specINTI
Toolbox

1. Introduction

This document discusses the use of the specINTI software in common and less common situations (it's up to you to judge!). It covers the fields of high and low spectral resolution. It pertains to version 2.5 and above of specINTI.

This is not an actual user manual. For that, refer to the program's website:
http://www.astrosurf.com/solex/specinti1_en.html

It is about a "toolbox" based on concrete examples and numerous tips and tricks for use. It is organized like a "pipeline" for preprocessing your spectra. This means that if you follow the different sections step by step, you should get a satisfactory result with your own data. Making the effort to read the contents of this "toolbox" carefully (not hesitating to refer to the general documentation, the reference manual in particular) should therefore help you become a specINTI expert.

The specINTI software has the particularity of differing from other current astronomical processing applications in that it interacts with the application through an almost singular text file. Therefore, we are far from the usual shiny graphical interfaces (but there is an interface that can help you write this text, it is the specINTI Editor).

So, operating specINTI is a bit like typing on a typewriter, with the advantage of great freedom, being able to share the written text, have it validated and certainly, if you are satisfied with it, not to go back on this work even several years later. This way of operating makes specINTI a formidable production tool, much simpler to use than it seems as long as one embraces its spirit.

The main text to be written is in a so-called "configuration" file. It describes your instrument and how to use it. There is a second file to be written, which describes the observation you want to process, also referred to as "reducing" in the jargon. This is the "observation" file. One can imagine that eventually some acquisition software will automatically write this last document for you (and this is already a bit the case).

Without replacing the main documentation of specINTI, here are some additional details on the function and use of these two files:

- The configuration file is a simple ASCII text file (whose extension must end with ".yaml"), located in a special subdirectory of the software installation directory (the "_configuration" subdirectory). In addition to comments, each line in the configuration file contains the name of a parameter followed by the value of this parameter. These parameters alone control the overall behavior of specINTI. When launching the software, it simply reads your configuration file and then sequentially executes operations following modes defined by the parameter values. It is important to note that the "_configuration" subdirectory is a kind of receptacle where you can place configurations of your choice, corresponding to specific uses of specINTI or various instruments. There are also small utilities, also taking the form of configuration files (we will use these in this toolbox).

- The observation file is also a simple ASCII text file (whose extension must end with ".yaml"), necessarily located in the directory containing your raw observation data (hereafter called the "working folder"). In blocks, the lines in this file specify the observational parameters of a given object (number of raw images, number of "dark" images, etc.). There may be multiple blocks of parameters, corresponding to as many distinct objects to be processed, as specINTI is capable of managing them sequentially in an automated way (this corresponds to the "in one go," or "batch" processing of an entire night's observation).

We do not describe in this toolbox the detailed operation of the interface "specINTI Editor," which will normally be the entry point for the software, facilitating the writing of configuration and observation files through automation, and also helping you with graphical tools (display of images, spectra...). You should refer to the general documentation of specINTI for more information.

Reading advice…

The reference manual: http://www.astrosurf.com/solex/spevinti6_en.html

The question-and-answer section, with many examples, more oriented towards the hardware, which complements this toolbox perfectly:

http://www.astrosurf.com/solex/specinti_annexe4_en.html

As will happen to you, to start, we begin with a blank page!

To help you, links are provided to download the raw data of the examples. It is strongly recommended that you replay them yourself in order to get a good feel for the software's operation and then replicate the right moves with your own data. Never skip steps!

This toolbox is based on a number of configuration files and utilities. You can download these specific files from the link:

http://www.astrosurf.com/buil/specinti2/dist_sp24/_configuration.zip

and copy them if you wish into the "_configuration" subdirectory of the specINTI installation.

2. About File Names

Before actually starting, let's address a topic that can be a source of frustration.

Just as it is risky not to hold a hammer by its handle to drive a nail, risking injury and failure, using specINTI requires adherence to a usage protocol and rigor. Indeed, while using a tool according to the rules of the art may seem binding at first, it always turns out to be beneficial in the long term.

Our subject concerns the way of naming the raw FITS format files when importing them into specINTI. It is true that this software is demanding compared to usual standards, but it is justified. Thus, taking too much liberty in mauling the name of an object is somewhat like misshaping a family name, which is neither pleasant nor practical for orientation.

Most often, the data to be processed are sequences of images generally indexed chronologically. The format accepted by specINTI for the file names is composed of a root, a separator, followed by an indexing number. This structure is then completed by an extension, either ".fits" or ".fit", both accepted (we will generally ignore the extension from now on).

Let's take an example:

M51-1
M51-2
M51-3

Here "M51" is the root, "-" is the separator, and the indexing numbers are 1, 2, 3. The whole consisting of the root and separator, "M51-", is sometimes called a generic name in this document.

First, the object file name root must be simple and recognized by the SIMBAD database (http://simbad.u-strasbg.fr/simbad/sim-fid).

To illustrate this, let's take the example of the observation of the galaxy Messier 51, also known as the "the Whirlpool Galaxy".

If you use a name such as "the Whirlpool Galaxy" - and there may be more far-fetched denominations - your data will not be recognized by SIMBAD, which could cause potential problems with specINTI, and your archiving will have neither technical nor scientific value.

On the other hand, designations such as M51, Messier51, NGC5194, UGC8493, ... guarantee compatibility with specINTI.

It is imperative to avoid spaces (or blanks) in file names (in the author's opinion, the acceptance of spaces in file names is one of the worst calamities in the history of computing - hence the issue!). Even if specINTI can, in some cases, accept spaces, prefer to use the character "" as a separator. Thus, returning to the example of Messier 51, instead of using a root name such as "M 51," favor "M_51", or even more simply "M51". It is noteworthy that the underscore "_" as a separator is recognized by SIMBAD, which is no coincidence.

The use of uppercase or lowercase characters is totally irrelevant in specINTI. Names such as M51, m51, Messier51, messier51... are all accepted.

Regarding the separator between the root name and the index, the dash "-" is recommended, although other forms are possible, as specINTI is flexible on this matter (the specINTI Editor software offers the possibility to choose your separator, what is called the "postfix"). However, the suggestion to use "-" is based on considerations of logic and readability. Thus, the file name "m_51-1" appears better structured and less ambiguous than "m_51_1", thanks to a better use of separators.

The trickiest part concerns the indexing of the raw files. Suppose you want to process a sequence of 3 images of the spectrum of Messier 51, and your raw files are saved on your hard drive under the following names:

M51-0001.FITS
M51-0002.FITS
M51-0003.FITS

Or even,

M51_gain200_20230912_881.FITS
M51_gain200_20230912_993.FITS
M51_gain200_20230912_998.FITS

specINTI will refuse these data, and this is certainly the topic that will cause the most annoyance. The proper way to name indexed files for specINTI is to use a simple name with an index starting at 1:

M51-1.FITS
M51-2.FITS
M51-3.FITS

or even, as we have understood,

M51_1.FITS
M51_2.FITS
M51_3.FITS

You can even use the following notation, although this is strongly discouraged due to the risk of confusion:

M511.FITS
M512.FITS
M513.FITS

Adhering to these few rules allows the implementation of certain specINTI automatisms for maximum efficiency and error avoidance.

If your acquisition software records file names that are incompatible with specINTI, you have three options: (1) rename them manually or automatically using an existing or to-be-created utility (for example, ISIS provides one), (2) change your acquisition software for another that generates compatible data, (3) do not use specINTI.

3. Master Images

To properly follow the procedure that will follow (a processing "pipeline"), you can download the illustration data (a set of raw images) from this link:

  http://www.astrosurf.com/buil/specinti2/dist_sp24/starex340.zip

This is an observation directory to be decompressed into your storage device. The observation in question concerns the star 10 Lacertae, a spectrophotometric standard.

In addition to the spectral images of our first target, we also have:

- An image of the offset signal, or bias, called "o-1.fits." This is an image exposed for 0.01 seconds in darkness.

- A sequence of 13 images of the thermal signal, or dark signal, each exposed for 900 seconds at a temperature of -12°C (the same temperature as during the object's observation). This sequence was carried out during the day with the spectrograph installed in a refrigerator. The corresponding files are named: n900-1, n900-2, … n900-13.

- A sequence of 50 spectra from a tungsten filament lamp (a MagLite type lamp, with a color temperature of 2700 K) illuminating the entrance slit of the spectrograph through a diffuser. This sequence corresponds to a series of images named: tung-1, tung-2,

…. tung-50. It is obtained outside the telescope by placing the spectrograph on a table during the day (we will come back to this).

The camera at the origin of these images is the ZWO ASI533MM model. Note that cropping was performed at acquisition to limit the format of the images to the useful area, with a margin (cropping is always recommended to avoid acquiring unnecessary data and making processing more burdensome).

A classic operation, also found in Deep Sky image processing, is to calculate "averages" of all these images to produce master images of the offset signal, dark, and flat-field, in which noise is minimized. This set of images is sometimes called DOF, for "Dark, Offset, Flat."

With specINTI, the calculation of the master DOFs is done transparently, from your first treatment on a target object. The software uses the raw images of offset, dark, and flat field to produce in the working directory the images "_offset," "_dark," and "_flat," our famous DOFs and always these names, which are in some way reserved.

Note: to clearly distinguish raw images from processed images, specINTI systematically adds the "_" character at the beginning of the name of all such files it generates. This is true for all your treatments, including that of the DOF files.

Normally, the calculation of the master offset file does not deviate from the rule (averaging a raw sequence o-1, o-2, o-3, … for example), but we can make an exception here…

Notice that in the provided raw DOF sequence, there is only one raw offset image, "o-1.fits." It is not at all recommended as the noise from this image will be transferred as is into your subsequent preprocessing, thus degrading the signal-to-noise ratio, which you should always seek to maximize.

The explanation lies in a particularity of CMOS sensors (a CMOS camera is used to produce the images in the example). The offset image is so uniform with modern versions of these detectors (at least with Sony) that the offset signal can be limited to a single numerical value that we apply to all pixels of the master "_offset" image.

This is the idea of a "synthetic" offset, which has the advantage of eliminating any source of noise in it. The level retained in the synthetic image is the average intensity level observed in a real offset image, here the image "o-1.fits." This is why it is necessary to acquire at least one raw offset image, but one is enough.

From the "Configuration" tab of specINTI Editor, load the configuration file "conf_make_offset.yaml." It is very short, as it is limited to launching the "_img_make_offset" function:

```
# *******************************************************************
# CONF_MAKE_OFFSET
# Synthesizes a uniform offset from an
# actually acquired offset (bias) image
# *******************************************************************

#-------------------------------------------------------------------
# Working directory
#-------------------------------------------------------------------
working_path: D:/starex340

#-------------------------------------------------------------------
# Call _img_make_offset function
#-------------------------------------------------------------------
_img_make_offset: [o-1, _offset]
```

In specINTI, a "function" is a special parameter that launches a computation procedure (usually a simple task) autonomously, mainly using the values provided as parameters (numbers, strings). The program stops as soon as the function has been executed.

In this case, the parameters of the "_img_make_offset" function use names of image files. The function knows that the files in question are located in a given working directory (here "d:/starex340", but this is just an example). For this, the configuration file must contain the "working_path" parameter, followed by the title of the path leading to the working folder.

As arguments of the "_img_make_offset" function, there is the name of a raw offset image (here "o-1") and the name of the synthetic offset file (here "_offset").

Launch the execution of this configuration file. You will then find the synthetic image "_offset" in the working directory.

Tip: If you do not change instrumentation, there is little chance that the content of the offset file will change, so the calculation we just performed only needs to be done once.

4.   How Master Images Are Used

Here we discuss how to use the DOF files from one night to another. First, it is recommended to dedicate a separate directory to each night of observation. Name these directories logically, including for example the observation date or appropriate indexing.

Suppose you have just processed the spectra present in the "starex340" folder, which is our current working folder. Each time you use a sequence of raw DOFs in processing, specINTI generates in the current working folder the master files (resulting from the addition of the raw images), which we have seen have names "_dark," "_offset," and "_flat." Note the "_" prefix, a distinguishing sign that specINTI adds to the elements it has processed.

When working on a target, instead of providing for instance a sequence of dark signal, which the software would feel compelled to process to generate a new "_dark" file (which would overwrite the old one), use the unique "_dark" file directly for your treatments. It provides equivalent quality while simplifying and speeding up operations.

In the example below, we show how to fill out the observation file from specINTI Editor:

Fichier(s) Offset :	_offset	nb :	0
Fichier(s) Dark :	n900-	nb :	13
Fichier(s) Flat :	tung-	nb :	50

It is requested to exploit the master image "_offset" that we just created here. Note that the number of images specified is 0 (we do not have a sequence of images). On the other hand, for the "dark" and the "flat-field," we use the set of calibration images in a raw form. Without you noticing, specINTI will generate in the working folder the master images "_dark" and "_flat," which are the sum of the 13 dark images and 50 tungsten lamp images, respectively.

Now suppose we have just finished an observation and the treatments have not been carried out yet. The raw data from this new observation are in the "starex341" folder on the hard disk. We want to use the master DOF files from the previous night (DOFs are rarely redone unless circumstances require it, such as a temperature change or a new area of interest in the images).

Under "normal" operation of specINTI, you must copy the DOF images from "starex340" to "starex341". However, instead of transferring the 50 flat-fields, for example, you can limit yourself to copying the "_flat" image.

These file copies can become a bit tedious over time, but they have the advantage of keeping a coherent track of the work done.

The software can operate differently for DOF images, especially if your spectrograph is considered stable (in which case the same DOFs can be exploited many times). To do this, create a folder somewhere in your storage space.

Call it, for example:

c:/specinti_master

In the configuration file, indicate the full path of this directory as the argument of the "master_path" parameter. For example, here:

```
c:/specinti_master
```

In the configuration file, indicate the full path of this directory as the argument of the "master_path" parameter. For example, here:

```
master_path: c:/specinti_master
```

Copy your master DOF files to the "c:/specinti_master" directory from the "starex240" folder, for instance. This operation is to be done only once. Then, slightly modify the name of these files by adding an additional "_". In the "specinti_master" directory, here is what you should find (note the double underscores, do not hesitate to change the names according to your preferences, it is allowed):

__offset
__dark
__flat

From now on, these master images can be exploited for the processing of spectra for the following nights without having to copy them from one directory to another.

However, the images in this master directory are only seen if you explicitly write the double

"__" in front of their names in the observation file. For example:

Fichier(s) Offset :	__offset	nb :	0
Fichier(s) Dark :	__dark	nb :	0
Fichier(s) Flat :	_flat	nb :	0

Here, for the processing of spectra, the offset and dark master images are loaded from the "c:/specinti_master" directory. On the other hand, the flat-field master image is searched for in the current working folder because its name has only one "_".

5.   Considerations Regarding The Wavelength Calibration of Spectra

Wavelength calibration, also referred to as spectral calibration, is an operation that associates a wavelength with the different pixels of an object's spectrum image along the color axis (the spectral dispersion axis).

Initially, we need a reference spectrum made with our instrument in which it is possible to identify details whose wavelength is known.

Operations are performed in sequence on this reference spectrum (isolating the raw profile, identifying the position of lines in this spectrum, then calculating the dispersion polynomial). We will describe them successively.

So, the first operation is to extract from the 2D spectrum image a graph translating the intensity observed in this image along the wavelength axis. This curve is the spectral intensity profile of the spectrum, more simply referred to as the "spectral profile."

The spectral profile has the advantage of being lighter to manipulate than an image. It better reveals the spectral distribution and provides better quantification. Some operations are also facilitated, for example, it is usual to linearize the spectral profile in wavelength, meaning that between two points on this curve, the step in wavelength is constant.

In the example covered, our reference light source is a star. Not just any star, but one that has several essential characteristics: a large number of spectral lines (but not too many), an even distribution in the spectrum, good line contrast, and, of course, precise knowledge of their wavelengths. Moreover, it is preferable that this star be relatively bright for easy observation, thus offering a satisfactory signal-to-noise ratio without much effort.

Our choice is the star 10 Lacertae, also known as 10 Lac, a well-established spectrophotometric standard, displaying a magnitude of 4.8 and a spectral type of O9V.

The star 10 Lac is particularly interesting because it will also later allow us to find the spectral intensity response of our instrument. By using 10 Lac, we are thus accomplishing two tasks in one, which is ideal (of course, other choices are possible).

It's important to note that to assess the calibration law, it is possible to use a natural source, as in our case, the spectrum of a star, but also an artificial spectral source producing a spectrum of fine emission lines. The problem with artificial sources is that they are not always easy to find, especially when we want a fairly homogenous spectral distribution of line wavelengths.

We have advantages in exploiting a star like 10 Lac, which is free and has the right properties. However, in most cases, a low-demand spectral emission line lamp is necessary to complete

the spectral calibration of each observed target; this point will be discussed in more detail later.

We are making the assumption that the spectral calibration equation (a polynomial of a certain degree) that links points in the spectrum to their wavelengths is an instrumental constant, remaining stable from one target to another. This is generally a valid assumption, with a few details that will be discussed later (in particular the issue of the "constant," the first term of the polynomial).

The spectrograph used for this example is a Star'Ex LR (Low Resolution) configured in low resolution (23-micron slit, 300 groove/mm grating, and ASI533MM camera). It's mounted at the focal point of a 150 mm F/5 Newtonian telescope:

Here is what one of the 2D spectrum images of 10 Lac looks like, exposed for 30 seconds:
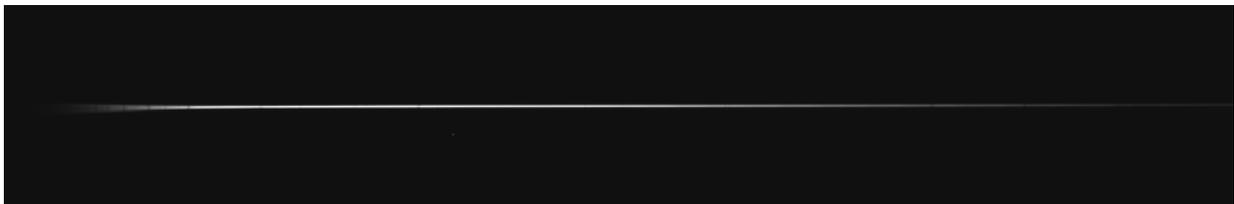
Initially, the sensor used has 3008x3008 pixels. From the acquisition, we only retain a sub-image ("crop") of only 2620 x 431 pixels, which is more than enough to capture the entire useful spectrum with a comfortable margin.

Tip: It is important to avoid working on the complete image to reduce file size and speed up processing. The window used, also called ROI (Region Of Interest), is limited to framing the slender trace of the spectrum while leaving space below and above to allow for an accurate measurement of sky background intensity.

We have 12 images of the spectrum of 10 Lacertae, with files named from acquisition (the .fits extension is ignored): 10lac-1, 10lac-2, 10lac-3, …, 10lac-12. We will explore two

methods for calculating the dispersion polynomial. First, a very manual method, which you will rarely use except in very specific situations. Then, we will present a much faster method in section 8, which will be favored.

However, we want to present the manual method because it implements a set of important tools and methods that may be useful to you one day, in particular the concept of "function" in specINTI. If you are in a hurry, you can skip directly to section 8.

6. Extracting the Raw Spectral Profile, the Level #0 Spectrum

Let's first examine the sequence of operations needed to determine the spectral dispersion law in manual mode from a star spectrum.

Let's start by calculating the raw spectral profile of 10 Lacertae. The use of the term "raw" indicates that the chart obtained at this stage will not be calibrated in terms of wavelength. However, it accurately reflects the distribution of apparent intensities recorded in the pixels of the 2D image.

In the specINTI editor, fill out the "Observation" tab (and therefore the observation file) as follows:

It is advisable to specify immediately to specINTI the path of the working folder by clicking on the "Browse" button. This folder contains the observations to be processed as well as, later on, the results.

