• Equipment overview
• Educational
• Pro/Am projects
Equipment
Discover spectroscopy: The Star Analyser is the simpler spectroscope, ideal to get started in this field with limited budget

Share your passion: Lhires Lite visual spectroscope for public outreach

Study: Lhires III (high resolution) and LISA (low resolution) are exploration tool allowing pro/am collaboration

Professional: eShel is an off-the-shelf optical fibre fed echelle spectrograph for higher RV accuracy and productive spectroscopy
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Spectral Domain</th>
<th>Resolving Power R</th>
<th>Resolution (500nm)</th>
<th>Slit</th>
<th>RV</th>
<th>Limit mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>eShel</td>
<td>430-710nm</td>
<td>&gt;10000</td>
<td>0.5 A</td>
<td>50µm F/6</td>
<td>50 m/s</td>
<td>~10</td>
</tr>
<tr>
<td>Lhires III</td>
<td>Visual (window of ~10nm)</td>
<td>~17000 with 2400 gr/mm grating</td>
<td>0.3 A</td>
<td>15-35µm F/10</td>
<td>~3 km/s</td>
<td>~9</td>
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<tr>
<td>LISA</td>
<td>390nm-1µm</td>
<td>600-1000</td>
<td>5 A</td>
<td>15-35µm F/5</td>
<td>n/a</td>
<td>~16</td>
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<tr>
<td>Star Analyser</td>
<td>Visual</td>
<td>~100</td>
<td>50 A</td>
<td>No slit</td>
<td>n/a</td>
<td>~15</td>
</tr>
<tr>
<td>Application</td>
<td>Description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| eShel             | High level education  
Bright stars line profile (Be stars, pulsations...)  
Abundances, classification  
Spectroscopic binaries & exoplanets |
| Lhires III        | (self) education with low / medium / high resolution modes  
Stellar classification  
Bright stars line profile (Be stars, eps Aur, Wolf-Rayet, Slow Pulsating B stars, Herbig Ae/Be...) |
| LISA              | Education: lamp, classification, nebulae, galaxie redshift...  
Faint variable stars: cataclysmics, novae, mira...  
Comets classification  
Asteroids classification  
... |
| Star Analyser     | Education: star temperature & classification  
Novae  
Faint variable stars  
Supernovae |
In practice: in the field

At the telescope (autoguiding)

Control room
- spectrograph
- calibration unit
- PC & observer :-)

(c) 2006 - Shelyak Instruments
From image to profile...

Diffuse objet spectrum (ex: sun)

Stellar 2D spectrum

Calibrated spectral profile
Educational projects
Light from the stars gives us information on:

- Their **temperature** [overall profile]
- **composition** and **physical conditions** of excitation and ionization (i.e., temperature) [visible lines]
- Quantitative chemical composition (**abundance**), **pressure**, **gravity** [line intensity and shape]
- **movements** [Doppler effect]
  - **radial velocity**
  - **rotation**
  - **expansion**
Solar spectrum (visual)
Spectro-Heliography
Neon
Thorium-Argon
unknown street lamp
Spectrum of the trees !!!

« Red Edge » / C. Buil ; C9 + LISA (IR mode) + QSI583
Planets – methan bands

Saturn & Titan
Saturn globe
Titan moon
Saturn rings
Rhea moon

Methane Bands in Atm of Saturn & Titan

Saturn globe
Titan moon
Saturn rings
Rhea moon
Planets – methan bands

Methan bands:
- on Saturn
- not on rings!
Planet's rotation

Saturn:
Shift = 7 pixels = 8.8 km/s
Period of 10.6 h >> R = 107511 km

\[ T^2 = \frac{(4\pi^2)}{\left(G(m_1+m_2)\right)} \alpha^3 \]
Planet's rotation: Saturn

Radial Velocities

\( \lambda 5890.421 \)

\( \lambda 5890.725 \)

\( \lambda 5891.241 \)

