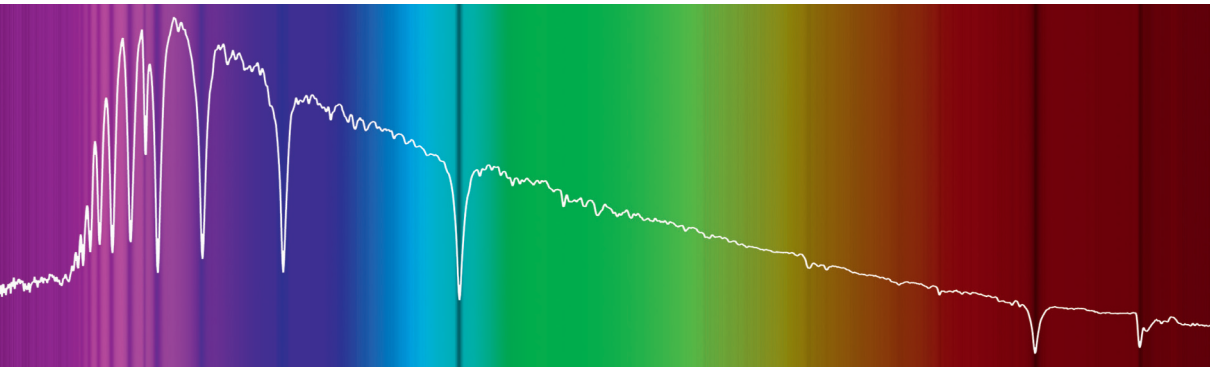


10 experiments in astronomical spectroscopy

for amateurs

Olivier Garde

edp sciences

10 experiments in astronomical spectroscopy

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The field of investigation of astronomical spectroscopy is vast and can provide a wealth of information about the celestial objects observed (Planets, stars, nebulae, novae, supernovae, galaxies, quasars) through the light they emit.

Indeed, this light can be broken down into an atomic spectrum, and based on its analysis and current knowledge of physics, it is possible to determine various characteristics of the star being studied.

This book presents methods and tools used for spectrum analysis and covers topics such as:

– the measurement of velocity (radial, orbital, rotational, redshift),

– the evolution over time in certain spectral lines,

– the explosion of a nova or supernova,

– the physical nature of an object (is it a planetary nebula? Is it a galaxy?).

Spectroscopy also allows for the reconstruction of an image by digitizing the surface of a planetary nebula at a given wavelength. It is also possible to estimate the temperature of a star and even evaluate its density.

For each chapter, the author indicates the type of equipment to be used (optics, camera, spectrograph) and explains step-by-step the methodology for producing the necessary data (acquisition, data processing, etc.) using ten concrete examples that the author has tested himself.

This book is intended for amateur astronomers who are curious to learn what can be gleaned from a spectrum so that they can then make their own observations and analyses sometimes rivaling those of professionals!

Amateur astronomer and holder of a university diploma in Astronomy and Astrophysics, ***Olivier Garde*** *is involved in numerous spectroscopy projects and helped found the 2SPOT association (spectral observations from Chile) and STAROS Projects (spectral database and design of a spectroheliograph, the SUNSCAN). He is also one of the validators of the BeSS spectral database at the Paris-Meudon Observatory and co-author of numerous scientific publications.*

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This book is based on data produced by the author in various observatories: Observatoire de Haute-Provence, C2PU Calern (Observatoire de la côte d'Azur, Astroqueyras, Mars Observatory in Ardèche France, Observatoire de la Tourbière in Isère region in France, Observatoire 2SPOT in Chile hosted by Deep Sky Chile.

All illustrations and photos in this book have been produced by the author unless otherwise stated.