Tip: The SpecINTI Editor retains the entered data. When you reopen the application, you will find the fields already pre-filled, as they were at the time of closure. You can identify the name of our object, "10 Lac", in the "Object List" field. By clicking on the "Auto" button, the software automatically fills in certain fields.

The generic (or root) name "10lac-" of our raw spectra is reconstructed in the "Image List" field. Note that the "File Img postfix" field contains the character "-", which you will likely

need to fill in once and for all if you name your data correctly.

Note: The provided object name is "10 Lac," with a space between the "10" and "Lac". This is referred to as a "Catalog" name. It is this object name, as is, that will be recorded in the header of the FITS file of the processed spectrum. This writing is both compatible with SIMBAD and readable for later analyses. Similarly, you will preferably write "NGC 891" as the catalog name (or "ngc 891"). However, note that specINTI removes all spaces when it comes to defining the names of the input files on your disk when you click "Auto". This is sort of the standard chosen for the definition of the generic names of the files at the entrance of specINTI (maximum simplicity in writing, so for example: ngc891-1, ngc891-2, ...).

At the same time, the software automatically determines the number of images in the sequence (in this case, 12 images). Here is where we start to understand the importance of naming raw images properly.

Also indicate the name of the DOF images in the corresponding fields. Notice that for the master offset image, we were careful not to indicate "o-", because otherwise, by clicking "Auto", the software would find only one image. This would give the correct number of images, but it would not be satisfactory, because this single image would introduce significant noise during processing. The best option is to indicate the "_offset" file name that we calculated earlier. Since it does not belong to a numbered series, you must use 0 as the number of images. In this way, specINTI will correctly recognize the "_offset.fits" image as the master offset image.

Tip: What if the DOF list is incomplete? SpecINTI can perfectly process your spectra in the absence of a DOF element, or even of all DOFs. For example, suppose you do not have dark signal images available. In the "Dark File" field, then write "none". Take this opportunity to set the number of corresponding images to 0 (do not leave this field blank). If you have neither offset, dark, nor flat, write "none" in all fields. This is great flexibility offered by SpecINTI.

Click on the "Save" button. The SpecINTI Editor then constructs and saves the observation file in the working folder. Before doing this, remember to give a name to this file. In the example, it will be named "10lac.yaml" (you are completely free to choose this name).

For the actual processing, we use the configuration file named "conf_extract_raw.yaml" (that is to say: extraction of a raw intensity profile from our 2D image sequence). Here is its content that you can display from the "Configuration" tab by clicking on the corresponding name in the list on the right.

Note: This list on the right shows the contents of the "_configuration" subdirectory. It is a kind of library of instrumental configurations or utilities that are displayed there.

The content of this file:

```
# ***********************************************************************
# CONF_EXTRACT RAW
# Extraction of a raw intensity profile from a 2D image
# Level 0
# ***********************************************************************
#
#-----------------------------------------------------------------------
# Working directory
#-----------------------------------------------------------------------
working_path: D:/starex340

#-----------------------------------------------------------------------
# Processing batch file
#-----------------------------------------------------------------------
batch_name: 10Lac

#-----------------------------------------------------------------------
# Spectrum extraction mode (uncalibrated)
#-----------------------------------------------------------------------
calib_mode: -5

#-----------------------------------------------------------------------
# Binning height
#-----------------------------------------------------------------------
bin_size: 30

#-----------------------------------------------------------------------
# Sky background calculation zones around the trace
#-----------------------------------------------------------------------
sky: [160, 20, 20, 160]

#-----------------------------------------------------------------------
# Geometric parameter calculation area
#-----------------------------------------------------------------------
xlimit: [600, 1800]

#-----------------------------------------------------------------------
# Output format (0: compact, 1: expanded)
#-----------------------------------------------------------------------
check_mode: 1
```

Here is a brief explanation of the parameters:

- working_path: the path of the current working directory.
- batch_name: the name of the observation .yaml file.
- calib_mode: the mode of use of SpecINTI. The value -5 indicates a special mode, namely, the extraction of a raw profile from the average of the input spectral images.
- bin_size: the binning height in pixels.
- sky: a list of values indicating, in pixels, the parts of the image where the sky background level is calculated (on either side of the spectrum trace).
- xlimit: the range in horizontal coordinates in pixels in which the geometric parameters of the spectrum are calculated, notably the inclination of the trace (the "tilt" angle).
- check_mode: specifies if you are in configuration file verification mode. When you're starting out, the value 1 is recommended, as SpecINTI then provides a lot of information about the program's progress and writes control files to the disk, which can be useful for identifying errors (the default value is 0 if the parameter is not set, with more sober display).

The height of the binning zone (the "bin_size" parameter) is set generously wide to ensure all the signal from our spectrum along its trace is collected. We also subtract the intensity of the sky background (the "sky" parameter), measured on either side of the trace in zones consistent with the

adopted binning height.

Click on the "Run" button to start the processing. After a few seconds, the raw profile "_10lac_raw.fits" is saved in the working folder (refer to the instructions in the output terminal). This represents the sum of the signal measured in our 12 2D images of the spectrum of 10 Lacertae. The calculated spectrum is said to be "level 0". Such a level of spectral product means that no calibration operations have been applied. This level simply represents in the form of a curve the spectral image provided by Star'Ex and pixelized by the detector.

You can display the content of this profile from the "View Profile" tab of SpecINTI Editor or from any other software capable of displaying a spectral profile, such as ISIS, for example. Here is the level #0 profile found.
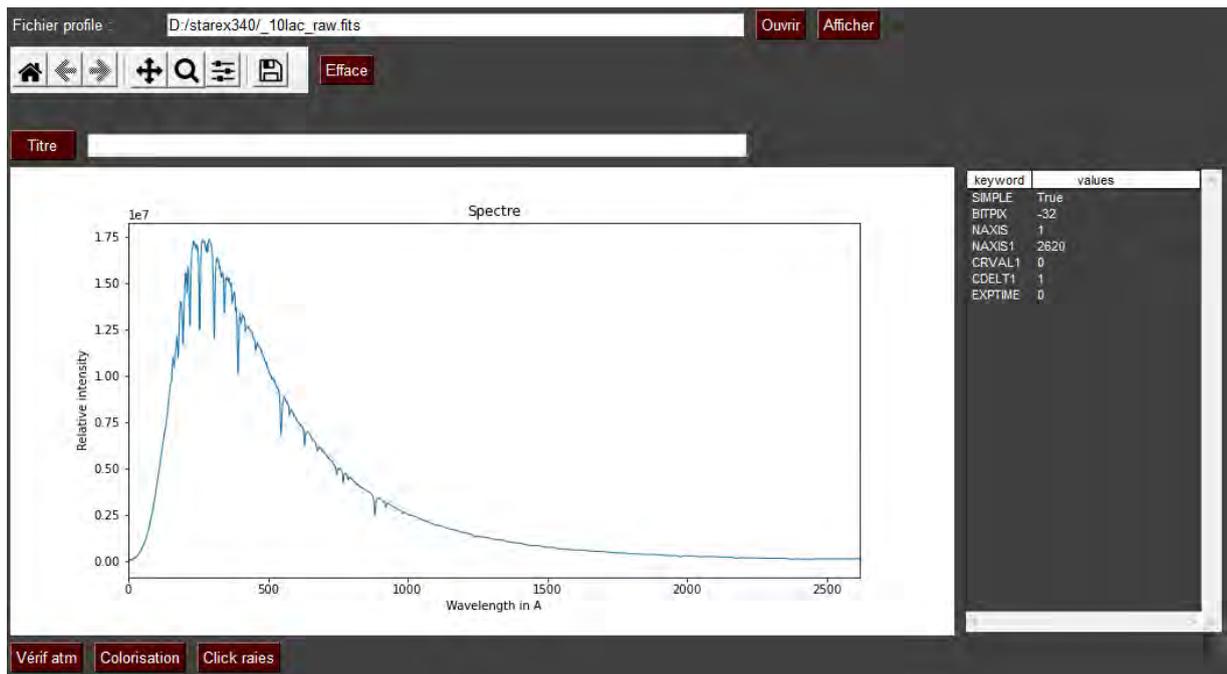
7. Identification and Measurement of Spectral Lines

The spectrum of 10 Lacertae contains numerous lines that are easy to identify and whose wavelengths are known. However, if the display clearly reveals these lines in the blue part (left), this is not the case in the red part. There are certainly lines present, but a visualization problem prevents them from being clearly seen due to the very large variation in intensity along the trace. Here, we propose a technique to address this difficulty, which also improves the accuracy of the measurements. It's also an opportunity to become more familiar with the principle of functions in specINTI.

The goal is to roughly model the continuum of the spectrum by a very vigorous smoothing of the profile, and then to divide the original raw profile by this smoothed profile. For this purpose, we use a small utility, the configuration file "conf_remove_continuum.yaml":

```
# **********************************************************************
# CONF_REMOVE_CONTINUUM
# Continuum rectification of a spectrum.
# **********************************************************************

#----------------------------------------------------------------------
# Working directory
#----------------------------------------------------------------------
working_path: D:/starex340

#----------------------------------------------------------------------
# Processing batch file
#----------------------------------------------------------------------
batch_name: 10Lac

_begin:
_pro_blur: [_10lac_raw, 200, p1]
_pro_div: [_10lac_raw, p1, p2]
_end:
```

In this listing, we use two functions. First "_pro_blur," which smoothes the "_10lac_raw" profile, resulting in the "p1.fits" profile, automatically saved in the working folder. The value 200 sets the force of the smoothing (a typical value for a first trial, the higher it is, the more powerful the smoothing). If necessary, you can perform tests by visualizing the "p1.fits" profile.

The subsequent function, "_pro_div," calculates the division of the original profile by the smoothed profile, and generates the rectified profile (without the continuum) under the name "p2.fits". You are, of course, free to choose the names.

Tip: It is possible to chain multiple functions, as here, by framing them with "_begin" and "_end."

Here is the result (there may be artifacts at the ends; then play with the magnifier to better perceive the parts of interest):
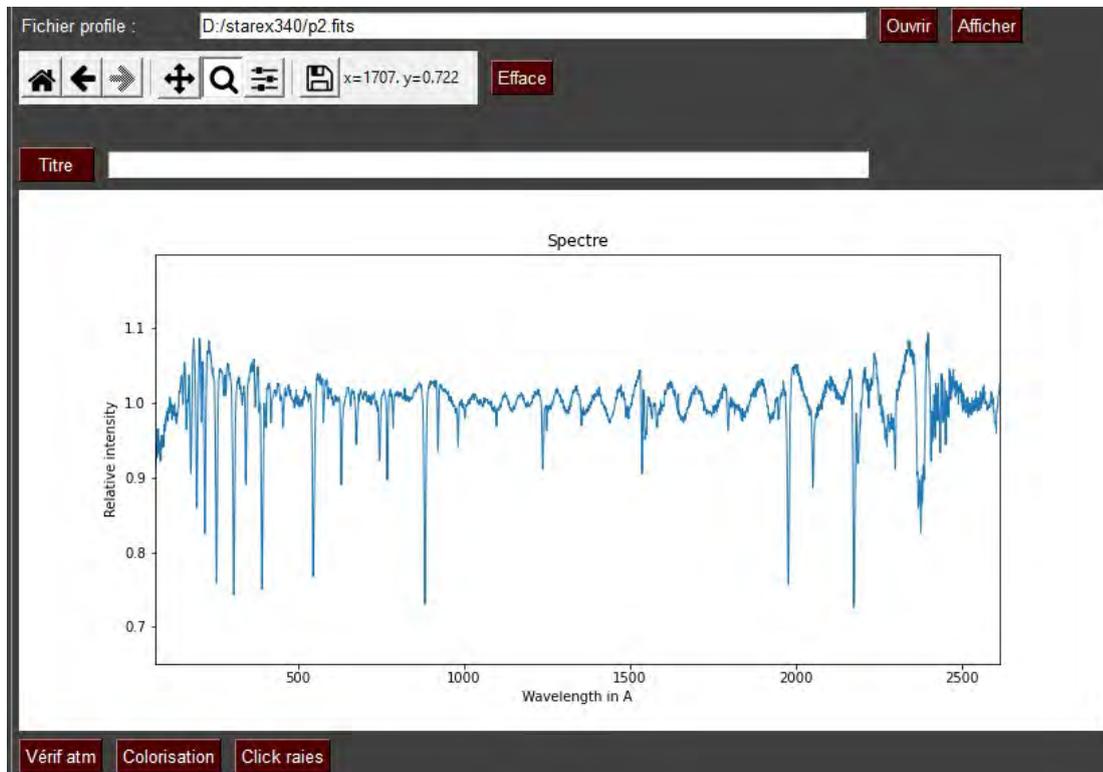
A number of defects affect this spectrum, including oscillations that are not of natural origin, but which result from instrumental effects (caused by the spectral response of the detector).

The resolution of these problems will be addressed later. For now, our priority is the identification and localization of the lines.

The following figure represents a sort of atlas of spectral lines in the spectrum of the star 10 Lacertae, with their precise wavelengths:
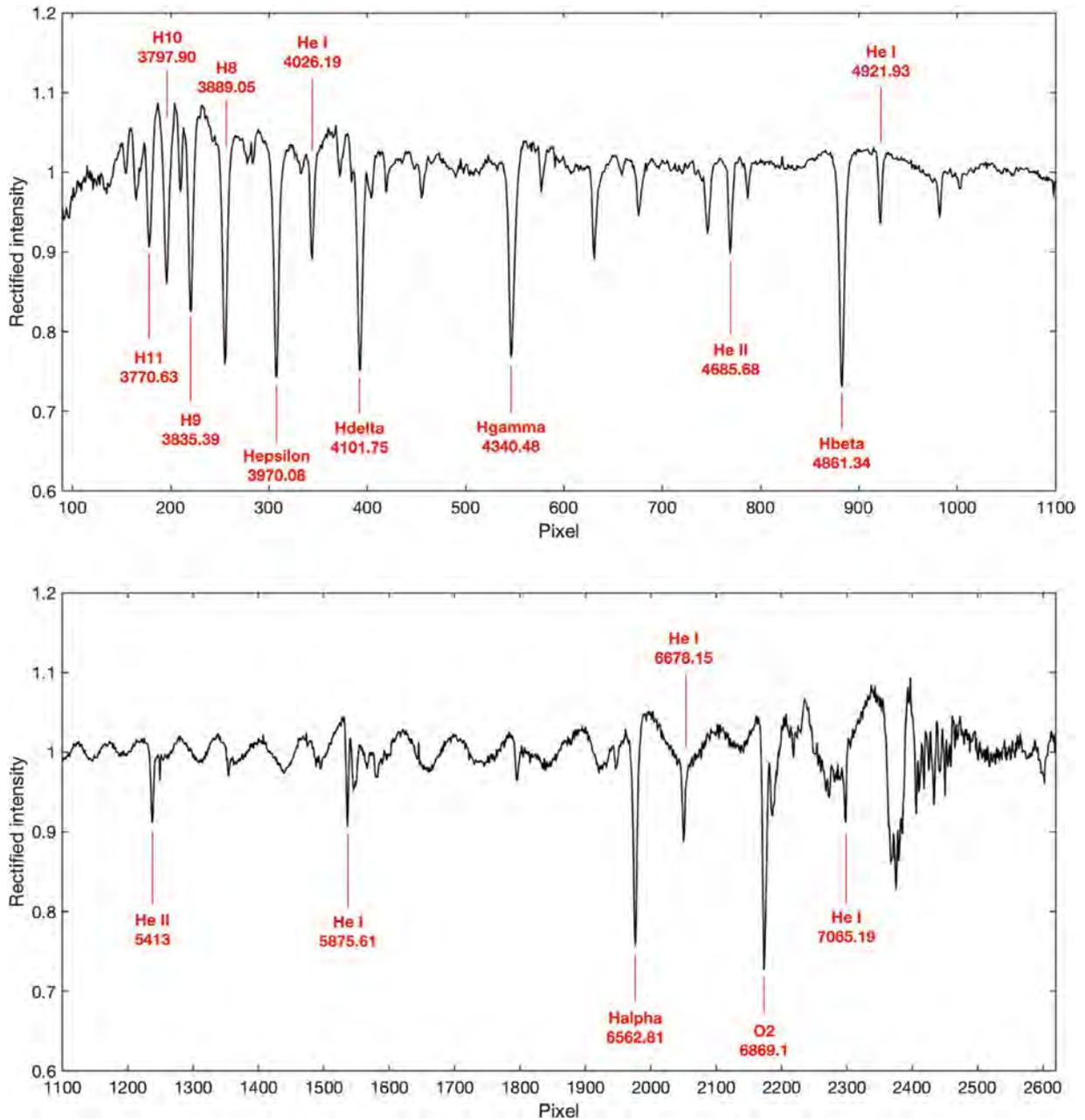
Among this set, here is the list of wavelengths that we choose to process the spectrum:

[3770.63, 3797.90, 3835.39, 3889.05, 3970.08, 4026.19, 4101.75, 4340.48, 4685.68, 4861.34, 4921.93, 5875.61, 6562.81, 6678.15, 7065.19]

The list is somewhat long; it includes 15 lines, which are as many points of measurement. We could choose less, but always well distributed in the spectral domain. Be vigilant when manually transposing values into the configuration file; do not make a mistake. Copy and paste is the best method.

In view of these wavelengths of lines, we must have a list of the same size containing the

coordinates in pixels of these same lines in the spectral profile. The one we have just calculated, without the continuum (i.e., it is rectified), is perfect for this task. At this stage, we are content to estimate the position of the center of the lines to the nearest pixel. Despite this approximation, the calibration accuracy will already be satisfactory due to the error smoothing mechanism. We will see later how to do better.

To estimate the horizontal coordinate (X-axis) in pixels of each line, you can rely on the "Profile display" tab of specINTI Editor, then the "Click Lines" tool, or use another software of your choice. Here are the results for our example (15 positions, therefore):

[178, 195, 220, 255, 307, 343, 392, 547, 769, 883, 922, 1536, 1976, 2050, 2297]

Tip: If you need to move within the spectrum with a zoom, it is recommended to deselect "Click Lines" and then reselect this option when you are in the desired part of the spectrum.

8. Calculation of the Spectral Calibration Polynomial

To calculate the spectral calibration polynomial, open a new utility, the configuration file "conf_compute_poly," which should look like this:

```
# ******************************************************************************
# CONF_COMPUTE_POLY
# Manual calculation of the dispersion law
# ******************************************************************************

#------------------------------------------------------------------------------
# Polynomial calculation from a list of points
#------------------------------------------------------------------------------
calib_mode: -4

#------------------------------------------------------------------------------
# Order of the dispersion polynomial to be evaluated
#------------------------------------------------------------------------------
fit_order: 3
#------------------------------------------------------------------------------
# Wavelengths of measured points
#------------------------------------------------------------------------------
fit_wavelength: [3770.63, 3797.90, 3835.39, 3889.05, 3970.08, 4026.19, 4101.75,
4340.48,4685.68, 4861.34, 4921.93, 5875.61, 6562.81, 6678.15, 7065.19]

#------------------------------------------------------------------------------
# Measured points' coordinates
#------------------------------------------------------------------------------
fit_posx: [178, 196, 220, 255, 307, 343, 392, 547, 769, 883, 922, 1536, 1976,
2050, 2297]
```

The "calib_mode" parameter here takes the value -4, another special mode, precisely dedicated to calculating a polynomial that fits a set of point pairs using least squares (see the specINTI reference manual).

The list of wavelengths and the list of positions of found lines are recognized as the respective arguments for the "fit_wavelength" and "fit_posx" parameters.