\( \lambda 5891.628 \)

eShel Shelyak Instruments echelle spectrograph (R~11000).
T0.28m f/6.3 Observatoire de Haute Provence – 2009, feb 27.
© Olivier Thizy / Shelyak Instruments
Stellar Rotation: $v \cdot \sin(i)$

- $v \cdot \sin(i) = 330 \text{ km/s}$
- $v \cdot \sin(i) = 0 \text{ km/s}$
Stellar Rotation: $v \cdot \sin(i)$

Effet de la rotation sur l'élargissement de raies spectrales.
eShel Shelyak Instruments echelle spectrograph ($R \sim 11000$).
T0.28m f/6.3; Observatoire de Haute Provence – 27 février 2009.
Idée de D. Gray (observation and analysis of stellar photosphere).
Stellar Radial Velocities

\[ \frac{\Delta \lambda}{\lambda} = \frac{\nu}{c} \]

SAO104807, Altair, & SAO112958
Spectroscopic binaries

Spectrogrammes de Beta Auriga (30 spectres sur 2006/2007) / O. Thizy et al.
Spectroscopic binaries

Spectrogrammes de Beta Auriga (30 spectres sur 2006/2007) / O. Thizy et al.
Spectroscopic binaries

**Paramètres orbitaux**

<table>
<thead>
<tr>
<th></th>
<th>Cette étude (VSpec)</th>
<th>Cette étude (PeakFit)</th>
<th>Nordström (1994)</th>
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<tbody>
<tr>
<td>$K_1$ (km.s$^{-1}$)</td>
<td>106 ± 3</td>
<td>108 ± 3</td>
<td>107.75 ± 0.40</td>
</tr>
<tr>
<td>$K_2$ (km.s$^{-1}$)</td>
<td>108 ± 3</td>
<td>110 ± 3</td>
<td>111.25 ± 0.40</td>
</tr>
<tr>
<td>$M_1/M_2$</td>
<td>0.98 ± 0.06</td>
<td>0.98 ± 0.06</td>
<td>0.97 ± 0.01</td>
</tr>
<tr>
<td>$V_γ$ (km.s$^{-1}$)</td>
<td>-20 ± 2</td>
<td>-21 ± 2</td>
<td>-17.0 ± 0.4</td>
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<tr>
<td>a.sin(i) (R$_{\text{sol}}$)</td>
<td>16.7 ± 0.5</td>
<td>17.1 ± 0.6</td>
<td>17.13 ± 0.04</td>
</tr>
<tr>
<td>$m_1$.sin$^3$(i) (M$_{\text{sol}}$)</td>
<td>2.02 ± 0.06</td>
<td>2.15 ± 0.06</td>
<td>2.19 ± 0.02</td>
</tr>
<tr>
<td>$m_2$.sin$^3$(i) (M$_{\text{sol}}$)</td>
<td>1.99 ± 0.06</td>
<td>2.11 ± 0.06</td>
<td>2.12 ± 0.02</td>
</tr>
</tbody>
</table>
Planetary Nebulae

Spectre de NGC2392, C11+Lhires III (600tt/mm) + Atik16
(c) Robin Leadbeater/O. Thizy – stage spectro OHP 2007
Diffuse Nebulae

Te = 10933 ± 174 K
Ne = 2537 ± 61 e-/cm³

Spectre de M42 - Lhires III (150tt/mm) + KAF1600 / Acquisition: Benjamin Mauclaire / Traitement: Olivier Thizy
Cf: http://bmauclaire.free.fr/astronomie/spectro/atlas/nd/m42/
Image de M42: Olivier Garde & Adrien Viciana (CALA)
Light pollution... not always human!