Cover picture: Horsehead nebula in the constellation of Orion, HII region called IC434. Acquisitions with a CCD SBIG STX 16803 (LRVB filters) and Ritchey-Chrétien telescope of 400mm in diameter.
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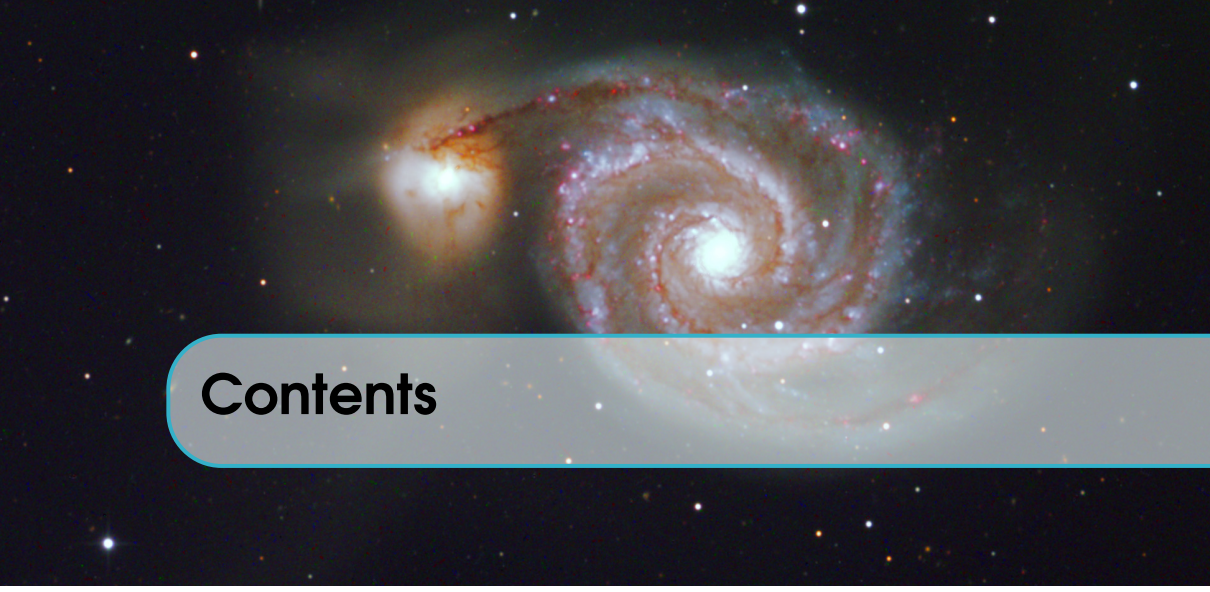
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About the author

Olivier Garde discovered astronomy at the age of 10, when his parents gave him a Newtonian 115/900 telescope for his birthday. Like many people, he was totally impressed by the eyepiece view of Saturn and its rings.

Olivier's visual introduction to astronomy soon led to imaging. He started with film photography and later moved to digital imaging when the first CCD cameras became available (Audine, SBIG ST6).

Olivier has also travelled the world to observe total and annular solar eclipses, taking photographs and videos which have been broadcast by various media (Venezuela, Chile, South Africa, Australia, Mongolia, Egypt, Zimbabwe, Spain, Iceland, USA).

In 1996, he obtained a University Degree in Astronomy and Astrophysics at the University of Paris Sud XI, and also became interested in photometry, taking light curves of asteroids and variable stars.

In 1998, he joined the Lyon Ampère Astronomy Club (CALA) and met many amateurs who taught him a great deal about how to observe through a telescope.

In 2000, Olivier discovered spectroscopy thanks to Valérie Desnoux and Christian Buil. It was a great moment for him to see what could be measured with this technique.

In May 2003, he was able to take part in a major and seminal meeting organized by the CNRS (French National Centre for Scientific Research) and, in particular, by Jean-Pierre Rozelot: " Les rencontres d'Oléron " where professional and amateur astronomers met to discuss pro/am collaborations. It was on this occasion that the first pro/am collaborative project in spectroscopy was born: Be-type stars and the creation of a dedicated spectral database: BeSS (Be Stars Spectra), set up by Coralie Neiner at the Paris-Meudon Observatory. For him, it was a major realization of what amateurs could contribute to science at their own level, a bit like the year zero of amateur spectroscopy, even if a few precursors had already started well before this meeting, but it did help to federate a few professionals and amateurs around a joint work project, particularly at the time around the Be stars.

He has also taken part in many astronomical observations on research telescopes, such as the Saint-Véran observatory (Astroqueyras - France), at the Mars observatory in Ardèche (France), at C2PU to the Côte d'Azur observatory on the Calern plateau (close to the french riviera), at the OHP (Observatoire de Haute-Provence) with the 1.52 m telescope.



Fig. — The 2003 Oléron pro/am meetings. Photo of the group of amateurs and professionals at these meetings organized by the CNRS in May 2003.

In 2017, during a workshop on Be stars at the Paris-Meudon observatory, he joined the team of validators of spectra of the BeSS database.

In 2018, Olivier joined the team at Shelyak Instruments (French manufacturer of spectrographs) as a technical consultant.

In 2019, Olivier and collaborators Stéphane Charbonnel, Pascal Le Dû, Lionel Mulato and Thomas Petit, founded 2SPOT (*Southern Spectroscopic Project Observatory Team*). 2SPOT operates 2 remotely piloted telescopes dedicated to spectroscopy in Chile, one in low resolution with an Alpy 600 spectrograph, the second with an Echelle (eShel) spectrograph in medium resolution. Extensive automated operation and processing software development has made 2SPOT an exceptionelly productive facility.

