observing session. When you observe several objects in the same night, you can reuse the calibration and the response curve - to the first order, you can consider that it only depends on the instrument, and not on the observing conditions (this may be a little bit more complex if you need a very accurate measurement).

We invite you to observe many spectra with this setup and run the data reduction process for each of them. For a new object, the only point to change is the input file and the source name in the tab "2. General" - and run the process in the "4. Go" tab. It takes only a few seconds.

Alpy 600 - Stellar spectroscopy in slitless mode

In the previous chapter you learned how to produce a basic spectrum. You know what images are needed and how to process them to get the actual signal contained in the light you observed. You are now ready to go to the telescope and to apply the same method on astronomical objects.

So far, you've worked with the Alpy 600 in slit mode. Ideally, you should do the same with the stars. But there is a problem: when using a slit spectroscope, the only field you get is the slit. With an extended source (daylight, calibration lamp...) it's easy to aim for the source. But stars are point-like and it's not obvious how to put it in the slit (If the star is in the slit, you get a spectrum, but if it is just beside the slit, you see... nothing and when you see nothing, there is no way to define in which direction you must move the telescope).

>From a practical standpoint, this is not feasible, at least when starting in spectroscopy. You'll see in chapter 4 how to deal with that. For now, switch to slitless mode, applicable for point-like sources..

Slitless mode has advantages. For instance, it collects the full light of the star, whereas slit mode has some loss at slit entry. This is useful for very faint objects, but it has also some drawbacks : there is no way to use a calibration lamp (which is an extended source), and the position of the spectrum will move in the field, depending on your telescope tracking.

In a few words, using the Alpy 600 in slitless mode is the way to work when you have no guiding device, but this is not the simplest way to get accurate measurements. The good news is that when you become familiar with this process, switching to a guided mode will reveal how easy it is to do spectroscopy !

> 💡 The observation itself must be done during the night, but the preparation of the telescope and the tuning of the Alpy 600 with the CCD camera has to be done during daylight.

3.1 Changing the slit position

You've seen in section 1.7 how to change the slit. Here, you should select the 3mm hole (the "big" one):
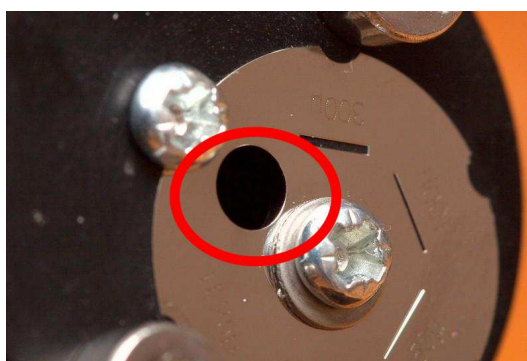
Now, if you take an image of Sun light, you'll see a very rough spectrum, as if if it were strongly defocused. It is in fact focused, but the light source is so big that the spectrum is unusable.

> 💡 Why not totally remove the slit ? You could do this but the size of the "high quality" field of the Alpy 600 is limited (it is very good over the whole 3mm hole, but decreases outside this area), and... keeping the slit in place is the best way to not damage or lose it.

3.2 Visual observation

To start with astronomical objects, we invite you to look visually at a star spectrum. Remove the Alpy 600 core element from the body (loosen the three small screws around the body):

Attach the Alpy 600 core element to the nosepiece (remove it from the external body):

This nosepiece can be put in a standard 1,25" eyepiece holder:

Select a bright star in the sky (preferably B or A type), and point the telescope at it. Now look through the Alpy 600 core element, and focus the telescope to give a very thin spectrum. Turn the Alpy 600 in such a way that the spectrum is horizontal, with blue on the left and red on the right.

You should see something like this:

You can now look at different stars and bright objects.

3.3 Recording a star spectrum

After observing visually, you will certainly want to record images. You've learned how to proceed with spectrum acquisition and reduction, you've put the spectroscope on your telescope: now, it's time to do both together !

3.3.1 Tuning the instrument

In section 2, you've seen how to tune your Alpy 600 (to produce a focused and horizontal spectrum with the CCD camera). You must start from there and switch to the slitless mode (change the slit to the

"3mm hole" position).

Ensure that spectrum is horizontal, with the right orientation (blue on the left) :

Assemble the external body and the eyepiece ring on the Alpy 600:

Put the whole assembly into the eyepiece holder of the telescope:

💡 The external body includes a standard T-mount thread (M42x0,75mm). If your telescope includes a 2" eyepiece holder, you can remove the Alpy 600 eyepiece ring and replace it by a T-mount to 2" adapter (optional).

Plug in the cables (power supply and USB), and balance the instrument.

💡 Do not forget to set your CCD temperature control.

💡 We recommend setting up an empty directory on your PC to record all the images of the night.

Select a star to observe. It must be bright, and you should preferably look for a hot star (A or B type), because its spectrum has a clear continuum, with some deep absorption lines. In the images below, we observed Regulus, which is a B7 type star.

When night falls, point at the star using the telescope finder. Take an image of the spectrum. Compared to the Sun spectrum you made previously, the exposure time must be much higher for stars! If only tenths of a second were enough for Sun, seconds or minutes can be required for stars. If you've chosen a bright star (magnitude 0 to 3), then only few seconds is enough - with a small telescope. Anyway, always control the exposure time to prevent saturation or low levels.

You should see something like this:
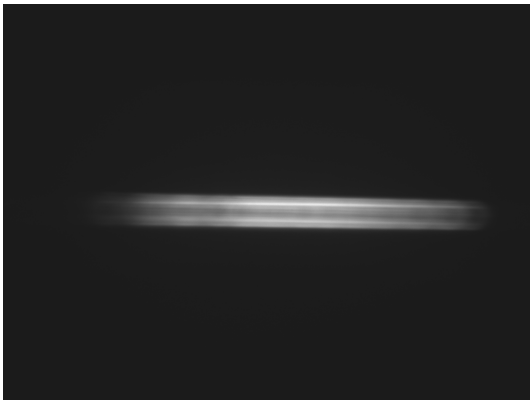
Move the telescope to position the spectrum in the center of the image.

