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**Editors:**  
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# Lhires III High Resolution Spectrograph

Olivier Thizy

Shelyak Instruments; Les Roussets, F-38420 Revel, France; <http://www.shelyak.com>

AUDE association, Paris, France; <http://astrosurf.com/aude>

CALA; 37 rue Paul Cazeneuve, F-69008 Lyon, France

[olivier.thizy@shelyak.com](mailto:olivier.thizy@shelyak.com)

## Abstract

By spreading the light from celestial objects by wavelength, spectroscopists are like detectives looking for clues and identifying guilty phenomena that shape their spectra. We will review some basic principles in spectroscopy that will help, at our amateur level, to understand how spectra are shaped. We will review the Lhires III high-resolution spectrograph Mark Three that was designed to reveal line profile details and subtle changes. Then, we will do an overview of educational and scientific projects that are conducted with the Lhires III and detail the COROT Be star program and the BeSS database for which the spectrograph is a key instrument.

## 1. Introduction

Almost 350 years ago, when Sir Isaac Newton first saw the light from the Sun passing through a prism, he used the word "spectrum" to describe the phenomenon that revealed several colors and appeared to scientists like ghosts coming from mysterious places. It is only 150 years ago that we started to understand relationship between chemical composition and spectral lines.

Today, a majority of professional astronomical work is done using spectrographs, from distant red shifted galaxies to subtle stellar movement due to exoplanets. Surprisingly, only a few pioneer amateur astronomers have done some scientific work so far. Thanks to commercial spectrographs and CCD technology now available, several serious scientific programs can be conducted from our backyards.

## 2. Spectroscopy Theory

Light has the fantastic ability, even after traveling billions of kilometers, to convey information about the chemical composition, temperature, pressure, and movement of the source. This information is coded in the spectrum of the source and a spectroscopist is like a detective, looking for clues to decode the signal and unveil the truth.

A spectrum is obtained by dispersing the light from the source, a celestial object in our case, through a spectrograph. Visual observation can procure great sensation – looking at solar spectrum is a unique experience. However, astronomers record spectra for future study, usually with a CCD camera. Resolved sources display extended spectra while

point sources only display a thin line. Those are "2D" spectra.

Scientists prefer to extract the density per column to display a graphical view of those spectra. A careful calibration in wavelength provides the X-axis scale and allows measurements of line profile details related to physical properties of the source (see Figure 1).

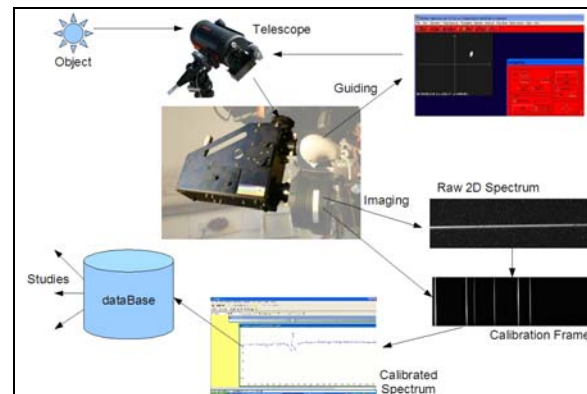


Figure 1.

Power of resolution,  $R$ , is a key parameter for a spectrograph.  $R$  is given by the equation  $R = \lambda/\Delta\lambda$ , where  $\Delta\lambda$  is the lowest line separation that can be split and not to be confused with the dispersion of the spectrograph.

Low-resolution spectrographs record a wide spectral domain showing the overall profile of the spectrum, providing some basic information on temperature and spectral class. High-resolution spectrographs focus on a small domain but reveal line profile details providing more information on chemical

composition, radial, expansion or rotational velocities, etc.

Resolution is independent of the size of the telescope. You can have in your hand a spectrograph that has the resolution of large spectrographs on 8m telescopes! The difference is the limiting magnitude of the accessible targets.

Kirchhoff laws (Kirchhoff 1859) are the basis of spectroscopic analysis.

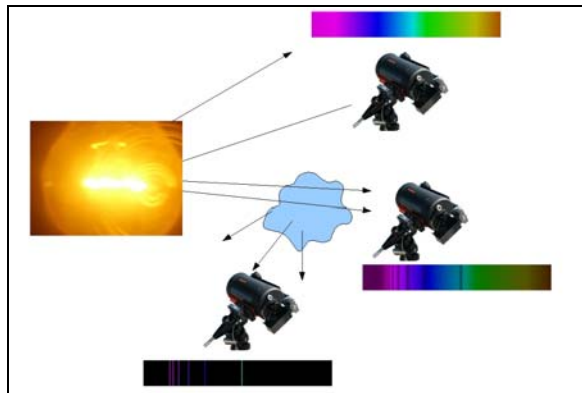


Figure 2. Kirchhoff's Laws.