In 2023, together with Christian Buil, Valérie Desnoux, Matthieu Le Lain and Guillaume Bertrand, they set up the STAROS Projects association, with the aim of launching spectroscopic measurement campaigns and developing new tools and instruments. Thus, in november 2024, they created the SUNSCAN, an all-in-one spectroheliograph to scan the Sun at various wavelengths.

Olivier is also involved in several pro/am collaborations in spectroscopy, and has co-authored numerous publications.

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My first thanks go to my parents Louis and Annie who got me interested in history, science, nature and music from an early age. Without them, I would probably never have taken up astronomy.

This book would never have seen the light of day if, in the course of my life, I had not met the people I am going to mention now, starting with my wife Florence, who has supported me now for over 20 years, but who, as a scientist herself, gave me a lot of pertinent feedback on how to write this book.

To my brother François, who is also my partner in an audiovisual company that we created and have been running together for over 30 years, where we produce many scientific videograms. Our collaboration is always in a spirit of innovation.

Since 1997, within CALA (Club d'Astronomie de Lyon Ampère), I have also met many people who have enabled me to take an interest in aspects of amateur astronomy that I knew little or nothing about. So I would like to thank the members of CALA, and especially:

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Thanks to Pierre Dubreuil and Alain Lopez, who introduced me to the Calern site and the two 1m telescopes of the C2PU where I was able to observe with the LISA and Whoppshel spectrographs.

Many thanks also to Joe Daglen and Ken Hudson for organizing the big spectroscopy meeting in 2019 in Las Cruces, New Mexico (SMSW-2: Sacramento Mountains Spectroscopy Workshop). It was a great opportunity to meet many amateurs and professionals all around the world.

My thanks also go to several astrophysicists and astronomy professionals, such as

Agnès Acker, Denis Gillet, Jaroslav Merc, Coralie Neiner, Jean-Pierre Rivet, Vincent Robert, Alexandre Santerne, Steven N. Shore who have all given up their time to integrate amateurs into their professional scientific research projects, providing us with relevant information in certain fields of astrophysics or helping us promote pro/am actions in astronomy. Without them, amateur spectroscopy would not be as advanced, efficient or useful.

Shelyak Instruments, founded in 2006, has also played a major role in motivating me to take up spectroscopy with the equipment it has designed for amateurs (and professionals too). Many thanks to François Cochard and Olivier Thizy for creating this unique company.

Thanks also to Daniel Vérilhac, who introduced me to the RC 600 at Mars Observatory in Ardèche (France). Together we made a number of spectra on this telescope. Daniel also did a thorough re-reading of my book, a long and tedious job.

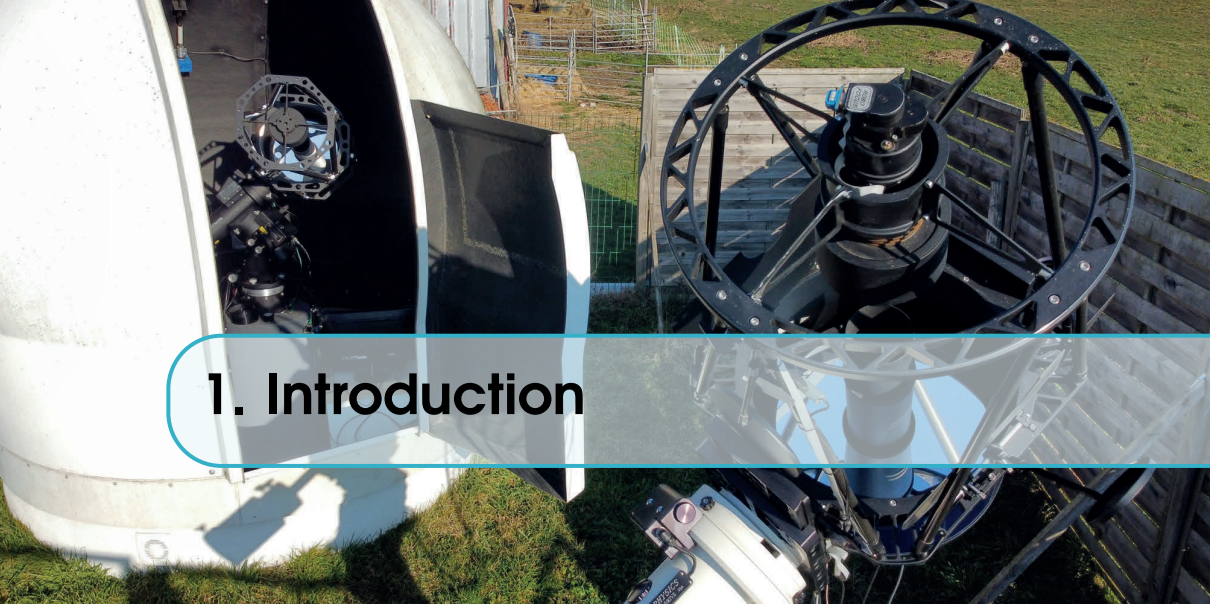
Thanks also to Christian Buil, Stéphane Charbonnel, Pascal Le Dû and François Teyssier for proofreading certain chapters. Their pertinent comments have been taken into account.