C9 + LISA + QSI583 (C. Buil)
Interstellar lines

Na (envelop)

Na (interstellar)

P Cygni spectrum - Jean-Noël Terry – Lhires III (2400 gr/mm)
Measure temperature

Altair (A7V): 10500K
Regulus (B7V): 30000K
Antares (M1.5Iab-b): 3000K
Albireo A (K3II+...): 5000K
Albireo B (B8Ve): 22000K
Visible: a small window

Source: Getting the measure of the stars (WA Cooper & EN Walker)
Precise temperature measurements

Measuring Equivalent Width of HeI $\lambda 4471$ & HeII $\lambda 4541$ ==> precise spectral type

HD 47839: HeI $\lambda 4471 = 0.799$ et HeII $\lambda 4541 = 0.533$ ==> type = O8

eShel Shelyak Instruments echelle spectrograph (R~11000)
T0.28m f/6.3; Observatoire de Haute Provence – 2009, february 27
Peculiar stars

eShel + C11
• Missing some blue part (aged stars in central part of M31)
• Halpha is less visible
Galaxies: M31

- Broader lines (M31 rotation?)
- Doppler shift ~-280km/s (M31 is moving toward us)
Galaxies red shift

Δλ = 108 A

⇒ z = 0.016
Galaxies red shift

Mrk 335
LISA (VIS) + C9 (D = 0.235 m) + QSI583
Exposure: 7 x 600 sec
Date: 08/06/2010

z=0.026

NGC7803
LISA (VIS) + C9 (D = 0.235 m) + QSI583
Exposure: 4 x 600 sec
Date: 08/06/2010

z=0.028
Some steps back...
The situation

- Very few pro/am collaboration (but some, see Buil Be star atlas), done with custom designed spectrograph.

Oleron 2003

- AUDE/CNRS pro/am official school
- Preceedings book to be published soon
- Kick off for Lhires III design
- Kick off Spectro-L list
- Kick off ARAS website front-end
La Rochelle: 2006

➢ Be Stars Spectra (BeSS) database kick off
  ➢ Structuring spectra collection & archiving
  ➢ Defining a spectra file format (FITS based)

➢ Workshop on Lhires III (AUDE first kits just received !)
La Rochelle: 2009

➢ 10000 amateur spectra in BeSS...
➢ Exoplanet newly observed: pushing the limits...
➢ Dozen of active amateur spectroscopists...

➢ ➢ More professional astronomers looking for help and support from amateurs!
OHP practical workshops

➢ 30-40 instruments, all with spectrographs!
➢ Different style
   ➢ workshop Vs talks, need for some theory
   ➢ structured project Vs autonomous groups
   ➢ courses Vs star party
➢ … the optimal format is hard to find!
OHP ambiance...
Pro/Am projects
Comété C/2006 Linear VZ13
T62 (http://AstroQueyras.com)
Lhires III (150tt/mm) + ST1603XME
11 Juillet 2007 – 3h de pose
Olivier THIZY / Jean-Pierre MASVIEL
exoplanets!
Exoplanet: tau Boo

The CCF is computed by using the spectral range 4400-6445 Å (the Halpha line is excluded).
The total velocity Doppler spectral amplitude shift represents only 1/25th part of the spectrograph resolution. The data are collected between March 19-March 29, 2009.

Christian Buil
Exoplanet: tau Boo

The final phase plot of Tau Boo (HD120136). The star is observed during 9 nights. The Doppler signature of planetary companion is clearly visible (the velocity error bar is estimated to +/-100 m/s).
Exoplanets: 4 done so far
Variable stars in general!

Source: Getting the measure of the stars (WA Cooper & EN Walker)
Novae

V1280 Sco

V4743 Sgr

RS Oph

50 Å

2500 km/s
V2491 Nova Cyg 2008 #2

C-14 LHRES III Spectrograph 1200 l/mm
SBIG ST-10

Relative intensity

Wave length

Hα

4-14-08 9:52 UT (purple)
4-21-08 11:02 UT (green)
4-12-08 10:05 UT (blue)
4-26-08 9:13 UT (orange)
4-25-08 10:06 UT (teal blue)

Source: Jim Edlin; Lhires III (1200 gr/mm) + ST10
Symbiotic stars: V407 Cyg

Note: another star spectrum is closed to V407 Cyg spectrum...

