



# **Installation & Maintenance Manual**

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## 1 Introduction

Eshel spectrograph is a powerful and easy-to-use instrument, that will give you high quality spectra from starlight. It have been designed for fully automated observations – even remotely.

To get the maximum quality and efficiency, you need to properly setup the instrument and the software. The purpose of this document is to give you all technical element to make this setup properly, and to maintain it over the time.

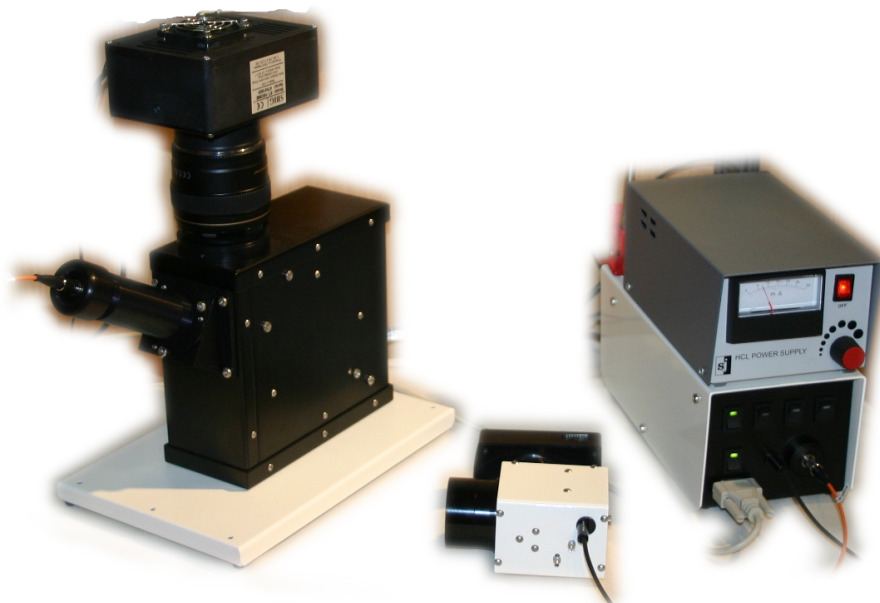
The installation must be done by a qualified person with proper tooling, who knows about spectrography, computing, and image processing. But when the instrument is setup, observations can be ran by non-qualified people (refer to eShel User Guide).

You control your telescope: pointing and guiding. You'll simply attach the guiding unit on the telescope, and ensure that star light will enter in the optical fibre.

The installation must be done during the day; don't waste observing time ! You can start with the solar spectrum, to complete the setup process – even in a cloudy day.

Eshel software is made to help you during the installation process, as well as during observations. This software include all operations required to get high quality processed spectra (calibration, darks...) : it covers tuning, acquisitions, and data processing. When properly setup, you can get fully processed data in few seconds – and transparently.

This document is written in the order of the setup process : hardware first, then software. When you'll have finished to read (and apply) this document, your spectrograph will be ready for observing.

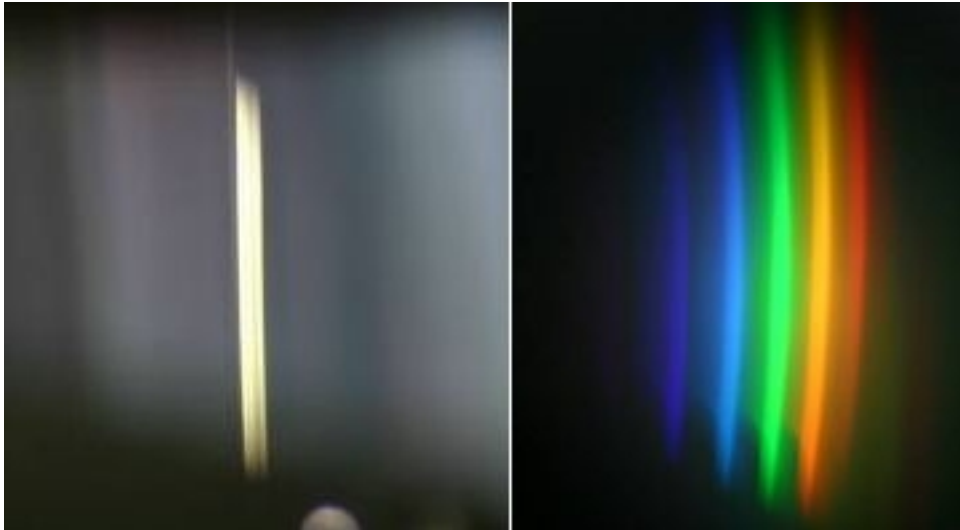


*Fig.: the three major modules of the eShel complete solution*

## 2 Overview of eShel spectrography

### 2.1 optical fiber fed echelle technology

An echelle spectrograph is a « cross-dispersed » spectrograph. This means a first dispersion is made by an echelle grating, used at high orders (typically order #32 to #52, ie 21 orders total, for eShel), and a second disperser (a prism for the eShel) separates the different orders. This allows to combine high resolution and large spectral domain coverage.



*Fig: smaller echelle prototype showing all orders merged and after cross-dispersion*

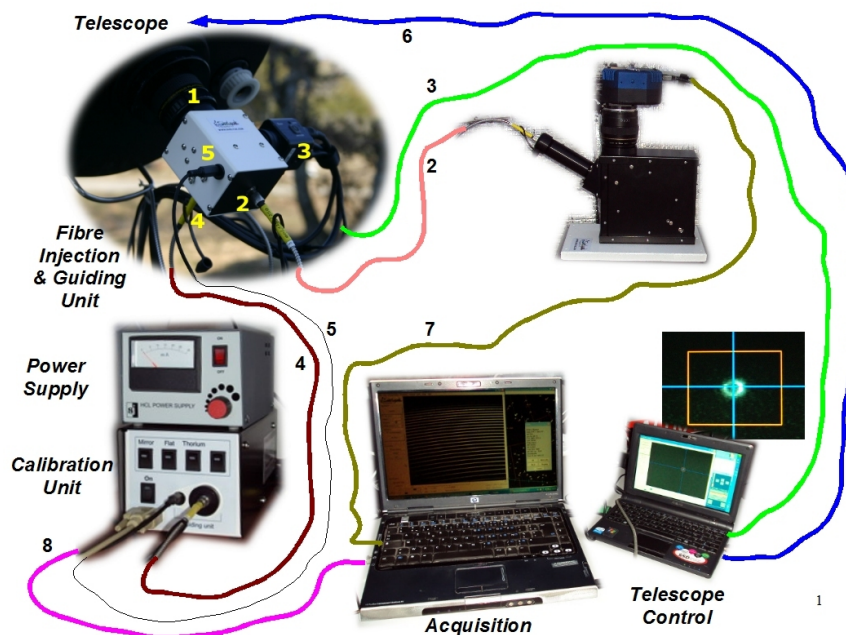
The light of the stars is collected by your telescope, focused on an optical fibre thanks to the guiding unit, transported to the spectrograph who disperse it, and sent to the acquisition CCD camera. Optical fiber link allow the best mechanical and thermal stability for your accurate Radial Velocity measurements.

### 2.2 instrumentation layout overview

Here is a typical instrumentation layout:

- Telescope → Fiber Injection & Guiding Unit + Guiding camera
  - 1/ Telescope mechanical interface (in our exemple: M42x0.75 → T-Adapter → 0.63x focal recucer → Schmidt Cassegrain)
  - 2/ Object fiber (50 $\mu$ m) → connected to the echelle spectrograph
  - 3/ Guiding camera (here a Watec 120N+ video camera)
  - 4/ Calibration fiber (200 $\mu$ m) → connected to the front of the calibration unit
  - 5/ Mirror control cable → connected to the front of the calibration unit
- Spectrograph + Acquisition camera
  - We recommend a QSI516ws or a QSI532ws CCD camera with the proper CCD adapter (BA0023).

- Calibration unit with 4 switches
  - a/ Mirror: activate the mirror of the Fiber Injection & Guiding Unit so the light from the calibration fiber feeds the 50µm object, thus the echelle spectrograph. This should active for all spectrograph references;
  - b/ LEDs: those are used in conjunction with Tungsten light (called a Flat) to illuminate all spectra orders; this image will be used to find the geometry of the spectrum on the image;
  - c/ ThAr: Thorium-Argon lamp for wavelength calibration;
  - d/ Tungsten: this will use alone to provide a smooth (without bumps) spectrum of 2800°K Planck function; it will be used by the software to correct the spectrum from the blaze function, ie the grating spectral vigneting on each order. The Tungsten is also added to the LEDs to bring more red signal to the Flat image.
- Computer to control the telescope
  - Your telescope could be controled by computer for autoguiding. Check that your autoguiding software can manage guiding through optical fiber where the star center disapear. AudeLA/Autoguiding module can provide such guiding if your telescope mount is supported by AudeLA software – check the AudeLA website for the list of support mounts.
- Computer to acquire spectra (can be the same as above or split)
  - AudeLA/eShel module provides all the require function to acquire spectra and process them automatically once properly setup;
  - AudeLA/eShel also control the calibration unit through RS232 serial link (eventually with a USB-to-Serial adapter) so the mirror activation and the lamp are controlled by the software, allowing easier or remote operations for exemple.



## 2.3 Software

### 2.3.1 Introduction

The eShel software has been specially written for the eShel spectroscopy solution. It covers instrument setup & tuning, acquisitions and spectra processing. It can also manage a video guiding camera through a grabber – check if your telescope mount is supported by AudeLA as this would allow also autoguiding. In brief, AudeLA is a all-in-one package.

AudeLA/eShel can also handle FITS file and perform a manual processing if you want to work that way. You will loose some automation - for exemple, AudeLA/eShel insert into the FITS files some keywords which are used for automatic processing. you will also have to use the calibration unit manually or writte your own code to interface with it.

You can also choose other software for spectra processing. Christian Buil has written a software to process eShel spectra (and other types of spectrographs): ISIS. The core routines are the same as AudeLA/eShel but the user interface is different and may be a better fit for your way of working. In any case, processing parameters are the same for ISIS and AudeLA/eShel. File naming convention are different - actually, AudeLA doesn't care about file naming but use FITS keywords to identify series of spectra.

This manual will focus on AudeLA/eShel.

### 2.3.2 AudeLA open source

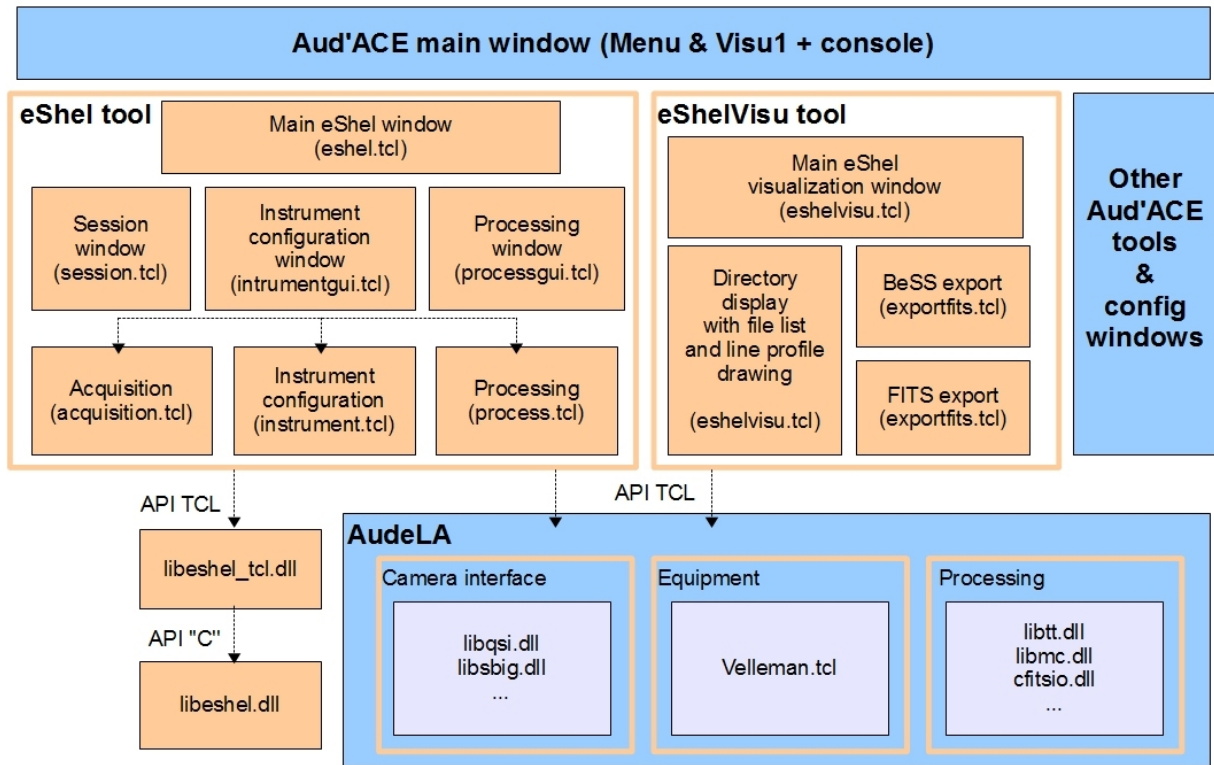
The eShel software is based on Audela platform ([www.audela.org](http://www.audela.org)), which is an Open Source general astronomy software. You can duplicate and distribute it as much as you want. It is written under TCL/TK language – you can even adapt the code to your needs but we then recommend you let us know as this code change could benefit to other users. Tcl/Tk allow powerful scripting – refere to AudeLA and Tcl/Tk language documentation for more information and discover much more functions than the one we use on the eShel module alone. AudeLA is open source and as such welcome any help in development, software testing and software documentation.