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I can not end these words of thanks without mentioning in particular Christian Buil and his wife Valérie Desnoux, both of whom have been involved in spectroscopy for many decades, the pioneers of amateur spectroscopy. They have greatly motivated me to take up this discipline, as have many other amateurs.

And then there is the whole team behind 2SPOT (Southern Spectroscopic Project Observatory Team): Stéphane Charbonnel, Pascal Le Dû, Lionel Mulato, Thomas Petit. Together, we have led an ambitious and exciting project to set up two telescopes and spectrographs in Chile controlled from a distance.

Then more recently, with Matthieu Le Lain and Guillaume Bertrand, two computer geniuses, together with Christian Buil and Valérie Desnoux, we created STAROS Projects for the management of spectroscopic databases and the development of tools and hardware for amateur spectroscopy.



1. Introduction

1.1 The goal of this book

The field of investigation in astronomical spectroscopy is vast. In this book, we aim to show just part of the diversity of measurements that can be made in this astronomical domain, whether measuring velocities, the evolution of a profile over time, or the spectral signature used to classify an object.

This book describes 10 practical projects that provide specific astronomical measurements. For each project we describe the equipment used, the method of acquisition and the free software used to complete the data processing.

In the following chapters, we will discuss:

1) Star temperature and spectral classification, determine whether it's a dwarf star or a supergiant.

2) The distance of galaxies and quasars, spectral shift measurement using the Doppler-Fizeau effect and measuring their escape velocity.

3) Spectro-imaging of planetary nebulae, how to digitize the surface of these objects and and take measurements with certain lines in the spectrum (electron density and temperature).

4) Studying Be-type stars, track their evolution over time and detect outburst.

5) Studying novae and supernovae by analyzing the evolution of their spectra, measure

the ejecta's expansion velocity. Determine the type of supernova based on spectral line present. presents.

6) How to confirm the nature of objects not yet referenced such as candidate planetary nebulae.

7) Measuring planetary rotation velocity, galaxies rotation velocity, disks of matter rotating around certain stars or accretion disks close to a black hole.

8) Creating time series over a short period of time and highlight spectrum changes on a particular line.

9) Studying spectroscopic binary stars, determine their periods, highlight the presence of one or more companions.

10) Measuring astronomical filters, slits and liquids using a spectrograph "on table" in the lab: the Lab'Ex.

Unless otherwise stated, all graphs, spectra, drawings, photographs and diagrams in this book were produced by the author.

1.2 Prerequisites in astronomy

To be able to carry out the various experiments proposed in this book, the reader must already have mastered:

• Setting up an equatorial mount by aligning it with the north or south celestial pole at less than 2 arc minutes. This precision is required to point at the right target and achieve precise autoguiding tracking.

• Precise pointing to a target to position it on the spectrograph slit.

• The acquisition software: for shooting with a CMOS or CCD camera, gain management for CMOS cameras. Note: it is advisable to acquire spectra in 1x1 binning with a CMOS camera.

• Doing autoguiding on a set point X, Y, on the target itself or on a neighboring star and visible on the autoguider's sensor.

• Setting the acquisition PC's clock to provide precise dating for each spectrum

produced (to be carried out before each observation).

• Adjusting your spectrograph, during daylight and on a table to produce the best possible spectra (focusing and orientation of the spectral camera, focus and orientation of the autoguiding camera).

• Spectrum processing (calibration in wavelength and intensity). Certain specific processing procedures and some useful clarifications on certain points will be described in this book.

These prerequisites should pose no problems for those who are already involved in deep-sky imaging. For spectra processing, software can be found on the Internet and there are plenty of tutorials on how to do it.

1.3 Units, conventions and physical values in spectroscopy

In this book, you will discover a number of physical values, conventions and units. Here is a description of some of the most commonly used:

1.3.1 Wavelengths

The wavelengths are expressed in ångströms (Å). It is a "historical" tradition in astronomical spectroscopy to use this unit when it would have been more appropriate to use IS units (international system): the nanometer noted nm or the micrometer noted μm with:

$$1\ \mu\text{m} = 1\,000\ \text{nm} = 10\,000\ \text{Å}$$

By convention, short wavelengths are placed to the left (the blue part of the spectrum) and long wavelengths on the right right (the red part).

