High Resolution Spectrography
Menu...

- What is a spectrum?
- A little bit of theory
- Lhires III spectrograph
- Some Projects
- Conclusion
What is a «spectrum»?

- Large object (ex: Sun)
- Slit
- Ponctual object (ex: star)

Large object (ex: Sun)
Extracting a spectrum is to extract a 1D profile from a 2D image.

A simple cut is not enough (poor signal/noise ratio).

Optimized spectrum extraction has been programmed in several softwares (L_OPT in IRIS)
Here is a comparison between a low and high resolution of Vega.

- **Low Resolution:**
  - Overall shape
  - Planck profile

- **High Resolution:**
  - Line profile (Voigt, gaussian, etc...)
  - FWHM
  - Equivalent Width
Kirchhoff's Laws

1. High pressure gas (liquide or solid), when heated, emit a continuous emission which contains all colours – a continuous spectrum;

2. Low pressure gas at low temperature, when located between a continuous source and an observer, absorbs some colours (absorption line spectrum);

3. A low pressure gas at high temperature will emit only some colours (emission line spectrum).
Black body profile

Profil de Plank

Intensité

Longueur d'onde (angstroms)

12.000 K
10.000 K
8.000 K
5.000 K
Electro-magnetic spectrum...
Visible: a very small window!

Source: Getting the measure of the stars (WA Cooper & EN Walker)
Information from the profile

➢ Stefan's law:
   Intensity (below the curve) = Constant * $T^4$

➢ Wien's law:
   $\lambda_{\text{max}} \times \text{Temperature} = \text{Constant}$
   $(2900 \, \mu m.K)$

=>$\text{Temperature} = \text{Colour} !!!$

Visible domain
   $= 400-700\,\text{nm} \, (4000\,\text{A}-7000\,\text{A})$
H-R diagram
• Solar spectrum is like the one of a black body (Teff=6000K)
• Solar atmosphere, cooler, absorbs some wavelength
Absorption lines

- Photosphère est très mince
- Les ailes des lignes proviennent de plus profond que le centre
You've heard of the spectroscope. It's the instrument that enables us to discover elements in stars, elements not yet isolated here on the earth. This is a spectroscopic photograph of the meteor which brushed past us today. Each of these lines, or each group of lines is characteristic of a metal. Those lines in the centre represent an unknown metal, which exists in the meteor. You follow me?

Source: Tintin, *the shooting star*
• Calibration/spectral lamp (here: internal Lhires III Neon lamp) are emitting emission lines.
Emission lines

- Diffuse and planetary nebulae are showing emission lines.
\[ \Delta \text{Energy} = h \times \nu = h \times \frac{c}{\lambda} \]
# Table of Elements

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<table>
<thead>
<tr>
<th>Period</th>
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<td>VII</td>
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<td>VII C</td>
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<td>Lu</td>
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Relative intensity per element
Doppler Effect

Universe expansion
red shift

\[ \frac{\Delta \lambda}{\lambda} = \frac{\nu}{c} \]
In summary...

Light coming from stars tell us about:

• their **temperature** [overall shape]
• their **composition** and **physical conditions** of ionisation & excitement (so temperature) [lines]
• quantitative chemical composition, **pressure**, **gravity** de l'étoile [line intensity]
• **movements** [Doppler effect]
  • *Radial velocity*
  • *Rotation*
  • *Expansion*
Specifications

Littrow design

**High Resolution** \(\lambda/\Delta\lambda\) of 17000 around H\(\alpha\)
Dispersion of 0.01nm (9\(\mu\)m camera)
Optimized for f/8-f/12 telescopes

**Adaptable** to most types of telescopes

**Universal** for acquisition: CCD camera, Digital SLR, webcam...

**Mirror Slit** for precise centering & guiding

**Compact** (250mm x 200mm x 83mm) et **light** (1.6kg)

**Optional grating/support** to adapt resolution to your project

Visual on the sun (without telescope) for public show

Can be used for Spectro-Heliography
Lhires III
2D spectra processing

From 2D to 1D
1D spectra analysis
Order of magnitude

- $0.1 \text{ Å} = 0.01 \text{ nm} = 5 \text{ km/sec}$
- Visible spectrum: 3000-7000 Å (300-700 nm)
- CCD sensitivity: 3000-9000 Å

<table>
<thead>
<tr>
<th>Grating – Lhires III – grooves/mm</th>
</tr>
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<tbody>
<tr>
<td>2400</td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>Dispersion ($H_α$)</td>
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<tr>
<td>km/s</td>
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<tr>
<td>Power of resolution</td>
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<tr>
<td>Spectral domain</td>
</tr>
<tr>
<td>Limiting magnitude</td>
</tr>
</tbody>
</table>

ETCL simulator: T200mm, Lhires III (30µm slit), KAF0400, 1 h exposure, S/N=100

Depending on your observations, you will have to compromise between Resolution, Spectral Field, Limiting Magnitude, Signal/Noise and Exposure Time.
Some projects...