Install AudeLA by using the latest version from <http://www.audela.org/>

We usually recommend you to have a look at Source Forge where all development of AudeLA are stored and look for beta releases for MS Windows. It is usually worthwhile to use the latest beta version of the software: <http://sourceforge.net/projects/audela/files/audela/current-development/>

**IMPORTANT:** you may need a Microsoft update « VCREDIST\_x86 » to properly run AudeLA/eShel module. Symptom would be a failure to process Flat filed. Look for that update on your CD-ROM, our eShel web page, or directly Microsoft web page.

### 2.3.3 AudeLA architecture



AudeLA is a set of tools for astronomy written in Tcl/Tk (or at least with a Tcl/Tk access) with a collection of equipment interfaces, processing function, file management, etc...

Aud'ACE is a front-end written in Tcl/Tk to allow users to access those tools and functions through a set of menu. Lot of additional functions can also be typed in Aud'ACE console or within Tcl/Tk scripts. You will access AudeLA through Aud'ACE and the eShel and eShel\_Visu tools written for that environment.

eShel\_Visu is a second module written to visualize your spectra (2D images or profiles) as well as some internal FITS tables. It is also the tool for you to export your spectra in standalone FITS file or in BeSS (Be Star Spectra) specific format.

You recommend you to familiarize with AudeLA environment with your CCD camera, video camera (through webcam/grabber camera control), and if possible with your mount before going into your eShel equipment.



## 2.4 Typical observing run

In order to extract the scientific information from the spectra images, we must complete the stars images with three sets of reference images :

- CCD references: bias, darks and CCD flat field (PRNU, optional) for preprocessing
- Spectrograph references: Flats, tungsten (optional) and Thorium-Argon calibration lamp spectra to allow spectrum identification in the image.
- Reference star: an initial spectrum of a reference star will complete this set of references to calculate the instrumental response

The acquisition of the reference images is controlled by the software. It must be done at the sunset, and possibly before every target during the night to check there is no change – or to take them into account. We have found some changes when temperature varies a lot during the night.

There are of course several options, but here a typical way to record your spectra.

### 2.4.1 CCD calibrations - once in a while (every 6 months)

**Bias:** Record a long serie (at least 15 but do not hesitate to take undreds to make a very low noise level) of bias. Then make the master bias reference using the AudeLA/eShel software. Simply copy this master bias reference in each session « reference » subdirectory before processing your spectra.

**Dark:** Record also a long serie of long exposure dark frames. Here, take at a minimum 9 dark frames but it is recommended to take an even longer serie during a full cloudy night. The dark frame will be of the maximum of your exposure time, for exemple 15min. Then create your master dark reference using the AudeLA/eShel software. Simply copy this master dark reference in each session « reference » subdirectory before processing your spectra. If you take shorter exposure, the software will extrapolate the proper dark frame using this master dark reference and the bias reference.

Extract the ***list of hot pixels*** from your master dark reference by looking at all pixels well above the median dark level. This list will be a key parameter to correct the spectra from the hot pixels.

**FlatField:** Then, record a CCD flat field with the camera alone. This is called a PRNU:



PRNU (Pixel Responsivity Non Uniformity) is acquired with the CCD camera alone, detached from the spectrograph. Cover the entrance with a light diffuser (several layers of a diffuse paper for exemple) in front of a uniform screen (a white wall for exemple), slightly enlighten. Several individual exposures (usually between 0.1 sec and 1 sec). The result should be an uniform (more or less) « flat » frame with intensity level around 1/3rd of the overall dynamic.

The picture above is a processed and reduced PRNU flat field of a KAF-3200 CCD chip. This image is overall uniform. But the devils is in the details. Figure 4 shows a portion of the PRNU image at 1x: some subtil vertical structures can be seen. They are linked to sensitivity difference pixel to pixel (difference under 1% here), column to column. They are due to CCD technology and architecture. This is precisely those types of non uniformity that the PRNU master frame will map so they can be corrected.

### 2.4.2 Typical session

Once equipment is prepared, open AudeLA/eShel and connect to:

- Acquisition camera
- Guiding camera
- Telescope mount
- Calibration unit

This can be done automatically if your equipment is fixed and you allways switch ON your equipement the same way to ensure MS Windows assigned the same interface port for each element.

Then click on « Session » to open a new session. You can either continue to use the same session or ccreate one every night (which we recommand). Go one level up and create a new directory to use for the night. In MS Window explorer, copy/past the CCD references frames (bias, dark and PRNU/FlatField) into the new reference subdirectory.

Then, the night is a continuous series of:

- **GoTo your target**, center the target close to the fiber hole
- Take Spectrograph references, for exemple:
  - Switch mirror ON
  - A serie of **Tungsten** (for exemple: 9 x 4sec; the signal should be at maximum 80% of the CCD dynamic);
  - A serie of **Flat = Tungsten + LEDs** on (for exemple: 9 x 4sec; the signal should be at maximum 80% of the CCD dynamic);
  - A serie of **ThAr = Thorium-Argon** (for exemple: 3 x 10sec; the intensity of the high voltage lamp should be set at around 8mA and the maximum intentisity of the four references ThAr lines (see later) is about 15000 ADU).
  - Switch mirror OFF

- **Autoguide** to bring the target on the fiber tip; check it didn't move – otherwise adjust the target position accordingly
- Select « Object Preview », enter the target name, take a **10sec preview**
- Take an **object serie**: adjust your exposure time between your maximum (exemple: 15min) and a time which will avoid saturation. Make sure to take some margin if your sky is foggy for exemple.

*If the maximum level of your 10sec exposure is around 3000 ADU with a background around 1000 ADU, this means you have approximatly 200 ADU/sec. Take a 180sec eposure will bring you at  $1000+200*180=37000$  ADU which seems reasonable if your camera saturates at 65000.*

*Take a serie of single exposures. A minimum of 5 is required to eliminate the cosmic rays for exemple. Maximum total time will depends on your target Signal/Noise ratio, event timing in case of a time-evolution spectrum and of course of your available telescope time.*

From time to time (every night initially but experience should show you can do every month or so), take a spectrum of a reference star, typically a A0 type star, to do the equipment instrumental response.

## **2.5 Installing your eShel spectrograph**

Of course, start the installation on day time. The setup process can be split in two parts :

- Hardware setup, to properly align optical elements in the spectrograph and in the guiding unit. The goal is that the spectrum is well focused on CCD image, with high efficiency – and well centered in the image.
- Software setup will give to the eShel software detailed information on hardware setup (instrument precise angles, position of the spectrum in the image...) to make it possible to run automatic image processing. It will also give some specific parameters of your installation, that will be recorded in all the images.

Even if the eShel software automatically processes the images, all the raw data are carefully stored on the hard disk of your computer. You can re-run the processing with other parameters – or even with an other software.

Raw data are stored in FITS format. Processed data are stored in specific eShel format (described in annexe). This format is based on FITS, of course, with multi-HDU : a single file contains all informations about the spectrum acquisition and processing. You can export each part of this file to common standard formats.

### 3 Spectrograph elements – detailed layout

Eshel spectrograph is a complete spectrography solution, which includes several and complementary elements.

#### 3.1 Spectrograph & acquisition camera

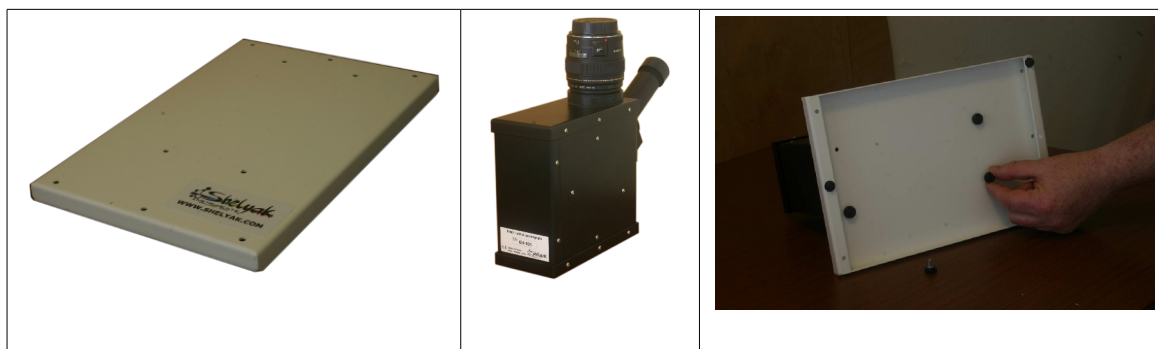
This is, of course, the central element. It spread out the light coming from the optical fibres, and send the dispersed image to the acquisition camera.

First, screw the Canon EOS lens on the spectrograph (remove the protective cap). The front of the lens will face the spectrograph:



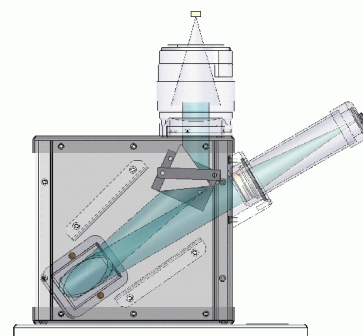
Ensure this is well secured with the three screws on the adapter in between, but note that you will have to rotate the lens once the CCD camera is setup to properly orientate the spectrum on the image. Good alignment is critical for spectra processing.

Then, assemble the base and the spectrograph with the four screws provided:



Inside, the echelle spectrograph is made of following optical elements :

- Collimator achromatic doublet, wich makes a parallel beam from the fiber light,
- Dispersion grating, the key component, which must be



precisely orientated,

- Cross-disperser prism, which separates the orders,
- Photographic lens, which focuses the spectrum on the CCD camera.

The CCD camera is based on a KAF1600 chip. This chip is well adapted to the eShel spectrograph : the size (approx. 13x9mm) allows good overlapping between orders (required to get a continuous spectrum), and pixel size (9µm) is adapted to the spectrograph dispersion (sampling). Backfocus should allow to mount the Canon EOS lens with proper adapters. For automated acquisition, camera should be supported in AudeLA software, such as SBIG or QSI cameras.

