Amateur Spectroscopy

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September 4th, 2010
-- BAA / OOL ; Sidmouth, UK --

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the “menu”...

- Starting in spectroscopy (with some history)
- Equipment
- Educational
- Pro/Am projects
Starting in spectroscopy
Light & colors

➢ Isaac Newton (1642-1726)
➢ a pionnieer
➢ 1670: prisme's experience
➢ Circular “slit” of 6mm: $\lambda/\Delta\lambda \sim 10$!
Light is a wave

➢ Thomas Young (1773-1829)
  ➢ Wave interpretation of light (1801)
  ➢ Worked with grating with 20 grooves/mm
Electromagnetic spectrum
Solar spectrum

➢ William Wollaston (1766-1828)
  ➢ ~150 years after Newton!
  ➢ First observation (in 1802) of dark lines
  ➢ Demonstrated the importance of the slit width
➢ Joseph Fraunhofer (1787-1826)
  ➢ Manufacturer of high quality glasses
  ➢ A, B (Hα), C, D (sodium doublet)... H, K (Calcium) lines
  ➢ Catalog of ~600 raies in 1814
  ➢ Also observed planets and some stars!
➢ Edmond Becquerel (1820-1891)
  ➢ First photography of the solar spectrum (June 13th, 1842)
Sodium in all shape!

Salt

Match

Pickle!

Sirius

Sun

Street lamp

(c) C. Buil / Benoit Minster
Chemical analysis & spectroscopy

➢ Léon Foucault (1819-1868)
  ➢ Comparison between spectra on Earth and solar spectrum (sodium lines, 1849)

➢ Gustav Kirchhoff
  ➢ In parallel, he made the experiment with salt and published in 1859 that sodium should exist on solar atmosphere!
  ➢ A key theoretical result: Kirchhoff laws

➢ Robert Bunsen (1811-1899)
  ➢ Heidelberg university like Kirchhoff
  ➢ Together, they published in 1860 a paper on « chemical analysis by spectroscopic observation », then in 1861-1863 the analysis of several chemical elements and their work on the solar spectrum

➢ Spectroscopy was born...
A **continuous spectra** is emitted by any solid of gaseous body under high pressure and high temperature. Stars are, under first approximation, like black body whose continuous spectra has a shape which depends on its surface temperature;

Absorption line spectra: a low pressure low temperature gaz crossed by a continuous light absorbs some photons. Spectra then shows dark lines in front of the continuous spectra;

Emission line spectra: a low pressure high temperature gaz emits a light made of few radiations, characteristics of the atoms that constitutes this gaz. Each chemical element has its own line spectra, true identity card of its composition and state.
Informations from Planck profile

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

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

\( \Rightarrow \text{Temperature} = \text{Color} !!! \)

Visible domain
   = 400-700nm (4000A-7000A)
Black body profile

**Profil de Plank**

- **Longueur d'onde (angströms)**
- **Intensité**

- 12.000 K
- 10.000 K
- 8.000 K
- 5.000 K
The simplest spectroscope

Converging beam from telescope

Zero order

First order

-> spectrum!
Multiple way to setup

As a filter (ex: front of webcam)

As a filter (ex: front of digital SLR)

Front of objective

(R. Leadbeater)
30sec digital SLR shot
Measure temperature:

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

Source: Getting the measure of the stars (WA Cooper & EN Walker)
A **continuous spectra** is emitted by any solid or gaseous body under high pressure and high temperature. Stars are, under first approximation, like black body whose continuous spectra has a shape which depends on its surface temperature;

**Absorption line spectra**: a low pressure low temperature gas crossed by a continuous light absorbs some photons. Spectra then shows dark lines in front of the continuous spectra;

**Emission line spectra**: a low pressure high temperature gas emits a light made of few radiations, characteristics of the atoms that constitute this gas. Each chemical element has its own line spectra, true identity card of its composition and state.
Absorption lines ?
Low-resolution Solar Spectrum

H / K (Calcium)
Hδ
Hβ
Triplet du Magnésium
Doublet du Sodium
Hα

Olivier Thizy – Janvier 2007
Lhires III – 300tt/mm; Digital Rebel / EOS300D
Pic du Midi (ie: no atmospheric lines!)
Photospheric lines

- The photosphere is actually very thin
- The «wings» of spectral lines come from deeper layers than the «core»

D’après: http://ircamera.as.arizona.edu/astr_250/Lectures/Lecture_14.htm
Absorption/Emission lines

\[ \Delta \text{Energy} = h \times \nu = h \times \frac{c}{\lambda} \]
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?