V407 Cyg
LISA (VIS) + C9 (D = 0.235 m) + QSI583
Exposure: 8 x 600 sec
Date: 8.901 / 08 / 2010
Symbiotic stars: CI Cyg
RR Lyrae: seeing stars pulsating live!
BW Vul: at the heart of a star !!!

Spectrogram of He I/Sodium doublet of BW Vul (5 min exposure, 60 cm f/3.5 telescope at Pic du Midi)
Herbig Ae/Be stars

C.Buil
P Cygni
other Active Hot Stars: Rigel, Deneb

Ref: arXiv:1007.2095v1 : Time, spatial, and spectral resolution of the Halpha line-formation region of Deneb and Rigel with the VEGA/CHARA interferometer
Wolf-Rayet

hd195177 (WC5; 1800sec)

hd197406 (WN7; 300sec)

hd201192 = ngc7026 (CSPN; 450sec)

hd201272 = ngc7027 (CSPN; 450sec)

hd205211 = ic5117 (CSPN; 300sec)

hd211853 (WN6+O; 300sec)

hd214419 (WN7+O; 270sec)

hd228766 (pre-WR P Cyg; 300sec)

Messier 57 (420sec)

O. Thizy
Radial Velocities

Rémy Fahed et al.
Rémy Fahed et al.: CIII 5696 flat top line as function of phase / excess emission (right)
Eps Aurigae eclipse

• Eclipse every 27 years !!!
• ~15 amateurs contributing
• Over 130 spectra to date ?

Robin Leadbeater

B star ?
~15000K
5.9 Msol

F type star ?
~7000K
2.7 Msol ?

Disk
~500K
Eps Aurigae eclipse : K I 7699 line

- New absorption line appearing!

Robin Leadbeater (Lhires III), Bob Stencel
Robin Leadbeater (Lhires III), Bob Stencel: Contour plot showing the evolution of the 7699A neutral potassium line after removal of the interstellar component seen outside eclipse. Coverage is 140 days before first contact to 100 days after predicted mid eclipse.
Eps Aurigae eclipse: KI 7699 line

Robin Leadbeater, Bob Stencel

• Disk structures in « rings »?
Eps Aurigae eclipse: Halpha line

Contour plot showing the evolution of the H alpha line from pre first contact to approximately 100 days after predicted mid eclipse. It is generated from 159 spectra from all observers.

A hidden emission component appeared in the core of the H alpha line close to the rest wavelength.

Robin Leadbeater, Bob Stencel: Contour plot showing the evolution of the H alpha line from pre first contact to approximately 100 days after predicted mid eclipse. It is generated from 159 spectra from all observers.
eps Aurigae pro-am campaign

➢ Complementary photometry / spectroscopy campaign
➢ Over 600 spectra collected (and increasing)!

➢ Contacts: Robert 'Bob' Stencel (Denver, USA)
  Jeff Hopkins (amateur; photometry lead)
  Robin Leadbeater (amateur; spectroscopy lead)

➢ Publications:
  ➢ http://www.threehillsobservatory.co.uk/astro/spectra_40.htm
  ➢ arXiv:0807.2855v1 : Gearing Up for Epsilon Aurigae's First Eclipse of the Millennium
  ➢ 2009SASS...28..157H : Epsilon Aurigae Hydrogen Alpha Emission Line Variation: The Horn Dance
  ➢ 2009CBET.1885....1W : Epsilon Aurigae (first detection !)
  ➢ Article in Sky & Telescope magazine!
A state-of-the-art pro/am project: Be stars

![Graph of Hα and Pashen lines](image)
Be stars

23 Tau

zet Tau
Hα - time evolution β Lyr

Phase: 0.01
Exemple of Be targets: $\upsilon$ Sgr
COROT targets: 64 Ser
BeSS database