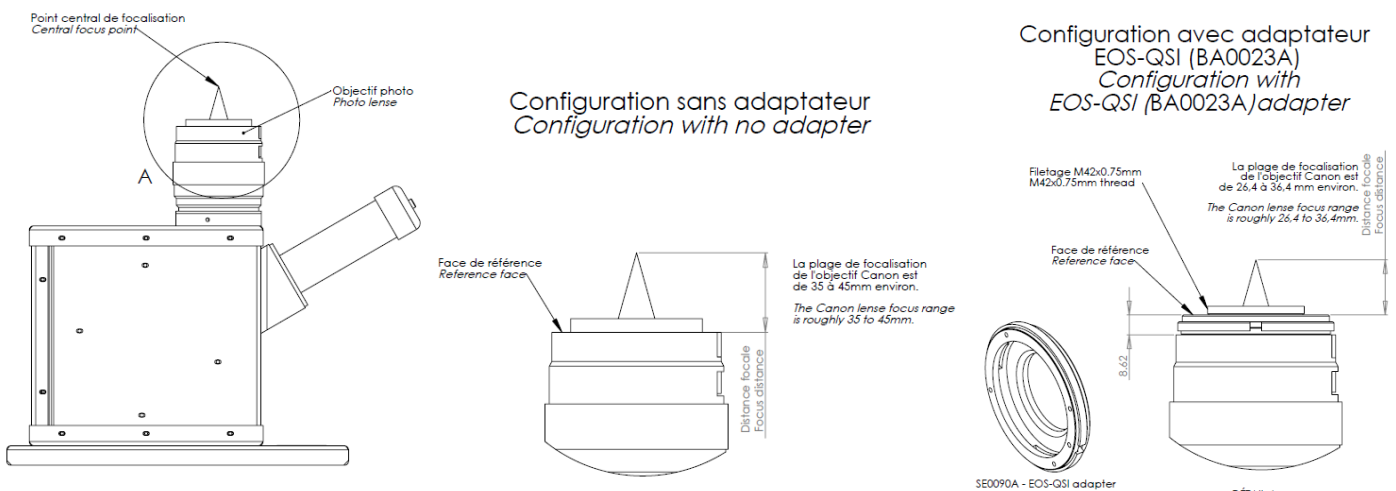
Of course, any camera that comply to the above requirements can be used on the eShel spectrograph... and even a Digital SLR. Since eShel lense is a Canon EOS, you can put very quickly a Canon Digital SLR – and get colored echelle spectra.

Install the CCD camera on the lens with the proper Canon EOS adapter.



Fig: Digital SLR, QSI 516, and ST1603me camera

Camera mounting is critical for proper focus, backfocus range is rather limited (less than 9mm) and you will need the right adapter to make it work.



At this stage, install the driver of the camera, update the driver from internet (SBIG or QSI web site for exemple), connect your camera to your PC and ensure the camera is recognized and is properly working.

In our eShel software, you can use either a SBIG or a QSI camera. Go in the setup/camera menu to declare your camera. You may have to mirror the image during acquisition to get the spectrum well oriented – but this can done later using a Thorium-Argon spectrum.

Do not try to focus the camera without fiber attached to the spectrograph the fiber normally acts as a slit and ensure spectrograph resolution is achieved. But you can try by simply connecting the object fibre (50 $\mu$ m) on one side and orientate the otherside toward the sky or a lamp for exemple. The object fiber can also be directly connected to the Calibration Unit for testing purposes so we suggest to move to the following setup: the calibration unit.

### 3.2 Calibration unit

A precise calibration lamp is required to calibrate the spectrum – associate the effective wavelength to any point in the spectrum image. This is done with a Thorium-Argon (ThAr) lamp, to get a lot of spectral lines in each order. This will be used to associate the wavelength to each pixel position in the order (the calibration law in each order is modeled by a polynomial law).

When you first receive your calibration unit, the Thorium-Argon lamp is outside the unit in a protective box. Make sure to spare the box and use it whenever you have to move/transport the calibration unit.



*Fig: installing the Thorium-Argon lamp inside the calibration unit*

Connect high voltage power supply (110-240V) to the calibration box (power cable and Thorium lap connector) and power in the calibration box with a 12V (positive center) power supply. You should have a 110-240V to 12V power supply provided with your eShel system.

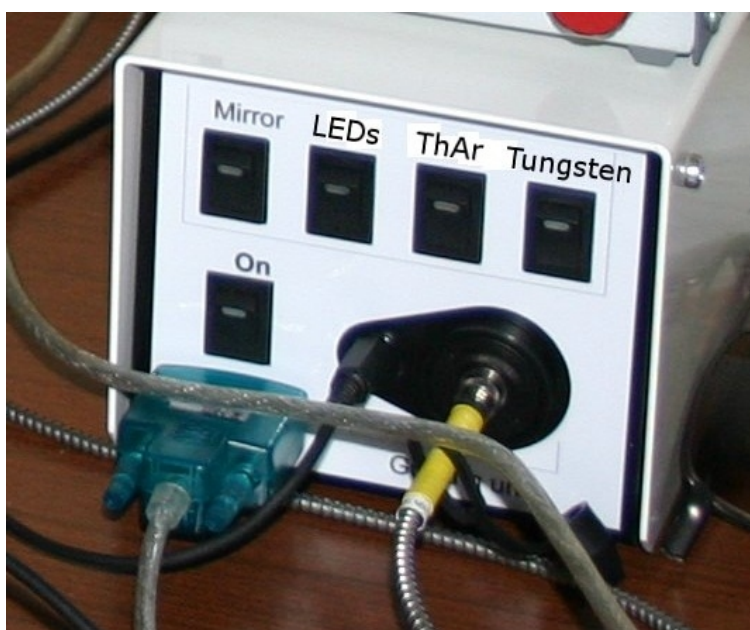
**WARNING:** before switching the high voltage power supply ON, check in the back that it is properly set for your country power : 120V or 240V...



*Fig: high voltage power supply and calibration unit*

Two other lamps are included in the calibration unit:

- a Tungsten (halogen incandescence) lamp. Software will correct each order blaze function using the smooth continuous spectrum of this tungsten lamp which is close to a 2800K planck function;
- several LEDs lamps which, when used with the Tungsten lamp, will provide more light into the blue part of the spectrum to ensure each order is well defined during the geometry part of the processing.



*Fig: front of the calibration unit with RS232 serial cable, mirror control cable and 200µm calibration fiber*

Those three lamps (with the Thorium-Argon) are now installed in the calibration unit, which focus both lights on a calibration 200 $\mu$ m optical fibres – the one which goes to the guiding unit.

In order to make fully automated observations, the software can control each light separately and the guiding unit mirror activation. This is done through the RS232 (serial) port of your PC (if your PC doesn't have any more serial port, you can easily get an USB to serial converter).

The mirror switch is powered by the calibration unit sending through the power cable connecting the guiding unit with the calibration unit about 15V for approximately 2-3sec and then go down to about 5V.

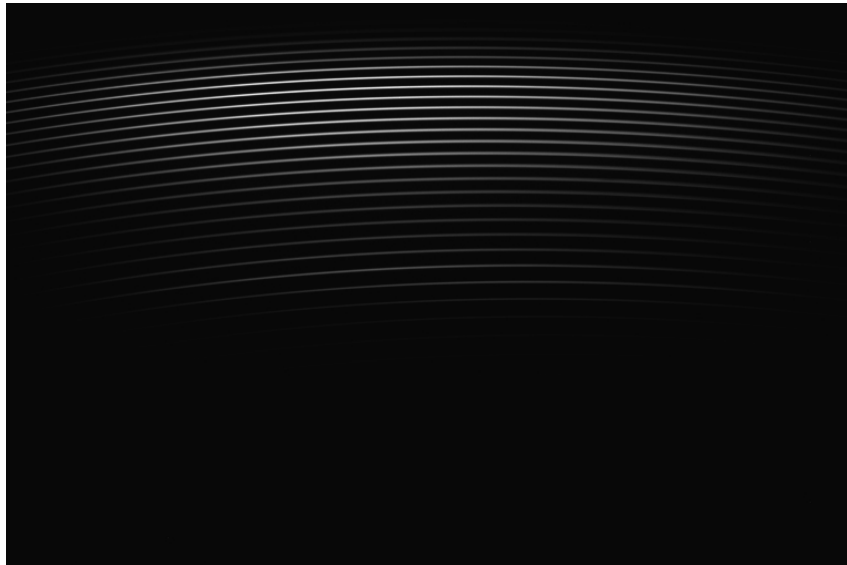
Note: in case the mirror blocks, try to unscrew just a little the 8 cover's screws to see if by untightening the cover you release the mirror holder which may be blocked.

**IMPORTANT:** ensure all your equipment, including telescope and accessories, share the same electrical Ground.

We recommend you to follow those installation steps to make sure all parts are properly installed before moving on to next step:

1. Switch ON the calibration unit, the switch light should go on. If not, check you properly powered the calibration unit with 12V power supply, positive center.
2. Switch ON the LEDs. Look through the FC fiber connector (ie: without the 200 $\mu$ m calibration fiber): you should see light coming out.
3. Switch ON the Tungsten. Look through the FC fiber connector (ie: without the 200 $\mu$ m calibration fiber): you should see light coming out.
4. Switch ON the Thorium-Argon. Look through the FC fiber connector (ie: without the 200 $\mu$ m calibration fiber): you should see light coming out. If not, you can connect your main power plug into the high voltage power supply and check if the power supply switch ON on its own (the Thorium-Lamp has to be connected). Turn the front button until the intensity reader is set around 8mA.
5. Connect the 50 $\mu$ m object fiber directly on the the Calibration Unit, by-passing the calibration fiber and the fiber Injection & Guiding Unit. Switch ON both LEDs and tungsten and look at the other side of the fiber, you should see some light coming out.
6. Connect now this other side of the 50 $\mu$ m object fiber to the spectrograph. Leave both LEDs & tungsten lamps ON and you should be able to focus the camera (turn the 85mm photo lens focus ring) so the spectrum looks like the following picture (you may need to reverse vertically your CCD image to see the same – make sure to adjust this in the AudeLA/Camera-Setup and keep this configuration for all your images acquisition):

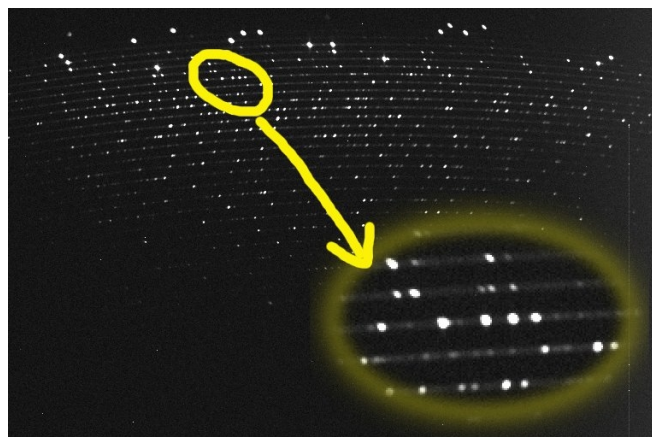




7. Make sure your spectra order are flat at the top of the order curve; rotate the CCD camera if necessary using the three little screws:



8. Switch now ON the Thorium-Argon and check you have the right orientation by looking at the following emission line pattern; finetune your focus on those lines (other option is possible but this would be a good setup):



It could be a good time to adjust your grating angle but this is preset during

manufacturing process and you shouldn't need to do so. This will be described later one when checking the value of the grating angle (gamma angle) when setting up software parameters.

### 3.3 Fiber Injection and Guider Unit (FIGU)

*Note: during initial installation, we recommend you try all element together on a single table or bench before mounting the unit.*

**ATTENTION:** this is a very sensitive optical part. We do recommend to keep the FC fiber connector and the front entrance cap when the unit is not at the telescope and the optical fibers are not set on.

Collecting the light from the target star is key in the spectrography process. A special care must be taken for that. Shelyak Instruments is providing a Fiber Injection and Guiding Unit that has been specially designed for astronomical purposes.



First, a mirror reflects the telescope sky field into a guiding camera. This helps to center the object using a C-mount guiding camera. If you have a CS-mount, use a CS/C extender for optimal performance.

A small hole (around 50µm – like the fibre diameter) is made in this mirror, aligned with the fiber end all the light which goes through the hole will be collected in the fiber.

At this time, we recommend you to install the guiding camera.

If you have a Watec 120N+ C-mount camera, ensure to use the CS/C extender for proper backfocus.

With C-mount, the tube inside the guiding port should exit the holder by about 1-2mm.



Connect the remote controller on the camera, the video cable, the grabber (install the grabber software before connecting it; follow the on-screen instruction of the grabber software). Connect the camera on the guiding port and power on.

In our eShel software, you can use a new Visu in the same software instance or open a new instance of the program - then setup a video (webcam → grabber → select B&W option) camera.

Use the Camera/acquisition to see the image of the guiding port. Focus the camera so the 50 $\mu$ m hole appears the best; then firmly attach the camera using two metal screws.