1. Continuous spectra are emitted by any solid of gaseous body under high pressure and high temperature.

A star is, under first approximation, like a black body whose continuous spectra has a shape that depends on its surface temperature, i.e., a Planck curve whose maximum is linked to temperature by Wien's law.

2. Absorption line spectra are emitted by low-pressure, low-temperature gas crossed by a continuous light that absorbs some photons. The spectra show dark lines in front of the continuous spectra.

A stellar spectrum shows dark lines in the overall continuous spectrum. Hot stars show few lines, i.e., hydrogen lines, while cool stars display several metallic lines. The presence and profile of absorption lines depend on chemical composition and temperature as well as pressure and gravity.

3. Emission line spectra are emitted by low-pressure, high-temperature gas. Each chemical element has its own line spectra, a true identity card of its composition and state.

For example, planetary and diffuse nebulae display emission lines. We also use spectral lamps with emission line spectra to calibrate our spectra.

Another important law in spectroscopy is the Doppler-Fizeau effect (Figure 3). An emitting source approaching the observer has its spectrum shifted toward lower wavelength (called the 'blue' side referring to the visual spectrum).

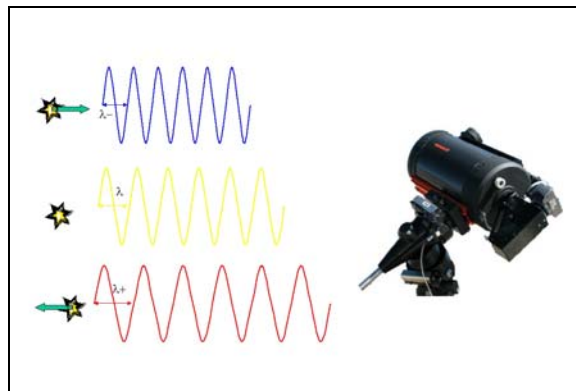


Figure 3. The Doppler Effect.

A source moving away from the observer has its spectrum shifted toward the 'red'. For non relativist sources, shift ' $\Delta\lambda$ ' is linked to the radial velocity ' $v$ ' and the speed of light ' $c$ ' (around 300 000 km/s) by the equation

$$\Delta\lambda/\lambda_0 = v/c$$

The Doppler-Fizeau effect allows us to measure the speed of Earth around the sun, the radial velocities of celestial bodies, rotational speed projected toward our line of sight [called ' $v \cdot \sin(i)$ '], or expanding velocities of ejected gas.

While analyzing in detail the information embedded in the spectra is professional work requiring time and knowledge, amateur astronomers can still do their own high-level analysis with only a few mathematical equations.

In summary, light from a celestial body gives us information about its temperature, chemical composition, physical conditions, pressure, and movements. Low-resolution spectrographs show broad features and overall spectra shape. Higher resolution spectrographs show details in spectra and line profiles and subtle changes over time.

### 3. Lhires III Specifications

In May 2003, a group of amateur and professional astronomers met together in Oléron to review current state of amateur spectroscopy. It quickly became clear that the resolution in commercially available equipment at that time was not high enough to see line profile changes. With support of AUDE association, a few amateurs (including Christian Buil, Fran-



Figure 4. The LHiRes III System.

çois Cochard and myself) worked on the design of a Littrow high-resolution spectrograph optimized for an 8" f/10 telescope so that many amateurs could do science from their backyard. This became after two preliminary versions the Littrow High Resolution Spectrograph Mark Three: LHIRES III (Figure 4). It was first distributed through AUDE association and then Shelyak Instruments (<http://www.shelyak.com>).

It was designed to be universal so it can be mounted on most amateur telescopes using a 2" (50.8mm) or a SCT (Schmidt Cassegrain Telescopes) adapter. Dispersion around H $\alpha$  is 12Å/mm (0.116Å/pixel for a KAF400 CCD camera). Most CCD cameras can be attached to the Lhires III using a set of available adapters. SLR cameras can be attached, too, using a standard T-ring. Last but not least, an eyepiece can be attached to visually watch spectral lamp or solar spectra.

The Lhires III is compact (250x200x83mm) and light (1.6kg) so that it can be used with most amateur

mounts. Signal loss from periodic errors along the RA axis is minimized when you align the spectrograph's slit with the RA axis.

The mirror slit can be adjusted in width but most important, it reflects the field of view toward a guiding camera (webcam, another CCD camera, etc.). This allows precise centering and continuous guiding during exposures.