1.3.2 Spectral resolution of a spectrograph

In spectroscopy, we often indicate the spectral resolution denoted R. It corresponds to the ratio between the observed wavelength and the full width at half maximum (FWHM) of a spectral calibration line measured in the same area (neon, argon/neon or thorium/argon lamps are probably the most common types). The power of resolution R is given by the following equation:

$$R = \frac{\lambda}{\Delta\lambda}$$

with:
λ: the wavelength over which resolution is calculated.

$\Delta\lambda$: the full width half maximum of an atmospheric line or calibration reputed to be "very thin" (FWHM), This concept is described in detail in section 8.4.

The higher the R, the more resolving the spectrograph and the possibility to show more precise details: very slow radial velocities, exoplanets or small changes in the spectrum. For example, for a $\Delta\lambda$ (FWHM) of 1.5 Å and a wavelength observed λ of 6 563 Å, we obtain a resolution

$$R = \frac{6\,563}{1.5} = 4\,375.33$$

• For $600 < R < 3\,000$, we are in the low-resolution domain.
• For $10\,000 < R < 20\,000$, we are in the medium resolution domain.
• With $R > 20\,000$, we are in high-resolution.

The limits indicated are purely arbitrary and depending on the publication, the definition of high, medium or low resolution may differ. Some professional spectrographs offer R resolution over 70 000. In the case of amateur spectrographs, the resolutions R range from around 100 to 30 000.

1.3.3 Wavelength ranges

For the purposes of this work, the wavelength domain is divided into 3 distinct zones:

• The visible domain (from 400 to 750 nm) which corresponds to what the human eye can see.

• The near infrared, IR (from 750 nm to around 1 µm).

• The near ultraviolet, UV (from 340 to 400 nm).

These limitations are essentially due to the capabilities of the sensors available to amateurs. There are, of course, professional cameras capable of capturing wavelengths other than the visible domain, but at prohibitive cost to the amateur astronomer.

1.3.4 The *ADU*

The term "*ADU*", for *Analog to Digital Unit*, is often used to indicate the signal level present on a pixel of a CCD or CMOS camera. Each photosite converts the light received in electrons, into an analogue signal, then as a digital signal (*ADU*). The maximum level possible of *ADU* (ADU_{Max}) depends on the dynamic range N of the sensor (generally 8, 12, 14 or 16 bits) with the relation:

$$ADU_{Max} = 2^N$$

For example, a sensor with a 16-bit dynamic range may have 65 536 different values (2^{16}) which correspond to shades of grey ranging from 0 = black (no signal) to 65 536 = white (maximum signal value). If a signal is greater than the maximum possible *ADU*, it will peak at this value. In this case, the pixel becomes saturated. It is therefore advisable not to exceed 2/3 of maximum capacity, which keeps the signal within the linearity range and avoid the consequences of possible variations in sky transparency during an observation.

1.3.5 1D and 2D files

A 2D spectral file corresponds to the image of the spectrum as recorded by the spectral camera. It consists of a matrix of pixels on 2 axes: X and Y. Each pixel has an intensity whose range of values depends on the dynamic range of the sensor (see section 1.3.4).

A 1D spectral file is a spectral profile (curve) containing the wavelength value on the x-axis and the intensity of the spectrum on the y-axis.

These 2 files must be in .fit or .fits format (can also be in .dat format, but without the advantage of the fit header).

1.3.6 Binning area

The binning area of a spectrum corresponds to the height of the 2D spectrum on which pixels in the same column are added together. Each processing program allows you to define this area.

1.3.7 Sky background subtraction areas

In the same way as the binning area, two zones are defined outside the useful spectrum to subtract the value of the background sky from the spectrum to be studied. These zones usually contain the interstellar lines, atmospheric airglow and absorbtion lines

and, as the case may be, light pollution lines. Spectrum processing software can be used to define these 2 areas.

1.3.8 Coordinates of a celestial object

The coordinates of an object in the sky are indicated in an equatorial reference frame by 2 values:

- The right ascension (α) noted RA in hours, minutes, seconds.

- The declination (δ) noted DEC in degrees, minutes, seconds.

These coordinates are usually followed by the term “J2000” which refers to coordinates calculated for the year 2000 (the positions of the stars move slowly across the sky!!!). JNow refers to coordinates at the time, take care to check witch software or telecospe controler is using.

1.3.9 Bias, darks, flats

As with astronomical imaging, calibration images are required:

Bias images are images taken with the camera shutter closed (complete black). They should be taken with the shortest possible exposure time: zero seconds. They are used to subtract read noise from the CCD or CMOS sensor matrix.