*Note: you can also use the Telescope/Autoguider module in AudeLA which will display the video flow which is usually easier to work with when doing focus.*

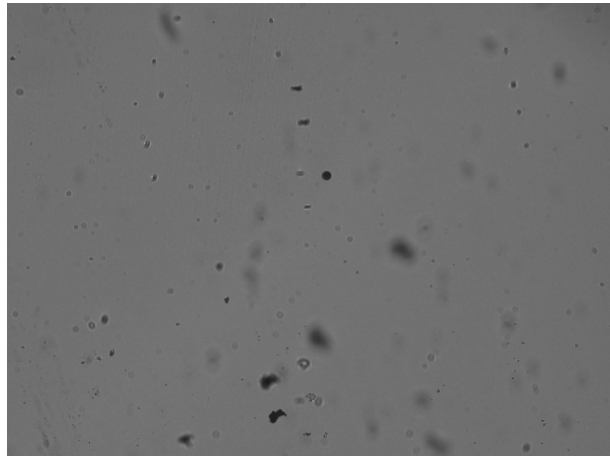


*Fig: the hole on the guiding image*

If the hole is not in the middle, you can adjust the main mirror by using the three screws opposite of the guiding camera. But normally, you shouldn't have to do it...



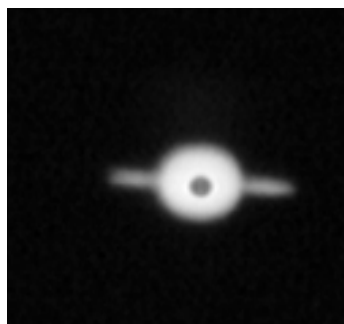
If the image is dirty on the guiding camera, check of course the front glass of your camera and you can clean the mirror with a coton tip and/or air spray:



*Fig: dirty guiding image requiring cleaning...*

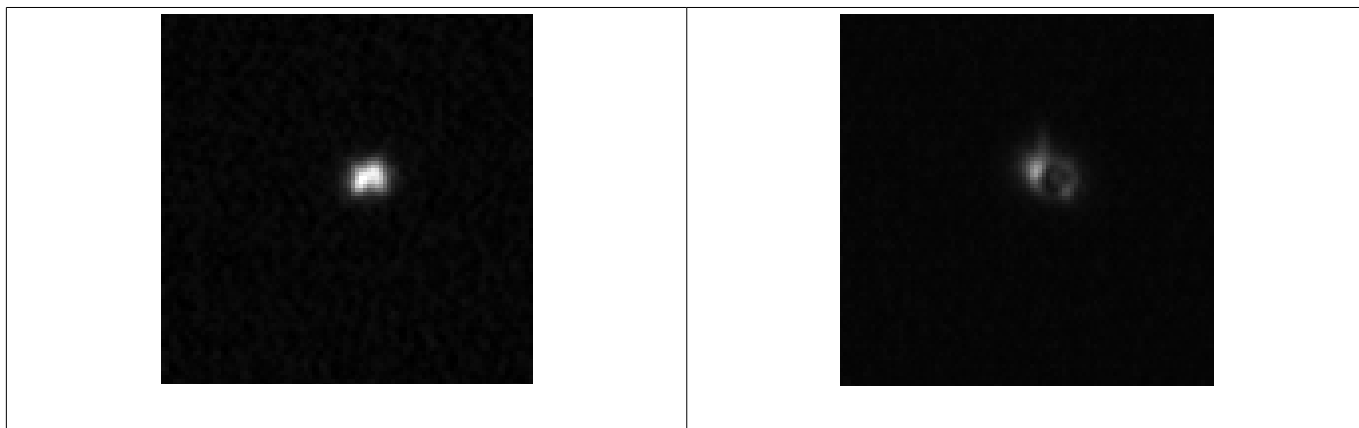
Install the Fiber Injection & Guiding Unit to your telescope. Its backfocus is around 45mm. You can either use the 2inch adapter provided or your T-adapter for your telescope. For f/10 Schmidt Cassegrain Telescope, we recommend the use of a standard SCT 0.63x focal reducer and a Variable T-adapter (using the 15mm extension tube).

*Note: there is a F/9 version of the Fiber Injection & Guiding Unit with a 75 $\mu$ m hole. The optical relay between the mirror hole and the object optical fiber tip is set to 1.5:1 ratio so the F/9 is converted into F/6 and the 75 $\mu$ m fits into the 50 $\mu$  optical fiber. This can save the need of putting a focal reducer at the back of your telescope, optimizing the light flux.*



*Fig: zoom of part of the guiding image with the hole on Saturn...*

When the star you observe is exactly aligned with the hole, it disappears from the guiding image. In other words, the less you can see the star on the guiding image, the more light is collected in the fiber. Of course, several parameters have a direct impact on the light collection : sky seeing, telescope focal length, guiding precision, telescope focusing... all these elements must be adjusted (well... not easy to adjust the seeing !) to get the maximum light in the fiber – and then increase the S/N ratio at the end of the process.



*Fig: image (with bad seeing!) outside and in the hole*

*Note that the guiding port has a 1.5x magnifier optical relay inside the unit which makes the field of view smaller than in prime focus. The typical guiding image field of view is almost unvignetted in a circle of about 7mm diameter.*

A moving mirror is installed in the guiding unit, controlled by an eletro-magnet. This allow to send the calibration light (see below) to the acquisition fiber. Calibration light is transported to the guiding unit through a secondary optical fibres, so called calibration fiber. The magnet is activated by a special power supply from the calibration unit which provides 13V for a brief time then a sustained 6V. It is also controled by software when you acquire spectra or calibration frames.

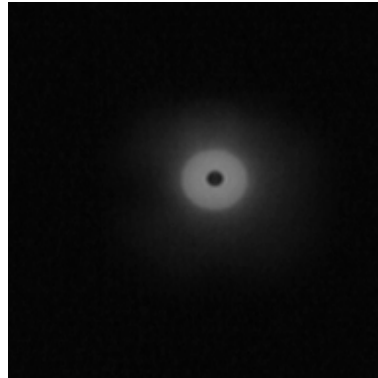
### **3.4 optical fibres**

The acquisition fiber is a 50 $\mu$ m (core diameter) silice-silice multi-mode fibre. Connectors are FC type : they are tightened by a nut, and positionned by an index (when you remove the connector, you'll put it back at exactly the same angular position). The optical fibre is protected in a metallic/plastic casing to prevent any dammage, specially in severe environnement. It also prevent external light going into the fibre.

The acquisition optical fibre connects the back of the Fiber Injection & Guiding Unit to the echelle spectrograph.

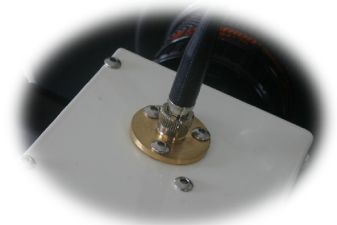
The calibration fiber is the same type (multi-mode silice), but is bigger (200 $\mu$ m diameter) to get more light (and then reduce the exposition duration for spectrograph reference images). It is also provided with FC connectors.

The calibration optical fibre connects the calibration unit to the side of the Fiber Injection & Guiding Unit. When a power source is on (Flat or Thorium-Argon) and the mirror properly activated, you will clearly see the hole in the guiding image – this can be useful to locate the hole during the night.



*Fig: crop view of the guiding image with Thorium lamp on*

If the spot from the calibration fiber is not exactly aligned with the mirror hole, you can adjust it by using the three screws on/around the calibration fiber connector of the guiding unit.



If the spot is not round but has a « comet » type shape, use the two screws close to the power cable connector to adjust the position of the reflective mirror inside the guiding unit.



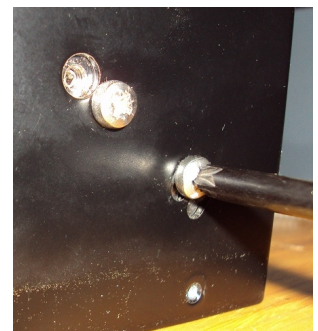
## 4 Spectrograph installation

### 4.1 Grating angles

This is a key parameter which varies from one eShel to another. The nominal angle is  $62.5^\circ$  (angle « alpha »).

The shifting angle (« gamma ») is usually  $5.75^\circ$  and you shouldn't have to change it in the software for processing.

Grating is a 79 grooves/mm echelle one. This should be a fixed parameter, do not try to change this one.



If required despite manufacturing adjustment, you can adjust the alpha angle and the vertical position of the spectrum on the CCD camera by using the two large screws on the side of the spectrograph. Be very careful as the adjustment is very sensitive.

You can also adjust the gamma angle by using the two smaller and inside screws close to the two previous ones. This will shift the horizontal position of the spectrum.

*Note: if the spectrum is not visible on your CCD image, check first your CCD size & cropping option in AudeLA/eShel software before trying to adjust the angle. Check also the min/max levels for visualization: we recommend you to stay in manual mode; click on the [...] icone at the bottom left of the AudeLA main window and select  No Automatic Calculation ; then click on the  icone when you want an automatic update.*

### 4.2 Camera alignment

Here is a full image of a Thorium-Argon lamp. Check that your image has the same orientation; otherwise rotate the camera/lens on the spectrograph and/or use the mirror options in setup/camera menu.

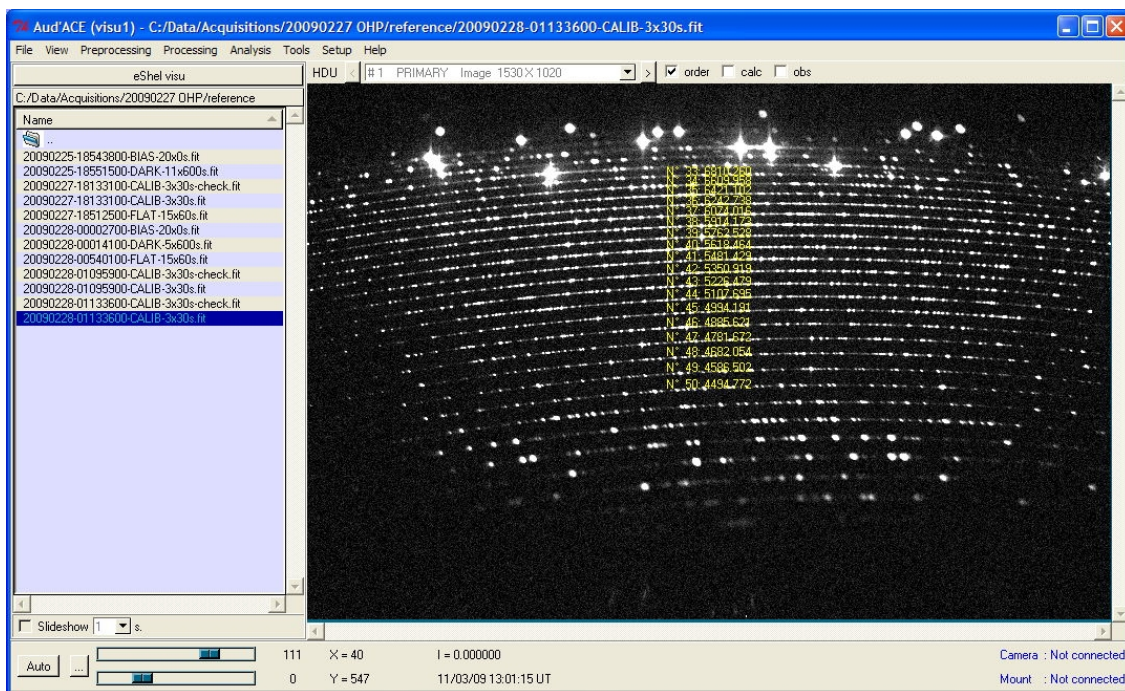
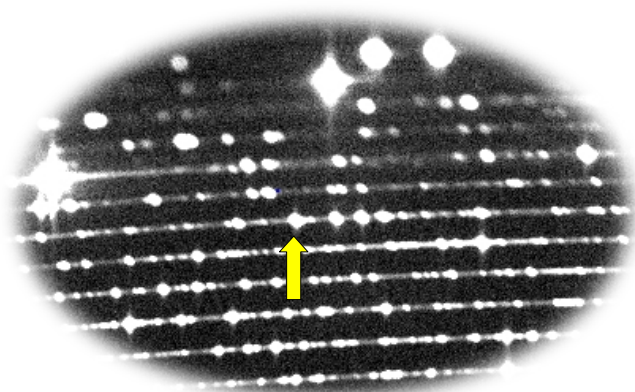


Fig: Thorium-Argon spectrum (viewed 0.5x)

Look for the following pattern which is on order #34 where H-alpha line is also located; check your image has the same orientation there:

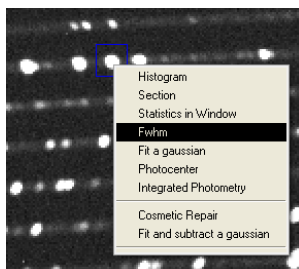


*Fig: Thorium pattern to recognize...*

Note the position of the line marked (X coordinate, indicated at the bottom of the eShel\_visu window); this will be used as a key parameter in the processing software later on.