Your telescope is probably unfocused. Take spectra continuously while focusing the telescope. Little by little, you'll see the spectrum get thiner and thiner. When focused, you should have this (it must be only few pixels wide):
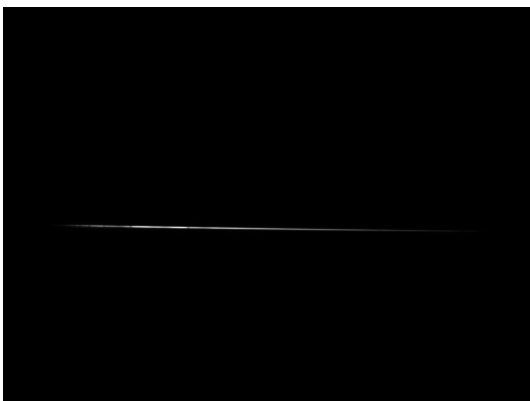
💡 In slitless mode, the width of the spectrum is directly linked to the star image size in the focus plane of the spectroscope (slit plane).

Look at the left end of the spectrum : there are clear absorption lines (only for hot stars):
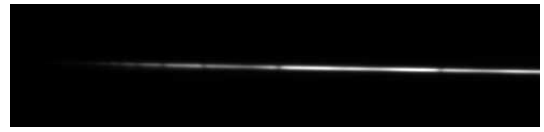
💡 If your image is black, it can be due to the image visualization thresholds. In AudeLA, click on the "auto" button (bottom left) to adapt the thresholds to the image.

You can rotate the Alpy 600 in the eypiece holder : the spectrum remains horizontal in the image. This is normal: the orientation of the spectrum only depends on spectroscope position vs the CCD camera. However, it does not mean that you should put the Alpy 600 in any position. If you want to make it easy to find and center the spectrum in the image, it is better to align the spectroscope axis to the telescope axis. Rotate Alpy 600 (the whole instrument, including CCD camera and external body) in such a way that when you move the telescope in Declination, the spectrum moves along the vertical axis.

Your instrument is now ready for observation.

3.3.2 Stars observation

Take some time to acquire several images of the star. Of course, if you make exposures of several seconds (which is more than probable), you must rely on the telescope tracking. If the tracking is bad, the spectrum will move in the image during the acquisition, and the result will be a band instead of a line:
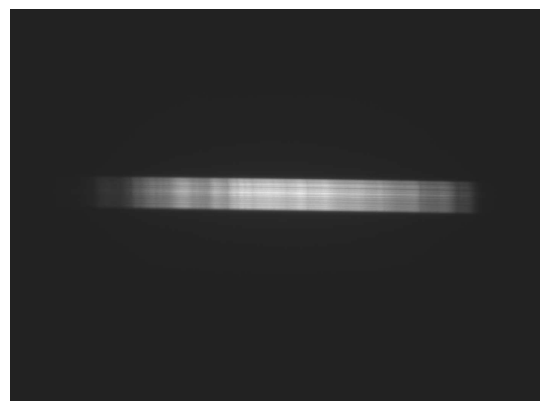
As you did with the Sun, you can immediately process your first spectra with ISIS. The only difference is that you now have a star spectrum (Regulus in our case), and you should ask ISIS to remove the sky background (in the "2. General" tab). You should get

a spectrum like this:
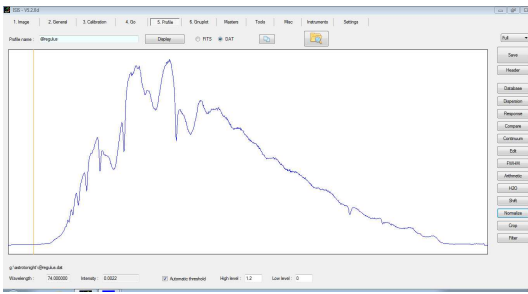
In astronomical imaging, the signal level (light level) is very low and all the instrumental defects are proportionally more important. It is even more important therefore to acquire the whole set of reference images, to ensure good data reduction.

In slitless mode, the flat field spectrum can be produced by putting a diffuser in front of the telescope (see an example below), and illuminating it with a tungsten or halogen lamp (during the night, to prevent any sunlight polluting the image).

The result will be like this (in flats taken without a slit, there is no evidence of the response curve. All the details are smoothed out):

The wavelength calibration and response curve correction will both be extracted from a reference star spectrum.

Here is the list of the reference images you need to take in slitless mode, to ensure a proper data reduction:

– 7 offset image or more (same as before)
– 7 dark images or more (same as before)
– 5 flat field images or more (take care of the right exposure time to get 80% of the maximum level)
– 5 spectra of the reference star (A or B type) or more
– Point at several stars (adapt the exposure time for each star), and take 3 to 15 spectra of each of them.

3.4   data reduction

Create master files for offset, dark, flat fields, and a cosmetic file from the master dark,

As you learnt in chapter 2, reduce your data in three steps to obtain the wavelength calibration and instrumental response curve.

3.4.1   First pass

First run the data reduction without wavelength calibration and response curve correction. You should get this (note that ISIS can export your profiles as PNG, using the GnuPlot graphics tool):
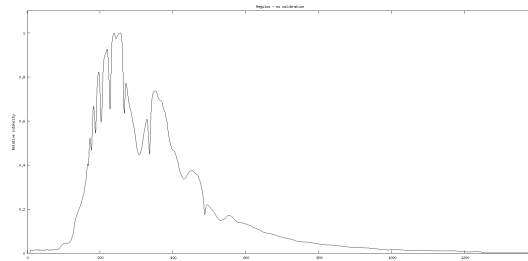
This profile is different from the first Regulus one because here we used the flat field. It is closer to the actual star spectrum, but is still strongly affected by the instrumental response curve.