Er... more or less...
Kirchhoff's laws

A **continuous spectra** is emitted by any solid of gaseous body under high pressure and high temperature. Stars are, under first approximation, like black body whose continuous spectra has a shape which depends on its surface temperature;

**Absorption line spectra**: a low pressure low temperature gas crossed by a continuous light absorbs some photons. Spectra then shows dark lines in front of the continuous spectra;

**Emission line spectra**: a low pressure high temperature gas emits a light made of few radiations, characteristics of the atoms that constitutes this gas. Each chemical element has its own line spectra, true identity card of its composition and state.
Planetary Nebulae

Forbidden lines
Names 'nebulium' originally!
Planetary Nebulae

Nebula continuous spectrum

Emission lines (nebula)

Central star spectrum

Nebula continuous spectrum

M57 spectrum (C. Buil; LISA, C9, QSI583, 70min)
Planetary Nebulae

NGC6826 - blink nebula

NGC7662 - blue snow ball
• **Calibration lamp** (here: internal neon lamp of a Lhires III spectrograph) create emission spectra
A **continuous spectra** is emitted by any solid of gaseous body under high pressure and high temperature. Stars are, under first approximation, like black body whose continuous spectra has a shape which depends on its surface temperature;

**Absorption line spectra**: a low pressure low temperature gaz crossed by a continuous light absorbs some photons. Spectra then shows dark lines in front of the continuous spectra;

**Emission line spectra**: a low pressure high temperature gaz emits a light made of few radiations, characteristics of the atoms that constitutes this gaz. Each chemical element has its own line spectra, true identity card of its composition and state.
Stellar classification

➢ Some pioneers: Lewis Rutherfurd (1816-1892), Angelo Secchi (1818-1878), William Huggins (1824-1910), Hermann Carl Vogel (1841-1907)
➢ A key work: Henry Drapper catalog from Harvard
  ➢ Edward Pickering (1846-1919) and his team (of women!); created AAVSO
  ➢ Williama Fleming (1857-1911): type A...Q; 26000 spectra
  ➢ Antonia Maury (1866-1952): type I...XX; first to put O type before A type in Flemming classification
  ➢ Annie Cannon (1863-1941)
    ➢ “OBAFGKM” types
    ➢ sub-divisions (B0..9)
    ➢ ~400000 spectra of her own !!!
Spectral Classification (Low Res.)

C8 – Lhires III (150tt/mm) – EOS 300D – 30 sec – no computer!
From ABC... to OBAFGKM !

Spectra by Benjamin Mauclaire; 12" telescope + Lhires III (150 gr/mm) + KAF1600 camera
Relative intensity per elements
Spectral Classification (High Res.)

$O_{h}-B_{e}-A-F_{ine}-G_{irl}-K_{iss}-M_{e}$

Sequence around Calcium triplet, near Infra-Red. © Christian Buil / Lhires III + Digital SLR
Spectral Classification (High Res.)
Stellar classification

➢ 1890: Drapper catalog of stellar spectra
➢ 1911-1915: 225300 stars reviewed by A.J. Cannon
➢ 1918-1924: HD (Henry Drapper) catalog published
➢ 1949: HDE: HD catalog extension
   ➢ Spectral type from HD catalog (Temperature): OBAFGKM
   ➢ Introduced class of luminosity I...V

E. Pickering team (all women!) in 1913.
Beginning of Astrophysics

➢ Ejnar Hertzsprung (1873-1967) & Henry Russell (1877-1957)
➢ Color/Luminosity (first published in 1911)
Doppler-Fizeau Effect

Expansion of galaxies
= red shift

\[
\frac{(\Delta \lambda)}{\lambda} = \frac{v}{c}
\]
In summary...

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**
Equipment
How does a spectrograph work?

➢ Dispersion can be done by a prism or a grating
➢ Slit is one key element for high resolution
➢ Littrow: collimator = objective
➢ Professional astronomers also use 'echelle' spectrographs with cross dispersing
Discover spectroscopy:
The Star Analyser is the simplier 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>
</tr>
<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>
</tr>
<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>Applications</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 :-)
From image to profile...

Diffuse objet spectrum (ex: sun)

Stellar 2D spectrum

Spectral profile

Calibrated spectral profile
Educational projects
Solar spectrum (visual)

Spectre Solaire
(de 4000 Å à 7100 Å)
Réseau de 2400 traits/mm + apn CANON 20Da

(c) Robin Leadbeater
Spectro-Heliography
Neon
Thorium-Argon
Helium lab lamp
Iodine lab lamp
Nitrogen lab lamp
unknown street lamp
Sodium street lamp
Light pollution... not always human!

*Some emission from NGC7000 nebula!*

C9 + LISA + QSI583 (C. Buil)
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!