### **4.3 Objective (Canon EOS lens) focus**

Switch on the Th-Ar lamp (or use Thorium preview in the eShel software) to acquire a Thorium-Argon spectra. Simply turn the Canon EOS lens to focus. Focus around order #34, ie where the above line pattern is. Draw a small rectangle (mouse left-click) around one of the isolated emission line and adjust the focus to minimize the horizontal FWHM of this line. Right click with your mouse to access a special menu :



You may want to focus a little bit further on order #40 for exemple – this is really a matter of choice as you can even focus mainly on the UC part or near Infra-Red portion of the spectrum.

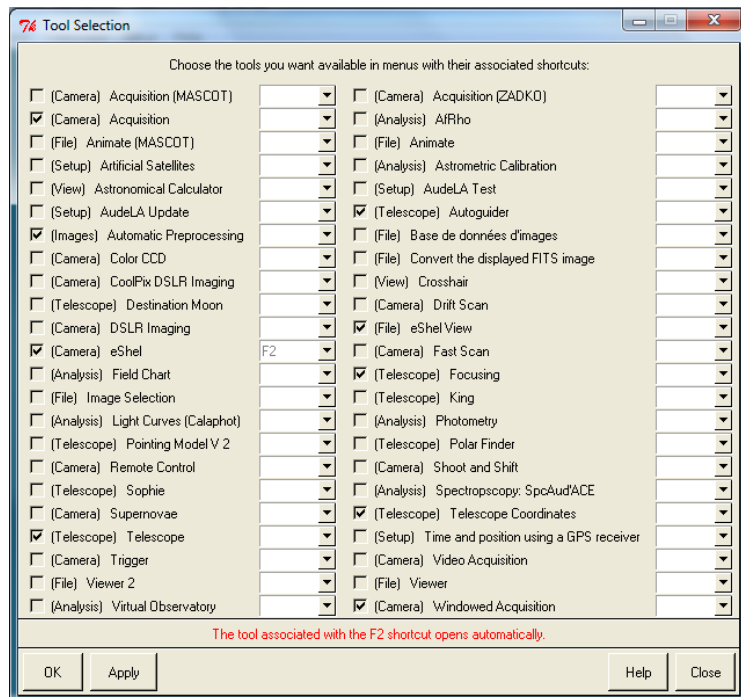


## 5 Using AudeLA/eShel software

Before continuing in the software installation, we invite you to read the User Guide, and specially the software part. Here, we focus on the parameters that are required to make the soft – specially the spectra processing – working fine.

### 5.1 General AudeLA configuration

If you want that eShel automatically start when you run Audela, you should go in tools/tool selection menu, and select F2 shortcut in front of eShel. We recommend that you start with a limited number of tools in your selection – for exemple:

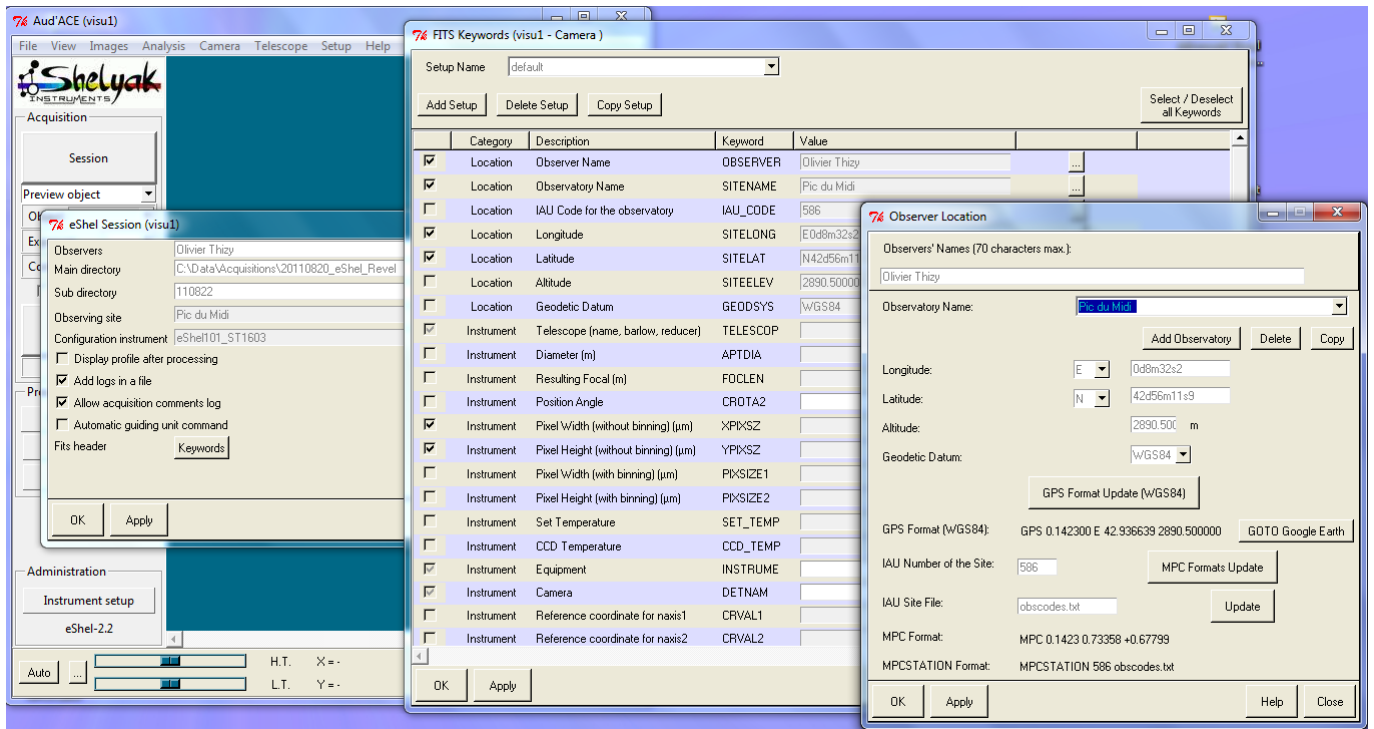


*Note: you can then select the tools that you want your users to be able to use in standard.*

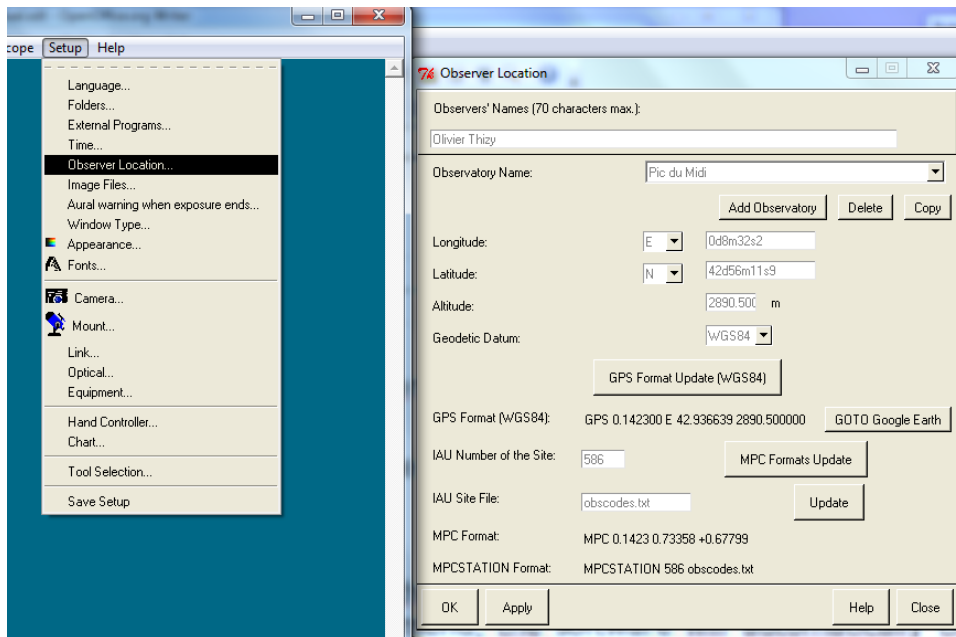
### 5.2 Observation sites

The first data to fill is the observation site parameters. These informations will be included in each images fits header – this is important to keep it for later scientific usage (such as heliocentric velocity).

Access to observations data is made through « Session » menu, then « Keywords » which open a long list of FITS keyword you may want (or not want) to register with each acquisition file. For exemple, click on the [...] icone to access the Observer Location configuration panel:



You could also access this panel through Setup / Observer's Location :



You can create as many observatory forms as you want (if you use your instrument in different locations).

Enter, at minimum, the observation site name, longitude, latitude and altitude.

*Note: be careful in case you plan to record Be star spectra to use an observatory code which is compatible with BeSS (Be Star Spectra database) format. For exemple, « OHP » is the code for the Observatory of Haute Provence, and not « Haute Provence ».*

Enter also there the observer name but this can also be changed at each session in case multiple users access your spectrograph.

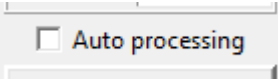
### 5.3 Images directory

Still in session menu, you can select the working directory. When you confirm the directory name, and exit the session menu, the software will automatically create following sub-directories :

- **archive** (where raw images are transferred after processing is completed)
- **processed** (where processed spectra are put)
- **raw** (where raw images are put until processing)
- **reference** (the images used for processing)
- **temp** (temporary directory)

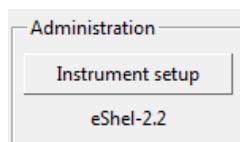
*Note: you can (should!) reuse CCD references from a previous night, typically CCD references such as master bias, dark and PRNU frames. Simply copy-paste them from your master directory into the 'reference' subdirectory created once you validated the session.*

### 5.4 Instrument parameters

Note: deactivate the  option when you install the spectrograph !

Here, we start the most difficult part of your installer job. Giving the most accurate parameters to the software is required to ensure the automatic processing works fine – and then getting a high quality results.

Click on the « Instrument setup » button :



A new window pops up. Here again, you can store different configurations, if you use your instrument in different conditions. Note that the default configuration cannot be cancelled (this is to recover default setup in case of...).

Note: the configuration name will be used when exporting in BeSS file format so we recommend you to be compatible with BeSS format and use the same configuration name as the one you will declare in BeSS when uploading your spectra.

Then you have different tabs. Go successively to each of them, following below recommendations.

### 5.4.1 Spectrograph

**Name** : Give the name of your instrument (our recommendation is to give here the serial number of the spectrograph, and eventual options such as camera). Exemple: « eShel\_6H-115\_QSI516 » would be a good name. « eShel101 » would be a minimum!

**Grating (lines/mm)** : For eShel Spectrograph, the exact value is 79 grooves/mm and there should be no reason for you to change this value.

**Incidence angle alpha** : this is the angle between the input parallel beam towards the grating and the grating normal axis. The nominal value from the grating manufacturer is 63,45°. This value (very, very sensitive !) depends on the exact tuning of your instrument. See below how to define this value. *This is the main parameter to play with when looking for the best processing parameters.*

**Diffraction angle beta** : this is set at 0 for the eShel. this has been introduced so you can reduce spectra of a 1<sup>st</sup> order grating based spectrograph such as the Lhires III or the LISA...

**Shift angle gamma** : this is the angle between input beam towards the grating and the output beam (from the grating to the prism). The nominal value is 5,75°. you may change this value but try to adjust the incidence (alpha) angle first.

**Obj Focal** : this is the focale length of the photographic lense. The value is 85mm; there should be no reason to change this value.