The "fit_order" parameter determines the degree of the fitted polynomial. Degree 3 is well-suited for a Star'Ex LR spectrograph (do not look for more). After clicking on the "Execute" button, you obtain the desired values of the polynomial terms in the output terminal:

```
-----------------------------------
Polynomial fit
calib_coef: [1.3697786967858392e-09, 4.7375755940865985e-07, 1.5459285880960587,
3495.239344027813]
-----------------------------------
O-C: [ 0.193 -0.37   0.009 -0.455  0.156  0.586  0.351 -0.748  0.718 -0.267
 -0.132 -0.257  0.397 -0.035 -0.148]
Root Mean Square Error = 0.3902 A
End.
```

It is always interesting to examine the final fitting error. In this case, it is about 0.4 Å, while the average spectral sampling is 1.55 Å per pixel and the spectral resolution is 8 Å. Therefore, the result seems very satisfactory, but it is nevertheless necessary not to rely solely on appearances. Although the polynomial fits perfectly to all the points we provided, the real question concerns the quality of the measurements (the precision of pinpointing to the nearest pixel on the apparent center of the lines, for example). Therefore, caution is required, as the actual error could be greater than the one indicated in the displayed RMS value. However, we are quite close to a good quality measurement in this case.

Tip: The way the result is presented in the terminal ("calib_coef: ...") facilitates copying and pasting into the configuration file, thus eliminating the risk of error from manual transcription. You might consider improving the precision of the spectral calibration by using more terms in the polynomial, for example by opting for degree 4, but the RMS error decreases only slightly, if at all. This indicates that a degree 3 polynomial is perfectly suited for adjusting the dispersion law. A degree 2 polynomial (a parabolic law) already gives a very satisfactory result in this case. It is important to note that this does not apply to all spectrographs, especially the Alpy600, which can be a bit more difficult to calibrate due to the presence of a "grism" (a combination of a diffraction grating and a prism that produces a specific spectral dispersion nonlinearity).

Tip: The quality of spectral calibration relies on a reasonably high oversampling of the observed spectrum. Thus, cameras with small pixels have an advantage. It may seem counterintuitive, but excessive use of 2x2 pixel binning at the time of acquisition is a mistake in most situations. Always prefer 1x1 binning with CMOS sensors. Filtering of non-Gaussian noise will also be more effective at the same time.

9. Improving Spectral Calibration and Speeding Up the Procedure

The precision of spectral calibration can be improved. Rather than relying on manual pinpointing of the centers of lines, let's allow specINTI to make a more accurate measurement, down to a fraction of a pixel, based on fitting the profile of each line to find a more probable center (taking into account the shape of the absorption lines). For this, we use the special mode -1. In addition to potentially increasing precision, this mode automates the operations of extracting the spectral profile and its smoothing. There is no longer any need to use tools like "conf_extract_raw" or "conf_remove_continuum" in this context. The calculation of the dispersion polynomial is then much simpler and faster. This will undoubtedly be your preferred mode if you are looking to calibrate a spectrograph using a star spectrum acquired with it. Here is the corresponding configuration file ("conf_compute_poly2.yaml"):

```
# **************************************************************************
# CONF_COMPUTE_POLY2
# Calculation of the dispersion polynomial based on a set of absorption lines
# whose position is evaluated by the software to a fraction of a pixel.
# Using mode -1
# **************************************************************************


#-------------------------------------------------------------------------------
# Working directory
#-------------------------------------------------------------------------------
working_path: D:/starex340


#-------------------------------------------------------------------------------
# Processing batch file
#
#-------------------------------------------------------------------------------
batch_name: 10Lac


#-------------------------------------------------------------------------------
# Search and calibration of a set of absorption lines
#-------------------------------------------------------------------------------
calib_mode: -1


#-------------------------------------------------------------------------------
# Order of the dispersion polynomial to be evaluated#
#-------------------------------------------------------------------------------
fit_order: 3


#-------------------------------------------------------------------------------
# Wavelengths of measured points
#-------------------------------------------------------------------------------
fit wavelength: [3770.63, 3797.90, 3835.39, 3889.05, 3970.08, 4026.19, 4101.75, 4340.48,
4685.68, 4861.34, 4921.93, 5875.61, 6562.81, 6678.15, 7065.19]


#-------------------------------------------------------------------------------
# Measured points' coordinates (approximations)
#-------------------------------------------------------------------------------
fit_posx: [178, 196, 220, 255, 307, 343, 392, 547, 769, 883, 922, 1536, 1976, 2050, 2297]


#-------------------------------------------------------------------------------
# Search interval for absorption lines
#-------------------------------------------------------------------------------
search_wide: 8


#-------------------------------------------------------------------------------
# Binning height
#-------------------------------------------------------------------------------
bin_size : 30


#-------------------------------------------------------------------------------
# Sky background calculation zones
#-------------------------------------------------------------------------------
sky: [160, 20, 20, 160]


#-------------------------------------------------------------------------------
# Order of the polynomial to be evaluated
#-------------------------------------------------------------------------------
poly_order: 3


#-------------------------------------------------------------------------------
# Binning width
#-------------------------------------------------------------------------------
bin_size: 30
#-------------------------------------------------------------------------------
# Geometric parameter calculation area
#-------------------------------------------------------------------------------
xlimit: [600, 1800]


#-------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded)
```

```
#------------------------------------------------------------------------------
check_mode: 1
```

The parameters are already those used in manual mode, but grouped into a single configuration file. Another important nuance: the values provided through the "fit_posx" parameter are now only approximations (positions of lines at +/- 4 pixels because the "search_wide" parameter value is set to 8, a tolerance range in pixels for searching absorption lines). It's specINTI that will refine these positions for you.

Here is the calculated polynomial, with the associated error:

```
Line coordinates find:
[ 179.67774178  196.86153141  221.45224697  256.21705029  308.41947413
  344.89519673  393.58831445  547.77860381  770.30299539  883.7254091
  922.72643671 1536.72803631 1977.08720072 2051.27596072 2298.3270732 ]
Calibration coefficients:
calib_coef: [1.085594959858908e-09, 5.813166788913862e-07, 1.5472939986711927,
3494.266662841573]
Computed wavelength:
[3770.75841205 3797.352492   3835.41098395 3889.21838427 3970.0214486
 4026.48653726 4101.87148859 4340.6451703  4685.442875   4861.30205269
 4921.79242928 5875.79242459 6562.50147892 6678.44630736 7065.13751516]
O-C: [-0.128  0.548 -0.021 -0.168  0.059 -0.297 -0.121 -0.165  0.237  0.038
  0.138 -0.182  0.309 -0.296  0.052]
Root Mean Square Error = 0.2272 A
End.
```

Tip: Over time, from day D to day D+n, due to the evolutionary nature of a spectrograph, it is not uncommon for the optical image of the spectrum to shift on the surface of the detector. The displacement along the spatial axis is not very critical, but that along the spectral axis (the wavelength axis) is a bit more delicate. A spectral shift implies changes in the values indicated in the "fit_posx" parameter. This translates into a global shift, for example, the values [178, 196, 220, ...] become [168, 186, 210, ...]. It is clear that the spectrum has shifted by 10 pixels to the left of the image.

Rather than manually retyping all the values in the "fit_posx" argument to update them, which would be tedious, keep the initial values of this parameter and add a new parameter wherever you like in the configuration file (at the beginning, in the middle, or at the end): the "shift_posx" parameter. In our example, since the displacement is -10 pixels from the reference measurement, you can simply write:

```
#------------------------------------------------------------------------------
# Accounting for a spectral shift
#------------------------------------------------------------------------------
Shift_posx : -10
```

Do not worry, this value does not need to be known very precisely (the pixel tolerance is given by the value of the "search_wide" parameter, remember, 8 pixels in the example (a typical recommended value, which can influence the result of the calculation more or less).

10.   The Level #1 Spectrum

Now that the polynomial dispersion law is known, we can move on to the more serious and interesting tasks. Our task is to calculate a spectral profile graded in wavelength rather than in pixel numbers. The result is a spectral product called level #1, which will resemble much more a true spectrum.

We use the configuration file "conf_level1_mode1":

```
# ******************************************************************************
# CONF_LEVEL1_MODE1
# Wavelength-calibrated spectrum extraction via polynomial (mode 1)
# Level 1 processing
# ******************************************************************************

#------------------------------------------------------------------------------
# Working directory #
#------------------------------------------------------------------------------
working_path: D:/starex340

#------------------------------------------------------------------------------
# Batch processing file #
#------------------------------------------------------------------------------
batch_name: 10Lac

#------------------------------------------------------------------------------
# Calibration from polynomial only (no reference spectrum) #
#------------------------------------------------------------------------------
calib_mode: 1

#------------------------------------------------------------------------------
# Coefficients of the spectral calibration polynomial #
#------------------------------------------------------------------------------
calib_coef: [1.3697786967858392e-09, 4.7375755940865985e-07, 1.5459285880960587,
3495.239344027813]

#------------------------------------------------------------------------------
# Binning width #
#------------------------------------------------------------------------------
bin_size: 30

#------------------------------------------------------------------------------
# Sky calculation areas #
#------------------------------------------------------------------------------
sky: [160, 20, 20, 160]

#------------------------------------------------------------------------------
# Area for calculating geometric parameters #
#------------------------------------------------------------------------------
xlimit: [600, 1800]

#------------------------------------------------------------------------------
# Normalization to unity range #
#------------------------------------------------------------------------------
norm_wave: [6620, 6640]

#------------------------------------------------------------------------------
# Cropping zone for the profile #
#------------------------------------------------------------------------------
crop_wave: [3650, 7150]

#------------------------------------------------------------------------------
# Estimated resolution power #
#------------------------------------------------------------------------------
power_res: 800

#------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#------------------------------------------------------------------------------
check_mode: 1
```

We find the coefficients of the previously calculated polynomial as the argument for the "calib_coef"
parameter (you can copy-paste them from the output console).

The "norm_wave" parameter specifies that we wish to normalize the intensity to unity based
on the average intensity found between wavelengths 6620 Å and 6640 Å. What exactly does

this mean? In the processed profile, you will notice that around the wavelengths 6620 Å - 6640 Å, the spectrum's intensity is near to the value 1. Of course, intensities vary on either side, but they are expressed relative to this unitary value. This is much more understandable than grading the spectrum using the raw image units (ADU, "Analog Digital Unit"). For example, it's much easier to spot the place in the spectrum where the signal is twice as intense compared to the chosen reference point.

Tip : The reference point defined with the "norm_wave" parameter is ideally selected in a region of the spectrum poor in spectral lines and where the continuum seems relatively uniform. It is recommended to choose this reference point once and for all and stick to it. In this way, you can easily compare the relative spectral intensity of different objects for which you have obtained the spectrum.

The spectrum is cropped between wavelengths of 3700 Å and 7150 Å, assumed valid at this stage (parameter "crop_wave").

Note that it is imperative to provide an estimated value of the spectral resolution power ("power_res"). Indeed, in calibration mode 1, SpecINTI does not have the option to determine this value automatically, since no emission line spectrum is used during processing, while this is the only method to obtain a reliable value of the resolution power, by measuring the width of the narrow lines at their base. An estimated value of the resolution power is necessary to correctly complete the header of the treated spectrum FITS file.

The result is the spectrum named "_10lac_20230727_107.fits," which has the appearance of the previous one, level #0, but is now calibrated in wavelength.

Note: The names of the resulting files processed by SpecINTI always begin with the character "_", which makes it easier to distinguish them from raw files and simplifies sorting. In addition, the date of the first image of the sequence is indicated in the file name.

11. Preparing Data for the Evaluation of the Spectral Response

Suppose the instrument has a higher sensitivity in the blue than in the red, meaning it captures a larger light flux in the blue relative to the red. In this situation, the instrument generates an artificially higher intensity in the blue and a reduced intensity in the red. None of these effects reflect the real spectral intensity distribution of the star. To obtain a faithful representation, the instrument (including the atmosphere) should react uniformly to all wavelengths, what we call a "flat response." This is far from the case.

The next operations involve determining the instrumental response as a function of the wavelength for the incoming flux, and then dividing the level #1 spectrum by this response curve. This brings us back to the ideal situation of a flat instrumental response, but through calculation. This leads to a spectrum calibrated in relative flux, called level #2.
It is important to note that if the instrument itself contributes to the distortion of the real signal from the star, our atmosphere, through which the star's light travels before reaching the telescope, also plays a role. We know that it causes the reddening of star colors, like the Sun as it approaches the horizon.

However, we must be careful to separate the contributions of the instrument and the atmosphere, as they will be treated differently later. The reason is simple: the intrinsic response of the instrument to spectral radiation remains constant (it's an instrumental constant), while atmospheric transmission is highly variable depending on the moment and the elevation of the star.

We have already used the reference spectrum of 10 Lac (in the SpecINTI database, it bears the name "c_10lac.fit" from Calspec). So its file should already be in the working directory.

Note: Regarding Calspec, see:
https://www.stsci.edu/hst/instrumentation/reference-data-for-calibration-and-tools/astronomical-catalogs/calspec.

In section 20 of this toolbox, we explain how to exploit the even richer Melchiors spectrum library, which can serve the same purpose here.

The intensities in this reference spectrum are in energy units (erg/cm²/s/Å), which complicates the comparison with our spectrum, which is in relative intensities. Thus, it is recommended to normalize the reference spectrum to unity at the same point as the observed spectrum (here, between 6620 and 6640 Å). For this purpose, use the "conf_make_norm" utility:

```
# ****************************************************************************
# CONF_MAKE_NORM
# Normalize a spectrum to unity
# ****************************************************************************

#----------------------------------------------------------------------------
# Working directory #
#----------------------------------------------------------------------------
working_path: D:/starex340

#----------------------------------------------------------------------------
# Spectral range normalization to unity #
#----------------------------------------------------------------------------
_pro_norm: [c_10lac, 6620, 6640, _ref]
```

Run the program. After the calculation, which is elementary and quick, the result is in the file named "_ref.fits" (an arbitrary choice, but convenient because it is short and means what it says).

The instrumental response is obtained by dividing the apparent observed profile by the real profile of our star (outside the atmosphere), i.e., the "_ref" spectrum. Thus, we will obtain the performance map of our instrument, that is, how it alters the initial signal.

We will evolve the level #1 configuration file (spectral calibration) towards the level #2 configuration file (spectral calibration + instrumental response correction). The transformation is simple. In the distribution of this toolbox, the result is a configuration file called "conf_level2_mode1.yaml." You can use it as is, except for a mandatory temporary modification that must be made now: you must comment out the line containing the parameter "instrumental_response" by adding a "#" in front of its name:

```
#----------------------------------------------------------------------------
# Instrumental response #
#----------------------------------------------------------------------------
#instrumental_response: _rep340
```

We will describe step by step the transformations in the level #1 configuration file to convert it to level #2.

First, let's compare our level #1 spectrum to the expected spectrum of the star 10 Lac (the "_ref.fits" profile precisely):
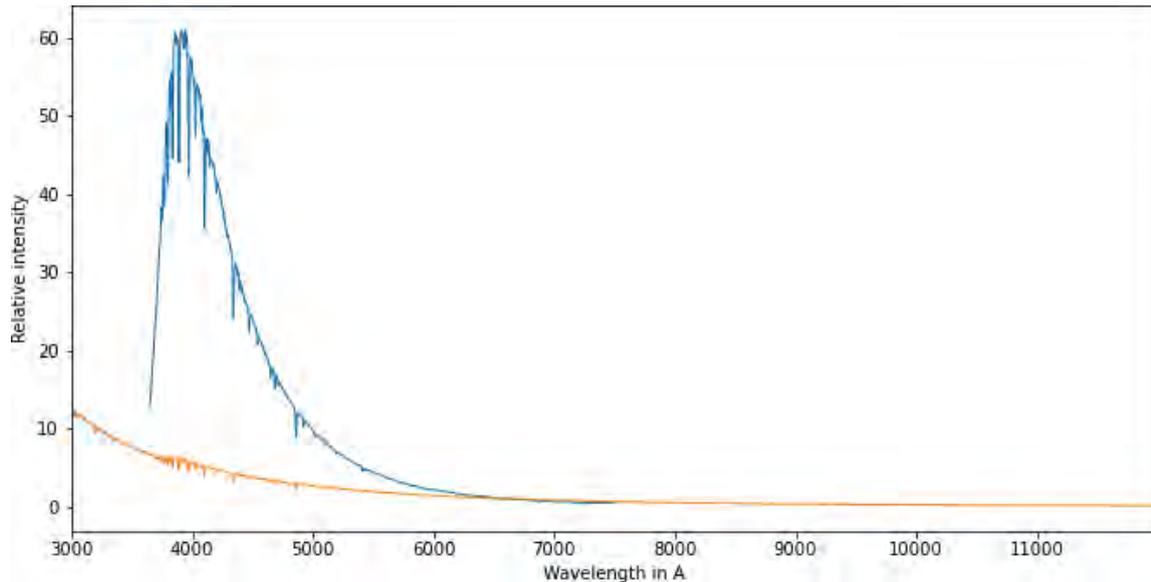
In blue, the observed spectrum (level #1), in orange is the reference spectrum of the star. There is a very large discrepancy, especially in the blue, which can be a source of uncertainty later on. Therefore, we're going to reduce this discrepancy by taking into account: (1) atmospheric transmission, (2) the color temperature of the flat-field lamp used.

On the side of atmospheric transmission, things are simple. SpecINTI is capable of automatically calculating it based on the coordinates of the celestial body and the date. Once done, the software corrects the apparent spectrum to resemble what we would see if there were no atmosphere. This is the "without atmosphere" spectrum.

For this, we need to tell specINTI where we are located on Earth, by adding the following lines to the configuration file:

```
#-------------------------------------------------------------------------------
# Longitude of the observation site #
#-------------------------------------------------------------------------------
longitude: 7.040


#-------------------------------------------------------------------------------
# Latitude of the observation site #
#-------------------------------------------------------------------------------
latitude: 43.5801


#-------------------------------------------------------------------------------
# Altitude of the observation site in meters #
#-------------------------------------------------------------------------------
altitude: 40
```

We also take this opportunity to provide other information that will end up in the header of the produced FITS files, thus making them compatible with databases (like BeSS):

```
#-------------------------------------------------------------------------------
# Observation site #
#-------------------------------------------------------------------------------
site: Antibes Saint-Jean


#-------------------------------------------------------------------------------
# Instrument description #
#-------------------------------------------------------------------------------
inst: T150 + StarEx _LR + ASI533MM


#-------------------------------------------------------------------------------
```

```
# Observer #
#-------------------------------------------------------------------------------
observer: cbuil
```

To correct our spectra for atmospheric transmission, simply add two more lines to the configuration file:

```
#-------------------------------------------------------------------------------
# Access to SIMBAD #
#-------------------------------------------------------------------------------
simbad: 1

#-------------------------------------------------------------------------------
# Atmospheric transmission correction #
#-------------------------------------------------------------------------------
corr_atmo: 0.13
```

The value of 1 for the "simbad" parameter specifies that we will retrieve the object's equatorial coordinates based on its name in the SIMBAD database (and not from the header of the FITS image files). The default value for this parameter is 0, meaning no action is taken. The second parameter indicates that we want to implement a correction using an aerosol optical depth (AOD) transparency parameter of 0.13. It's a somewhat all-purpose value.