Dark images are also taken with the shutter closed. They must be made at the same temperature and have an exposure time greater or equal to the longest time exposure.

These images are used to subtract the thermal noise generated by the sensor depending on the exposure time, its temperature and the camera gain if the sensor is a CMOS.

Flat images: flats are images with uniform illumination, produced using a light source from a halogen lamp, with no spectral lines. As in imaging, Flats are used to eliminate the effects of dust on the sensor or vignetting in the optical chain.

In spectroscopy, they must be made in large numbers, in order to improve the signal-to-noise ratio because the flux of halogen flat lamp is very low in the blue part of the spectrum.

1.3.10 The F/D ratio

For a telescope or refractor, we often indicate the aperture ratio F/D, which corresponds to the ratio of its focal length to its diameter. For example, a telescope with a focal length of 1 500 mm and a diameter of 300 mm will have an F/D ratio of 5.

It is important to respect this aperture ratio, which depends on the spectrograph used, optimized to operate at a defined F/D ratio. However, it is possible to use a Barlow or focal reducer lens to adjust the F/D of the telescope or refractor used. For example, an Alpy 600 will perform optimally when used with a telescope or refractor open to F/5 or even F/4.

1.4 The spectrographs

There are many spectrographs within the financial reach of amateurs. This chapter describes the main models used by amateurs, but also by some professionals at the time this book was written. This list is not exhaustive.

As with telescopes, there is no such thing as a universal, all-purpose spectrograph. Depending on the field of study and the nature of the target, you need to be able to choose the one that's right for you. This is why we find a large range of instruments that differ greatly in terms of resolution or spectral range, fiber optic, with slit or slitless.

For example, we are not going to use the same instrument to study spectroscopic binaries or the redshift of galaxies.

By contrast, the study of spectroscopic binaries stars requires high spectral resolution. On the other hand, the accessible magnitude will limit us to the brightest stars (because the light is dispersed over a larger area).

Studying the redshift of quasars or galaxies requires the ability to take spectra of very faint objects while offering a wide range of wavelengths. In this case, a low-resolution spectrograph is the best choice.

There are several solutions available to those wishing to venture into astronomical spectroscopy.

1.4.1 Building your own spectrograph

You can build your own instrument using the plans that are freely available on the Internet. In recent years, the advent of 3D printers has made it possible to produce high-performance spectrographs at low cost.

In 2024, there are four 3D-printed spectrograph projects. Printable files can be found on the websites of their authors:

• The **UVEX 4**: a spectrograph designed by Christian Buil, which was taken over by the "Nice People Team" (Pierre Dubreuil, Alain Lopez, Jean-Luc Martin and Stéphane Ubaud) for the 3D-printed mechanical part. A comprehensive website is dedicated to this project: http://spectro-uvex.tech

• **Low Spec**: a spectrograph designed by Paul Gerlach. The project and the files are presented on the Thingiverse website: https://www.thingiverse.com/thing:2455390

The Sol'Ex and Star'Ex projects: designed by Christian Buil, which, depending on the configuration used, produce high-resolution spectra at $R = 20\ 000$ or low resolution at $R = 800$.

• The **Sol'Ex** is dedicated to spectroheliography (scanning the solar disk at various wavelengths).

• The **Star'Ex** allows you to make stellar spectra thanks to the addition of a slit and an autoguiding module.

A website dedicated to the construction and use of these 2 spectrographs can be consulted on Christian Buil's website: https://solex.astrosurf.com/

The Sol'Ex and Star'Ex optical kits are sold by Shelyak Instruments on their website.

• **FlexSpec**: an open source spectrograph project whose plans, codes and documentation can be found on the website: https://flexspec1.readthedocs.io/en/latest/

1.4.2 Buying a spectrograph

A number of instrument manufacturers are also on the market which offer a variety of ready-to-use models with different resolutions and spectral ranges:

• SBIG, a US manufacturer, launched the first commercial spectrograph, the SGS in

the 2000s followed by the DSS-7. These 2 models are no longer in the manufacturer's catalog. The SGS was a particularly interesting model for users of SBIG ST7, ST8, ST9 and ST10 CCD cameras, because it used the 2 sensors of these cameras: one for autoguiding on the spectrograph slit, the second for spectrum acquisition. To this day, the SGS remains a high-performance spectrograph thanks to its all-mirror optical design. It offers 2 gratings (600 and 150 lines/mm) and you can switch from one to the other very easily. The SGS has 2 different slit widths (25 μm and 100 μm).

• Baader Planetarium, a German manufacturer, which markets the Dados and the BACHES Echelle spectrograph. Dados can be used with various gratings of 200, 900 and 1 200 lines/mm and various slit widths: 25 μm, 35 μm and 50 μm with a possible spectral range from 350 nm to 950 nm. BACHES is a Echelle-type, so a multi-order spectrograph. It provides the entire spectral range between 390 and 800 nm at high resolution ($R = 18\,000$).