C. Buil – Lhires III (1200gr/mm) – Digital SLR, near IR region (Calcium Triplet)
Planet's rotation

Saturn:
Shift = 7 pixels = 8,8 km/s
Period of 10,6 h >> R = 107511 km

\[ T^2 = \frac{(4\pi^2)}{(G(m_1+m_2))} \alpha^3 \]
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~11000). T0.28m f/6.3; Observatoire de Haute Provence – 27 février 2009. Idée de D. Gray (observation and analysis of stellar photosphere).
\[ \frac{\Delta \lambda}{\lambda} = \frac{\nu}{c} \]

Stellar Radial Velocities

SAO104807, Altair, & SAO112958
Spectroscopic binaries

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

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

![Graph showing spectroscopic binaries](image)

### Parameters of orbits

<table>
<thead>
<tr>
<th>Parameter</th>
<th>This study (VSpec)</th>
<th>This study (PeakFit)</th>
<th>Nordström (1994)</th>
</tr>
</thead>
<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>$V_\gamma$ (km.s$^{-1}$)</td>
<td>-20 ± 2</td>
<td>-21 ± 2</td>
<td>-17.0 ± 0.4</td>
</tr>
<tr>
<td>$a \cdot \sin(i)$ (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>$m_1 \cdot \sin^3(i)$ (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>$m_2 \cdot \sin^3(i)$ (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

\[ Te = 10933 \pm 174 \text{ K} \]
\[ Ne = 2537 \pm 61 \text{ e-/cm}^3 \]

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)
Interstellar lines

Na (envelop)

Na (interstellar)

P Cygni spectrum - Jean-Noël Terry – Lhires III (2400 gr/mm)
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
- Missing some blue part (aged stars in central part of M31)
- Halpha is less visible
• Broader lines (M31 rotation?)
• Doppler shift ~-280km/s (M31 is moving toward us)
Galaxies red shift

\[ \Delta \lambda = 108 \text{ A} \]

\[ \Rightarrow z = 0.016 \]
Galaxies red shift

Mrk 335
LISA (VIS) + C9 (D = 0.235 m) + QSI583
Exposure: 7 x 600 sec
Date: 9.08.2010

z = 0.026

NGC7803
LISA (VIS) + C9 (D = 0.235 m) + QSI583
Exposure: 4 x 600 sec
Date: 8.08.2010

z = 0.028
Pro/Am projects
Comète C/2006 Linear VZ13
T62 (http://AstroQueyras.com)
Lhires III (150tt/mm) + ST1603XME
11 Juillet 2007 – 3h de pose
Olivier THIZY / Jean-Pierre MASVIEL
Asteroids classification
exoplanets!
Exoplanet: tau Boo

The CCF is computed by using the spectral range 4400-6445 Å (the Hα 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

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)

Wave length

Relative intensity

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

Note: another star spectrum is closed to V407 Cyg spectrum...
Symbiotic stars: CI Cyg

CI Cyg
LISA (VIS) + C9 (D = 0.235 m) + QSI583
Exposure: 12 x 240 sec
Date: 8.854 / 08 / 2010
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)

λ (nm)

587.562 He I
589.592 Na
588.995 Na

Radial Velocity

time (phase)

Christian Buil
Valérie Desnoux
Michel Pujol
Olivier Thizy
Herbig Ae/Be stars

C. Buil
P Cygni
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)
Radial Velocities

ORBITAL ELEMENTS OF WR 140

<table>
<thead>
<tr>
<th>Element</th>
<th>WR</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K \text{ (km s}^{-1}\text{)}$</td>
<td>$82.0 \pm 2.3$</td>
<td>$30.5 \pm 1.9$</td>
</tr>
<tr>
<td>$a \sin i \text{ (10^{10} km)}$</td>
<td>$0.154 \pm 0.007$</td>
<td>$0.057 \pm 0.004$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>assumed: 0.0</td>
<td>$3.1 \pm 1.0$</td>
</tr>
<tr>
<td>$P \text{ (days)}$</td>
<td>$2899.0 \pm 1.3$</td>
<td>...</td>
</tr>
<tr>
<td>$e$</td>
<td>$0.881 \pm 0.005$</td>
<td>...</td>
</tr>
<tr>
<td>$T_0 \text{ (HJD 2,440,000+) }$</td>
<td>$6147.4 \pm 3.7$</td>
<td>...</td>
</tr>
<tr>
<td>$\omega$</td>
<td>$46.7 \pm 1.6$</td>
<td>...</td>
</tr>
</tbody>
</table>
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
Eps Aurigae eclipse: KI 7699 line

- New absorption line appearing!