Tip : if you are making the spectrum of an object whose name is not recognized by SIMBAD (a comet, a nova, etc.), you can indicate the name of an object close to the target, which is identified by SIMBAD. This is done through the "near_star" parameter. For example, add the line (but remember to remove it or put a "#" in front of it when you process another object!):

```
near_star : epsilon Peg
```

The color of the light emitted by the tungsten lamp used to create the flat-field master image is far from white: much more red than blue. To obtain a representative response of the instrument and easy to model, we must take this fact into account (a color temperature of 2700 K in this case), which is a calibration bias. We add a parameter in the configuration file that computes and brings the spectral distribution of this lamp to that of a "perfectly" white source:

```
#-------------------------------------------------------------------------------
# Color temperature of the tungsten lamp #
#-------------------------------------------------------------------------------
planck: 2700
```

It is important to understand how the flat-field was obtained: on the table (outside the telescope), by adequately illuminating the entrance slit of the spectrograph with a type of halogen torch lamp. See:

At section 5.4 of this page: http://www.astrosurf.com/solex/specinti2_en.html

At section A1 of this page: http://www.astrosurf.com/solex/specinti_annexe_en.html

Launch the software (make sure to comment out the "instrumental_response" line if you are using the original "conf_level2_mode1.yaml" file). Here is the result:
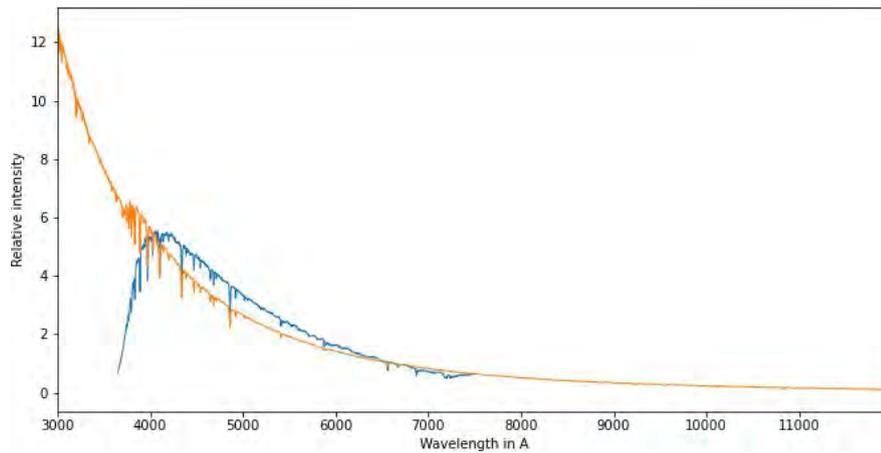
These two profiles are much closer together, except for wavelengths below 4000 Å where the instrument's response dips. But there is significant improvement, showing that the color temperature of the flat-field lamp has a strong impact, which must be taken into account (especially in low-resolution spectroscopy).

12. The Flat-Field Shift

A touch-up is needed on the flat-field image. Examination of the observed profile indeed reveals a phenomenon of oscillations in the continuum, particularly in the red part of the spectrum. This structure is clearly generated by the instrument (the actual continuum of the star 10 Lac is very uniform).

The origin of these oscillations, which can exhibit modulation up to 5%, lies in the quantum efficiency of the detector, which shows similar fluctuations, as evidenced by the master image "_flat":

The problem is that between the time we acquired the spectra of the star 10 Lacertae on the telescope and the time we carried out the flat-field shot on the table, the spectrograph underwent deformations due to effects such as gravity and temperature variations. We anticipated this difficulty: when acquiring the spectra of the star 10 Lacertae, we added an exposure using a neon emission line lamp (an electric night light) placed in front of the telescope (it was here simply waved by hand). Similarly, when taking the shot for the flat-field, we placed a lamp of the same type in front of the spectrograph entry to obtain an equivalent image.

The result of these actions is translated into two images named respectively "10lac_neon-1.fits" and "tung_neon-1". By measuring the position of the neon lines using the mouse cursor between these two documents, we observe a shift in X (spectral axis) of about +10 pixels in the tungsten image compared to the image captured from the sky. It is this shift of +10 pixels that is responsible for the "fringes" phenomenon. The flat-field is therefore misused due to

instrumental deformation that occurred between the two shots.

To correct this defect, before processing the spectrum, indicate to SpecINTI to take into account the shift via the "Advanced Modes" menu in SpecINTI Editor (field "Flat shift list"): [Image or graphical representation of SpecINTI Editor's interface showing the advanced modes settings]

Note three things: (1) take into account the sign of the shift; in any case, if you make a mistake, you will quickly realize it because the correction does not work at all, and you will have to change the sign, (2) the value of this shift is quite constant in value and sign from one observation to another, (3) SpecINTI Editor remembers the value of this shift as long as you do not change it, which simplifies the processing of subsequent objects.

Rerun the processing considering the instrumental shift.

In the following graph, the spectrum before the correction of the flat-field shift:

In the following graph, after applying the shift:
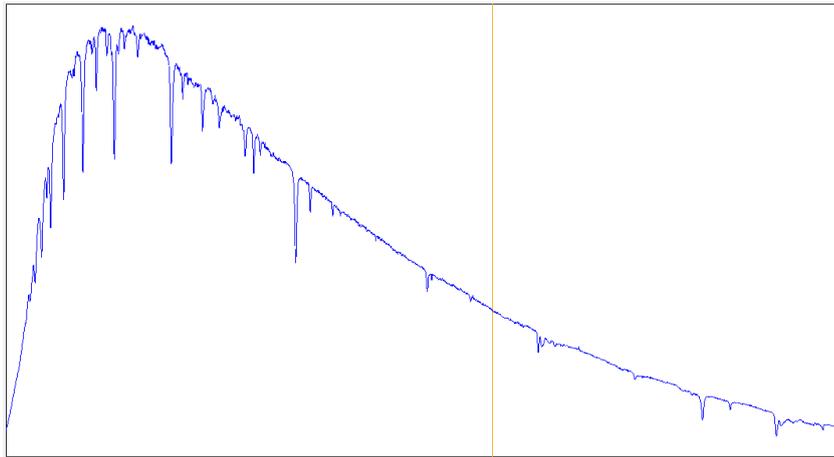
The operation is a reflex to develop. It is very much related to the way the flat-field is acquired (outside the telescope and in a delayed time to gain precious minutes during observations). In practice, it turns out that the touch-up we just described is a small thing compared to the constraint often posed by acquiring flat-field at night, with a real tungsten lamp (definitely not here an LED panel, with a very distorted spectral distribution and therefore unsuitable).

The spectrum we just obtained is an intermediate result. We now need to find the actual instrumental response.

13. Calculating the Instrumental Response

At this stage, we have in hand a spectral profile of the star 10 Lac with a well-applied flat-field correction and corrected for atmospheric transmission. Simultaneously we have a reference spectrum of this same object (origin NASA CalSpec), which looks like what we aim to approach.

The spectral response is obtained by dividing the first by the second. If we perform the operation (we'll see how in a few lines), here is the result:
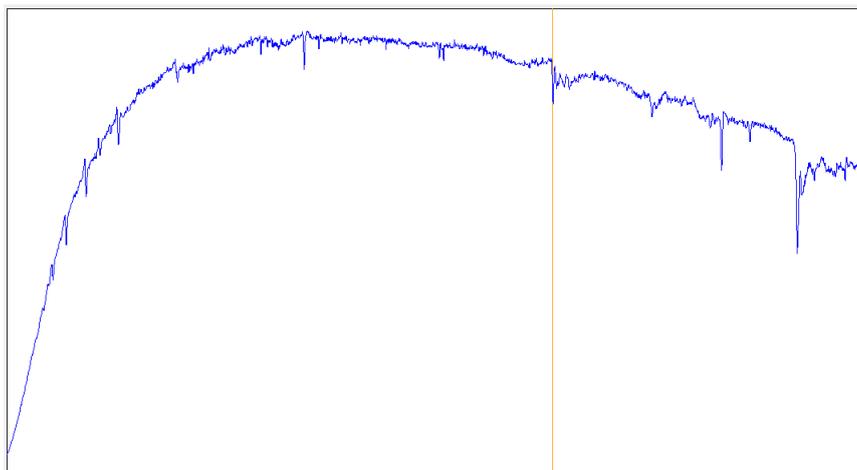
The general appearance for an instrumental response is correct (by experience!). But there is noise and a residue of the star's spectral lines. In the deep red, we even observe the spectral signature of the O_2 molecule around 6900 Å – diatomic oxygen – coming from our atmosphere, intact, because it is absent from the reference spectrum (so the division did not remove it).

We can do much better by using a small utility presented as a sequence of functions. Naturally, everything revolves around the division of two profiles. This is the file "conf_make_response.yaml," which you can adapt to your liking:

```
# ****************************************************************************
# CONF_MAKE_RESPONSE
# Calculation of the instrumental response
# ****************************************************************************

#----------------------------------------------------------------------------
# Working directory #
#----------------------------------------------------------------------------
working_path: D:/starex340

#----------------------------------------------------------------------------
# Remove telluric lines, divide by reference, smooth #
#----------------------------------------------------------------------------
_begin:
_pro_clean: [_10lac_20230727_107, 6850, 6990, tmp1]
_pro_div: [tmp1, _ref, tmp2]
_pro_blur2: [tmp2, 1000, _rep340]
_end:
```

Let's interpret the content of this file.

Before dividing the observed spectrum by the reference spectrum of the star, we erase the details of the spectrum between 6850 Å and 6990 Å, an area corresponding to the absorption bands of O_2, with a linear interpolation performed between these points. This is the purpose of the "_pro_clean" function. We generate an intermediate file "tmp1" in the working folder following this function.

Tip : you can put several "_pro_clean" functions in a row to erase as many details that bother you. However, you must index the names of the functions in question: _pro_clean2, _pro_clean3, ... For example (look carefully at the use of the intermediate file "tmp1"):

```
_pro_clean: [_10lac_20230727_107, 6850, 6990, tmp1]
_pro_clean2: [tmp1, 6540, 6580, tmp1]
```

Then comes the division via the "_pro_div" function. The three terms in this function are:
- The name of the observed profile before the instrumental response correction.
- The name of the reference profile.
- The name of the instrumental response profile.

After the division, the result undergoes smoothing to eliminate roughness unrelated to the effective response, as well as noise. This is the purpose of the "_pro_blur2" function. The smoothing is stronger the larger the value of the parameter.

The sought-after spectral response is contained in the file "_rep340".

Tip : a good idea is to compose the name of the response with the root "_rep" followed by the night's number (here the 340th night with the described configuration). This allows one to distinguish the response files from one night to another, from one month to another..., useful if a change is observed.

Notice the creation of intermediate files, tmp1, tmp2, associated with the different stages. They are not deleted, and you can inspect them for a check on operations.

Below is the spectral response calculated by the described method, "_rep340.fits":
[Graphical representation of the calculated spectral response "rep340.fits"]
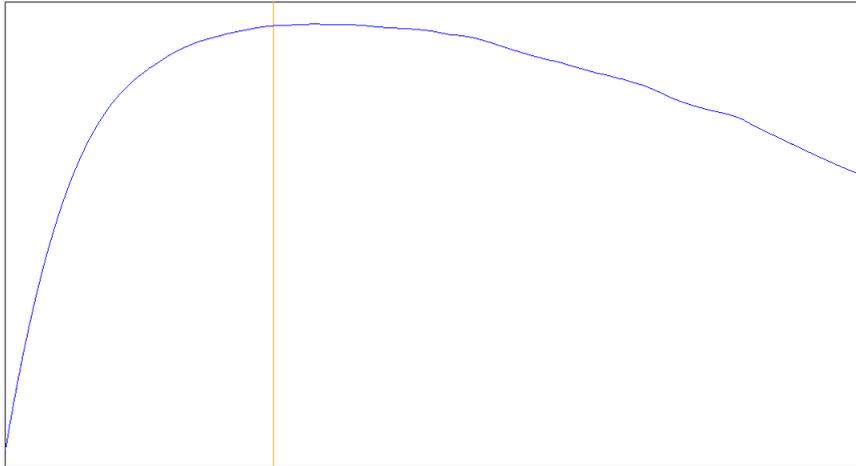
From a distance, the small utility "conf_make_response.yaml" may seem complex, but in reality, its use is immediate and very fast. Note that SpecINTI Editor, via the "Response" tab, allows you to perform the same operations interactively.

The obtained response curve is that which we would obtain if our instrument were located in space. Therefore, it is not affected by atmospheric transmission, by the difference in the angular height of celestial bodies, etc. It proves to be very stable if you do not disassemble the instrument. The operations previously described around the response are therefore to be carried out only very sporadically.

14. The Level #2 Spectrum

All that remains is to take into account the instrumental spectral response in the treatment. Make the following line operational in the "conf_level2_mode1.yaml" file:

```
instrumental_response: _rep340
```

As soon as you define the "instrumental_response" parameter with the name of the instrumental response file, the correction of the instrumental response is automatically applied. Here is the final result of processing the data of the star 10 Lac:
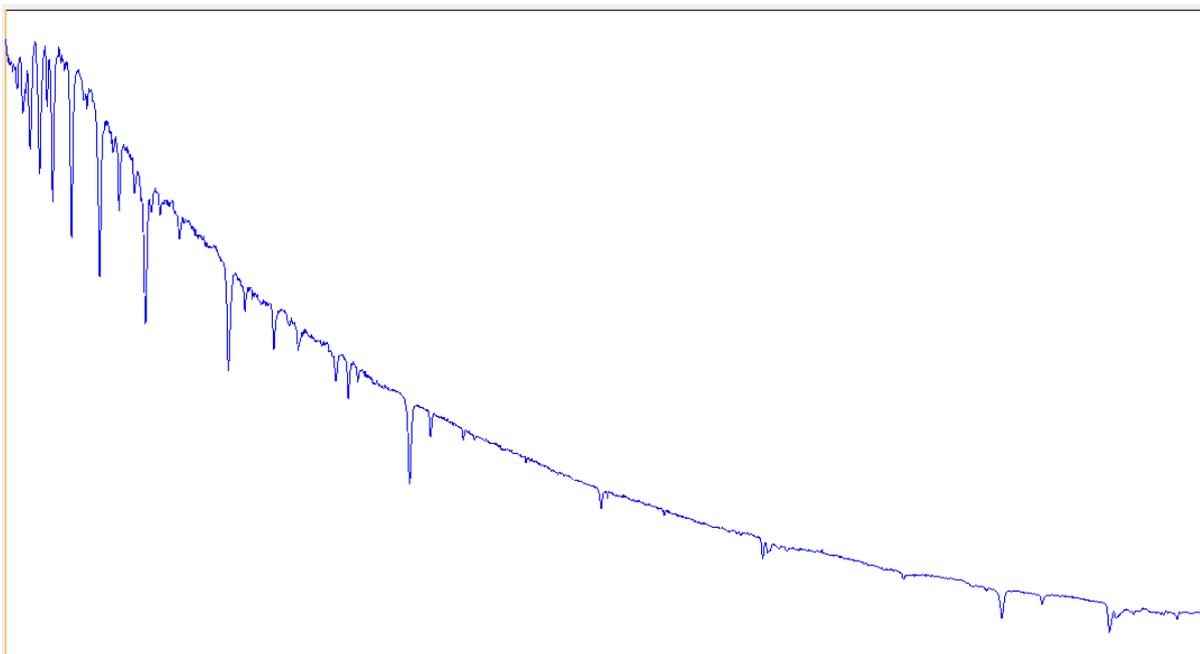
Below is the complete level #2 processing configuration file:

```
# ************************************************************************
# CONF_LEVEL2_MODE1
# Wavelength-calibrated spectrum extraction via polynomial (mode 1)
# Level 2 processing
# ************************************************************************

#-------------------------------------------------------------------------
# Working directory #
#-------------------------------------------------------------------------
working_path: D:/starex340


#-------------------------------------------------------------------------
# Batch processing file #
#-------------------------------------------------------------------------
batch_name: 10Lac


#-------------------------------------------------------------------------
# Calibration from polynomial only (no standard spectrum) #
#-------------------------------------------------------------------------
calib_mode: 1


#-------------------------------------------------------------------------
# Coefficients of the spectral calibration polynomial #
#-------------------------------------------------------------------------
calib_coef: [1.3697786967858392e-09, 4.7375755940865985e-07, 1.5459285880960587,
3495.239344027813]


#-------------------------------------------------------------------------
# Binning width #
#-------------------------------------------------------------------------
bin_size: 30


#-------------------------------------------------------------------------
# Sky calculation areas #
#-------------------------------------------------------------------------
sky: [160, 20, 20, 160]


#-------------------------------------------------------------------------
# Area for calculating geometric parameters #
#-------------------------------------------------------------------------
xlimit: [600, 1800]


#-------------------------------------------------------------------------
# Color temperature of the tungsten flat lamp #
#-------------------------------------------------------------------------
planck: 2700


#-------------------------------------------------------------------------
# Requesting access to SIMBAD #
#-------------------------------------------------------------------------
simbad: 1


#-------------------------------------------------------------------------
# Atmospheric transmission correction #
#-------------------------------------------------------------------------
corr_atmo: 0.13


#-------------------------------------------------------------------------
# Normalization range to unity #
#-------------------------------------------------------------------------
norm_wave: [6620, 6640]


#-------------------------------------------------------------------------
# Cropping zone for the profile #
#-------------------------------------------------------------------------
crop_wave: [3700, 7150]
```

```
#--------------------------------------------------------------------------------
# Longitude of the observation site #
#--------------------------------------------------------------------------------
longitude: 7.0940


#--------------------------------------------------------------------------------
# Latitude of the observation site #
#--------------------------------------------------------------------------------
latitude: 43.5801


#--------------------------------------------------------------------------------
# Altitude of the observation site in meters #
#--------------------------------------------------------------------------------
altitude: 40


#--------------------------------------------------------------------------------
# Observation site #
#--------------------------------------------------------------------------------
site: Antibes Saint-Jean


#--------------------------------------------------------------------------------
# Instrument description #
#--------------------------------------------------------------------------------
inst: T150 + StarEx300 + ASI533MM


#--------------------------------------------------------------------------------
# Observer #
#--------------------------------------------------------------------------------
observer: cbuil


#--------------------------------------------------------------------------------
# Resolution power (mandatory in mode 1) #
#--------------------------------------------------------------------------------
power_res: 800


#--------------------------------------------------------------------------------
# Instrumental response #
#--------------------------------------------------------------------------------
instrumental_response: _rep340
#--------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#--------------------------------------------------------------------------------
check_mode: 1
```

In the following graph, the spectrum of 10 Lac observed with Star'Ex LR on a 150 mm
telescope and the reference spectrum of this star found in the Calpec database
(spectrophotometric standard). The spectra are deliberately offset by 0.5 in intensity to make
the comparison more readable:
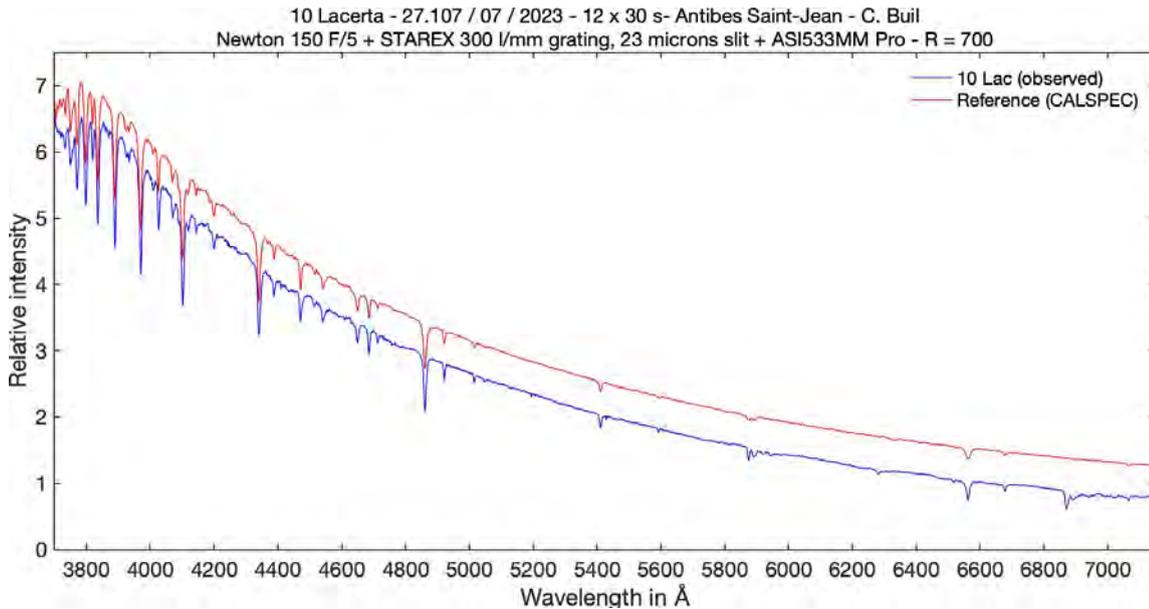
The agreement is very good.