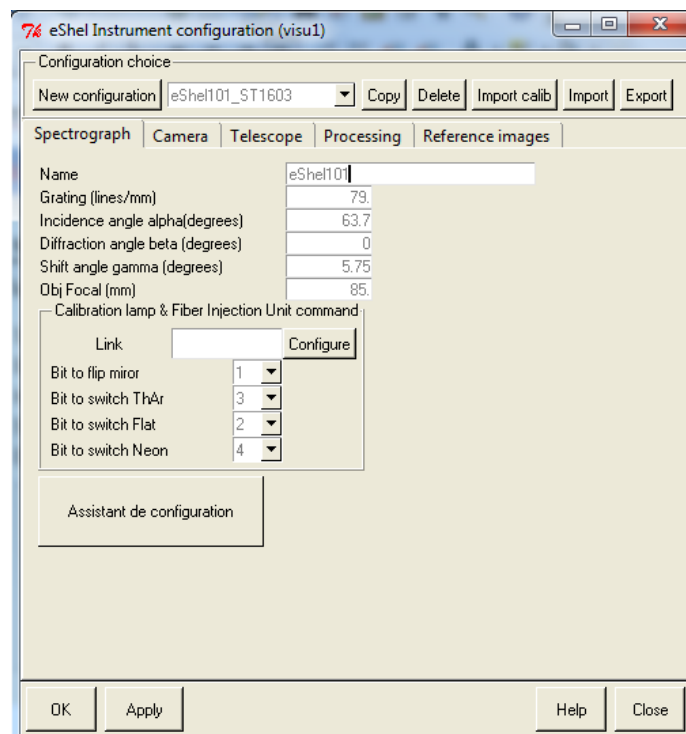


Fig: spectrograph configuration exemple

Configure the Calibration unit to connect to your right serial port. Then configure the bits properly as shown on the figure below: Mirror flip=1; Thorium=3; Flat (this is actually the LEDs lamps)=2; Neon (this is actually the tungsten lamp)=4.

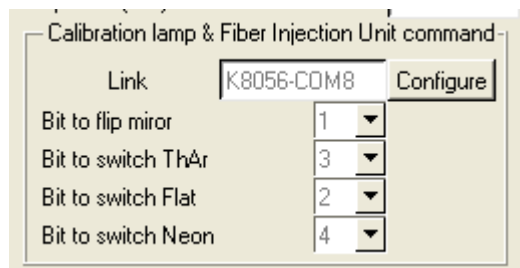



Fig: configuring the RS232 serial link to the Calibration Unit

Note: the  button is not working yet. This is work-in-progress and will be a wizard to help in the configuration steps.

### 5.4.2 Camera

The CCD camera parameters are easier. Give your camera name (most probably SBIG or QSI). Make sure to download latest drivers for your camera.

Since eShel spectrograph works with a Kodak KAF1603 CCD chip, the other values should be :

- Pixel size = 0,009mm (=9 $\mu$ m)
- Image width = 1530 pixels (or more for QSI camera displaying covered pixels area)
- Image height = 1020 pixels
- Window = 1 - 1 - 1530 - 1020 (as QSI camera download hidden pixel area on the side, use the proper window position to crop the images; this is not mandatory).

Hot pixels: enter here the list of pixels followed by 'P' (for 'Point'). Exemple:

```
P 838 4
P 1103 4
P 838 5
P 838 6
P 838 7
```

You can get this list using IRIS software. Load a dark frame in IRIS and use the command « FIND\_HOT cosme 800 » and get the list from cosme.lst file. Adjust the level (here: 800) depending on your dark frame median level in order to get around 1000 hot pixels.

*Note: you can now also use ISIS software to create this hot pixel list; ISIS is a replacement for IRIS for all spectroscopy processing.*

**Cosmics:** click here if you want to remove cosmic during processing. Most people prefer to keep them and remove them in the spectral profile using a spectral analysis software. If you want to remove them, enter a threshold (400 is a good default value).

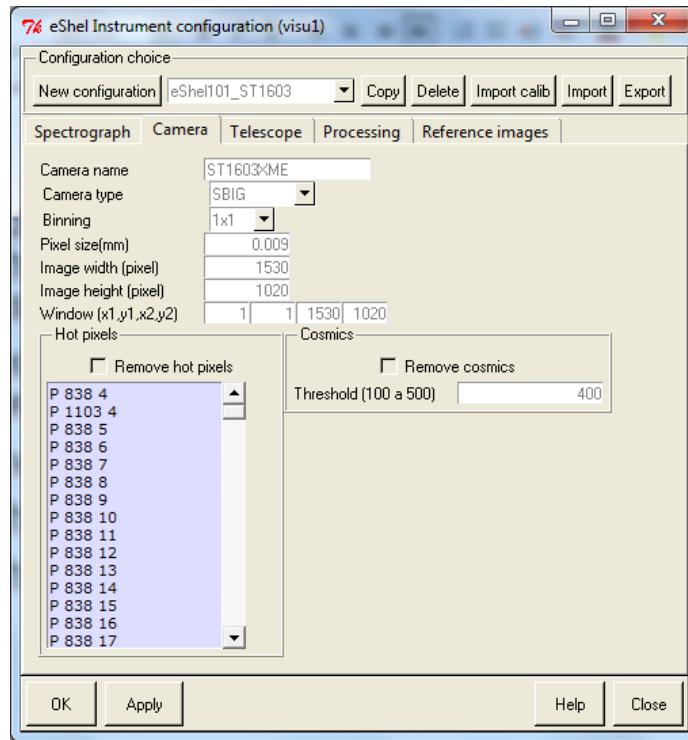


Fig: camera configuration exemple

### 5.4.3 Telescope

Simply give the name of your telescope. This name will be put in all FITS images.

### 5.4.4 Processing

Here, we enter in the parameters that will make the software able to recognize the different orders in the image.

The first thing to do is to take an image of a known spectrum – for instance, the ThAr Thorium-Argon calibration lamp spectrum. In this spectrum, you must identify one known line; by « known line », we mean that you know its exact wavelength.

We recommend to use the 6583.9 Angstrom line in Thorium-Argon in the order #34:

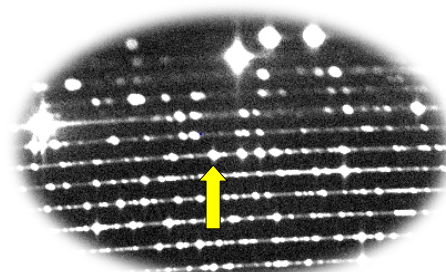


Fig: Thorium line 6583.9A at order #34

In the spectrum image, note at which pixel 'X' position is this line (you can move the cursor in the image, and the cursor position is dynamically shown in the bottom part of the screen). The required precision is not that critical. The software uses this data to identify the line, but it will measure it with accuracy.

Enter your values in the « reference order » sub panel: X & Y:

- Reference line Lambda (Angstrom)  : this is a fixed parameter – do not change;
- Reference order N°  : this is a fixed parameter – do not change;
- Reference line X abscisse (pixel)  : this is the X coordinate of the reference emission line in Thorium-Argon spectrum;
- Middle order Y coordinate (pixel)  : this is the Y ordinate the reference order (#34) in the middle of the image.
- Detection threshold (ADU)  : this detection threshold adjust the sensitivity to order detection on a Flat file (LEDs + Tungsten lamps). This value depends on how many file you have taken (and summed up) and on your exposure time. Play with this value until you find the right value. You can also pass your mouse over the Flat reference spectrum and check the intensity value between orders.

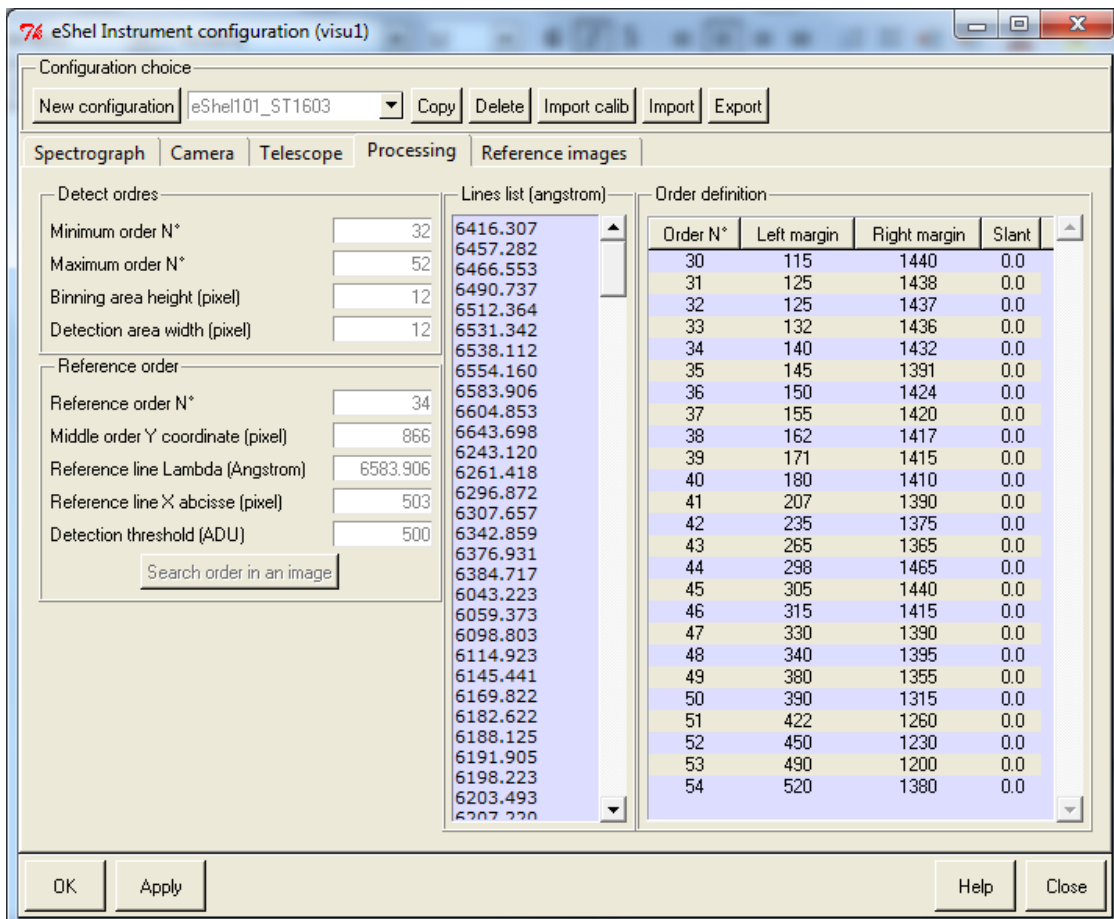
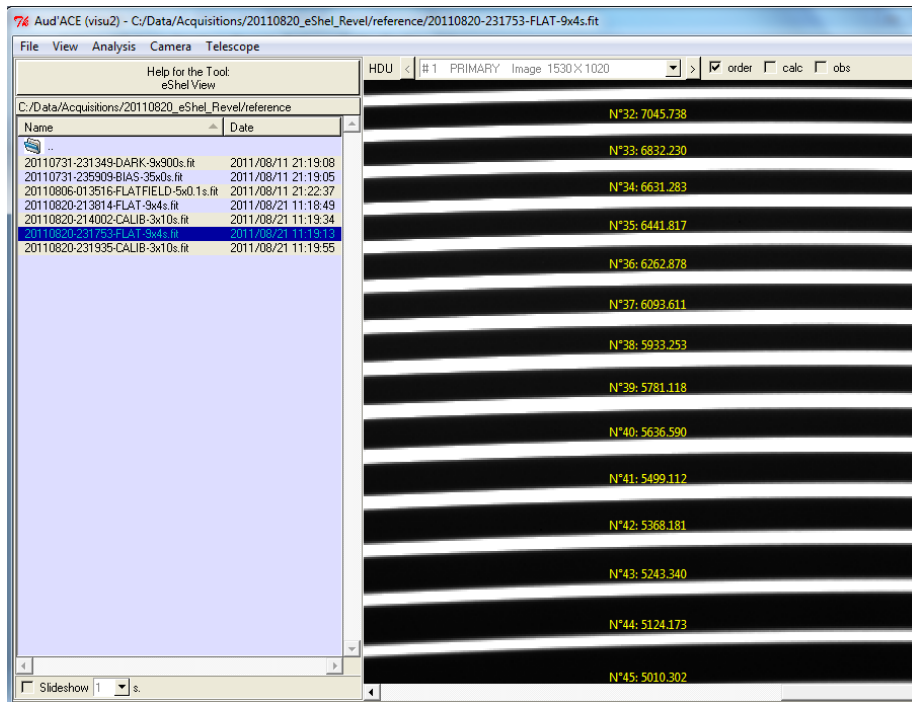


Fig: processing configuration panel



*Fig: eShel Visu panel  
click on « order » to display orders on the CALIB or FLAT images*

Then, you have to fill the « detect orders ». Default values are:

- **Minimum order N°**  : nominal value is 32. Start with 34 when first installing the software and finding the parameter and extend the order range when you are satisfied with the key parameters;
- **Maximum order N°**  : nominal value is 52. Start with 34 when first installing the software and finding the parameter and extend the order range when you are satisfied with the key parameters;
- **Binning area height (pixel)**  : software will search vertically within this width for the maximum to find where the order is exactly located; the typical value is around 120µm on the CCD chip; with 9µm pixel size, use 12 to 14; with 6.8µm pixel size, use 17-18.
- **Detection area width (pixel)**  ; this is the width for the emission line detection when performing the wavelength calibration. you can start with a higher value initially but need to reduce it to get accurate calibration. Typical value is the same as the binning area height.