Robin Leadbeater (Lhires III), Bob Stencel
Eps Aurigae eclipse: KI 7699 line

Robin Leadbeater, Bob Stencel

• Disk structures in « rings »?
Be stars

Hα

Pashen lines !!!
Be stars

23 Tau

zet Tau
Hα - time evolution β Lyr

Phase: 0.01
Exemple of Be targets: \( \nu \) Sgr
COROT targets: 64 Ser
BeSS database

URL: http://basebe.obspm.fr
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>Count</th>
</tr>
</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><strong>Total Résultat</strong></td>
<td><strong>66</strong></td>
</tr>
</tbody>
</table>

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

http://arasbeam.free.fr
## ARAS BeAm « to do » list

### 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>
</tr>
</thead>
<tbody>
<tr>
<td>dei Sco</td>
<td>143275</td>
<td>+16 00 20.0</td>
<td>-22 37 18.2</td>
<td>2.29</td>
<td>141</td>
<td>89</td>
<td>0</td>
<td>2008-08-30</td>
<td>19:30:41</td>
</tr>
<tr>
<td>zet Tau</td>
<td>37202</td>
<td>+05 37 38.7</td>
<td>+21 08 33.2</td>
<td>3.03</td>
<td>343</td>
<td>43</td>
<td>9</td>
<td>2009-01-15</td>
<td>17:07:19</td>
</tr>
<tr>
<td>14 Lac</td>
<td>216200</td>
<td>+22 50 21.8</td>
<td>+41 57 12.2</td>
<td>5.93</td>
<td>178</td>
<td>40</td>
<td>1</td>
<td>2008-11-22</td>
<td>20:33:19</td>
</tr>
<tr>
<td>QR Vul</td>
<td>192685</td>
<td>+20 15 15.9</td>
<td>+25 35 31.0</td>
<td>4.76</td>
<td>1890</td>
<td>28</td>
<td>3</td>
<td>2008-12-07</td>
<td>17:25:36</td>
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</table>

Terminé
ArasBeAm: detecting outburst

8 outbursts discovered (2 during last 2 weeks!)
delta Sco : 2011 periastron !!!

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Source</th>
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<tbody>
<tr>
<td></td>
<td>3-jun-2000</td>
<td>S. &amp; D. Morata; Buil atlas</td>
</tr>
<tr>
<td></td>
<td>8-aug-2010</td>
<td>Thierry Garrel; BeSS</td>
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</table>

Be stars identified as such in 1993
Outburst in 2000 with sudden increase of visual brightness
delta Sco : 2011 periastron !!!

Ernst Pollmann

Tango et al. 2009
delta Sco : 2011 periastron !!!

The orbital elements for δ Sco

<table>
<thead>
<tr>
<th>Element</th>
<th>Ref. a</th>
<th>Ref. b</th>
<th>This Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period $P$ (yr)</td>
<td>10.58 ± 0.08</td>
<td>10.58°</td>
<td>10.74 ± 0.02</td>
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<tr>
<td>Epoch of periastron $T$</td>
<td>B1971.41 ± 0.14</td>
<td>J2000.693 ± 0.008</td>
<td>J2000.69380 ± 0.00007</td>
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<td>Eccentricity $e$</td>
<td>0.92 ± 0.02</td>
<td>0.94 ± 0.01</td>
<td>0.9401 ± 0.0002</td>
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<tr>
<td>Semimajor axis (mas) $a''$</td>
<td>107 ± 7</td>
<td>107°</td>
<td>98.3 ± 1.2</td>
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<tr>
<td>Inclination $i$</td>
<td>48°5 ± 6°6</td>
<td>38° ± 5°</td>
<td>38° ± 6°</td>
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<tr>
<td>Long. of asc. node $\Omega$</td>
<td>24° ± 13°</td>
<td>-1° ± 5°</td>
<td>19° ± 0°1</td>
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<tr>
<td>Systemic RV $V_0$ (km s$^{-1}$)</td>
<td>159°3 ± 7°6</td>
<td>175°</td>
<td>175°2 ± 0°6</td>
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<tr>
<td>RV amplitude $K_A$ (km s$^{-1}$)</td>
<td>-6 ± 0.5</td>
<td>-6.72 ± 0.05</td>
<td>23.84 ± 0.05</td>
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<tr>
<td>Semimajor axis of primary $a_A$ (km)</td>
<td>(7.1 ± 0.1) $\times 10^8$</td>
<td>0.9 ± 0.4</td>
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<tr>
<td>Mass function $M_B^2/(M_A + M_B)^2$ (M$_\odot$)</td>
<td>Ref. a Hartkopf et al. (1996)</td>
<td>Ref. b Miroshnichenko et al. (2001)</td>
<td>c Value assumed from Ref. a</td>
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</table>

Interferometric orbit for delta Sco and orbital elements (Tango et al., 2009)

Recent interferometric observations (Tango et al., 2009) led to new orbital elements and masses estimation: $M1 = 15 \pm/\pm 7$ M* and $M2 = 8.0 \pm/\pm 3.6$ 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 !!!
in summary...

• Spectroscopy reveal 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.socastrosci.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! Thank You !!!