15. Calibration Using a Spectral Lamp

Let's now proceed with the treatment of a faint object, the galaxy Markarian 917, with a magnitude of 14.1. To do this, we will continue to use the previously calculated spectral calibration coefficients, but with one caveat.

Although coefficients with high degrees can be considered stable in terms of values (they are linked to the very concept of the spectrograph), on the other hand, the first term of the polynomial, "A0," depends much more on the conditions of use of the spectrograph. For example, if the image of the spectrum moves on the detector due to a mechanical bending effect, it is this term of the dispersion polynomial that is primarily altered.

In other words, to perform high-quality precision observations, it is necessary to monitor and update this so-called "constant" term of the polynomial. In the polynomial used, it amounts to 3495.24 Å.

To take into account the accidental shift of the spectrum image according to the wavelength, we need a reference spectrum taken at the same time as the shots on the studied object, or at least at a very short time interval. In the case of Mark 917, we have 2 images exposed for 900 seconds each. Moreover, we have at our disposal the image of the spectrum of a neon pilot light, captured just after these two long shots on the target, without moving the telescope. For this particular occasion, the spectrum of the neon lamp was carried out simply and basically, by waving the lamp in front of the telescope opening during a 30-second exposure. Here is the image of the neon lamp thus obtained:
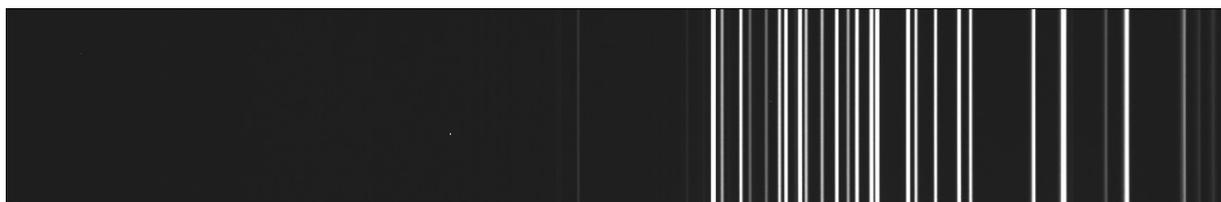
It is characteristic, with fine emission lines, especially here localized in the red part of the spectrum.

We note down to the pixel (not serious if you are wrong by 2 or 3 pixels) the X coordinates (horizontal) of some lines whose wavelengths we otherwise know. To know everything about the position of the lines in spectra of this type:
http://www.astrosurf.com/solex/specinti_annexe3_en.html

Here they are put into perspective in the form of two lists for selected lines, one concerning with the wavelengths (parameter "wavelength") and the other with the positions in pixels measured in the image (parameter "line_pos"):

```
wavelength: [5944.83, 6266.49, 6678.28]
line_pos: [1583, 1789, 2053]
```

The "Observation" tab is filled in as follows:

In the "Observation" tab of specINTI Editor, we write the generic name of the neon spectrum image, as well as the number of images available (here only one). By clicking on the "Auto" button, the software writes these for you.

Note how the name of the neon image is formed: the name of the associated object, then the qualifier "_neon-". specINTI Editor will assist you if you follow such a protocol and if you define the corresponding postfix in the designated field in the specINTI Editor interface (field "Cal File Postfix").

The work of specINTI will consist of processing the astronomical spectra as we have seen previously, but also processing the spectral calibration spectra. It will use this last information to adjust the dispersion polynomial to comply with the observation conditions of the moment. In doing so, we have just described the calibration mode 2 of specINTI.

Since we are treating a low-brightness target, we must also take care of the possible noise reduction in the final profile, but without altering its content (meaning we must be reasonable). Let us specify that the data in question were obtained in an urban environment and in conditions of poor atmospheric transparency (with a 150 mm Newton telescope and the Star'Ex LR spectrograph).

Here are tools you can use to reduce noise. These are simple lines that you add to your current

configuration file:

```
#------------------------------------------------------------------------------
# Median filtering pattern #
#------------------------------------------------------------------------------
kernel_size: -3


#------------------------------------------------------------------------------
# Gaussian filtering #
#------------------------------------------------------------------------------
sigma_gauss: 0.75


#------------------------------------------------------------------------------
# Optimal extraction #
#------------------------------------------------------------------------------
extract_mode: 1
gain: 0.083
noise: 1.3
```

The "kernel_size" parameter is associated with median filtering of images. The fact that the value of the parameter is negative specifies that the applied filtering is optimal for removing RTS noise (also known as "salt-and-pepper" noise), while preserving details in the spectrum. The filter kernel is 3x3 pixels.

The "sigma_gauss" parameter is associated with low-pass filtering of images, here at a higher frequency than the optical cut-off frequency. Here again, most details are preserved, so the spectral resolution is very little altered. The value of the parameter defines the strength of the filter – between 0.5 and 1.0, the impact on the sharpness of spectral details is generally marginal.

The presence of the "extract_mode" parameter with a value of 1 implies that optimal binning is performed to go from the image to the spectral profile, a critical step. Do not touch the "noise" and "gain" parameters associated with "extract_mode". The positive effect of this type of binning is only noticeable when treating low-intensity spectra.

All this work in the configuration file means that the level of processing goes from level #2 to level #3. A level #3 spectrum can be disseminated for scientific studies.

Note : there is a level #4, which is distinguished by the fact that the data is provided in absolute physical units (such as ergs, but this is beyond the scope of this toolbox).

To process at level #3 by exploiting a spectral lamp for adjustment, take inspiration from the "conf_level3_mode2.yaml" configuration file:

```
# ****************************************************************************
# CONF_LEVEL3_MODE2
# Wavelength-calibrated spectrum extraction via updated polynomial
# with a spectral lamp (constant)
# Level 3 processing
# ****************************************************************************


#------------------------------------------------------------------------------
# Working directory #
#------------------------------------------------------------------------------
working_path: D:/starex340


#------------------------------------------------------------------------------
# Batch processing file #
#------------------------------------------------------------------------------
batch_name: mrk917


#------------------------------------------------------------------------------
# Calibration from polynomial only (no standard spectrum) #
```

```
#-------------------------------------------------------------------------------
calib_mode: 2

#-------------------------------------------------------------------------------
# Coefficients of the spectral calibration polynomial #
#-------------------------------------------------------------------------------
calib_coef: [1.080925343279991e-09, 5.919400721871533e-07, 1.5472908312138407,
3494.26602194136]

#-------------------------------------------------------------------------------
# Wavelength of standard emission lines #
#-------------------------------------------------------------------------------
wavelength: [5944.83, 6266.49, 6678.28]

#-------------------------------------------------------------------------------
# Pixel position of standard emission lines #
#-------------------------------------------------------------------------------
line_pos: [1583, 1789, 2053]

#-------------------------------------------------------------------------------
# Search width for calibration lines #
#-------------------------------------------------------------------------------
search_wide: 15

#-------------------------------------------------------------------------------
# Binning height #
#-------------------------------------------------------------------------------
bin_size: 16

#-------------------------------------------------------------------------------
# Sky calculation areas #
#-------------------------------------------------------------------------------
sky: [160, 15, 15, 120]

#-------------------------------------------------------------------------------
# Sky extraction mode (0: basic; 1: optimal) #
#-------------------------------------------------------------------------------
sky_mode: 1

#-------------------------------------------------------------------------------
# Area for calculating geometric parameters #
#-------------------------------------------------------------------------------
xlimit: [600, 1800]

#-------------------------------------------------------------------------------
# Color temperature of the tungsten flat lamp #
#-------------------------------------------------------------------------------
planck: 2700

#-------------------------------------------------------------------------------
# Requesting access to SIMBAD #
#-------------------------------------------------------------------------------
simbad: 1

#-------------------------------------------------------------------------------
# Atmospheric transmission correction #
#-------------------------------------------------------------------------------
corr_atmo: 0.13

#-------------------------------------------------------------------------------
# Median filtering pattern #
#-------------------------------------------------------------------------------
kernel_size: -3

#-------------------------------------------------------------------------------
# Gaussian filtering #
#-------------------------------------------------------------------------------
sigma_gauss: 0.75

#-------------------------------------------------------------------------------
```

```
# Optimal extraction #
#--------------------------------------------------------------------------------
extract_mode: 1
gain: 0.083
noise: 1.3


#--------------------------------------------------------------------------------
# Normalization range to unity #
#--------------------------------------------------------------------------------
norm_wave: [6620, 6640]


#--------------------------------------------------------------------------------
# Cropping zone for the profile #
#--------------------------------------------------------------------------------
crop_wave: [3700, 7150]


#--------------------------------------------------------------------------------
# Longitude of the observation site #
#--------------------------------------------------------------------------------
longitude: 7.0940


#--------------------------------------------------------------------------------
# Latitude of the observation site #
#--------------------------------------------------------------------------------
latitude: 43.5801


#--------------------------------------------------------------------------------
# Altitude of the observation site in meters #
#--------------------------------------------------------------------------------
altitude: 40


#--------------------------------------------------------------------------------
# Observation site #
#--------------------------------------------------------------------------------
site: Antibes Saint-Jean


#--------------------------------------------------------------------------------
# Instrument description #
#--------------------------------------------------------------------------------
inst: T150 + StarEx300 + ASI533MM


#--------------------------------------------------------------------------------
# Observer #
#--------------------------------------------------------------------------------
observer: cbuil


#--------------------------------------------------------------------------------
# Instrumental response #
#--------------------------------------------------------------------------------
instrumental_response: _rep340


#--------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#--------------------------------------------------------------------------------
check_mode: 1
```

Note : You have complete freedom as to the arrangement of this file and the comments. Adapt it as you wish, don't hesitate to be creative. Just make sure to respect the syntax of the parameters.

Everything should seem familiar to you. Note the three neon lines we have selected. As expected, SpecINTI establishes the relationship between the theoretical wavelengths of these lines and the observed wavelengths, and then corrects the A0 term of the dispersion polynomial accordingly. Here is the result:
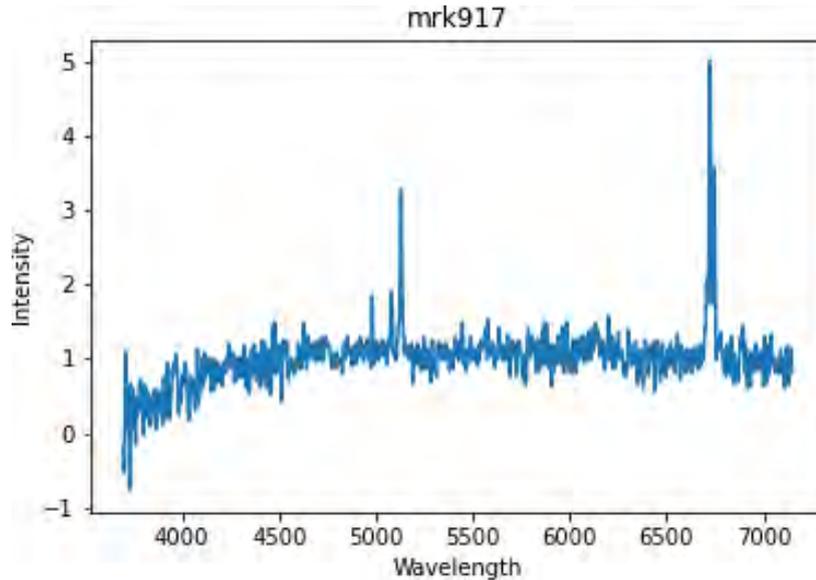
16. Lateral Calibration Mode

In this toolbox, we provide some examples and tips for exploiting a powerful principle for wavelength calibration of spectra, known as "lateral" calibration.

Still with the idea of adjusting the A0 term (the "constant") of the dispersion polynomial, you can also exploit the natural lines of the sky background or those of light pollution. Here are two identified in one of the raw images of the spectrum of Mark 917:
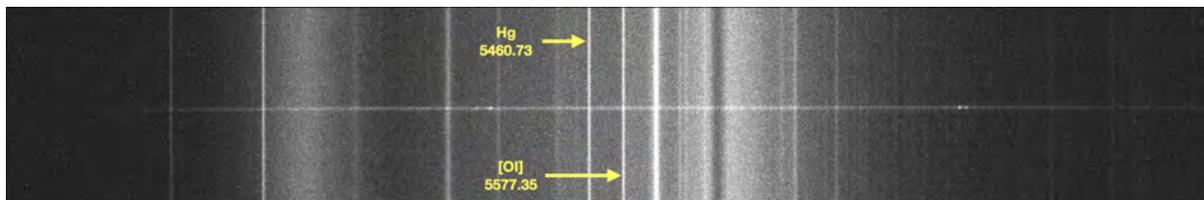
This is indeed a spectrum acquired in low spectral resolution, as you would obtain with a spectrograph like Alpy600, for instance. We mark a line coming from urban pollution (mercury line, Hg) and a line emitted from the Earth's upper atmosphere (OI).

Consequently, we no longer even need a spectral lamp to calibrate our spectrum in wavelength. Here is how the observation file is now organized (notice the "none" in the "Calibration List" field):

Our two accidental lateral lines, which are imprinted in the galaxy's spectrum but are quite useful, are measured at coordinates x = 1273 and x = 1348. Both of them will serve us to adjust the previously established dispersion polynomial obtained by observing the spectrum of the star 10 Lac (a single line could be used, but precision will generally be higher with two).

This lateral calibration mode is identified by number 4 in the specINTI nomenclature. Here is the corresponding typical configuration file:

```
# ****************************************************************************
# CONF_LEVEL3_MODE4
# Wavelength-calibrated spectrum extraction via an updated polynomial
# in lateral mode with sky background lines (mode 4)
# Level 3 processing
# ****************************************************************************

#----------------------------------------------------------------------------
# Working directory #
#----------------------------------------------------------------------------
working_path: D:/starex340

#----------------------------------------------------------------------------
# Processing batch file #
#----------------------------------------------------------------------------
batch_name: mrk917

#----------------------------------------------------------------------------
# Calibration from the polynomial alone (no standard spectrum) #
#----------------------------------------------------------------------------
calib_mode: 4

#----------------------------------------------------------------------------
# Coefficients of the spectral calibration polynomial #
#----------------------------------------------------------------------------
calib_coef: [1.080925343279991e-09, 5.919400721871533e-07, 1.5472908312138407,
3494.26602194136]

#----------------------------------------------------------------------------
# Wavelength of standard emission lines #
#----------------------------------------------------------------------------
```

```
wavelength: [5460.73, 5577.35]

#--------------------------------------------------------------------------------
# Position in pixels of the standard emission lines #
#--------------------------------------------------------------------------------
line_pos: [1273, 1348]

#--------------------------------------------------------------------------------
# Width of the calibration line search area #
#--------------------------------------------------------------------------------
search_wide: 30

#--------------------------------------------------------------------------------
# Binning height #
#--------------------------------------------------------------------------------
bin_size: 16

#--------------------------------------------------------------------------------
# Sky background calculation zones #
#--------------------------------------------------------------------------------
sky: [160, 15, 15, 120]

#--------------------------------------------------------------------------------
# Sky extraction mode (0: basic; 1: optimal) #
#--------------------------------------------------------------------------------
sky_mode: 1

#--------------------------------------------------------------------------------
# Geometric parameters calculation area #
#--------------------------------------------------------------------------------
xlimit: [600, 1800]

#--------------------------------------------------------------------------------
# Flat tungsten lamp color temperature #
#--------------------------------------------------------------------------------
planck: 2700

#--------------------------------------------------------------------------------
# Request access to SIMBAD #
#--------------------------------------------------------------------------------
simbad: 1

#--------------------------------------------------------------------------------
#Atmospheric transmission correction#
#--------------------------------------------------------------------------------
corr_atmo: 0.13

#--------------------------------------------------------------------------------
# Median filter pattern #
#--------------------------------------------------------------------------------
kernel_size: -3

#--------------------------------------------------------------------------------
# Gaussian filtering #
#--------------------------------------------------------------------------------
sigma_gauss: 0.75

#--------------------------------------------------------------------------------
# Optimal extraction #
#--------------------------------------------------------------------------------
extract_mode: 1
gain: 0.083
noise: 1.3

#--------------------------------------------------------------------------------
# Unit normalization area #
#--------------------------------------------------------------------------------
norm_wave: [6620, 6640]

#--------------------------------------------------------------------------------
```

```
# Profile cropping area #
#--------------------------------------------------------------------------------
crop_wave: [3700, 7150] #


#--------------------------------------------------------------------------------
# Longitude of the observation location #
#--------------------------------------------------------------------------------
Longitude: 7.0940


#--------------------------------------------------------------------------------
# Latitude of the observation location #
#--------------------------------------------------------------------------------
Latitude: 43.5801


#--------------------------------------------------------------------------------
# Altitude of the observation location in meters #
#--------------------------------------------------------------------------------
Elevation: 40


#--------------------------------------------------------------------------------
# Observation site #
#--------------------------------------------------------------------------------
Site: Antibes Saint-Jean


#--------------------------------------------------------------------------------
# Instrument description #
#--------------------------------------------------------------------------------
Inst: T150 + StarEx300 + ASI533MM


#--------------------------------------------------------------------------------
# Observer #
#--------------------------------------------------------------------------------
Observe: cbuil


#--------------------------------------------------------------------------------
# Instrumental response #
#--------------------------------------------------------------------------------
instrumental_response: _rep340


#--------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#--------------------------------------------------------------------------------
check_mode: 1
wavelength: [5460.73, 5577.35]
line_pos: [1273, 1348]
```

Note that the "wavelength" and "line_pos" parameters accept a list of values, here the data for our two calibration lines.

Tip : the "sky_mode" parameter gives two choices for removing the background noise from the images. If its value is 0, the sky background level is a median intensity calculated in the "sky" zones that frame the object's spectrum, column by column. If the value is 1 (as here), distinct Legendre polynomials are subtracted for each column. In principle, this latter option provides the best result, but the calculation time is longer. Make trials.

17. Processing the Spectrum of an Extended Object

We are processing a sequence of 7 spectra of the Messier 57 nebula, each exposed for 600 seconds, taken with Star'Ex low resolution on a 150 mm f/5 Newton telescope. Here is one of the raw images:
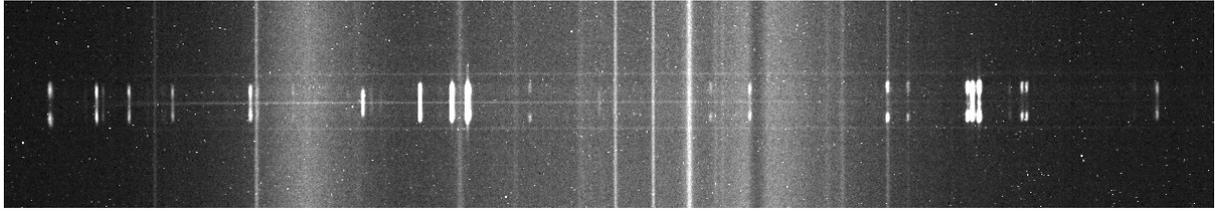
You can download the raw data for this example by clicking on this link:

http://www.astrosurf.com/buil/specinti2/dist_sp24/starex341.zip

In addition to the emission lines produced by the nebula, we notice the spectral signature of light pollution coming from the city of Antibes, from where this spectrum was taken.

If specINTI knows how to find the position of star trails in an image, in the present case, the object, due to its apparent surface, complicates the task. We are obliged to manually designate where the nebula is in the image, and pass this information (approximately) through a parameter, "posy", for Y position, or vertical position:

```
posy : 210
```

Here, the center of the trail is 210 pixels above the bottom edge of the image. We need to define a large binning height to integrate the maximum signal from the object. The sky calculation zones are also adapted.