As you can see, you can define the min/max order's range to be processed. Nominal values should be min = 32 and max = 52. The ability of the software to process an order depends on several parameters :

- The focus of the photographic lense, which can be either toward the red or toward the blue area of the spectrum; we recommend the middle in most



applications. But in some cases, you can choose to focus on certain orders (ie near IR or blue part).

- The available ThAr Thorium-Argon lines (or more generally calibration lines) for this order. The more they are, the best it is.
- The accuracy of the spectrograph parameters.

There line list is for the ThAr lamp. These lines are used to calibrate the spectrum. We recommend to keep the default values – except if you perfectly know what you are doing.

Finally, you have to define, for each order, the margins (pixel columns) and the slant angle for more precise spectral profile extraction.

*IMPORTANT: If you merged spectrum display clear waves, you may want to reduce those margins. You may also want to ensure your instrumental response has been calculated with a reference spectrum processed with the same FLAT as your object spectra. Using Tungsten lamp and new code should help in minimizing this wave effect but some may still remain, even some million dollars spectrograph display some order merging artefact and in lot of case, astronomers work on invidual orders instead of the merged profile. Individual orders is for exemple the BeSS file format for echelle spectra.*

### 5.4.5 Reference images & tuning your parameters

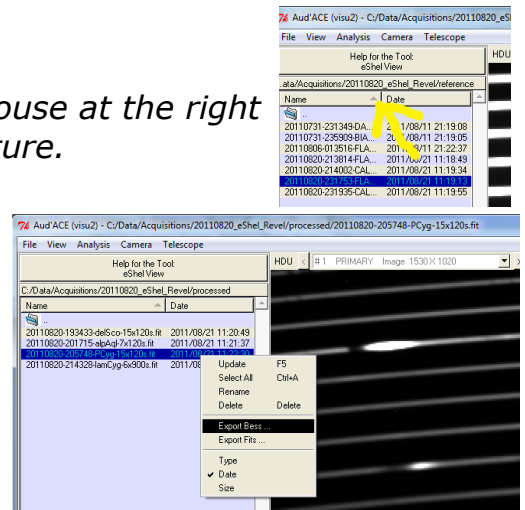
Once you have filled all these parameters, we need to adjust the spectrograph parameters (incident angle and main spectro angle). These values will be used to predict where the calibration lines are in the image. If the parameters are correct, all the lines will be identified, and the calibration will be very fine. If the parameters are not precise enough, then part of the lines will not be detected, and calibration will be poor.

Acquire Dark and Bias frames, then a flat and a Thorium-Argon frame. Process them and you will obtain reference spectra (in « reference » sub-directory) you can look at with eShel/Visu tool.

First, check all orders are identified. If an order is skipped, this may be because the order detection threshold is too low.

*Tip 1: in eShel/Visu, double right-click with your mouse at the right side of the « Name » title to trigger auto-width feature.*

*Tip 2: in eShel/Visu, select a file and use right-click with your mouse to activate a context menu. you can there export your spectra in BeSS format or FITS format for exemple. You can select which HDU (parts of the FITS file) you want to save...*



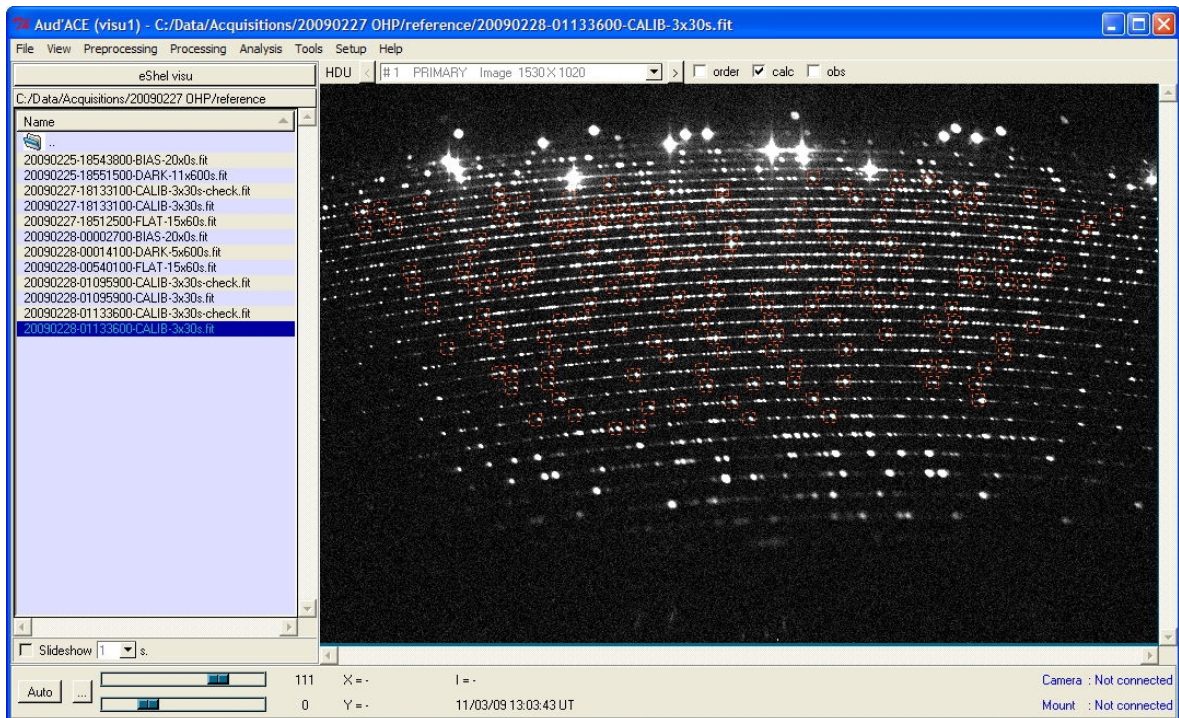


Fig: click on « calc » to visualize the calculated position of reference lines

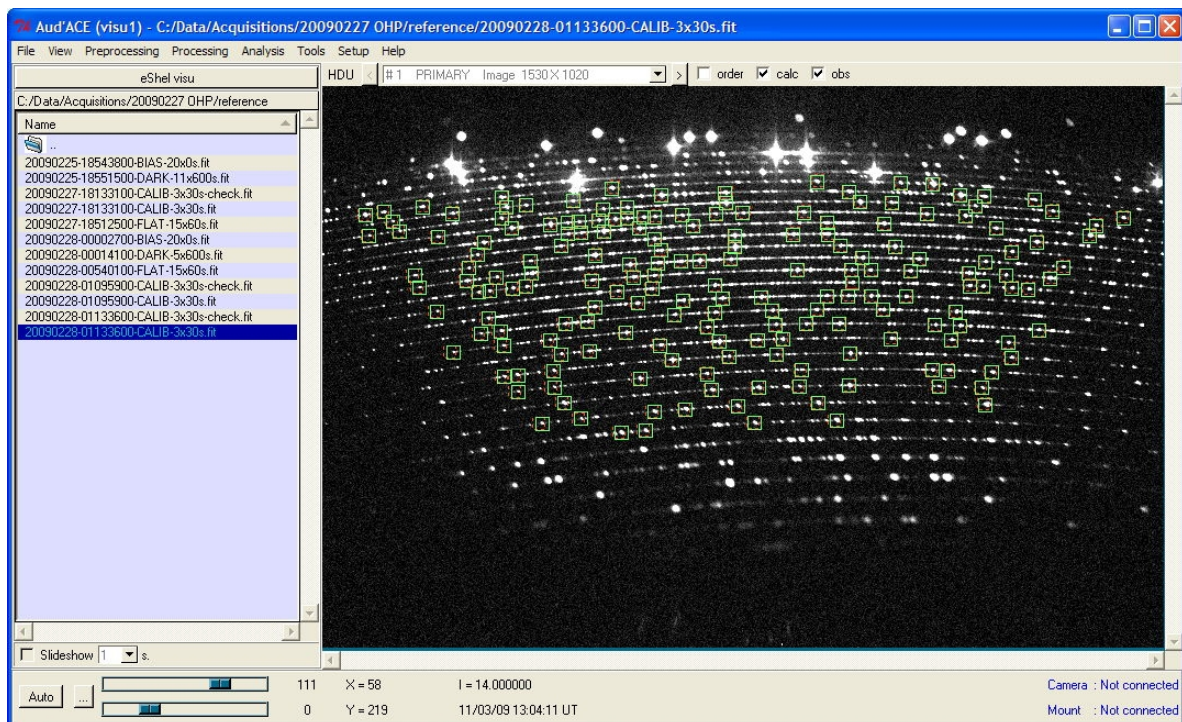


fig: click on « calc » & « obs » to compare calculated and observed reference lines

## 5.5 Response Curve

This should normally done once in a while but we recommend you do start by doing one every night.

To calculate the instrumental response, you could use VisualSpec software which can divide spectra (<http://www.astrosurf.com/vdesnoux/>):

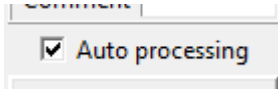
- a/ take a spectrum of a reference star (Altair or Regulus for exemple)
- b/ export the merged profile in FITS
- c/ load the FITS profile in VisualSpec
- d/ load a profile from VisualSpec library of a star with same spectral class
- e/ divide the reference star spectral profile by the one from the library
- f/ smooth the result (fit continuum) to remove artifact from absorption lines or telluric lines
- g/ export this instrumental response into a FITS file

*note: make sure the CDELTA1 keyword is set at a value of 1.0. If not saving your profile in a DAT form in VisualSpec, then reloading the DAT file to export it in proper FITS format. Another way is to change the CDELTA1 keyword value to 1.0 (with fitsview software for exemple).*

ISIS software also includes a way to create your instrumental response. It comes with a good library of reference spectra.