3.4.2   Second pass

The wavelength calibration law can be established using the Balmer lines (hydrogen lines), which are the most visible in the spectrum. They are spread out all along the visible spectrum, like a geometrical series. Here is the list of Balmer lines:

wavelength	Line
3835 Å	Hη (eta)
3889 Å	Hζ (dzeta)
3970 Å	Hε (epsilon)
4102 Å	Hδ (delta)
4340 Å	Hγ (gamma)
4861 Å	Hβ (beta)
6563 Å	Hα (alpha)

These lines are located as below:
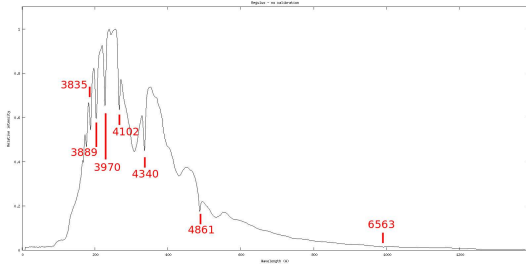
With this information, you can establish the calibration law - select a 4th degree polynomial (because there are several available lines).
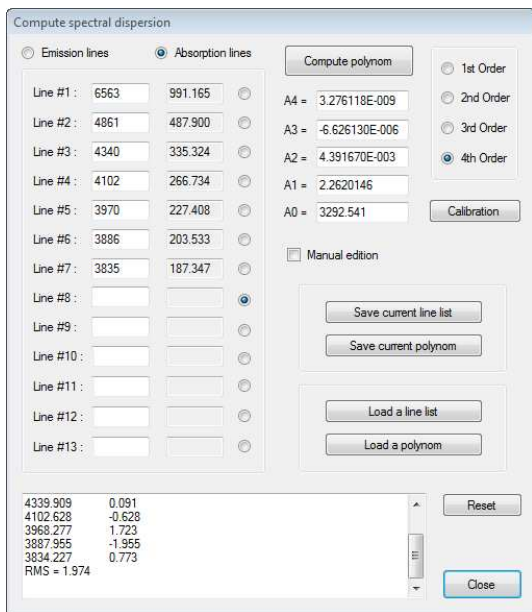
When the polynomial is available, re-run the data reduction process, including the wavelength calibration. You will get the same profile, but now calibrated in Å(see the scale in the bottom axis - note that the spectrum has been cropped between 3650 and 7300 Å):
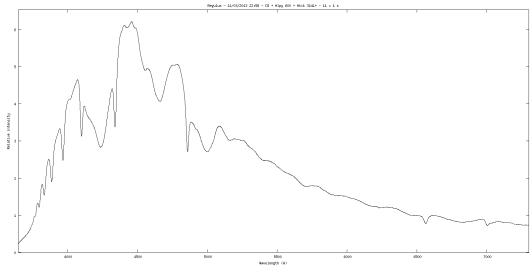
3.4.3 Third pass

The last operation is to establish the instrumental response curve. In this document, we used Regulus as reference star. This is a B7V. In the ISIS database (Pickles), there is no B7V, but we can select a B8V - the difference is not significant at our level. Display this profile, and save it in the current directory:
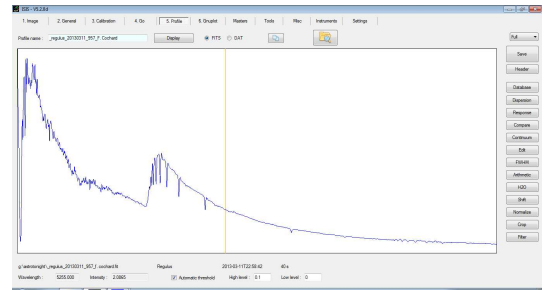
The spectrum has a much wider range than yours: it goes from 1.000 to 10.000 Å. Reload your spectrum, and click on "Response":
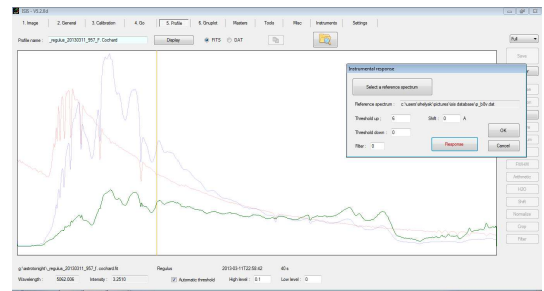
Click on OK, to get just the raw response curve. Remove the lines and smooth the curve to reduce the noise:
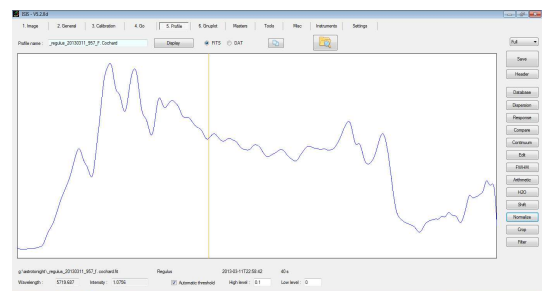
This response curve is very embossed.

This is different from what you saw on the Sun, without the flat correction, all the flat field details were smoothed.

Save the profile, and re-run the data reduction process, including the response file name (in "2. General" tab).

Now the result is only the star profile:
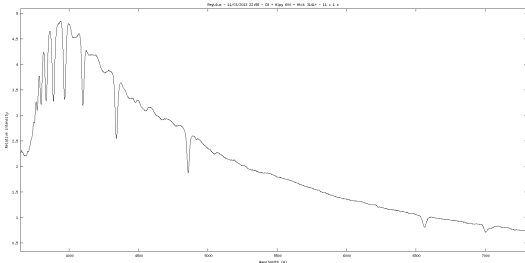
You have now finished the data reduction for your reference star, and you now have the dispersion law and the response curve - these data will be reused for all the stars you observed during the night. For the other stars, you need run the data reduction process only once.