#### 4. Lhires III Performance

With the standard 2400 lines/mm grating, Lhires III's power of resolution  $\lambda/\Delta\lambda$  is around 17000 but can be adjusted for lower-resolution projects by simply changing the grating case, which is available in 150, 300, 600, or 1200 lines/mm. This can lower the resolution down to  $\lambda/\Delta\lambda$  around 600. With a Digital SLR camera, the full visible spectral domain can be shot in one part with a 300 lines/mm grating. In high resolution, around 20 parts are needed. See Table 1 for performance obtained for each available gratings

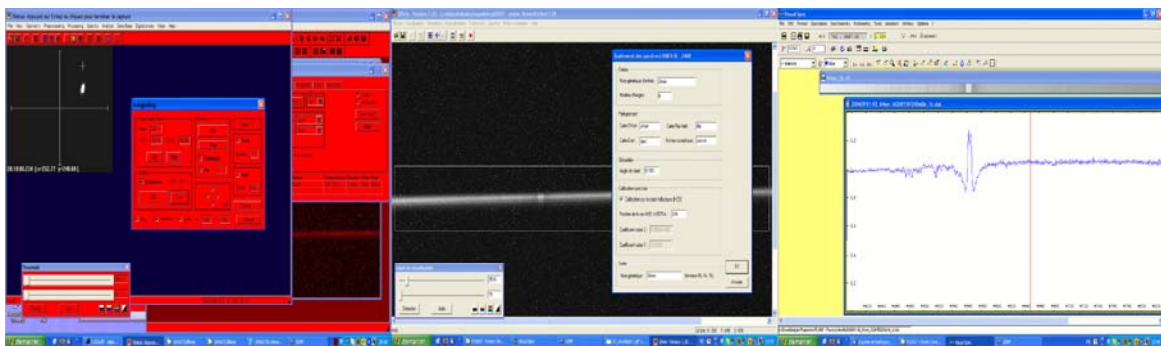


Figure 5.

|                          |       | Grating – Lhires III – grooves/mm |      |      |      |      |
|--------------------------|-------|-----------------------------------|------|------|------|------|
|                          |       | 2400                              | 1200 | 600  | 300  | 150  |
| Dispersion (H $\alpha$ ) | Å/pix | 0,1                               | 0,3  | 0,7  | 1,5  | 3,0  |
|                          | km/s  | 5                                 | 17   | 35   | 75   | 150  |
| Power of resolution      |       | 17000                             | 6000 | 2700 | 1300 | 600  |
| Spectral domain          | Å     | 85                                | 250  | 550  | 1100 | 2300 |
| Limiting magnitude       |       | 5                                 | 6    | 7    | 8    | 9    |

Table 1.

(based on ETCL simulation tool for a 200mm f/10 telescope, 30 $\mu$ m slit, KAF0400 camera, 1h exposure, Signal/Noise of 100).

## 5. Spectra Processing

There are basically three steps when doing spectroscopy with a Lhires III (see Figure 5).

1. Acquisition
2. Extraction
3. Analysis

The Lhires III spectrograph fits between a telescope and a camera (reflex camera, CCD camera, or webcam). Spectra are captured with standard acquisition software. To center the target and to continuously guide on it, additional software may be required. Note that IRIS software, which is free, can autoguide with a webcam with a special algorithm that takes the slit into account.

Spectra extraction is a complex process. IRIS software (as well as PRIM or AudeLA/SpcAudace for example) also includes a special module for spectra processing called SpIRIS. This module allows the spectra to be corrected automatically for geometrical distortion. It can combine multiple exposures, extract spectrum with a special algorithm, and carefully calibrate spectra using atmospheric lines or integrated Neon lamp spectra. The last step of the extraction is to correct for instrumental response; this can be done in AudeLA/SpcAudace or VisualSpec for example.

Last but not least, spectral analysis is usually where the fun starts with the interpretation of line profile details. This can partially be done by amateurs with free software such as VisualSpec or SpcAudace. In any cases, relevant data should be shared with professional astronomers.

## 6. Projects

There are lot of projects to conduct with Lhires III spectrograph and even small size amateur telescopes. Here is a short list of projects that have high educational interests and then a focus on a professional amateur collaboration on Be Stars with the COROT program.

Usually the first spectroscopist's experience is to watch solar spectrum visually. The low-resolution mode will show main absorption lines first identified by J. Fraunhofer. High-resolution mode will detail hundreds of absorption lines revealing some chemical composition of the Sun. This makes it a great tool to educate the public to spectroscopy. With a digital SLR camera, you can quickly record spectra of the

Sun but also house lamps or laboratory spectral lamps. A very educational experience is to compare spectra of the Sun, a star, a street lamp, and burning salt. All show the Sodium doublet but at different distances!