ISIS: <http://astrosurf.com/buil/isis/isis.htm>

## 6 Concluding your installation

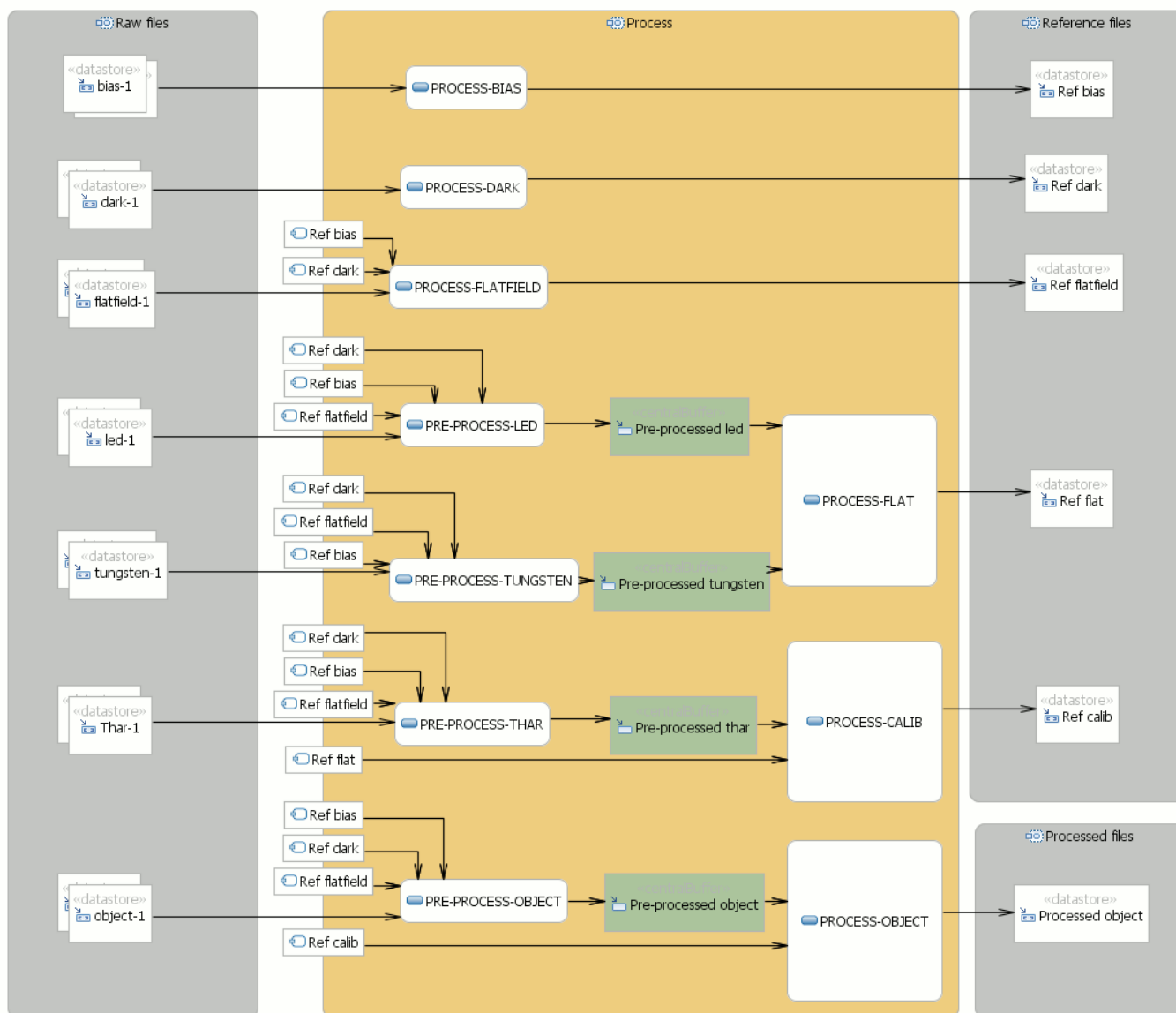
Once your parameters are set, you can active the  and release the spectrograph for the end users to start observing in an automatic mode. They should refer mainly to the eShel User Guide.

You should in general try to leave the main camera on the spectrograph so you won't have to find the new parameters every time. The Fiber Injection & Guiding Unit can on the other side easily be removed and replaced at your telescope focus whenever you need.

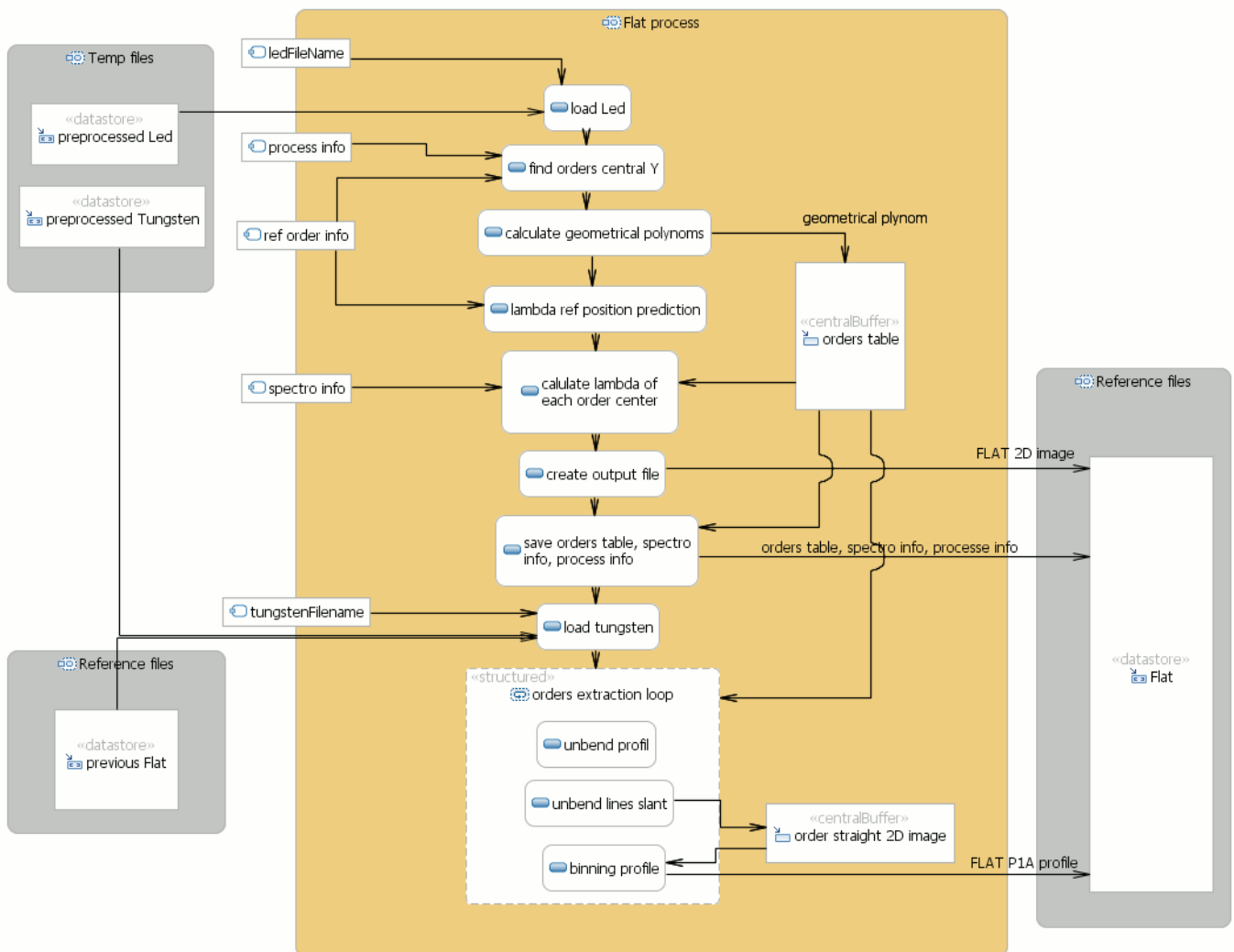
Last but not least, feedback and support request can be sent to [olivier.thizy@shelyak.com](mailto:olivier.thizy@shelyak.com). A discussion group has also been initiated to allow more user interactions: <http://groups.yahoo.com/group/spectro-eShel/>

## 7 Annexe: Processing flowcharts

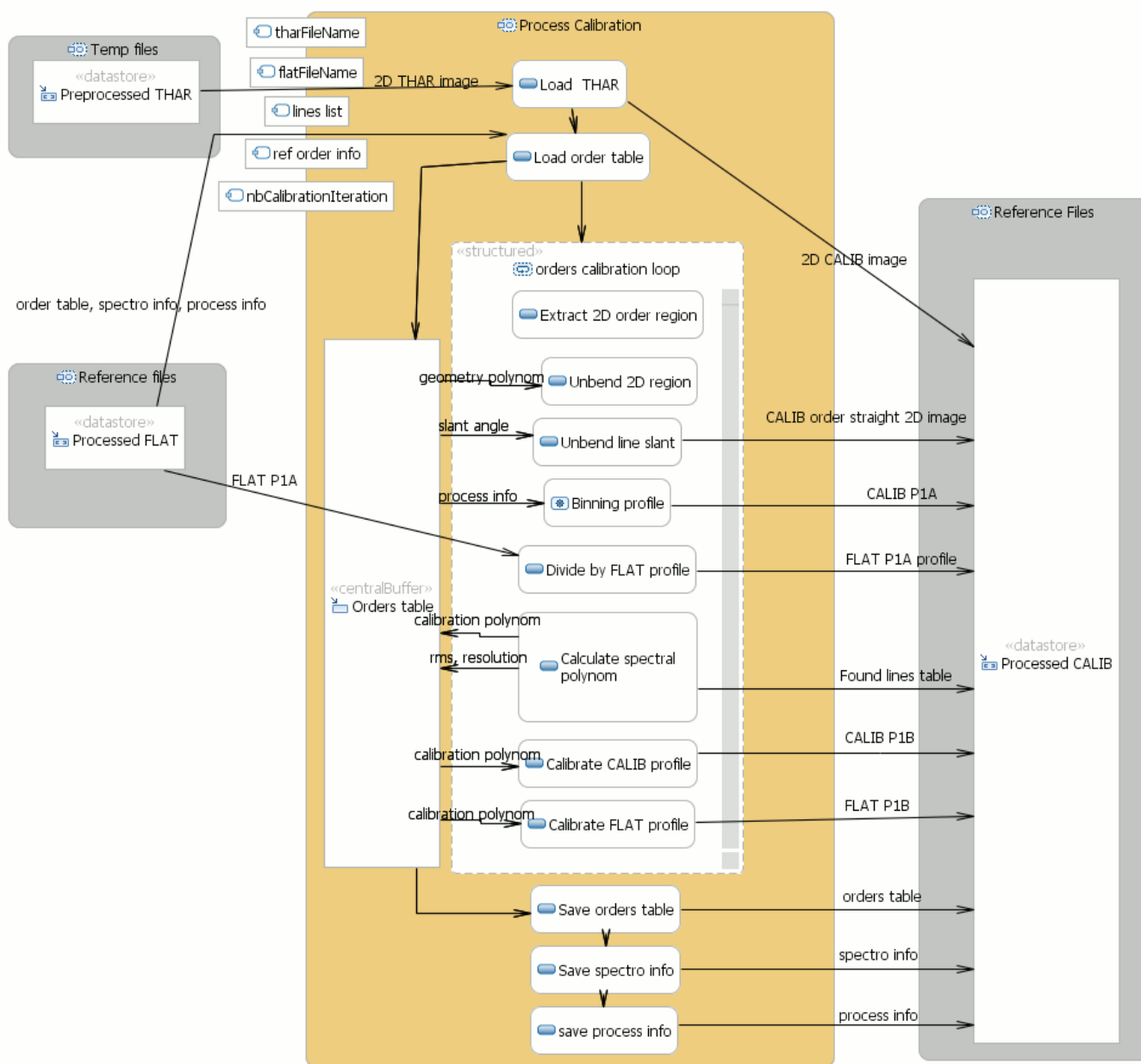
### 7.1 Overall eShel processing flowchart



## 7.2 Flat processing flowchart



### 7.3 Wavelength calibration flowchart



## 8 Annexe: Calibration Unit RS232 serial interface

Serial port configuration: 2400/8/n/1

Command format (5 bytes)

- **Byte 1 : chr\$(13)**  
packet start
- **Byte 2 : address (1 to 255)**  
peripheral ID number (1 by default). Required if more than one Calibration Units are connected to the same port (unlikely).
- **Byte 3 : command**
  - E : Emergency stop all cards, regardless of address. Carefull, relays turned on by open collector inputs will not be turned off by this command.
  - D : Display address. All cards show their current address in a binary fashion. (LD1 : MSB, LD8 : LSB)
  - S : Set a relay. S instruction should be followed by relay # 1 to 8 (9 sets all relays at once)
  - C : Clear a relay. C instruction should be followed by a relay # 1 to 8 (9 clears all relays at once)
  - T : Toggle a relay. T instruction should be followed by a relay # 1 to 8.
  - A : Change the current address of a card. A instruction should be followes by the new address (1...255)
  - F : Force all cards to address 1 default.
  - B : Send a byte. Allows to control the status of all relays in one instruction, by sending a byte containing the relay status for each relay (MSB: realy1, LSB: relay8 )
- **Byte 4 : parameter**  
command paramter (see above)
- **Byte 5 : checksum**  
complement to two of the 4 previous bytes sum:  
 $256 - (\text{Byte1} + \text{Byte2} + \text{Byte3} + \text{Byte4}) \text{ MOD } 256$

## 9 Annexe: translating AudeLA/eShel

For those interested (specially if you have local students using your eShel), it is possible to translate AudeLA, AudeLA/eShel and AudeLA/eShelVisu modules.

For exemple, go to your program file and edit the files:

eShel: <AudeLA directory>\gui\audace\plugin\tool\eshel\eshel.cap

eShel Visu: <AudeLA directory>\gui\audace\plugin\tool\eshelvisu\eshelvisu.cap

Copy the english version or french version to create a new language section and simply translate each line. Then if you select your language as AudeLA main language, the module will be in that language. Nine languages are currently supported in AudeLA but only two for eShel and eShel/Visu modules.

If you make a translation, send it to [olivier.thizy@shelyak.com](mailto:olivier.thizy@shelyak.com) so it could be integrated within an official AudeLA release.