Internet website: https://www.baader-planetarium.com/en/spectroscopy.html

• Starlight Xpress a UK manufacturer: they proposed the SX spectrograph in 2016, followed by the Spectrograph Pro. The grating used is 550 lines/mm. It has several slits of different widths to best adapt the resolution depending on telescope focal length. The resolution can vary from $R = 1\,500$ to $R = 1\,800$ according to the slit used. The possible spectral range is from 340 to 900 nm.

Internet website: https://www.sxccd.com/product/sx-spectrograph-pro/

• Shelyak Instruments, a French manufacturer, offers a wide range of high and low resolution spectrographs:

- Alpy 600 and Alpy 200
- LISA
- LHIRES III
- UVEX
- eShel

Internet website: www.shelyak.com

1.4.3 The spectrographs used in this book

Here are the characteristics of some commercial instruments used to produce the results presented in this book. Other spectrographs could have been used too with the same quality of results, but some of the spectra published in this book are more than 10 years old that could not be produced by more recent spectrographs.

They were made using the range available at this time. Many spectra have been acquired from our 2SPOT setup in Chile with the eShel and Alpy 600 spectrographs.

They are also the most widespread commercial versions in the world at the time of writing this book (2024).

1.4.4 The Star Analyser



Fig. 1.4.1 — Star Analyser SA 100.

This spectrograph is the simplest and least expensive on the market. It has the external appearance of a 31.75 mm diameter astronomical filter (1.25 inch) which can be screwed directly in front of the camera or place in a filter wheel.

It features a diffraction grating with a transmission grating of 100 or 200 lines/mm (SA 100 or SA 200). The Star Analyser disperses the flux of the light passing through the filter and produces a spectrum.

It simply mounts in front of the camera with extension rings to adapt spectrum dispersion on the camera sensor.

The SA 100 has a nominal resolution R of 100 and its big brother, the SA 200 has a resolution of 200. All you need to do is orient it correctly to obtain horizontal spectra.

It is ideal for amateurs who want to get started with spectroscopy at low cost and can be used to observe very faint targets, such as supernovae or quasars.

On the other hand, its low resolution and lack of a slit will quickly limit its potential use in astronomical spectroscopy.

Spectral processing remains a delicate issue especially if the area under study contains many stars on large targets (e.g. galaxies, planetary nebulae) or in a highly light-polluted environment.

1.4.5 The Alpy 600



Fig. 1.4.2 — The Alpy 600. Equipped with its 2 cameras (spectral and autoguiding) as well as the calibration and autoguiding module.

It is with this spectrograph that we are starting to make some interesting measurements. As the Alpy 600 is modular, you do not have to buy all 3 modules up front (spectrograph + autoguiding module + calibration module).

We can start with the spectrograph body alone which makes it possible to study the sunlight spectrum, the spectrum of various light sources or measure the bandwidths of astronomical filters. It is equipped with a grism, a transmission grating glued to a prism which returns the light beam perpendicular to the sensor.

If you want to get started in celestial observation, then you need the autoguiding module which reflects the image of the slit onto a guide camera sensor to position the target correctly and hold it in place on the slit.

The calibration module completes the package for easy flat production and spectra from a calibration lamp (integrated halogen and argon/neon bulbs).

This spectrograph, equipped with a 23 µm slit, has a nominal resolution of $R = 600$, it is very compact and fairly lightweight. It can therefore be used on a small telescope or refractor without adding significant weight to the entire chain. Its compactness makes it less sensitive to mechanical bending and to temperature variations. This stability makes it a major asset for remote use. This is why it is used by our 2SPOT team in Chile.

This is the ideal low-resolution spectrograph for reflecting telescopes or refractors from 72 to 305 mm in diameter. On larger instruments, it loses some of its potential because we'll have to increase the slit width by 23 µm to 35 µm or even 50 µm,which reduces the resolution.

Its compact size means it can be used in "Lab'Ex" mode on table, to produce spectral measurements in laboratory mode on various light sources, filters, liquids or minerals. This possibility is described in Chapter 11 of this book.

A very low-resolution version (Alpy 200) is also available for very weak targets with a resolution of the order of $R = 100$ which can be used on supernovae, for example. Externally, it is totally similar to an Alpy 600, only the grism changes.

1.4.6 The LISA

The LISA spectrograph has a nominal resolution of $R = 1\,000$ thanks to its high luminous efficiency (it acts as an internal focal reducer). It is dedicated to the study of weak objects like supernovae, novae, candidate planetary nebulae.