URL: http://basebe.obspm.fr
BeSS catalog

- Plenty of BRIGHT stars to work on !!!
BeSS database

>11000 amateur spectra from over 30 different users
Equipment used

<table>
<thead>
<tr>
<th>Type</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Lhires III</td>
<td>42</td>
</tr>
<tr>
<td>Pro</td>
<td>13</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
</tr>
<tr>
<td>eShel</td>
<td>5</td>
</tr>
<tr>
<td>Total Résultat</td>
<td>66</td>
</tr>
</tbody>
</table>

- Amateur telescope size: 12cm to 62cm
- Mainly Lhires spectrographs used by amateurs
- eShel echelle spectrograph provides larger spectral coverage
ArasBeAm “amateur” front end

http://arasbeam.free.fr
### List of Be stars with Magn lower than 6
#### Limit Declination : -25

<table>
<thead>
<tr>
<th>Star</th>
<th>HD #</th>
<th>RA</th>
<th>DEC</th>
<th>Magn.</th>
<th>Tot. nb</th>
<th>1 year</th>
<th>2 months</th>
<th>Last</th>
<th>Obs Period</th>
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<td>del Scu</td>
<td>143275</td>
<td>+16 00 20.0</td>
<td>-22 37 18.2</td>
<td>2.29</td>
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<td>+20 15 15.9</td>
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<tr>
<td>4 Aql</td>
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<td>2008-09-27 18:47:35</td>
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<tr>
<td>12 Vul</td>
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<td>+19 51 04.1</td>
<td>+22 36 12.2</td>
<td>4.89</td>
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<td>22</td>
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<tr>
<td>31 Peg</td>
<td>212076</td>
<td>+22 21 31.1</td>
<td>+12 12 18.7</td>
<td>4.81</td>
<td>168</td>
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<td>30</td>
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<tr>
<td>phi Per</td>
<td>10516</td>
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<td>8 Lac A</td>
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<td>5.73</td>
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<td>2008-11-26 20:26:32</td>
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<td>gam Cas</td>
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ArasBeAm: detecting outburst

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<tr>
<th>Spectra</th>
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<td>obs. date: 2009-01-04 21:35:59</td>
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<tr>
<td>instrument: NOU 16</td>
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<tr>
<td>observation duration: 1531 s.</td>
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<tr>
<td>resolution: 6000</td>
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<tr>
<td>observation site: PIERA</td>
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<tr>
<td>observer: Joan Guarro Fló</td>
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</table>

Wavelength range: 6470.07 - 6729.08 angstroms

<table>
<thead>
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<th>Mozilla Firefox</th>
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<tr>
<td>obs. date: 2009-03-20 08:35:16</td>
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<td>instrument: NEWTON 254 - LHIRES-B12t - AUDINE 403</td>
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<tr>
<td>observation duration: 4496 s.</td>
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<tr>
<td>resolution: 7000</td>
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<tr>
<td>observation site: STA. MARIA DE MONTMAGISTRELL</td>
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<tr>
<td>observer: Joan Guarro Fló</td>
<td></td>
</tr>
</tbody>
</table>

Wavelength range: 6482.04 - 6715.96 angstroms

several outbursts discovered
delta Sco : 2011 periastron !!!

- Be stars identified as such in 1993
- Outburst in 2000 with sudden increase of visual brightness

**snapshots of delta Sco spectrum (H-alpha) through the years...**
delta Sco : 2011 periastron !!!

Anti-correlation of Hα-EW and V-Brightness

Ernst Pollmann

Tango et al. 2009
Recent interferometric observations (Tango et al., 2009) led to new orbital elements and masses estimation: $M_1 = 15 \pm 7$ M$^*$ and $M_2 = 8.0 \pm 3.6$ M$^*$
delta Sco : 2011 periastron !!!

• Exact periastron date unknown (around beginning of July 2011)
• Radial Velocity will change drastically few weeks before
• Monitoring of H alpha is key
• Monitoring of He I 6678 is very interesting too

==> amateur Spectroscopy is required !!!
Recent telegram...

Dear colleagues!

Myron Smith, Computer Sciences Corporation, Space Telescope Science Institute and my mentor in issues of gamma Cas, is asking for Halpha-EW observations during the coming observation season.