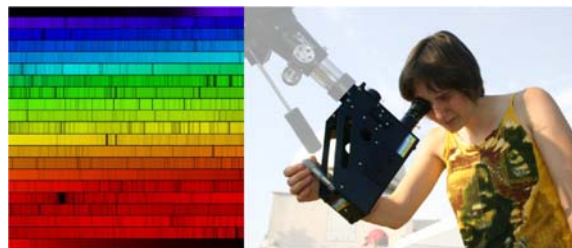


Figure 6.

Using a video camera and a small reflector, you can continuously record spectra of the sun as it passes in front of the slit. By taking a fixed wavelength in each frame, you can recombine the solar image at that wavelength. This scanning method is called spectro-heliography. It requires some hard processing work but the result is a set of solar images at different wavelengths with very narrow bandwidth.

In low-resolution mode, a simple digital SLR camera can reveal the overall profile of stellar spectra and show the variety of spectral classes. We have done, with astronomy students, the spectra of bright stars with 30 sec exposures using a 8" Schmidt-Cassegrain telescope and a Digital Rebel. High-resolution mode will show detailed absorption lines that are more and more visible as we go toward cooler stars.

Benjamin Mauclaire, a Lhires III user, has taken spectra of nebulae with students and used them to calculate temperature and electron density. We insist on the educational aspect of such observation since, through simple measurements on a spectrum, students can calculate some key parameters of the physical conditions of the nebula.

It is with the Doppler effect that spectroscopists, with a simple math formula can tell a lot of information! The FWHM of an emission line profile of a nova directly gives the speed of the expansion of the gas outward the star. Wavelength shift of stellar lines directly gives the radial velocity of the source, of course after careful correction of Earth velocity around the Sun. Following a line's swing on spectroscopic binaries will give details on those celestial bodies. Measuring the tilt of absorption line on Jupiter or Saturn will reveal the rotational speed of those planets (Figure 7). The same effect enlarges absorption lines as stars rotate around themselves.

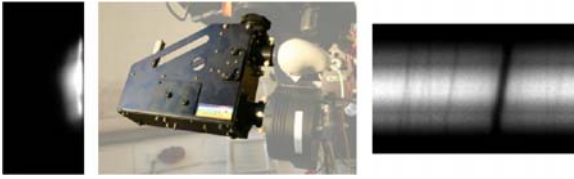


Figure 7.

These projects have been highlighted because of their educational interest. However, with a Lhires III, you can go further and record spectra that can be useful to professional astronomers. This is one of the reasons that we originally designed this high-resolution spectrograph.

While there are several areas of work such as RR Lyrae, Herbig Ae/Be objects, etc., we will focus here on the Be stars.

## 7. Be Stars

Be stars are hot (10000K to 30000K) B type, non-super giant luminous stars (III-V type) that show at least one Balmer emission line. Even if the star stops emitting, it keeps the Be classification. Sometimes, Helium and Iron emission lines can be seen.

The first observation of Be star spectra were done in 1866 by Secchi with beta Lyrae (a special class as it's a close binary system with mass transfer and polar jets) and gamma Cas, the perfect prototype of a Be star.

Around 15% to 20% of B stars are Be. Merrill has made a list of 410 stars, mostly Be stars (Merrill, 1933). As B stars are the largest population of naked eye stars, this makes the number of bright Be stars significant and opens the door for continuous high-resolution spectral monitoring even with small sized telescopes.

The emission line in a Be star is explained by the presence of a ring around the star (Struve 1931, Slettenbak 1988). Linear radial velocity of the material can reach 300km/s, which explains the large broadening of some emission lines. Depending on the geometry and density, the emission line can be a single line, a profile with two peaks, or an absorption line with emission line(s) inside. Be stars that are seen nearly pole-on are called "Be-Shell." Some Be stars are part of a binary system and show even more complex profiles, zeta Tau (Pollmann, 2005) is a good example. Monitoring emission lines or V/R ratio (Violet/Red line intensity ratio) is easily done by amateurs. For example, the recent observations of the changing features in delta Sco (Figure 8), Miroshnichenko 2003.

How those stars create those rings is still a mystery. Fast rotational speed helps as does the presence

of a companion, e.g., beta Lyrae, Figure 9. However, not all Be stars are binaries. Another possible cause are non radial pulsation (NRP) modes. Continuous monitoring of those stars would help tying photometric and spectroscopic variability (Hubert 1998). Porter and Rivinius made a detailed review of classical Be stars knowledge only few years ago (Porter 2003).