It has its own calibration module with a halogen lamp for flats and an argon/neon or neon-only lamp for spectral calibration. Designed for use in the visible range, its spectral range extends from 390 nm to 750 nm. A near-infrared version is also available, providing spectra down to 1 μm.

A autoguiding module is integrated into the spectrograph eand any C-mount or C/S-mount camera can be attached (back focus of 12.5 mm or 17.5 mm).

It is suitable for use with telescopes of 305 mm in diameter and larger. LISA currently operates on telescopes from 0.6 m to 1 m in diameter, by producing spectra of high-magnitude objects. We used it on the C2PU 1m telescope at the Côte d'Azur

observatory (close to the french riviera) and on the 0.6 m telescope at the Mars Observatory in Ardèche in France.

Of course, the width of the slit will have to be adapted according to telescope focal length. The larger it is, the wider the slit needs to be. Other slits are available as options, ranging from 10 µm to 100 µm. The trade off is a reduction in spectral resolution which will be around $R = 700$ with a 35 µm slit or $R = 500$ with a 50 µm slit.

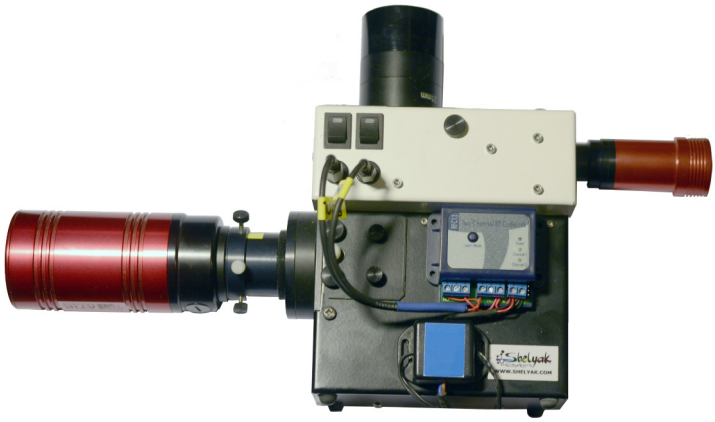


Fig. 1.4.3 — The LISA. Equipped with 2 cameras (spectral and autoguiding) and the calibration module (in white on the photo). In this picture, it is also equipped with a radio module for remote control of calibrations lamps.

1.4.7 The UVEX

In addition to the 3D-printed version of UVEX 4 mentioned in section 1.4.1, an industrial version is available from Shelyak Instruments. It is a pretty versatile instrument which offers an extended wavelength range (from near UV around 340 nm to 1 μm in the near IR).

This is made possible by the use of mirrors rather than lenses, so there's no chromatism in this spectrograph, which allows it to go quite far into extremes, without optical distortion.

It can be used at different resolutions by simply changing the the grating (150, 300, 600, 1 200 ou 1 800 lines/mm), to obtain resolutions around between $R = 300$ to $R = 6000$ on the $H\alpha$ line. A wide range of slits is also available.

A motorized version is available as an option to remotely control the spectrograph's internal focus, grating orientation and the 2 calibration lamps. It uses the Alpy 600 modules for autoguiding and calibration. The spectrograph can therefore be operated perfectly by remote control, either via the ASCOM driver designed for this motorization, or via a dedicated application.

Because of its optical design (Czerny-Turner), it is hardly possible to produce spectra of non-point objects because the astigmatism of this spectrograph is quite high as you move away from the optical axis. On the other hand, it will express its full potential on pointlike stellar targets even at high magnitudes.

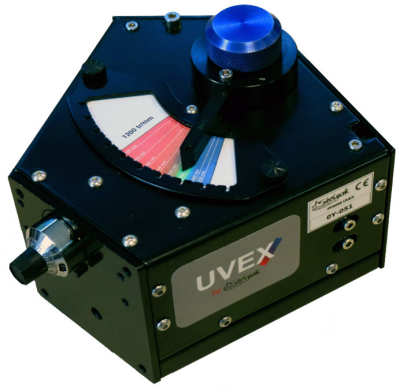


Fig. 1.4.4 — The UVEX. Alone, without motorization, calibration and autoguiding module.

1.4.8 The LHIRES III

One of the world's oldest high resolution spectrographs! It was conceived in 2003 during CNRS meetings between professionals and amateurs in Oléron (on the French west coast).

This spectrograph is equipped as standard with a holographic grating of 2 400 lines/mm and achieves a resolution of $R = 17\,000$ with a 23 µm slit.

A micrometer screw adjusts its inclination and thus vary the observable wavelength range in the visible range. Various gratings can be easily mounted on this spectrograph and enable lower resolutions (gratings of 1 200, 600, 300 ou 150 lines/mm).