He and his colleague Greg Henry are very interested in correlation between Halpha-EW and photometric brightness within the UBV-system. Meanwhile they monitored the star in this way for 13 years (see fig. 3).

Actually, I gave him the attached compiling plots (fig. 1 & 2) of Halpha EW and visual brightness observations of my colleagues in Hungaria and Germany.

It would be great, if interested observers could measure the Halpha EW for the coming months of visibility.

Ernst Pollmann
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Active Spectroscopy in Astronomy
http://www.astrospectroscopy.de

==> mag 2 star!
## ProAm projects overview

<table>
<thead>
<tr>
<th>Spectrograph</th>
<th>Star Analyser</th>
<th>LISA</th>
<th>Lithes III</th>
<th>eShel</th>
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<tbody>
<tr>
<td>Resolving Power</td>
<td>$R \sim 100$</td>
<td>$R \sim 1000$</td>
<td>$R \sim 600 - 17000$</td>
<td>$R \sim 11000$</td>
</tr>
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</table>

### Solar System
- Earth atmosphere: Aurora spectra.
- Meteors: Meteor spectra: how useful??
- Moon: Geology changes during impact.
- Planet atmosphere: Spectra of atmospheric features (near IR ?)
- Comets: Composition, classification. 150-300: Composition, classification.
- Asteroids: Classification.
- Bright comets?

### Binaries
- Spectroscopic binaries: 2400: bright binaries period/orbit follow up
- Exoplanets: Binaries period and orbital elements improvements
- Orbital elements follow up. Discoveries around A-type stars?

### Variable Stars
- **Be Stars**
  - Line profile changes (days/years).
- **Binary Be Stars:**
  - delta Sco, VV Cen, zeta Tau, ups Sco...
  - Monitoring, Outburst detection.
- **Herbig Ae/Be**
  - 1200: spectral changes in few hours.
  - 300-600: changes over the years / outburst
- **LBV (P Cygni)**
  - 1200-2400: line profile changes (years)
  - Line profile changes (years ?)
- **Active hot stars**
  - 1200-2400: line profile changes (years ?)
  - Line profile changes (years ?)
- **Wolf-Rayet**
  - Classification.
  - Line profile changes (years ?)
- **Binary Wolf-Rayet:**
  - WR 140...
  - Periastron studies. Orbital elements, spectral changes.
- **epsilon Aurigae** (every 27 years ?)
  - 2400: line profile change, K1 line change (modified Lithes III). Eclipse follow up.
- **Cataclysmic variables**
  - Outburst monitoring. Initial classification, monitoring.
  - Line profile changes at initial stage. Expansion speed.
  - Line profile changes at initial stage. Expansion speed measurement.
- **Novae**
  - Initial classification, monitoring.
  - Line profile changes at initial stage. Expansion speed.
  - Expansion speed measurement.
- **Mira**
  - Monitoring during all period.
  - 1200: at maximum brightness.
  - Follow up: during (almost) all period.
- **Pulsating stars** (RR Lyrae, BW Vul, SPB...)
  - 600-1200: RV of absorption lines.
  - RV changes of absorption lines.
- **Supernovae**
  - Initial classification (SN type)
  - Initial classification (SN type)
in summary...

- Spectroscopy reveals hidden details from the stars
- Equipment is available off-the-shelf
- Educational projects are numerous and fun
- Pro/Am collaboration is increasing with more amateur contributing with more professionals requesting support

==> join us !!!
Some books...

More on www.Shelyak.com (bibliography)
Some useful links

Groupe ARAS:  http://www.astrosurf.com/aras/
Liste Spectro-L:  http://groups.yahoo.com/group/spectro-l/
SAS:  http://www.socastrosoci.org/
CDS Strasbourg  http://cdsweb.u-strasbg.fr/
ADS (articles)  http://adsabs.harvard.edu/abstract_service.html
Shelyak Instruments  http://www.shelyak.com/
Stars won’t look the same!

www.SHELYAK.com

Thank You !!!