The "Observation" tab for this object:

The modified configuration file for treating a wide-angle object (we're also adopting calibration mode number 2 here):

```
# ***************************************************************************
# CONF_LEVEL3_MODE2_WIDE
# Extraction of the spectrum calibrated in wavelength via an updated polynomial
# with a (constant) spectral lamp
# Level 3 processing - Adaptation to processing an object with an extended surface
```

```
# ********************************************************************

#-------------------------------------------------------------------------
# Working directory #
#-------------------------------------------------------------------------
working_path: D:/starex341

#-------------------------------------------------------------------------
# Processing batch file #
#-------------------------------------------------------------------------
batch_name: m57

#-------------------------------------------------------------------------
# Calibration from the polynomial alone (no standard spectrum) #
#-------------------------------------------------------------------------
calib_mode: 2

#-------------------------------------------------------------------------
# Coefficients of the spectral calibration polynomial #
#-------------------------------------------------------------------------
calib_coef: [1.080925343279991e-09, 5.919400721871533e-07, 1.5472908312138407,
3494.26602194136]

#-------------------------------------------------------------------------
# Wavelength of standard emission lines #
#-------------------------------------------------------------------------
wavelength: [5944.83, 6266.49, 6678.28]

#-------------------------------------------------------------------------
# Position in pixels of the standard emission lines #
#-------------------------------------------------------------------------
line_pos: [1583, 1789, 2053]

#-------------------------------------------------------------------------
# Width of the calibration line search area #
#-------------------------------------------------------------------------
search_wide: 15

#-------------------------------------------------------------------------
# Vertical position of the object #
#-------------------------------------------------------------------------
posy: 210

#-------------------------------------------------------------------------
# Binning height #
#-------------------------------------------------------------------------
bin_size: 140

#-------------------------------------------------------------------------
# Sky background calculation zones #
#-------------------------------------------------------------------------
sky: [190, 90, 90, 200]

#-------------------------------------------------------------------------
# Sky extraction mode (0: basic; 1: optimal) #
#-------------------------------------------------------------------------
sky_mode: 1

#-------------------------------------------------------------------------
# Geometric parameters calculation area #
#-------------------------------------------------------------------------
xlimit: [600, 1800]

#-------------------------------------------------------------------------
# Flat tungsten lamp color temperature #
#-------------------------------------------------------------------------
plank: 2700

#-------------------------------------------------------------------------
# Request access to SIMBAD #
```

```
#-------------------------------------------------------------------------------
simbad: 1

#-------------------------------------------------------------------------------
#Atmospheric transmission correction#
#-------------------------------------------------------------------------------
corr_atmo: 0.13

#-------------------------------------------------------------------------------
# Median filter pattern #
#-------------------------------------------------------------------------------
kernel_size: -3

#-------------------------------------------------------------------------------
# Gaussian filtering #
#-------------------------------------------------------------------------------
sigma_gauss: 0.5 #

#-------------------------------------------------------------------------------
# Unit normalization area #
#-------------------------------------------------------------------------------
norm_wave: [6620, 6640]

#-------------------------------------------------------------------------------
# Profile cropping area #
#-------------------------------------------------------------------------------
crop_wave: [3700, 7150]

#-------------------------------------------------------------------------------
# Longitude of the observation location #
#-------------------------------------------------------------------------------
Longitude: 7.0940

#-------------------------------------------------------------------------------
# Latitude of the observation location #
#-------------------------------------------------------------------------------
Latitude: 43.5801

#
# Altitude of the observation location in meters #
Elevation: 40

#-------------------------------------------------------------------------------
# Observation site #
#-------------------------------------------------------------------------------
Site: Antibes Saint-Jean

#-------------------------------------------------------------------------------
# Instrument description #
#-------------------------------------------------------------------------------
Inst: T150 + StarEx300 + ASI533MM

#-------------------------------------------------------------------------------
# Observer #
#-------------------------------------------------------------------------------
Observe: cbuil

#-------------------------------------------------------------------------------
# Instrumental response #
#-------------------------------------------------------------------------------
instrumental_response: _rep340

#-------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#-------------------------------------------------------------------------------
check_mode: 1

#-------------------------------------------------------------------------------
# Tilt angle imposed #
#-------------------------------------------------------------------------------
```

```
tilt: 0
```

The result in 2D and profile:
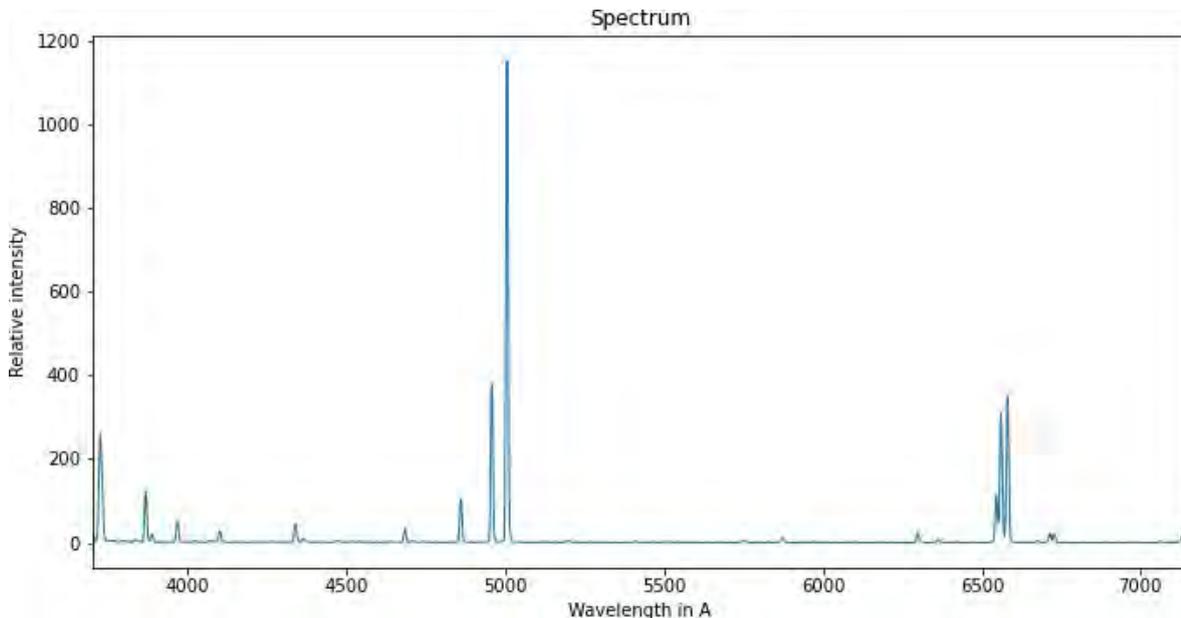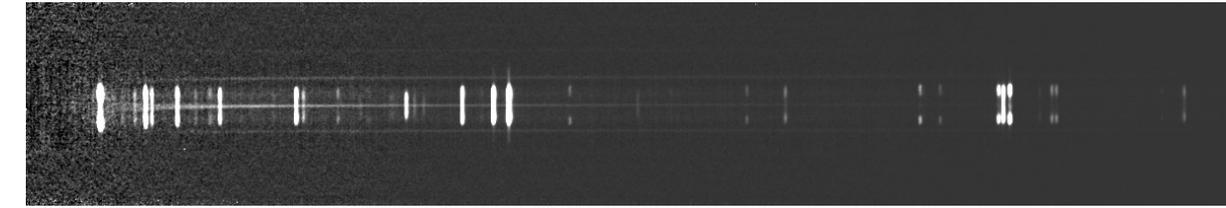
Note the width adopted for binning through the "bin_size" parameter: 140 pixels. We got this value by measuring the size of the nebula on the slit's height (use the "_step101" image file, which contains the programmed traces of sky zones and binning after an initial treatment for help).

Tip : you can ask specINTI not to remove the sky background signal. To do this, use the "sky_remove" parameter with the value 0:

```
sky_remove: 0
```

This ability is interesting if you want to observe the faint extensions of a nebula or galaxy, the distant coma of a comet, sky pollution, etc. By default, the value of this parameter is 1, which implies the removal of the sky background, the normal behavior of specINTI.

Notice that the value of the tilt angle is forced by the presence of the "tilt" parameter in the configuration file. It's very difficult to ask the software to find this angle on an extended object. Keep this remark in mind; sometimes you must be wary of automatism and help the software by switching to "manual."

18. Processing a High-Resolution Spectral Spectrum

We're now treating a spectrum achieved in high spectral resolution with a Star'Ex HR, equipped with a 2400 groove/mm grating and a 19-micron slit (80 / 125 mm configuration). The spectrograph is adjusted to observe the H-alpha line. The acquiring instrument is an Askar 80PHQ telescope (f/7.5):

We observe the spectrum of the star alpha Dragonis, a spectroscopic double system. You can download the raw data for this example by clicking on this link:

http://www.astrosurf.com/buil/specinti2/dist_sp24/starex332.zip

Regarding the creation of the flat-field image, we use an LED panel placed in front of the telescope. We consider this solution satisfactory because, in the very small spectral interval observed, the illumination is deemed to be sufficiently uniform spectrally (despite a strong deficit of red light):

For spectral calibration, it relies on a sequence of lines (here telluric in origin) that we adjust by a polynomial (degree 2 is sufficient here):
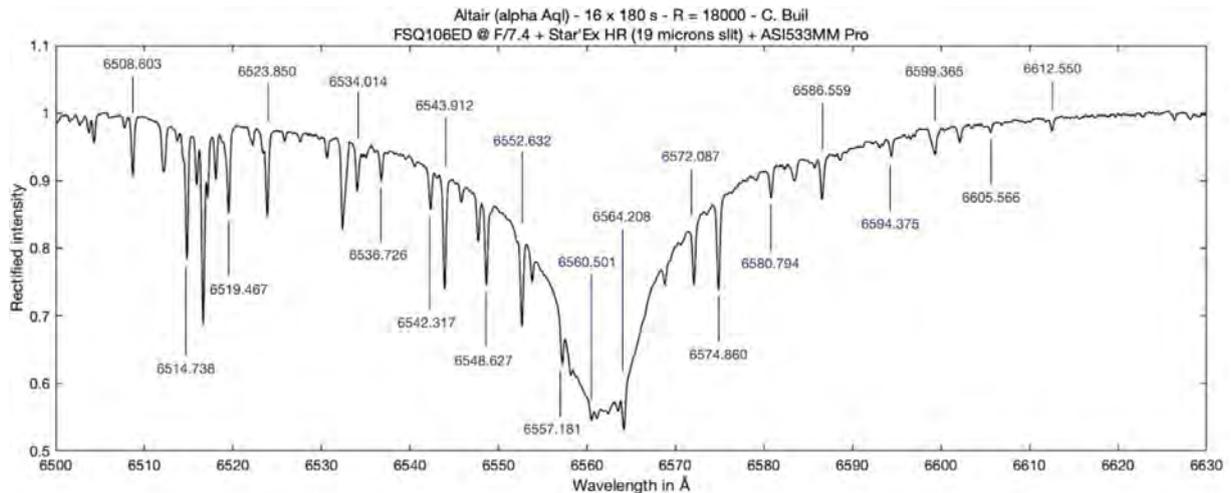
The way to find the dispersion polynomial from the telluric lines (H2O) is explained in detail in part A4.3 of this page:

http://www.astrosurf.com/solex/specinti_annexe4_en.html.

To account for temporal flexure, we work in lateral mode, but this time with a local artificial source: an optical fiber that carries the light of a neon pilot light to the entry of the telescope. This calibration lamp is turned on permanently, so we simultaneously observe the spectrum of the star and that of the standard lamp:
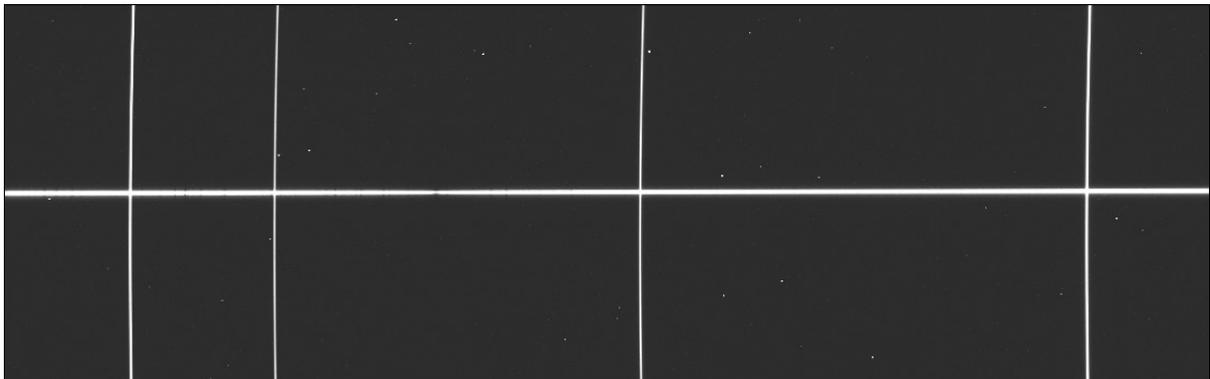
We are exploiting specINTI's calibration mode 4. Recall that this is a mixed mode. The dispersion law is first calculated (here from the telluric lines, which gives high precision over a good spectral width), and then the final touch is made from the neon lamp lines exploited in lateral mode, which are used to adjust the A0 term of the polynomial to local conditions.

The observation tab (and file) is arranged as follows:

Here's the characteristic configuration file for the treatment of high-resolution spectra captured with our 80 mm telescope and in mode 4:

```
# ****************************************************************************
# CONF_LEVEL3_MODE4 (high spectral resolution)
# # Extraction of the spectrum calibrated in wavelength via an updated polynomial
# in lateral mode with lines from the sky background (mode 4)#
# ****************************************************************************

#------------------------------------------------------------------------------
# Working directory #
#------------------------------------------------------------------------------
working_path: D:/starex332

#------------------------------------------------------------------------------
# Processing batch file #
#------------------------------------------------------------------------------
batch_name: alphadra

#------------------------------------------------------------------------------
# Spectral calibration mode #
#------------------------------------------------------------------------------
calib_mode: 4

#------------------------------------------------------------------------------
# Calibration polynomial #
#------------------------------------------------------------------------------
calib_coef: [-1.147614869142545e-06, 0.10002814151183108, 6484.353249168842]

#------------------------------------------------------------------------------
# Automatic search for neon calibration lines #
#------------------------------------------------------------------------------
auto_calib: [6490, 6690]

#------------------------------------------------------------------------------
# Width in pixels of the neon calibration line search area #
#------------------------------------------------------------------------------
search_wide: 40
```

```
#-------------------------------------------------------------------------------
# Binning width
#-------------------------------------------------------------------------------
bin_size: 18


#-------------------------------------------------------------------------------
# Sky background calculation zones #
#-------------------------------------------------------------------------------
sky: [160, 16, 16, 160]


#-------------------------------------------------------------------------------
# Erasing calibration sidelines #
#-------------------------------------------------------------------------------
clean_wave: [6506.5, 6532.8, 6598.9, 6678.3]
clean_wide: [1.1, 0.8, 0.9, 1.0]


#-------------------------------------------------------------------------------
# Radius of curvature of the smile #
#-------------------------------------------------------------------------------
smile_radius: -16000


#-------------------------------------------------------------------------------
# Sky extraction mode (1 = optimal) #
#-------------------------------------------------------------------------------
sky_mode: 1


#-------------------------------------------------------------------------------
# x terminals for geometric measurements #
#-------------------------------------------------------------------------------
xlimit: [400, 1800]


#-------------------------------------------------------------------------------
# Instrumental response #
#-------------------------------------------------------------------------------
instrumental_response: _rep332


#-------------------------------------------------------------------------------
#Atmospheric transmission correction#
#-------------------------------------------------------------------------------
simbad: 1
corr_atmo: 0.20


#-------------------------------------------------------------------------------
# Median filter pattern #
#-------------------------------------------------------------------------------
kernel_size: 0


#-------------------------------------------------------------------------------
# Gaussian filtering # 0.0: R = 19500
#-------------------------------------------------------------------------------
#0.5: R = 18100
#0.75 R =: 16900
#1.0: R =15600 #
sigma_gauss: 0.75


#-------------------------------------------------------------------------------
# Optimal extraction #
#-------------------------------------------------------------------------------
extract_mode: 1
gain: 0.083
noise: 1.3


#-------------------------------------------------------------------------------
# Unit normalization area #
norm_wave: [6640, 6660]
#-------------------------------------------------------------------------------


#-------------------------------------------------------------------------------
# Profile cropping area #
#-------------------------------------------------------------------------------
```

```
crop_wave: [6489, 6691]

#-------------------------------------------------------------------------------
# Longitude of the observation location #
#-------------------------------------------------------------------------------
Longitude: 7.0940 #

#-------------------------------------------------------------------------------
# Latitude of the observation location #
#-------------------------------------------------------------------------------
Latitude: 43.5801

#-------------------------------------------------------------------------------
# Altitude of the observation location in meters #
#-------------------------------------------------------------------------------
Elevation: 40

#-------------------------------------------------------------------------------
# Observation site #
#-------------------------------------------------------------------------------
Site: Antibes Saint-Jean

#-------------------------------------------------------------------------------
# Instrument description #
#-------------------------------------------------------------------------------
Inst: Askar80PHQ + StarEx2400 + ASI533MM

#-------------------------------------------------------------------------------
# Observer #
#-------------------------------------------------------------------------------
Observe: cbuil

#-------------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#-------------------------------------------------------------------------------
check_mode: 1

#-------------------------------------------------------------------------------
# Request S/N calculation #
#-------------------------------------------------------------------------------
snr: [6650, 6665]

#-------------------------------------------------------------------------------
# Spectral shift requested #
#-------------------------------------------------------------------------------
spectral_shift_wave: -0.008
```

Recall that the values of the spectral dispersion polynomial coefficients:

```
calib_coef: [-1.147614869142545e-06, 0.10002814151183108, 6484.353249168842]
```

were found previously from the trace of the telluric lines present around the H-alpha line. Observe the appearance of the "auto_calib" parameter. Thanks to it, specINTI automatically searches for neon lines in the provided spectral interval, so here between 6490 and 6690 Å. There's no longer need to give the position of the lines or their wavelengths; the software does everything automatically (identification of the lines present and measurements)

Tip: We also find two fairly common parameters when working in lateral mode, "clean_wave" and "clean_wide":

```
clean_wide: [6506.5, 6532.8, 6598.9, 6678.3]
clean_wide: [1.1, 0.8, 0.9, 1.0]
```

They instruct the software to erase artifacts at the intersection of the spectrum trace and the standard lines, left by an imperfect removal of the sky background at these spots. The problem is particularly sensitive when using a small telescope and a fine slit, as here. The

operation simply consists of a linear interpolation of the continuum at the specified wavelengths and for the specified spectral widths in angstroms.

One point to note concerns the value of the "kernel_size" parameter for median filtering. The size of the filter pattern (kernel) is set to 0, which means that median filtering is not applied. The reason is that the spectral trace delivered by the telescope is so narrow that such median filtering causes radiometric defects judged not acceptable. Be careful if you are working with small instruments; the details are then very fine, yet the sensor pixels (even small ones). We are often in a regime of undersampling, which is never very good and requires attention.

Also, note a manual adjustment of the spectral calibration: a spectrum shift of -0.008 Å (parameter "spectral_shift_wave"). This shift value is found by exploiting the "Check atmo" tool in the "View profile" tab under specINTI Editor.