However, you must pay special attention to an important point. You're working in slitless mode, and there is no way to put the next star exactly in the same position as your reference star spectrum. There will necessarily be a shift between the reference star and the new target. The dispersion law remains the same, but it must be shifted to match the new star position. To do it, you need to identify one line in the new spectrum, and give its wavelength to ISIS.

For instance, here is a spectrum of 38 Lyn, another hot star. In the 2D image, you can easily identify the Balmer line at 4861 Å. Measure its position, and enter it in the ISIS field at the "3. Calibration" tab:
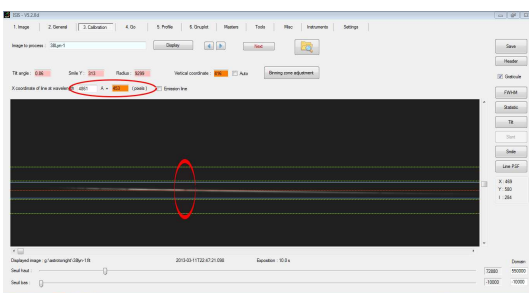
Run the process, and get the fully processed spectrum:
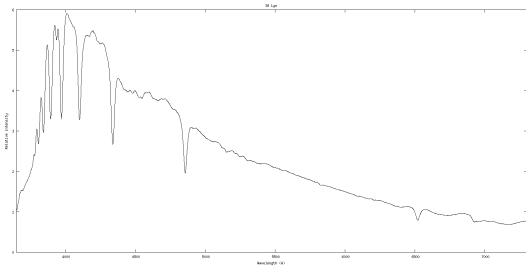
Continue with the same process for all the stars you observed during the night. Here is an other example, mu Leo which is K2III:
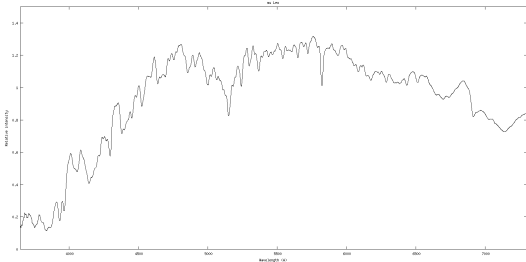
and a last one, Betelgeuse (M2I type):
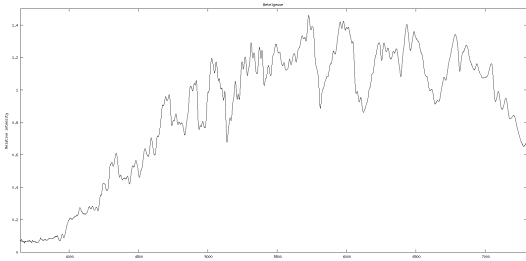
💡 You may observe that there are some shifts in the calibration law from one star to the other, despite the realignment you made using a known line. This is due to the fact that the dispersion law can be dependent on the spectrum position in the image. To minimize this effect, always put the spectrum exactly at the same position in the image.

You now know how to proceed with a complete and precise data reduction. With experience, you'll do this process in a few minutes for the reference star, and in a few seconds for all the stars of the night.

Star spectra in slit mode

In previous chapters, you've see how to use the Alpy 600 in slit mode (see chapter 2) and slitless mode (see chapter3). Slitless mode allows you to find your target more easily, and capture all the light, which is important for faint objects.

But slit mode has several advantages:
– A better wavelength calibration (using calibration lamps),
– Observation of extended objects (nebulae, comets, galaxies...),
– Allows the sky background to be removed (useful for faint objects or urban observing conditions),
– The resolution depends only on the slit, not on observing conditions (tracking, seeing, telescope focus...).

For these reasons, most observations are made in slit mode. In this chapter, you'll see how to work around the problem of pointing and tracking a star in slit mode, though

the best solution is definitely to add the Alpy guiding module to your Alpy 600. This is a device which shows you the entrance of the slit: you can see the star you are observing. You can use this image to move the star onto the slit and track it. If you plan to make regular observations of astronomical objects, this is a required device - for comfort and efficiency, but also for the quality of your measurements. It is described in 7.1.1

However, there are some ways to observe in slit mode, even without the guiding module. It requires some experience - most astronomers like challenges ! There are two approaches:

1. Observing with the wide slit and a flip mirror,

2. Observing with the narrow 25μ slit.

The first one is really accessible. The second one is clearly a challenge - but we did it ourseleves.

Observing with the wide slit

The Alpy 600 includes several slits (refer to section 1.7). One of them is the wide slit, 300μm wide. This is a trade-off between the thin slit and the slitless mode. Compared to slitless mode, the size of the slit means

that your spectrum is always at roughly the same position horizontally in the image, and reduces the uncertainty in wavelength calibration. Also, it reduces the sky background effect, and gives more detail in the flat field.

The difference with the thin slit is that the spectrum resolution is still given by the star image size, whereas the thin slit ensures that the resolution comes from the instrument itself. Of course, because of the field of view, it is much easier to center the star.

To help you in star pointing, we recommend using a flip mirror (with a reticle eyepiece) between the telescope and the Alpy 600:

This optional device will help you to put the star in a very precise position, enough to put it in the wide slit at least.