1. Sodium in all its shape!
2. Visual solar spectrum
3. Low resolution solar spectrum
4. Spectro-Heliography
5. Stellar Spectra Classification - Low Res
6. Stellar Spectra Classification - High Res
7. Line profile
8. Nebulae spectra
9. Novae: expansion speed
10. Radial Velocities
11. Earth rotation... and solar mass!
12. Jupiter / Saturn rotation
13. Stellar rotation - V.sin (i)
14. Spectroscopic binaries
15. Herbig Ae/Be stars
16. Be Stars (pros-amateurs collaboration, BeSS database)
1 – Sodium in all its shape!

Salt
Match
Pickels!
Sirius
Sun
Street lamp

(c) C. Buil / Benoit Minster

(c) Robin Leadbeater
3 – Low Resolution solar spectrum

H / K (Calcium)
H\(\delta\)
H\(\beta\)
Triplet du Magnésium
Doublet du Sodium
H\(\alpha\)

Olivier Thizy – January 2007
Lhires III – 300gr/mm; Digital Rebel / EOS300D
Pic du Midi observatory (few atmosphere!)
4 – Spectro-Heliography
5 – Stellar spectra – Low Res.

C8 – Lhires III (150gr/mm) – Digital Rebel SLR – 30 sec exp. – no computer!
5 – Spectral Classification – Low Res.

Source: Benjamin Mauclaire; Lhires III (150 gr/mm) + KAF1600
6 – Spectral Classification – High Res.

$O_h - B_e - A - F_{\text{ine}} - G_{\text{irl}} - K_{\text{iss}} - M_e$

Sequence around Calcium triplet & Paschen sequence.
Temperature is cooler from top to bottom.
© Christian Buil
7 – Line profiles
Spectre de M42 - Lhires III (150gr/mm) + KAF1600 / Acquisition: Benjamin Mauclaire / Processing: Olivier Thizy
Image of M42: Olivier Garde & Adrien Viciana (CALA)
9 – Novae: expansion speed

V1280 Sco

V4743 Sgr

RS Oph

2500 km/s

50 Å
10 – Radial Velocities

Spectra of SAO104807, Altaïr, et SAO112958
11 – Earth movement... and solar mass!

\[ T = 2\pi \frac{a}{V} \]

\[ T^2 = \frac{(4\pi^2)}{G(m_1 + m_2)} a^3 \]

- **January:**
  - \( V = -30 \text{ km/s} \) (-6 pixels)

- **July:**
  - \( V = 30 \text{ km/s} \) (+6 pixels)
Ex. for Saturn:
Shift = 7 pixels = 8.8 km/s
Period of 10.6 h --> R = 107511 km

... Rings are turning as a solid body!
13 – Stellar Rotation: $V \cdot \sin(i)$

$v \cdot \sin(i) = 330\text{km/s}$

$v \cdot \sin(i) = 0\text{km/s}$
14 – Spectroscopic Binaries

With 3rd Kepler law, we can get to mass ratio of the two stars!

beta Auriga
2 spectra
72h apart

beta Aurigae over 3h...
15 – Herbig Ae/Be stars
Figure 12.1 A Hertzsprung Russell diagram showing the approximate location of various types of intrinsically variable star discussed in the text. Cataclysmic variables are binaries containing a compact star (usually a white dwarf) together with a red giant or main sequence star.

Source: Getting the measure of the stars (WA Cooper & EN Walker)
16 – Be Stars – COROT program

Magnetism, Pulsations?

Your measures can help!

Amateurs – Professionals Collaboration
Want to go further?

- Subscribe to Spectro-L discussion group:  
  http://groups.yahoo.com/group/spectro-l/

- Participate to meeting, star parties, training courses...

- Play with software & tutorials

- Contact me: olivier.thizy@shelyak.com

Two conditions for a good start:

Know your telescope
Know your camera
Useful links

ARAS portal: http://www.astrosurf.com/aras/
Spectro-L group: http://groups.yahoo.com/group/spectro-l/
C. Buil: http://www.astrosurf.org/buil/
Audela: http://www.astrosurf.com/aude/
Prism: http://www.astroccd.com/prism/fr/
BeSS: http://basebe.obspm.fr/basebe/Accueil.php
Projet Corot: http://www.astrosurf.org/buil/corot/data.htm
CDS Strasbourg http://http://cdsweb.u-strasbg.fr/
ADS (articles) http://http://adsabs.harvard.edu/abstract_service.html
Useful books

**Stars and their spectra**; James B Kaler, Cambridge edition
A must have in your library... Be careful: this book is dangerous! :-)

**Practical Amateur Astronomy**; Springer edition. collective book – a must have too!

**Spectroscopy, the key to the stars**; Springer edition. Missing the practical side of the subject, but an excellent starting point on spectroscopy theory.

**Stellar Photospheres**; David F. Gray, Cambridge edition
Excellent detailed book on the subject.
Thank You...

Stars won't look the same!