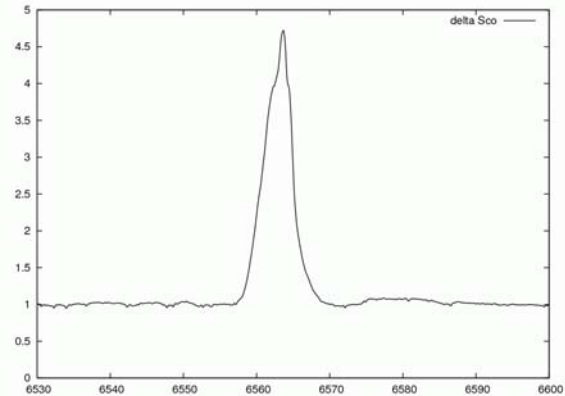


Figure 8.

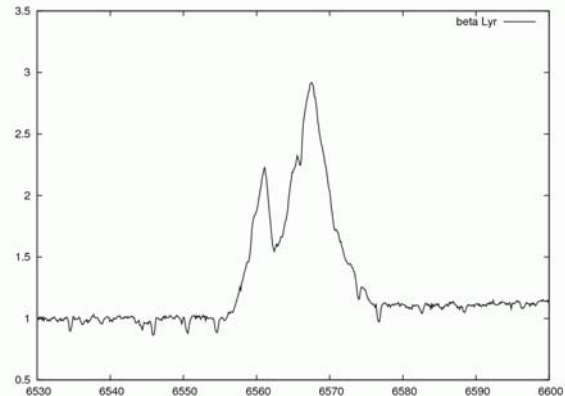


Figure 9.

In December 2006, the COROT satellite was launched. It will monitor some faint stars for exoplanets but will also monitor some bright stars for asteroseismology. Professional astronomers have targeted some Be stars for high precision continuous photometric monitoring. Parallel spectroscopic monitoring, even with amateur size telescope, is required to make that correlation. The first target has been 64 Ser (Figure 10).

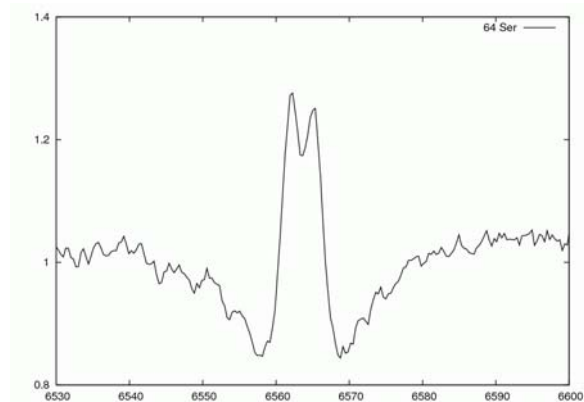


Figure 10.

In parallel to this project, a spectral database for Be Star Spectra (BeSS) has been developed by a team at “Observatoire de Paris-Meudon” with help from some amateur astronomers. This database is collecting Be Star Spectra from the two communities.

## 8. Further Reading

In addition to references, further reading can be found on the following web sites:

- Shelyak Instruments web site gives more information on the Lhires III spectrograph at <http://www.shelyak.com/en/lhires3.html>
- Spectro-L is a discussion group around amateur astronomical spectroscopy, more information at <http://groups.yahoo.com/group/spectro-l>
- ARAS is a portal on pro/am collaboration and can be accessed at <http://www.astrosurf.com/aras>
- Christian Buil maintain a dense web site at <http://www.astrosurf.com/buil>
- SpIRIS is a free software to process spectral images with special modules for the Lhires III: <http://www.astrosurf.com/aras/spiris/spiris.htm>
- VisualSpec is a free software to analyze spectra. It is available at <http://astrosurf.com/vdesnoux/>
- SpcAudace is a free module to process and analyze spectra, either on Windows or Linux: <http://bmauclaire.free.fr/astronomie/softs/audela/spcaudace/>

## 9. Conclusion

Amateur spectrography is at a turning if not a revolution point. More and more books are being published on the subject, equipment such as Lhires III are commercially available, and astronomers are grouping together such as the Spectro-L group. Within a short time, amateurs will be able to partici-

pate to pro-am collaboration using spectroscopic observations.

## 10. Acknowledgments

The author would like to thank Olivier Garde for the authorization to publish his solar spectrum and Steve Dearden for his continuous advice. Lhires III would never exist without the leadership and vision of Christian Buil, the work of François Cochard, and the support from AUDE association (André Rondi, Yvon Rieugné, Patrik Fosaneli and some others) and its president François Colas.

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