The instrumental response file "_rep332" was evaluated by comparing the observed spectrum of the star Altair and the HR reference spectrum of this object (file "UVEX_altair.fits" in the specINTI database). Below is the result of the treatment:
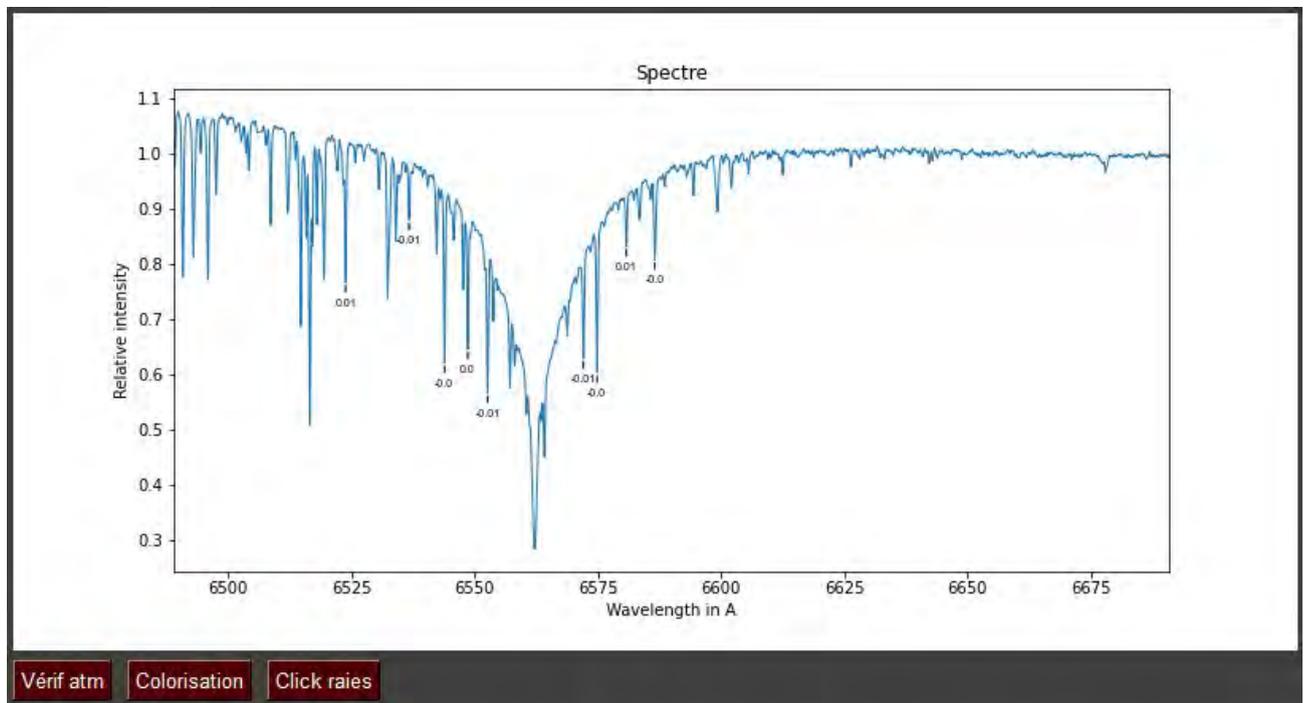
The spectral calibration error is less than 0.01 Å, which is an excellent result.
It may be useful to indicate that it is easy to transform the current configuration file, suitable for calibration mode 4, to work in calibration mode 3. The author of these lines often juggles between these two modes depending on the brightness of the high-resolution spectral observation object. This takes less than a minute, although it is not always necessary to multiply configuration files.

Mode 3 is perhaps the most practical and simplest of all. Indeed, it is enough to position one or more neon lamps (or fibers) in front of the opening of the telescope or refractor to acquire the standard spectra in lateral mode (spectrum of the object and the standard source in the same spectral image), then activate automatic calibration during treatment (parameter "auto_calib").

The only real transformation to be made consists of specifying that we are in mode 3 and adjusting the degree of the polynomial as follows:

```
calib_mode: 3
poly_order: 2
```

The only drawback to mode 3 is that the accuracy of calibration, although very good and satisfactory for most situations, is sometimes slightly lower than that obtained using telluric lines to determine the dispersion polynomial.

Tip : in most cases, it is recommended not to acquire only a single spectral image of an object, so as to be able to potentially filter certain artifacts. Suppose you have made 10 spectra of a target. The usual work of specINTI consists of calculating a sum of these 10 individual spectra to produce the final spectral profile. However, you can also ask the software to record the processing results of each individual spectrum in the working folder. This processing is exactly the same for individual spectra as for the cumulated spectrum. This capability to have the treated individual spectra is useful if you want to study a temporal evolution between these 10 spectra. To do this, just add the following line to the configuration file:

```
seq_mode: 1
```

The individual files take the catalog name of the treated image, but specINTI adds an index number and the character "@" in front of the name, for example:

@10dra-1
@10dra-2
...
...
@10dra-10

Tip : One should not forget one of the strengths of specINTI: its ability to process lists of objects (which could represent an entire night of observation, for example) without requiring your intervention. This means that you can go about other activities while the software works. One of the most spectacular uses is to be able to use the software in real-time on the telescope, on the fly, and for example process the object being observed, stopping when the number of images is judged sufficient for a given result. All this is done with a single click or almost.

Here, for example, is what the "Observation" tab looks like for processing three targets in a sequence:

You just need to enter the catalog names of the objects in the object list field with a comma as a separator (the "Night" button can also help here), then click on "Auto" and finally on "Execute". That's all.

Tip : Notice the generic name adopted for the dark signal images. It's a habit taken by the author: an "n" to indicate that it is an image taken in the dark, a "900" to indicate the exposure time in seconds, and a "_12" to indicate that the detector temperature is -12°C. This convention makes it easier to build reference image libraries and to check at a glance if the dark images are well suited to the objects to be processed. Also, it is important to note that 19 images n900_12-xxx were made with a 900-second exposure, which is also the maximum exposure time here used for the targets of the night. Of course, these calibration images were acquired during the day, by placing the spectrograph with its camera in a fridge and a cap in front of the slit, taking care not to open the door too often!

19. Spectroscopy of Very Low Intensity Objects

specINTI is flexible enough to adapt to most situations. In reality, a processing solution is always available, but it may require more or less effort and sometimes advanced software knowledge.

A difficult situation arises, for example, when the trace of an object's spectrum is barely perceptible in the 2D image, even after a very long exposure.

One of specINTI's important automatisms can fail in such a situation: the search for the vertical position of the spectrum (its Y-coordinate relative to the bottom of the image).

Failure can be due to noise, hot spots, or a poorly treated portion of the image, which can mislead specINTI because the intensity of the trace is much weaker than these defects.

There are several techniques for trying to resolve this problem.
Suppose that after displaying at high contrast, we locate the trace at the Y-coordinate = 423.

Note : If the spectrum appears slanted in the image due to poor camera orientation, always

measure the Y value in the center of the image along the horizontal axis.

The first step is to limit the search area for the star's trace along the vertical axis. For this, we use the parameter "posy_exclude". For example, here:

```
posy_exclude: [380, 460]
```

This means that the search for the trace will not be done over the entire height of the image, but between the Y-coordinates = 380 and Y = 460. You can, of course, widen or narrow this search area.

"posy_exclude" is a powerful tool that you can use in many situations. For example, if the trace you want to extract is next to the trace of a much brighter star. Leaving specINTI in full automatic mode, you will always get the spectrum of the brightest star. "posy_exclude" allows you to eliminate this risk and enable specINTI to automatically find the appropriate target.

If this solution fails, you must use the "posy" parameter by writing in the configuration file:

```
posy: 423
```

This completely blocks the automatic search for the trace and forces specINTI to perform the treatments around the Y-coordinate = 423 (including binning).

Although this solution is very effective, it is unfortunately not always satisfactory. Suppose we have obtained 3 spectra of the same object, but for one reason or another, the Y-coordinate changes slightly each time: Y1 = 423, Y2 = 421, Y3 = 419.

Writing

```
posy: 423
```

specINTI adds all traces assuming that the average is around Y = 423. However, this is not the case. By freezing the vertical search with "posy," specINTI also prevents the automatic vertical centering of all spectra in the sequence, which is a normal software function to maximize the signal-to-noise ratio, even in the presence of accidental vertical movements.

However, there is a solution. Write instead:

```
posy: -423
```

The negative value of the parameter is deliberate. Of course, it is the positive value that will be retained, but indicating a negative number fundamentally changes the software's operation.

Indeed, you most likely have something like this in your configuration file (because it is a mandatory parameter):

```
bin_size: 14
```

This is the vertical binning height (aggregation) that the software uses to gather the pixel intensity, column by column, to build the spectral profile. This area is normally centered on the Y-coordinate = 423 in our example. In this case, binning takes place between the coordinates Y' = 423-7 = 416 and Y'' = 423+7 = 430.

This seems perfect at first glance because our three spectrum traces fall into the considered binning area. But there is a better approach. By giving a negative value to the Y-coordinate, specINTI recenters all three spectra using only an image strip between Y = 416 and Y = 430.

This approach often works well because the risk of facing an aberrant pixel on such a narrow band is relatively rare (and you also have the freedom to choose the height of the binning). This trick is similar to the "posy_exclude" solution but is simpler and more precise in complex situations.

What if it still doesn't work if specINTI still refuses to extract the spectrum in the right place?

Tip: An excellent idea, if you have set the value of 1 for the "check_mode" parameter, is to examine the intermediate control image produced by the software in the working folder under the name "_step101.fits". This image is often a mine of valuable information. It contains the sum of all sequence images, processed, recentered on the best trace, without the sky background, possibly filtered. Moreover, and this is crucial, you will see horizontal lines on this image. These lines delimit the sky calculation zones you have requested, the binning zone, and finally, a central line supposedly corresponding to your target. If this is not the case, it is time to act!

Our last resort is to limit the trace search to the image's width. Normally, this search is done on a vertical projection of the entire image width. However, this is no longer the case if you use, for example:

```
xlimit: [750, 980]
```

The trace search is then performed between the X-coordinates = 750 and X = 980 in pixels. The trick is to adjust these bounds to frame the most intense part of the spectrum. This method can be combined with the previously described vertical search restrictions.

Note: In very difficult cases, specINTI may not be able to automatically find the tilt angle of the spectrum trace (the inclination of the trace) or the slant angle. In this case, if necessary, you will have to force these angles, for example:

```
tilt: 0.32
slant: -0.12
```

Tip: Flip through the reference manual, and you'll find plenty of inspiration. It is relatively short because specINTI exploits a limited number of parameters for work, performing many operations automatically. Here's a reminder of the link to the reference manual:

http://www.astrosurf.com/solex/spevinti6_en.html

## 20. Exploiting Melchiors' Spectra Library

20.1 Introduction

Melchiors is a vast library of 3,256 spectra covering the spectral range from 380 to 900 nm, with a resolution of R = 85,000. These spectra were acquired using the HERMES spectrograph installed on the Mercator telescope at the Roque de Los Muchachos Observatory in La Palma.

This database is publicly accessible at the following address:

https://www.royer.se/melchiors.html.

For detailed information, please consult Royer et al. 2013:

https://www.royer.se/melchiors/royer_etal_melchiors.pdf.
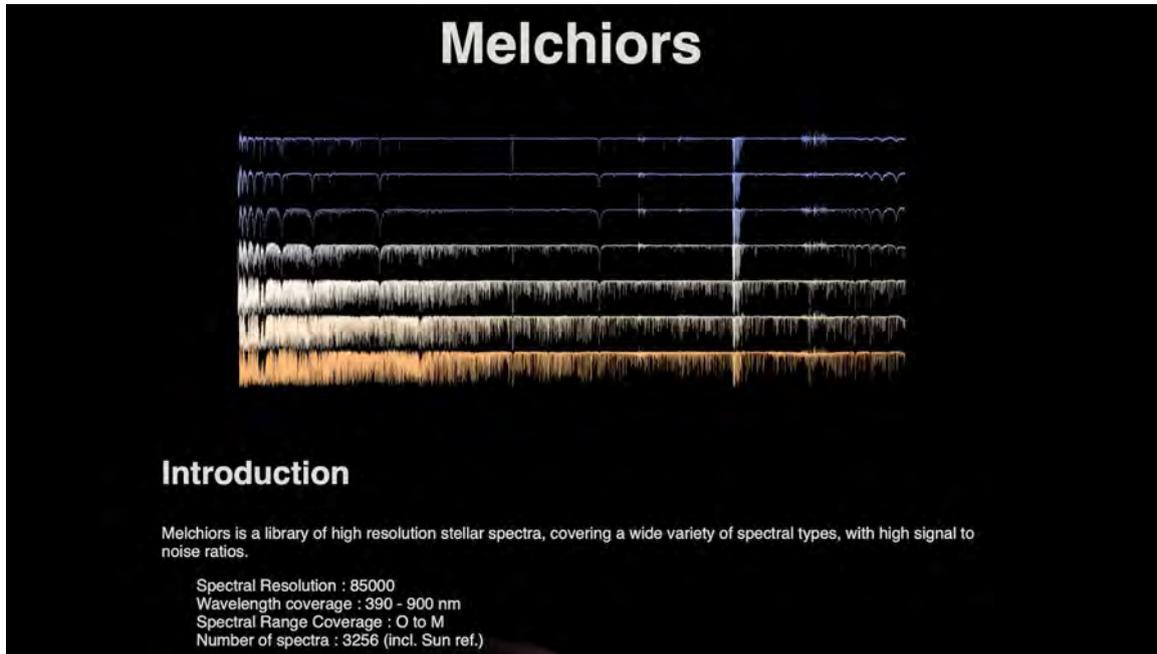
The spectra are of high quality, brought to a barycentric reference frame for radial velocities and available in various formats. The most relevant for us is the one where atmospheric absorption is corrected (the spectra are thus presented as they would be observed from space). The intensities are relative (not in absolute values, such as in erg units). Sometimes, several spectra are available for the same star. There is also a spectrum of the Sun, very useful (Ganymede Sun). The magnitudes of the stars cover a range from the brightest in the sky to magnitude 8.

This library is revolutionary for us, amateurs (and probably just as important for professionals), because it offers a very extensive set of reference spectra in the sky on which we can rely to calibrate raw data.

The availability of this database confirms the strategy proposed in this toolbox, aiming to determine the instrumental response by separating it from atmospheric transmission. The Melchiors base makes this data reduction technique even simpler (see section 11). Additionally, the spectral resolution (R) of the spectra being high, it also facilitates the calibration of our own spectra in wavelength, including in "high resolution", from these natural sources (calculation of the terms of degrees higher than 1 of the calibration polynomial - refer to section 6 for low resolution and section 18 for high resolution and lateral mode 4).

The FITS format of the spectra in this base is quite complex, with numerous extensions. A small utility has been created in specINTI (from version 2.5) in the form of a simple function to convert Melchiors spectra into a simplified FITS format, directly compatible with specINTI and many other processing software. This is the function "_pro_conv_melchiors", whose use will be described later.
Note that this addition in specINTI allows immediate use of the spectra from the Melchiors library, but this is not the only way to access the spectra from the library. In particular, a web application is currently under construction (STAROS association) which will make exploiting this resource even more operational in the future.

20.2 Extracting a Melchiors Spectrum

As an example of exploiting the Melchiors library, we will show how to extract a spectrum and use it by focusing on a very concrete observation of the star 10 Lacertae (itself a photometric and spectrophotometric standard).

The method chosen here to exploit the Melchiors library is to bring the entirety of this base to local storage. From the main page, download the two compressed folders, "Spectra Part I" and "Spectra Part II" (they are each 9 GB, but this remains reasonable nowadays).

The Melchiors library contains a spectrum of the star 10 Lac. Our aim is to compare this spectrum with the observed one to evaluate the spectral response of the instrument used to the incident stellar flux and to check the quality of the spectral calibration.

The files in the Melchiors library are organized by numbers, for example:

00307233_melchiors_spectrum.fits

To identify the correct file, we need to match the star's name with this file number. The Excel (Microsoft) file "Melchiors_lib.xlsx" is a correspondence table (you can sort by magnitude, celestial coordinates, etc.). You can download this file at the following address:

http://www.astrosurf.com/buil/specinti2/melchiors/excel/melchiors_lib.xlsx.

Locate in the spreadsheet the line(s) concerning 10 Lac:

3057	374023	HD 214203	HIP 111601	6,42	A1III	22:36:36.30	11:41:47.90
3058	376041	HD 214454	* 9 Lac	4,63	A9VkA7mA6	22:37:22.40	51:32:42.40
3059	585269	HD 214454	HD 214454	4,63	A9VkA7mA6	22:37:22.40	51:32:42.40
3060	389330	HD 214665	V* V416 Lac	5,17	M4+III	22:38:37.90	56:47:44.30
3061	478113	HD 214734	* 30 Cep	5,19	A0IV	22:38:39.10	63:35:04.09
3062	374024	HD 214567	HD 214567	5,82	G8II	22:38:52.60	19:31:20.10
3063	416436	HD 214680	* 10 Lac	4,88	O9V	22:39:15.70	39:03:01.01
3064	478110	HD 214680	* 10 Lac	4,88	O9V	22:39:15.70	39:03:01.01
3065	584854	HD 214680	HD 214680	4,88	O9V	22:39:15.70	39:03:01.01
3066	835841	HD 214749	LTT 9143	7,84	K4.5Vk	22:40:43.38	-29:40:28.13
3067	374025	HD 214850A	BD+13 4971A	6,05	G4V	22:40:54.00	14:33:00.00
3068	366666	HD 214923	* zet Peg	3,41	B8V	22:41:27.70	10:49:52.90
3069	366667	HD 214923	* zet Peg	3,41	B8V	22:41:27.70	10:49:52.90

We notice that the library contains in fact two spectra of 10 Lac. We are interested in the first one (for example), whose rank number is 416436.

The best at this stage is to copy the corresponding FITS file from the library to your current working folder:

00416209_melchiors_spectrum.fits	13 mars 2023, 15:14	6,7 Mo	Flexible...cument
00416210_melchiors_spectrum.fits	13 mars 2023, 15:14	6,7 Mo	Flexible...cument
00416281_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416282_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416283_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416285_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416434_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416436_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416437_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416438_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416439_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument
00416440_melchiors_spectrum.fits	13 mars 2023, 15:15	6,7 Mo	Flexible...cument

The conversion of the Melchiors file into a more conventional FITS file is done through the "_pro_conv_melchiors" function, whose syntax is as follows:

_pro_conv_melchiors: [input, output, telluric]

- input: the name of the Melchiors file (without the FITS extension);
- output: the name of the file after conversion;
- telluric: a parameter that allows you to choose to extract a file with (value: 1) or without (value: 0) atmospheric absorption lines.

This function is executed inside a "yaml" parameters file "_conf_melchiors.yaml" (you are free to choose a name), in which the pat
h of the working directory where the file to convert is located is also specified. Here is the complete content of the "yaml" file we are using for this example (you need to change the name of the path). You can copy/paste this content into your own configuration folder, named "_configuration":

```
# ****************************************************************************
# CONF_MELCHIORS
# Conversion of a Melchiors FITS file into a spectrum FITS readable by specINTI
# ****************************************************************************

#----------------------------------------------------------------------------
# Working directory #
#----------------------------------------------------------------------------
working_path: D:/starex374

#----------------------------------------------------------------------------
# Conversion #
#----------------------------------------------------------------------------
pro_conv_melchiors: [00416436_melchiors_spectrum, 10lac_ref, 0]
```

We identify the reference of the Melchiors file for the star 10 Lac. We opt for the name "10lac_ref" for the resulting file. Finally, we wish for the atmospheric lines to be absent (the authors of the Melchiors base took care to produce a version of the spectra in which these parasitic lines coming from our own atmosphere are removed, and it's the one we are using).