Centering the star

Use the telescope finder to locate the star (start always with a bright one), and flip the mirror to see the telescope field in the eyepiece. Put the star well centered in the Field of View (FOV). Then, flip back the mirror to let the starlight enter the spectroscope. Take continuous images, until you can see a spectrum in the image. If there is nothing, put all the thresholds at max sensitivity, and change the focus of the telescope - the first time you install the flip mirror, the telescope is probably very unfocused. When star becomes focused, you should see a large spectrum (band), which will become brighter and brighter. The band is due to the fact that an unfocused star is like

an extended object. When you're close to the optimal focus, the spectrum may disappear : This is because the star image is now small, and may be outside the slit. In this case, slowly move the telescope across the slit: you should soon recover the star. If not, turn back the focus, to extend again the object size, until you recover its spectrum. Step by step, you will be able to focus the telescope perfectly and put the star right in the middle of the slit.

At this point, look through the flip-mirror's eyepice, and note the actual position of the star. This position will have to be the same for the next observations. If you put any star exactly at this position, you'll have its spectrum in the Alpy 600 camera each time.

Tracking the star

You've been able to put the star in the Alpy 600 slit... now, you have to keep it there during the whole observation. This depends of course on the quality of your mount, and if it is precisely aligned or not. You need to adapt the exposure time to ensure that spectrum remains very thin, with no visual effects of tracking issues. The spectrum must be thin, and absorption lines must be sharp.

If after some exposures, the spectrum disappears, this is because the star moved out of the slit. You can of course flip the mirror and look for it again, but in practice, it is probable that the star always moves in the same direction, due to a mount alignement error. So to return the star to its original position, you can just move the telescope in the right direction. You will quickly find this direction and the level of required corrections after some trials.

We may even suggest, in some conditions, to slightly misalign the mount. This way, the star will slowly move in the FOV, but always in the same direction. Then, with experience, you will know in which direction you need to move the telescope when spectrum level is decreasing.

💡 Of course, if you have spent hours to align your mount, this could be bad advice ! Only misalign your mount if you consider there is no such risk.

Pointing and tracking in wide slit mode with a flip mirror requires some experience, but this is a real improvement compared to the slitless mode. You will not be wasting your time if you do it !

Observing with the narrow (25μm) slit

This section is for people who like challenges ! It is possible to observe in "full slit mode" (using the 25μm slit), but it requires still more accuracy and patience

compared with the wide slit. The process is exactly the same as for the previous section, but the tolerance for star positioning is more than ten times smaller (300μm vs 25μm). However, this is really feasible - we did it... even without a flip mirror (only a finder).

The main tip is to slightly unfocus the star. It becomes bigger in the focal plane (slit plane), and easier to find. We recommend first working in slitless mode, to be sure that telescope is close to focus. If the focus plane is too far out, the star can be huge (even bigger than FOV) and the light level very low.

💡 Be careful : if you unfocus the telescope, only a samll fraction of the light will enter the spectroscope. This is applicable only for bright stars.

Also, with some experience, and if your telescope is precise enough, you can use your finder (or even better, an electronic finder) to put the star very close to the slit .

Then, depending on the spectrum level, you can decide to refocus the telescope step by step. By doing that, the star may go out of the slit, because it becomes smaller and smaller. Then, move the telescope again until you recover it. You can make several iterations, until you juge that the star size and spectrum level are compatible with your observing conditions.

Again, proceeding this way is more of a a fun challenge than a recommended observing method. But it can show you the significant difference between slitless and slit spectra: you'll quickly see that in most cases, there is a much higher potential in slit spectroscopy.

Then, keep in mind that by using the Alpy guiding unit, you'll get the high quality of a slit spectroscope, in a very easy way, because you can permanently see the star you are observing in your guiding image.

You have now passed all the steps to produce your first reduced spectra. With experience, you will perform the acquisition and data reduction more and more efficiently. In this section, we've put some tips and tricks to improve your observations. Improved observations means better data quality (up to professional quality level data), and better efficiency (or productivity) in your observing procedures. Most of the advice below assumes that you're working in slit mode, ie you have a guiding module.

5.1 Improve data quality

5.1.1 Signal / Noise Ratio (SNR)

Star light is faint... and you spread it out with your spectroscope. At the end of the chain, only a few photons reach each pixel of your CCD camera. The whole instrument (telescope, spectroscope, camera) limits your ability to detect faint signals. The quality of your spectrum is directly linked to the level of signal you get on your CCD compared to the "noise" of the instrument, which is its limit of detection. This is what we call the Signal / Noise Ratio (SNR).

Improving SNR can be done in two ways: reduce the noise or increase the signal.

Reducing the noise is hard: it is limited by physics. But we can do it to a certain extend. For instance, by cooling down the camera, you reduce the internal activity of the CCD, and reduce the noise.

The best way to improve SNR is then to increase the Signal. It can be done by several ways:

– Increase exposure time (the SNR will be increased as the square root of the time multiplication factor),
– Increase the telescope size (this is why all astronomers are always looking for bigger telescopes),
– Ensure that most of the light is going through the spectroscope. Star images and slits are very small (a few μm), and it is very easy to lose a high proportion of the light at the instrument.

The two main reasons for losing light at the spectroscope entrance are usually:

– Telescope focusing. If the focus is not optimal, the object size will be bigger than the slit width,

and only some percentage of the object's light will enter in the instrument.
– Position of the star in the slit. When working in slit mode, it is very easy to put the the star partly outside the slit. The result is the same: you lose a high percentage of your source.

The best way to improve this point is to check that when the star crosses the slit (if any), it almost disappears from your guiding image. Carefully tune your guiding camera exposure time to prevent any saturation.

> 💡 If the star disappears from the guiding image when crossing the slit, it means that most of light is going through the spectroscope.

With the experience, you will know how much signal your instrument will get for a given magnitude. You should also compare your data with others with similar equipment, as an external reference (see section 5.3). If you see that this level is lower than is usual, take some time to find the source of this loss.

To go further into SNR improvement, you can measure the total power of your spectrum, and tune the telescope focusing to optimize this measurement.

5.1.2 Resolution

If you work in slit mode, the resolution of your spectrum comes mainly from the spectroscope itself. The resolving power of the Alpy 600 [1] is approximately R=600 around Hα. The ISIS software calculates the actual resolving power as part of the data reduction. Check that your actual result is close to this value.

> 💡 The resolution is calculated from the width of the calibration lines ($\Delta\lambda$ = FWHM of calibration lines. The better the focus of the calibration lines, the better is the resolution.

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1. Resolution power gives the ability of the spectroscope to see details. It is calculated as $\lambda/\Delta\lambda$, where $\Delta\lambda$ is the smallest visible detail in the spectrum.

5.1.3 Wavelength calibration

Take special care when performing the wavelength calibration. Normally, you should have an RMS smaller than 0.5 Å. Take the time to record a calibration quite often, and use this image for the data reduction. Always double check that there is no major error in the calibration. The simplest way is to look at the positons of the balmer lines, visible in most types of stars.

Also, remember that the calibration law can change across the FOV. The key is to always put the spectrum at the same position in the image. If you work in slit mode, the horizontal position is constrained by the slit but also ensure that the spectrum is always at the same position vertically.

5.1.4 Autoguiding (guiding module)

Autoguiding is very dependent on your equipment. Autoguiding means that you send the guiding image to the computer, which controls the telescope based on star movement in the image. AudeLA software can do that (like many other software).

Autoguiding is not only for comfort (when you activate the autoguiding, you don't need to permanently check the guiding image any more), but it also improves the spectrum quality, because it always reproduces the same conditions. Consider autoguiding a high priority for obtaining good results.

5.1.5 Cosmetic file

The CCD chip has some "hot pixels". These pixels are much more sensitive than others. These pixels will give wrong measurements. It is better to remove them from your image. This can be managed by ISIS software, by creating a map of hot pixels. All pixels considered as hot are replaced in the image by an average of the surrounding pixels. To generate the hot pixel map, you use a dark frame and record all pixels above a certain value. In ISIS, go to the Master images tab, and focus on the "Computing a cosmetic file" area. Enter the threshold value - for instance 100 ADU (in the dark we use, most of the pixels are close to 0 ADU). Click on the Go button, and look at the console: you'll see the number of hot pixels detected. Around 100-500 hot pixels is considered normal.

💡 The master dark is not really a dark frame, but the thermal map of the camera after the offset has been removed. This is why the average level of the image is close to zero.

You can use the hot pixel map in the "2. General" tab. Simply enter the name of your map file in the field "Cosmetic file", and re-run the data reduction. ISIS will now include this hot pixel list in its calculation.

5.1.6 Instrumental Response curve

We have already described a simple way to get the Instrumental Response curve with ISIS. In fact, this is a tricky operation. The response curve can evolve with some parameters, like sky conditions, target position in the sky (air mass), reddening, and so on. To be perfect, you need a reference star close to your target, of the same spectral type, with similar magnitude... and this never happens. Getting a bad response curve will have an immediate effect: the general shape of your spectrum will be distorted. It is a too long story for this document, but keep in mind that getting the proper Instrumental Response curve requires some experience.

5.1.7 Write a log file

It can take various formats, but we strongly encourage you to write a detailed log file when observing. Note all the conditions of your observations - setup, weather, goal, target list, problems encountered during the night. It will help you, in the future, to make the best use of your data.

5.2 Improve productivity

5.2.1 Keep the same setup

The best way to improve your productivity is to always keep the same setup, and always process the same way. Of course, observers often want to improve their setup (this is a good behavior), but as soon as you change parameters in your setup, you have to adapt (to change...) your process. Sometime, it is preferable to keep the same conditions, for both quality and productivity.

5.2.2 Dark frames library

Dark frames are long exposure time images (at least as long as the exposure time of your objects). And the more darks you take, the better (you will improve the SNR of the dark frame). This is a very time consuming operation - something we should do at the end of the night, when we know the longest exposure time.

But dark frames are an intrinsic charateristic of your equipment. They only depend on the temperature and exposure time. They don't depend on the observing conditions. So there is no need to do them during the observing session itself: you can do them once, for instance during a cloudy night (or even during the day - just take care of light leaks).

We suggest that you make your own dark frame library, with different exposure times and camera temperatures (you could even put the camera in the fridge

to simulate a cold night). Take a large number of images, and create a set of master darks from them just once.

5.2.3 Exposure time

We suggest you always use the same exposure time for your observations (typically 5 minutes - 300 seconds - for faint objects). Of course, the total exposure time will depend on the object magnitude, but you can adapt the total exposure time by changing the number of exposure. They are several avantages to proceeding this way:

– You can always use the same dark frames,
– Data reduction is very fast (no parameter is changed),
– No risk of error during acquisition (you never change the time).

There are some limits with this process, for instance for bright or extremely faint objects, but in general it will make your life easier.

5.2.4 Prepare for your observation

Amateur astronomers often wait for the last minute to decide what to observe. We recommend to prepare for your observation well in advance. If you properly organize your observing session, you will optimize the target order, their position in the sky (higher is better), and so on. You can even define the exposure time for each object, depending on their brightness.

If you are looking for target and observing programs, you can look at the Shelyak Instruments website [2]: we've listed many ideas, ranging from from easy to ambitious.

5.2.5 One directory per observing session

This is a basic advice, but doing spectroscopy will quickly produce a high volume of files. To be sure that you will be able to proceed with a reliable data reduction, it is important to not mix files from different observing sessions. We recommend that you to create a new empty directory at the beginning of each observing session (an observing session is generally an observing night). Put your log file (see section 5.1.7) in this directory.

5.2.6 Reduce your data quickly

It is very common that astronomers use the time during the night to observe and wait until the day after to reduce the data. Be careful: if you wait too long, you'll probably never reduce your data. And having just raw data on your hard disk is the same as if you did nothing. We strongly encourage you to reduce your data immediately after acquisition. This way it is all fresh in your mind, and there is much less risk of mistakes during the data reduction.

5.3 Share your results

Our experience shows that the best way to improve your data is to compare your results with others. When you compare your spectra with the results from experienced people - with comparable instruments, of course - you can get an idea of the potential for improvement you have in front of you. We encourage you, for instance, to observe Be stars, and look at the BeSS database [3] for comparable observations. You can even send your spectra to the database - they will be checked by administrators who give feedback on potential improvements.

In addition, spectroscopy is certainly still at a pioneering stage. All the data you collect are of the highest interest for the scientific community: don't keep them to yourself.

5.4 Get pro-like quality spectra

Very often, amateur astronomers think they are not able to provide high quality data, comparable to those produced by professionals. Of course, amateurs usually don't have professional quality instruments - but the quality of the data is more a question of methodology than instrumentation and you will quickly see that you can reach professional quality, with just as much rigour. You can even contribute to research in several Pro-Amateur collaborations. In a few words, to get good quality data, you need to pay attention to:

– Accurate auto-guiding
– Repeatable configuration and processing
– Correct data reduction: SNR, Wavelength calibration, Instrumental response curve correction.
– Standard file format (see for instance BeSS file format)
– Archiving and backing up the raw data

> 💡 Never forget that when you're observing the spectra of an object, you're probably the only one doing it at this time on earth - this is incredibly valuable data... and you must absolutely archive it very carefully (raw images as well as processed data).

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2. www.shelyak.com - menu spectroscopy / educationnal & projects

3. http://basebe.obspm.fr/basebe/Accueil.php?flag_lang=en

Typical observing session

Here is a summary of a typical observing session, to ensure data quality and productivity. It is a basic checklist that you can use every time you observe.

Preparation

– Start-up the equipment, and cool down the acquisition camera (max 80% of cooling power),
– Check your session parameters in AudeLA and ISIS: observer's names, observing site, equipment, working directory...
– Prepare your session directory,
– Check your computer time, to better than 1 second (the exposure date & time will be based on it),
– Open a log file,
– Run a test for all images: sky (Sun's spectrum), calibration, flat, and check that all is Ok (images correct, file headers with proper data...),
– Prepare your target list,
– Acquire dark and offset images and prepare master images (or copy from the master directory),
– Get flat field images.

During observation

For each target observation, you will need to:
– Locate the target (start with a reference star),
– Run the acquisition,
– Get the calibration images,
– Fill in the log file with any significant information that will help in the future to remember the observing conditions,
– Check that the images are properly recorded in the session directory,
– *(Reduce the data as soon as possible),*

At the end of the night

– Double check that you have all reference images (dark frames, offset, flat fields, neon, reference star, objects)
– Archive your raw data securely.

7.1 Alpy Modules & Accessories

7.1.1 Alpy Guiding module

As explained in this document, working in slit mode gives some key improvements to your observations. But in this mode, you cannot see the telescope field, and it is difficult to position the star on the slit.

The Alpy guiding module makes it possible to observe the slit entrance with a second camera (usually called the guiding camera). This allows you to position the star precisely on the slit, and to track it continuously. This gives comfort, of course, but also improves the quality of data, and allows long exposure times. If you're using your Alpy 600 for astronomical observations, the Alpy guiding module is almost mandatory.
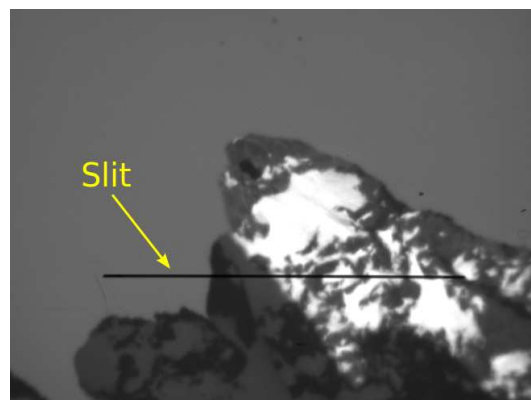
During the night, you can observe and control the star position vs the slit:
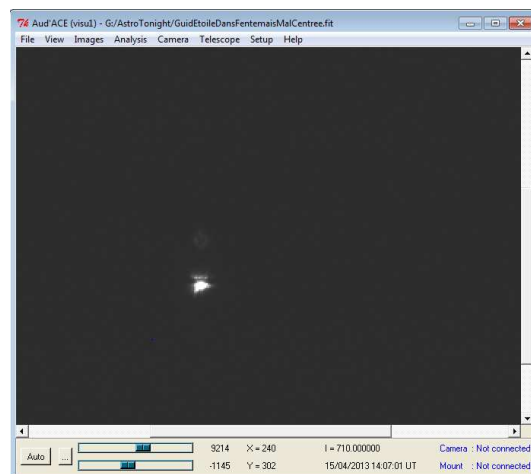
In the image below, you can see the telescope field and the Alpy 600 slit:

7.1.2 Alpy Calibration module

As described in this document, getting high quality spectra requires reference images. These images can be made "manually", by putting a calibration or flat lamp in front of the telescope. But this operation is dramatically simplified by using the Alpy calibration module. This module includes a halogen lamp for flat field images and an Argon-Neon lamp for calibration. It can even be used remotely, to avoid any operations at the telescope during observations. The Alpy calibration module is not required to produce

quality data, but it improves the repeatability and efficiency of your observations.

Calibration and flat field images made with the Alpy calibration module:
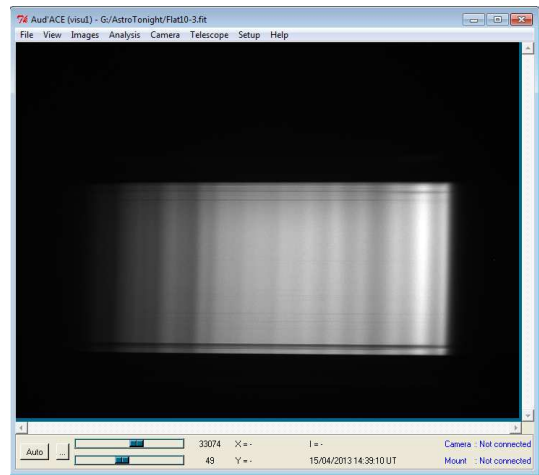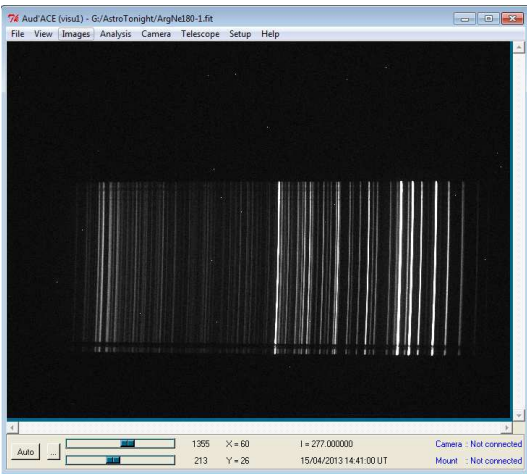
7.1.3 DSLR camera barlow adapter

The Alpy 600 has a short backfocus, to comply with compact CCD cameras. However, in some conditions, a longer backfocus is required. This is the case for DSLR camera usage. A DSLR camera with a T-mount adapter has a long backfocus (54,85mm) compared to most CCD cameras (15-25mm range). The Alpy DSLR camera barlow adapter extends the Alpy 600 backfocus to match that required by DSLR cameras.

Here, the DSLR camera barlow adapter is mounted on the Alpy 600:

Even though a CCD camera is generally better for astronomical applications (cooling, sensitivity, no color

bayer matrix effect...), using a DSLR camera makes astronomical spectroscopy accessible with a low budget. How to use a DSLR camera with the Alpy 600 is described in section 7.2 below.

7.1.4 C-mount camera adapter

Most CCD cameras are today using T-mount thread (M42 x 0.75mm). But there is also a large range of compact CCD cameras which use a C-mount thread instead (1" diameter). Some of them can be used with Alpy 600 thanks to the optional C-mount camera adapter - just keep in mind the CCD size, which must be at least 8.5mm to get the full spectrum.

The C-mount adapter replaces the main T-mount adapter of the Alpy 600:

7.1.5 Optical fiber adapter

Alpy 600 can be used with a fiber optics. The optical fiber adapter has a Type-FC connector:

7.2 Alpy 600 with a DSLR camera

Your Alpy 600 can be used with a DSLR camera. A lot of people today have such a camera at home, and it allows you to start in spectroscopy with a low investment. Because of the long backfocus of DSLR cameras, you must add the barlow adapter. In the nominal configuration, the spectrum length is about 18mm (it is 6mm without the barlow). Since pixels are usually small in a DSLR camera (5-6μm range), the spectrum is over-sampled.

Installing the DSLR camera barlow adapter

The DSLR camera barlow adapter is mounted on the back of the Alpy 600. If necessary, remove the main ring for better access to the thread. Make sure to tighten it firmly:
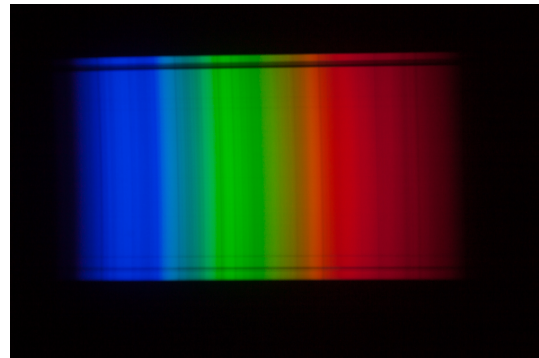
The Alpy 600 is mounted on the DSLR camera with a standard T-mount adapter:
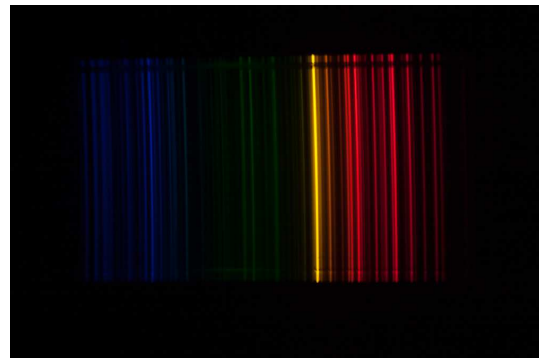

Focusing the Alpy 600

We suggest installing your DSLR camera on a tripod. Focus the Alpy 600 with the same method as for

a CCD camera (refer to section 2.1). You can use sunlight to make this operation.

But you may also use any lamp with emission lines, such as Neon or Argon.

DSLR camera vs CCD camera

You can use your Alpy 600 and DSLR camera with all Alpy modules and accessories (guiding, calibration, fiber optics...), for lab activities as well as for Astronomy. However, keep in mind that a DSLR camera doesn't have the same performance as a CCD camera. The main differences are:

– Sensitivity. A CCD camera is roughly ten times more sensitive than a DSLR camera. It means that for the same result, you will need ten times longer

exposures. This is not a problem for bright objects, but it limits the observation of faint targets.

– Spectral bandwith is smaller for a DSLR camera. A CCD camera can go up to near UV and near IR, where DSLR camera is strictly limited to the visible domain. Note that it is better to remove the IR-cut filter from the DSLR camera, to cover Hα (this is a usual operation in astronomy).

– The DSLR camera has a color sensor. This makes raw images more complex to work with (there is the Bayer matrix to manage). Note that the oversampling in the DSLR camera configuration means that the Bayer matrix has no effect in practice on the Alpy 600 spectra resolution.