Here's what the Melchiors spectrum looks like in its full spectral extent, sampled with a step of 0.05 angstroms by specINTI:
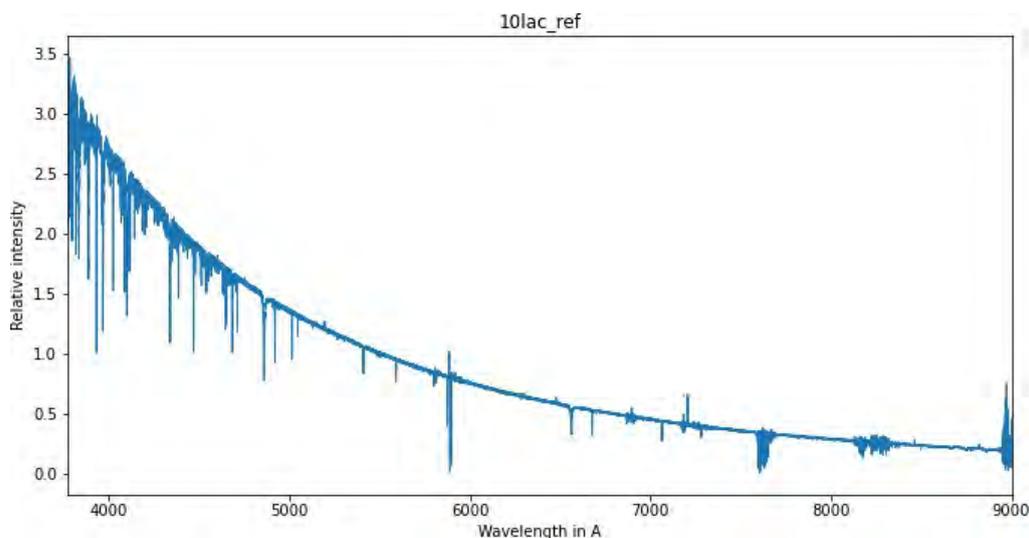
We keep it aside for later use.

20.3 Calculation of the 10 Lacertae Spectrum Without Instrumental

Correction

The data was acquired on November 8, 2023, with an Askar 107PHQ telescope (107 mm diameter, 750 mm focal length), a Star'Ex HR spectrograph (2400 lines/mm grating), and an ASI533MM pro camera. In all, 7 spectra of this object were taken around the H-alpha line, with an exposure time of 300 seconds each. Spectral calibration is carried out via a 1.5 mm diameter plastic fiber constantly sending the signal of a neon lamp to the center of the 107 mm lens (this is the lateral mode). The flat-field is created by placing an LED panel in front of the objective (38 exposures, with an exposure time of 6 seconds for the model used). The observation site is located in Antibes Juan-les-Pins, in the south of France.

The raw data for this observation corresponding can be downloaded at this address:
http://www.astrosurf.com/buil/specinti2/melchiors/data/10lac.zip

The configuration data useful for this example can be downloaded here:
http://www.astrosurf.com/buil/specinti2/melchiors/configuration/configuration.zip

This content will allow you to replay the processing and better understand the approach used in this case. Do not hesitate to do it. Note that to reduce the volume of data, images of offset, dark, and flat-field (DOFs) are provided in a pre-processed form. The following picture shows one of the 7 images, in which, in addition to the spectrum, the calibration lines are superimposed:
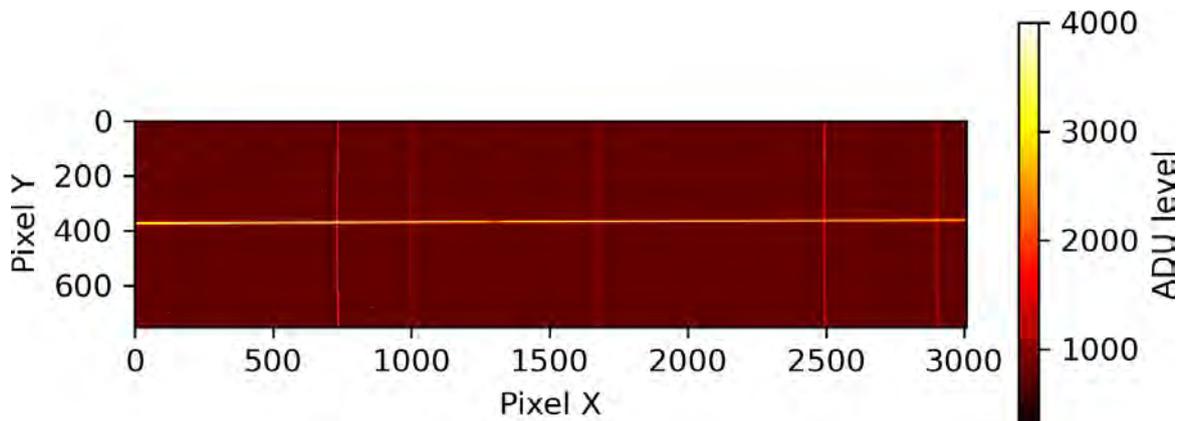
The 7 images of the spectrum of 10 Lac are treated in the usual way with specINTI, here in mode 4 (lateral mode with a pre-established spectral dispersion law). However, we do not apply the correction of the instrumental response, this being assumed to be unknown at the moment. Here is the complete listing of the configuration file used:

```
# *****************************************************************************
# CONF_HR1_10lac (mode 4)
# *****************************************************************************

#-----------------------------------------------------------------------------
# Working directory #
#-----------------------------------------------------------------------------
working_path: D:/starex374

#-----------------------------------------------------------------------------
# Processing batch file #
#-----------------------------------------------------------------------------
batch_name: 10lac

#-----------------------------------------------------------------------------
# Spectral calibration mode #
#-----------------------------------------------------------------------------
calib_mode: 4
```

              Christian Buil

```
#-------------------------------------------------------------------------------
# Calibration polynomial #
# observation #374
#-------------------------------------------------------------------------------
calib_coef: [-1.092363802124218e-06, 0.10117821188182664, 6433.414563476807]


#-------------------------------------------------------------------------------
# Automatic search for neon calibration lines #
#-------------------------------------------------------------------------------
auto_calib: [6490, 6690]


#-------------------------------------------------------------------------------
# Width in pixels of the neon calibration line search area #
#-------------------------------------------------------------------------------
search_wide:40#


#-------------------------------------------------------------------------------
# Binning width #
#-------------------------------------------------------------------------------
bin_size: 20


#-------------------------------------------------------------------------------
# Sky background calculation zones #
#-------------------------------------------------------------------------------
sky: [160, 22, 22, 160]


#-------------------------------------------------------------------------------
# Erasing calibration sidelines #
#-------------------------------------------------------------------------------
clean_wave: [6506.5, 6532.8, 6598.9, 6678.27]
clean_wide: [1.1, 0.8, 0.9, 0.5]


#-------------------------------------------------------------------------------
# Radius of curvature of the smile #
#-------------------------------------------------------------------------------
smile_radius: -18000


#-------------------------------------------------------------------------------
# Sky extraction mode (1 = optimal) #
#-------------------------------------------------------------------------------
sky_mode: 1


#-------------------------------------------------------------------------------
# Horizontal terminals for geometric measurements #
#-------------------------------------------------------------------------------
xlimit: [400, 1800]


#-------------------------------------------------------------------------------
# Instrumental response #
#-------------------------------------------------------------------------------
# instrumental_response: _rep374


#-------------------------------------------------------------------------------
#Atmospheric transmission correction#
#-------------------------------------------------------------------------------
simbad: 1
corr_atmo: 0.20


#-------------------------------------------------------------------------------
# Median filtering pattern (0 = no median filtering) #
#-------------------------------------------------------------------------------
kernel_size: 0


#-------------------------------------------------------------------------------
# Gaussian filtering #
#-------------------------------------------------------------------------------
sigma_gauss: 0.75


#-------------------------------------------------------------------------------
# Optimal extraction #
#-------------------------------------------------------------------------------
extract_mode: 1
gain: 0.083
```

```
noise: 1.3

#---------------------------------------------------------------------------
# Unit normalization area #
#---------------------------------------------------------------------------
norm_wave: [6640, 6660]

#---------------------------------------------------------------------------
# Final profile cropping area #
#---------------------------------------------------------------------------
crop_wave: [6500, 6700]

#---------------------------------------------------------------------------
# Longitude of the observation location #
#---------------------------------------------------------------------------
Longitude: 7.093

#---------------------------------------------------------------------------
# Latitude of the observation location #
#---------------------------------------------------------------------------
Latitude: 43.581

#---------------------------------------------------------------------------
#---------------------------------------------------------------------------
# Altitude of the observation location in meters #
Elevation: 40

#---------------------------------------------------------------------------
# Observation site #
#---------------------------------------------------------------------------
Site: Antibes Saint-Jean

#---------------------------------------------------------------------------
# Instrument description #
#---------------------------------------------------------------------------
Inst: Askar107PHQ + StarEx2400 + ASI533MM

#
#---------------------------------------------------------------------------
# Observer #
#---------------------------------------------------------------------------
Observe: cbuil

#---------------------------------------------------------------------------
# Output format (0: compact, 1: expanded) #
#---------------------------------------------------------------------------
check_mode: 1

#---------------------------------------------------------------------------
# S/N calculation is requested #
#---------------------------------------------------------------------------
snr: [6650, 6665]

#---------------------------------------------------------------------------
# Spectral shift requested #
#---------------------------------------------------------------------------
spectral_shift_wave: 0.025

#---------------------------------------------------------------------------
# Correction of the barycentric speed of the Earth #
#---------------------------------------------------------------------------
corr_bary: 0
```

As always, you can get inspiration from this configuration file for your own observations, but be careful, it is presented here in an intermediate version that should not necessarily be adopted as is. Four points are to be noted:

Firstly, the line "instrumental_response" is for the moment commented out, as the parameter is not evaluated yet.

Secondly, notice the presence of the "corr_bary" parameter to which we attribute the value 0. This forces specINTI to correct the barycentric velocity of the Earth at the time of the

observation (in other words, the radial velocity of the object is the one we would see from the center of the Sun). Indicating 0 means that, on the other hand, the object's own radial velocity is not corrected, which is also the case in the Melchiors data.

Thirdly, the correction of atmospheric transmission (excluding molecular lines) is carried out through the "corr_atmo" command. The AOD adopted here is 0.2 since the sky is not considered very transparent (on average, use 0.13). This correction is a fundamental element because it will allow us to find the true "instrumental response."

Finally, note that the "spectral_shift_wave" parameter has a value of +0.025 angstroms. This slight correction is due to the fact that the fiber illumination of the pupil is too pinpoint, which can generate this bias in spectral calibration. Make a control by performing a first treatment, then verify the calibration on the telluric lines using the "Verif atmo" tool in the "View profile" tab under specINTI Editor. Here is the content of the "Observation" tab for our example, allowing you to generate the "10lac.yaml" observation file:

Click on the "Execute" button to run the processing. At the end, you get the following result, plotted in blue, while in orange is plotted the Melchiors library spectrum extract for the star 10 Lac:
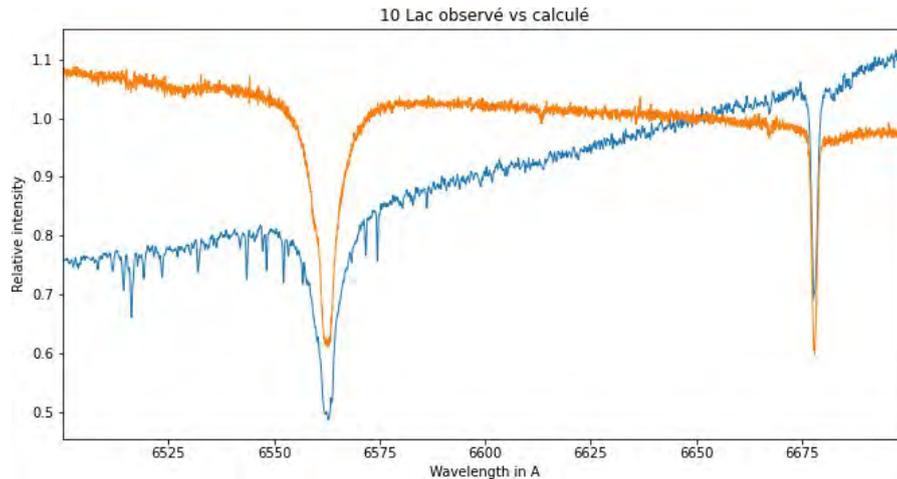
The appearance of the continuum is very different between these two spectra, and rightly so, since we have not performed an instrumental response correction. The fact that our spectrum, in blue trace, appears to be more intense in the red than in the blue comes from the use of an LED panel to create the flat-field. LED light has a deficit of red relative to blue, causing an over-correction when raw images are divided by the flat-field master image. It's precisely this type of problem that we will now remedy by exploiting the reference spectrum from the Melchiors library.C'est à ce type de problème que nous allons remédier à présent en exploitant le spectre de référence de la librairie Melchiors.

Tip: you can use the "_pro_norm" function to normalize the Melchiors reference spectrum to unity over a given wavelength range to facilitate comparative display. Here, the spectra are normalized towards the wavelength of 6650 Å (see also the "norm_wave" parameter in the configuration file).

20.4 Calculating the Instrumental Response

The instrumental response is the result of dividing the observed spectrum by the reference spectrum of the star associated with an observation outside the atmosphere. We will perform this operation with the help of a small configuration file, here is its listing:

```
# ***************************************************************************
# CONF_MAKE_CONTINUUM
# Fits a stellar continuum to a parabolic function #
#***************************************************************************


#---------------------------------------------------------------------------
# Working directory #
#---------------------------------------------------------------------------
working_path: D:/starex374


#---------------------------------------------------------------------------
# Normalization to unity in a spectral interval #
#---------------------------------------------------------------------------
_begin:
_pro_gauss: [_ref_10lac, 6, tmp1]
_pro_div: [_10lac_20231108_856, tmp1, tmp2]
_pro_fit: [tmp2, 6505, 6585, 6625, 6690, _rep374]
_end:
```

After defining the path of the working directory, we find three functions that launch in sequence.

First, we perform a Gaussian smoothing of the reference profile _ref_10Lac to degrade its

spectral resolution from R = 85,000 to R = 20,000, this latter value corresponding to the resolution power of the Star'Ex spectrograph we are using. The filter width is 6 pixels (you can choose this value), and the result is saved in a file under the name tmp1.fits.

Then, the "_pro_div" parameter commands the division of tmp1.fits by the 10 Lac spectrum calculated in the previous section. The result of this division is a file named tmp2.fits (you can choose the name, here "temp" for "temporary").

Finally, we adjust a parabolic profile to the result of the division, which will become the actual instrumental response. As a parameter of the "_pro_fit" function, we provide the name of the profile to be adjusted (here "tmp2") and a list of 4 wavelengths associated with intensities from which specINTI will adjust its parabola. It is advisable to choose areas without lines and uniformly distributed to calculate the instrumental response. The name chosen for the file describing the instrumental response is _rep374.fits (it is common to associate the response file with the data that allowed its calculation, here the night number 374 made with Star'Ex, knowing that this same file is usable for subsequent nights).

Here is the result after launching the script written in the "conf_make_continuum" configuration file:
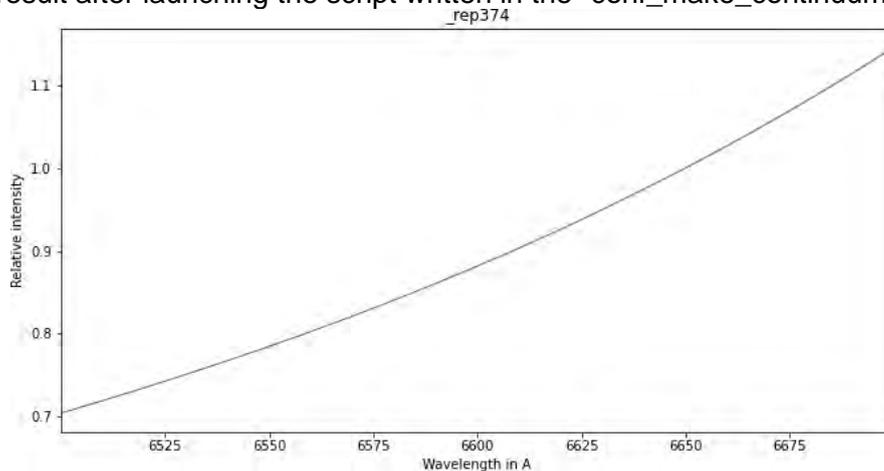
Here we make an important remark: the appearance of the calculated response is quite uniform; we only notice a slope and a slight curvature. When working in high spectral resolution and on a particularly narrow spectral interval, there is no reason for it to be otherwise. If this is not the case, it may indicate a problem in the processing protocol, such as incorrect use of flat-field (or lack of use!), poor profile extraction, among others. It is imperative to correct these elements because there is no valid reason to obtain anything other than what is presented here, at least in high resolution (it can be a bit more complex in low resolution).

The response curve is supposed to be so monotone that we have allowed ourselves to define only 4 points in the spectrum to adjust a simple parabola (a polynomial of degree 2). This procedure is secure, precise, and simple because it is automated.

However, it is honest to acknowledge that the evaluation of the instrumental response can always hold surprises. For more complex cases and to further improve the result, specINTI offers the functions "_pro_fit2" and "_pro_fit3," where this time, it is necessary to provide respectively 5 and 6 points in the spectral interval for adjustment according to a polynomial of degree 3. For example here:
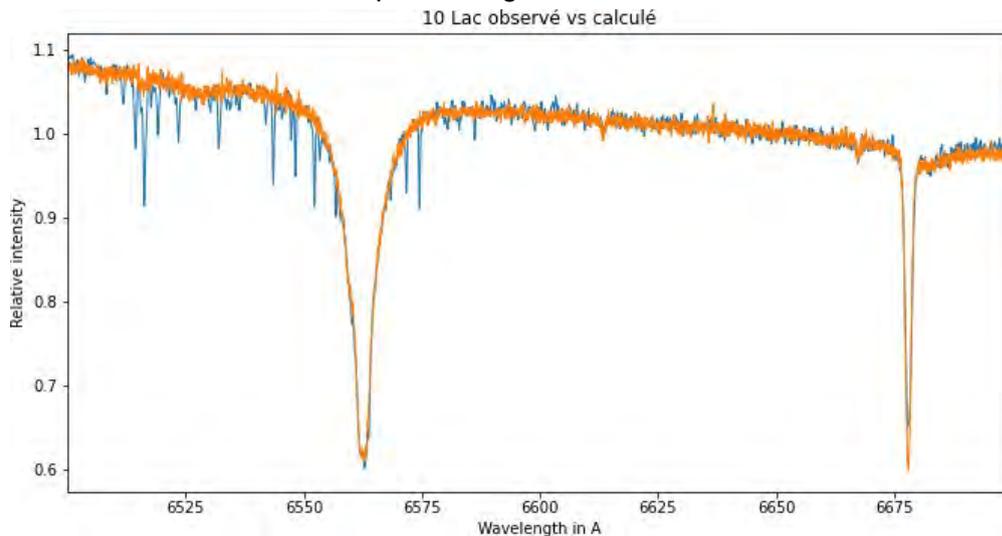
_pro_fit3: [tmp2, 6505, 6530, 6540, 6584, 6625, 6690, _ref374]

20.5 Calculating the Spectrum of 10 Lacertae with Instrumental Correction

To apply the instrumental response correction, simply uncomment the "instrumental_response" line.

```
instrumental_response: _rep374
```

All that's left is to restart the entire processing, so here is the result:

In blue, our spectrum; in red, that from the Melchiors library. Let's take the opportunity to check that the wavelength calibration is correct, which seems to be the case here (note the superposition of the profiles).

In reality, it is not quite finished yet. When you distribute a spectrum for study, for example to feed the BeSS database or participate in a STAROS campaign, it is not always required to perform the barycentric velocity correction. At this stage, be sure to comment out the "corr_bary" line (remove the # character in front of it) if you work in these contexts. Then restart the process, and your spectrum will be ready for exploitation!

The response thus calculated can be used to treat other spectra. Once evaluated, it is an "instrumental constant," usable over many nights without requiring reevaluation. Here, for example, is the result of processing the spectrum of the star Deneb (in blue), taken under similar conditions (107 mm lens, Star'Ex, here 30 x 120 seconds) and with the same instrumental response – and in orange the spectrum of Deneb (alpha Cyg) also present in the Melchiors database: