Initiation to Spectroscopy

...stars won't look the same !

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Norman Lockyer Observatory, UK
9 october 2015

Photo: Jim Edlin, OHP

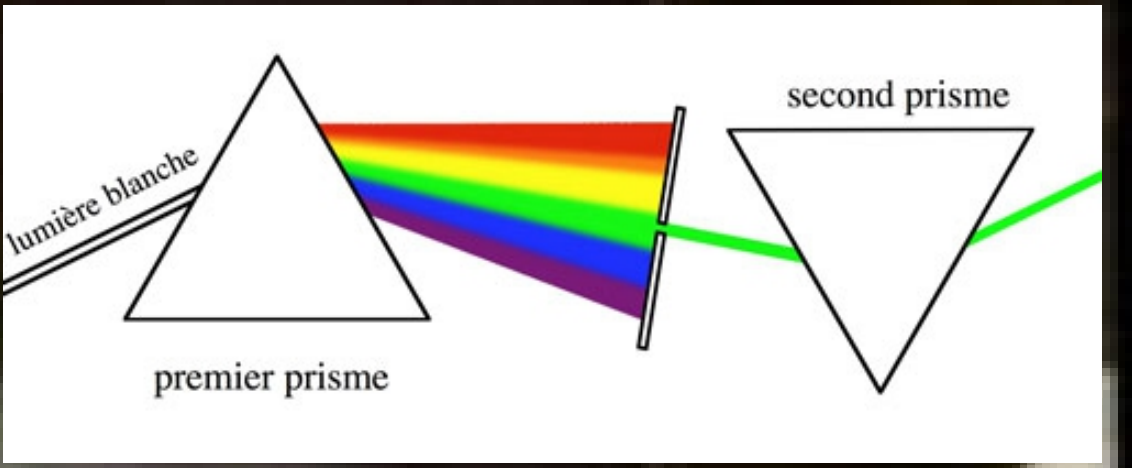
Agenda

- What is light ?
- How does a spectroscope work ?
- What does a star spectrum show ?
  - Kirchhoff's laws
  - Doppler-Fizeau effect
- A walk with a Swan

Photo: Jim Edlin, OHP

What is light? Let's call a friend...

Breaking light into a rainbow



- Isaac Newton : a pioneer
- 1670: prism experiment
- Circular “slit” 6mm: $\lambda/\Delta\lambda$ ~10 !
- Observation of a "ghost", a "spectrum"

Photo: Wikipedia

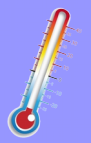
Natural rainbows... and artificials ones !

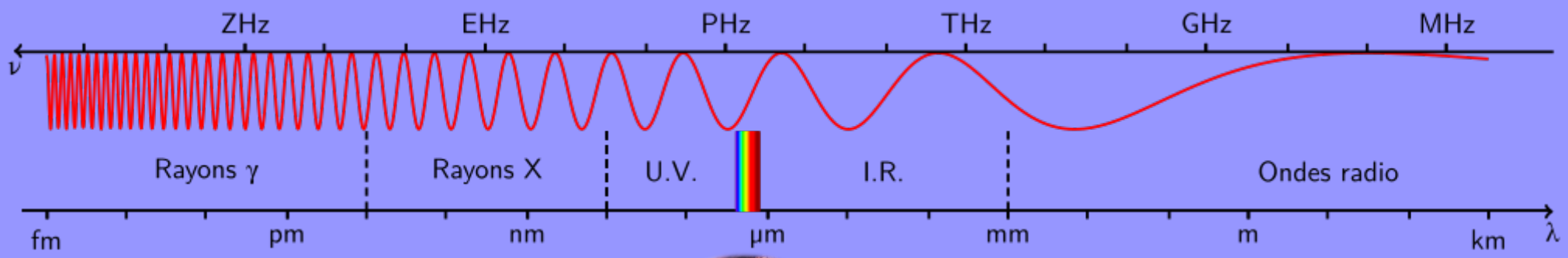
- Explained by René Descartes
- Theorised by Isaac Newton
- Further studied by Thomas Young

Photos: F. Cochard / C. Buil / O. Thizy

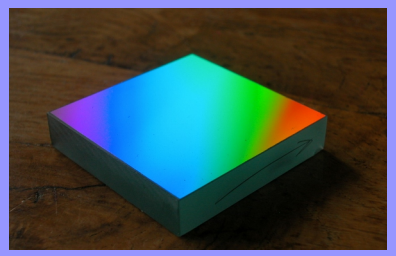
Light is a wave

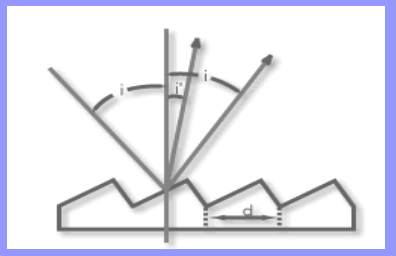


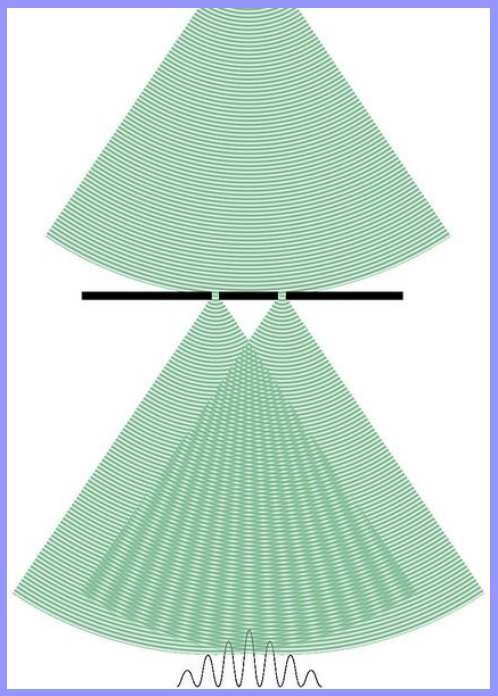





- 1800: W. Hershel discovers the Infra-Red
- 1801: J. W. Ritter discovers Ultra-Violet
- 1801: T. Young, wave theory of light

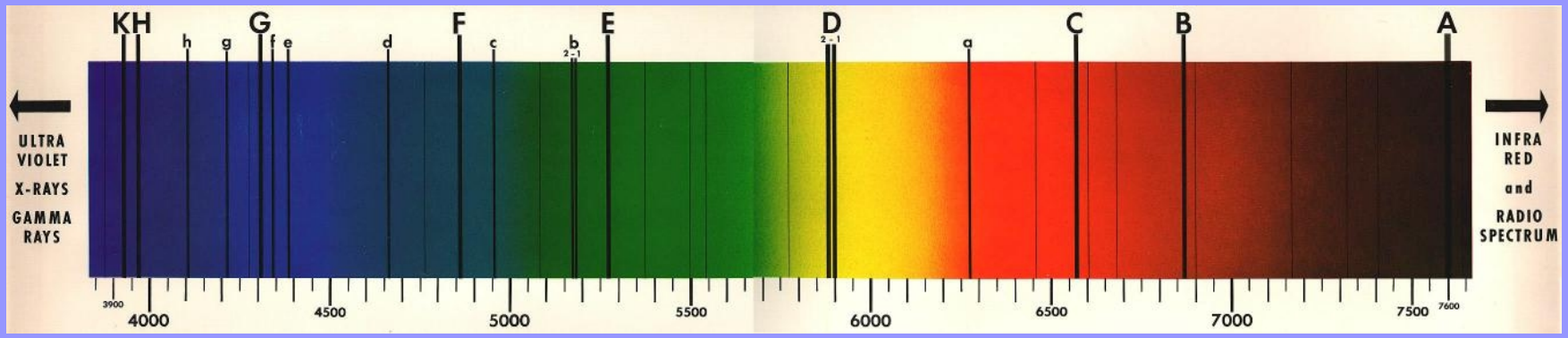






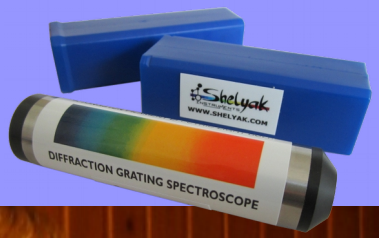
Source: Benjamin ABEL & images libres

First spectra: Sun's light

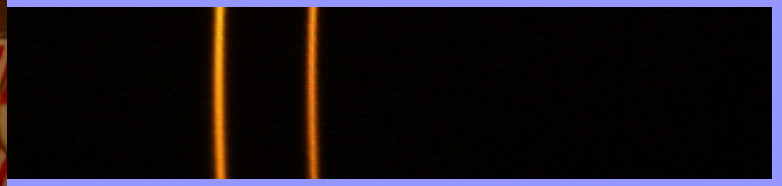


- William Wollaston (1766-1828)
  - ~150 years after Newton !
  - First observations (1802) of dark lines
  - Displayed the importance of the slit width
- Joseph Fraunhofer (1787-1826)
  - High quality glass manufacturing
  - A, B (H alpha), C, D (sodium doublet)... H & K (calcium doublet)
  - Catalog of ~600 lines in 1814
  - Observed some planets and stars too
- Edmon Becquerel (1820-1891)
  - First photography of solar spectrum (1842)

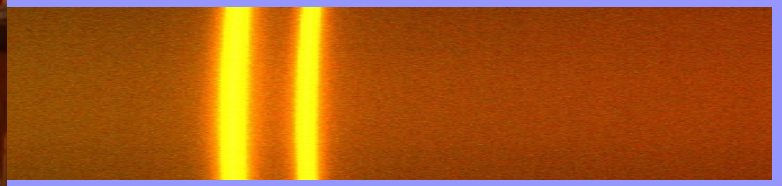
Photos : Wikipedia



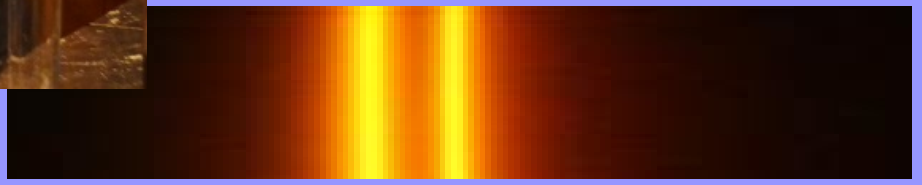
Sodium in different shapes



Salt



Match



Pickles !

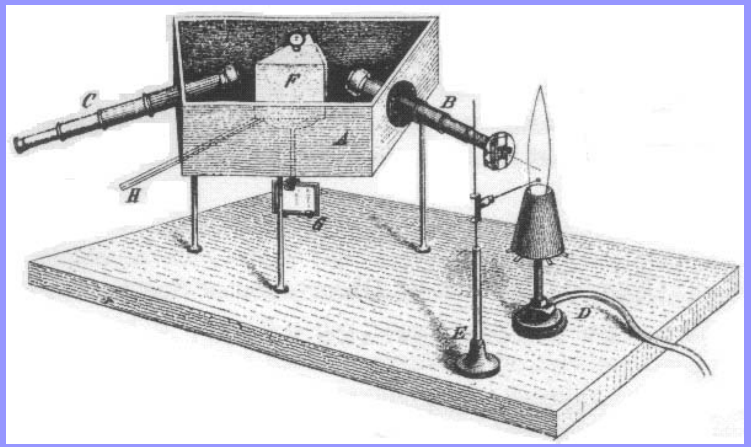
Street lamp

Sun

Crédits: C. Buil / B. Minster

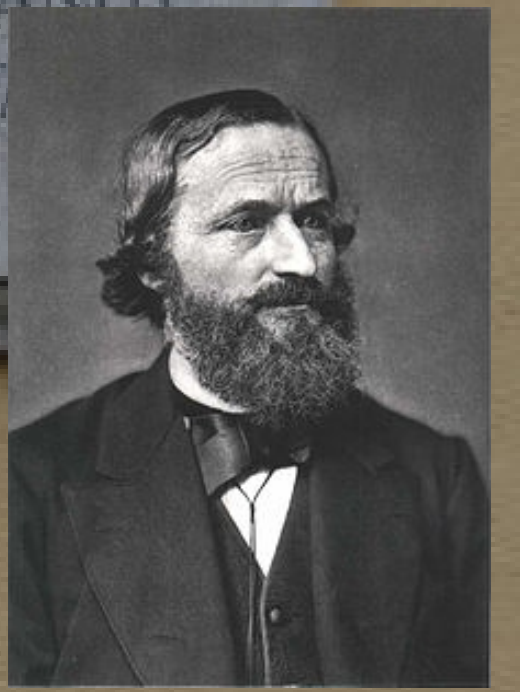
Chemical analysis & spectroscopy

- **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 theoritical result: Kirchhoff laws
- **Robert Bunsen (1811-1899)**
  - Heidelberg university (same as Kirchhoff)
  - Together, they published in 1860 a paper on « chemical analysis by spectroscopic observation », then in 1861-1863 the analysis of several chemical elements & their work on the solar spectrum



Photos : Wikipedia

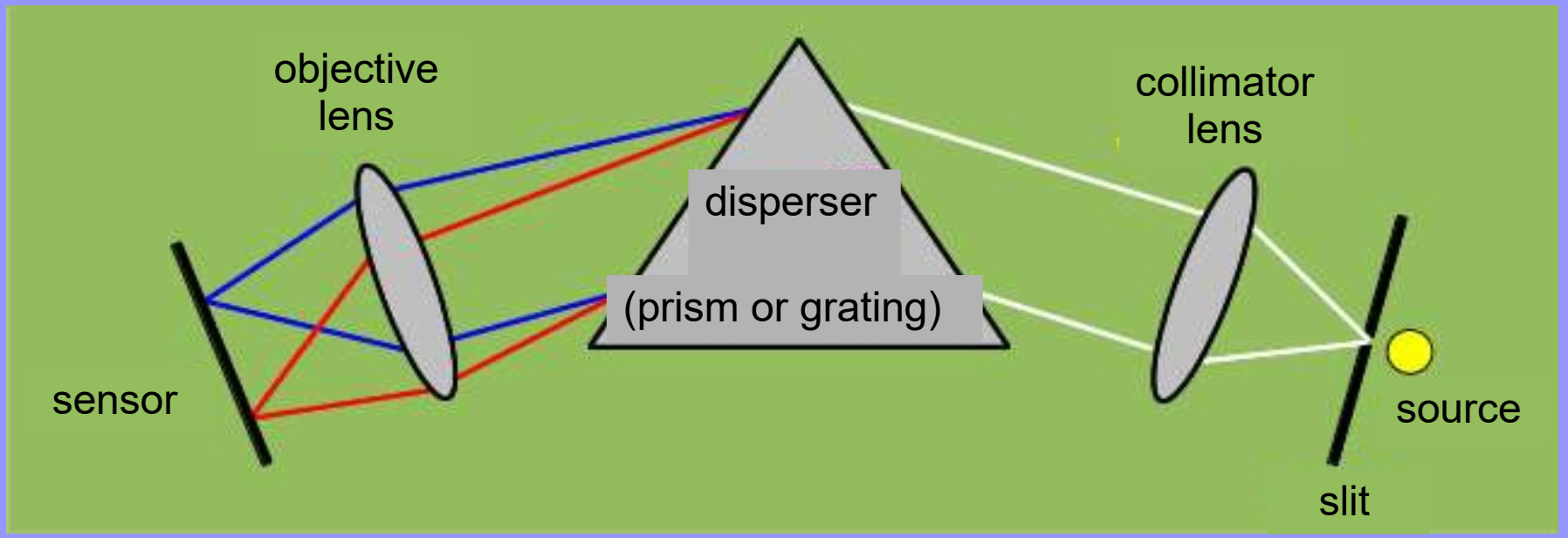
Spectral Analysis was born !



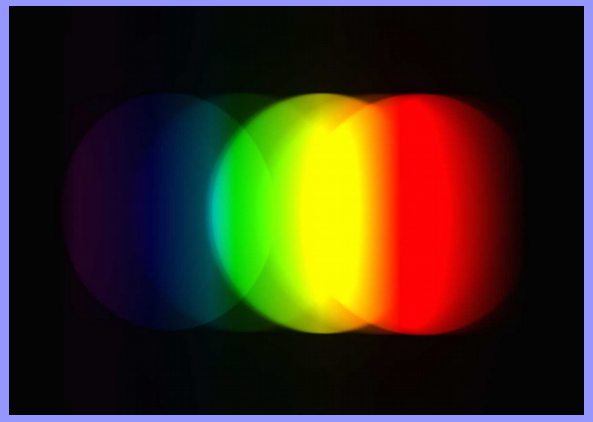
Photos : Wikipedia / O. Thizy

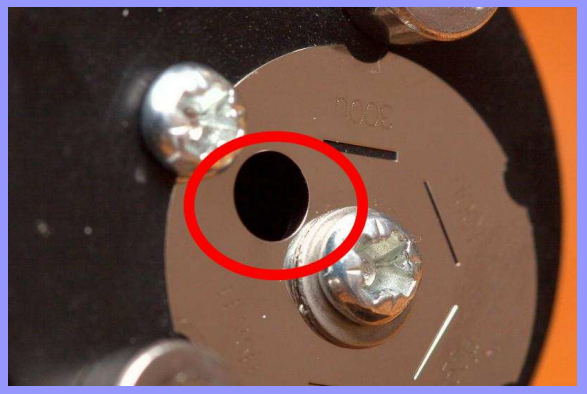

And for the stars ?

How does a spectroscope work ?

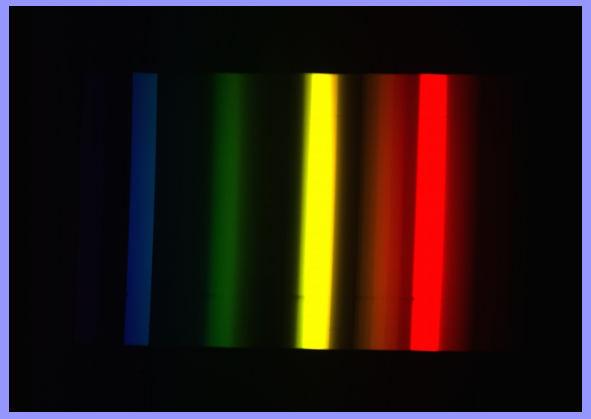


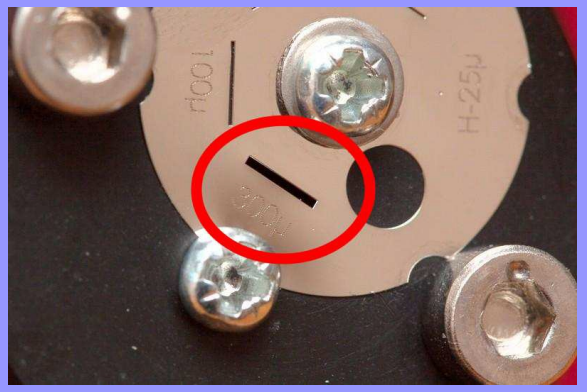
Importance of the slit



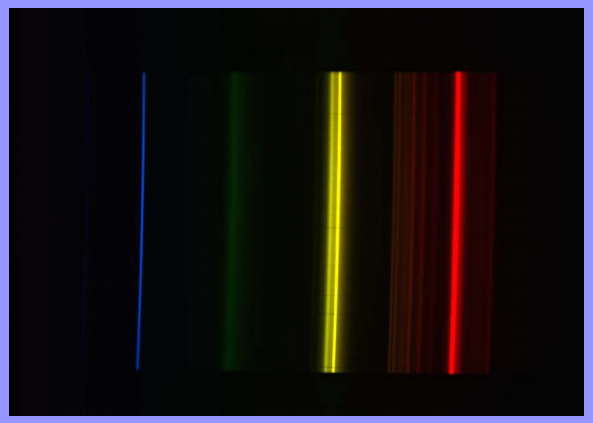


3mm slit (hole)



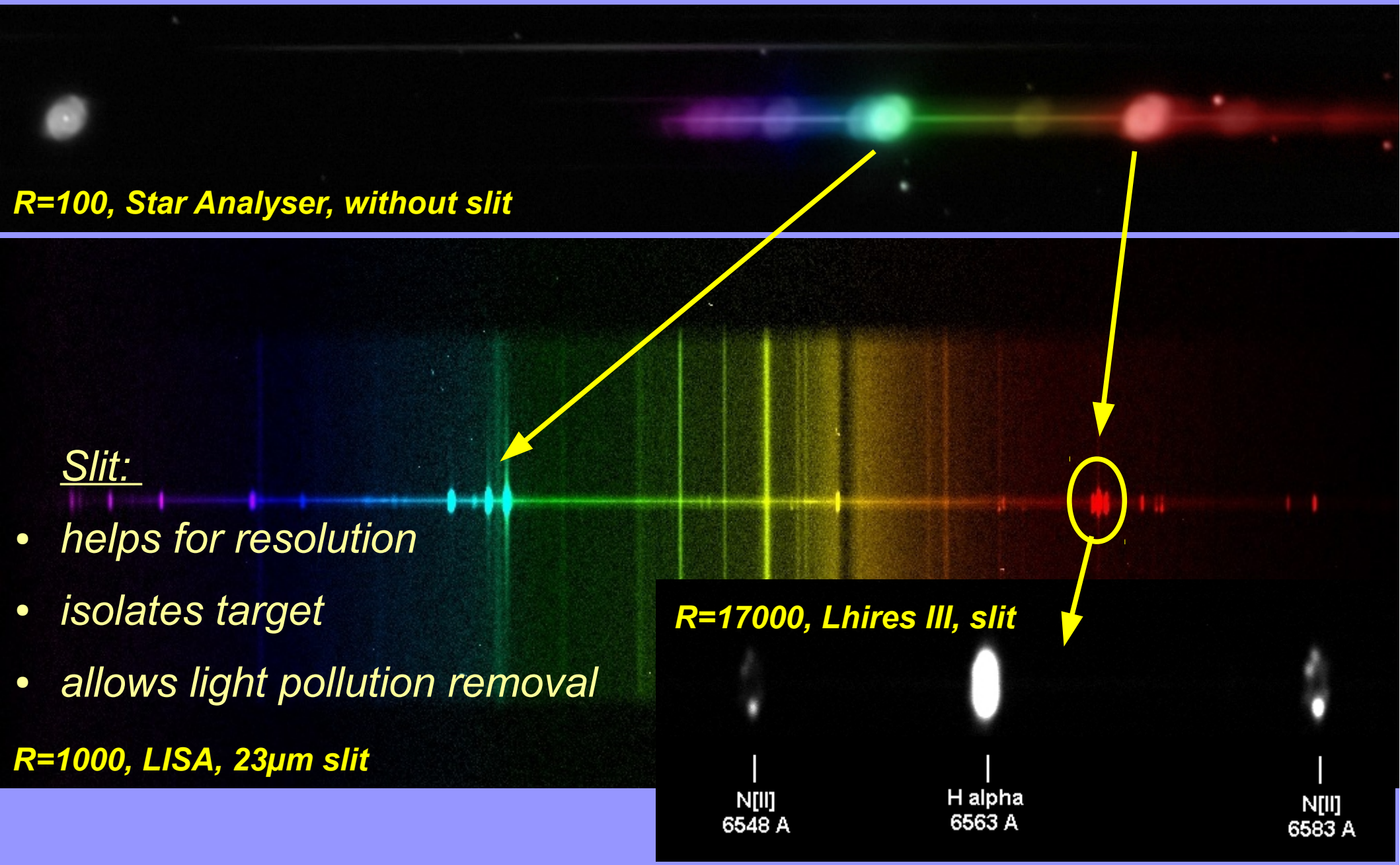


300µm slit



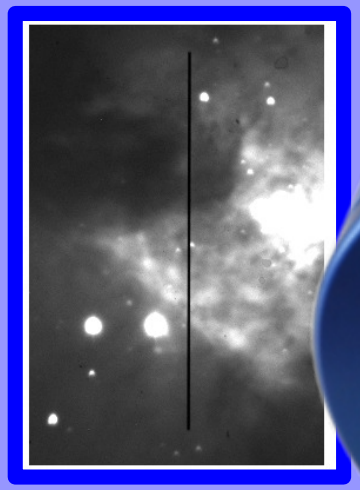
25µm slit

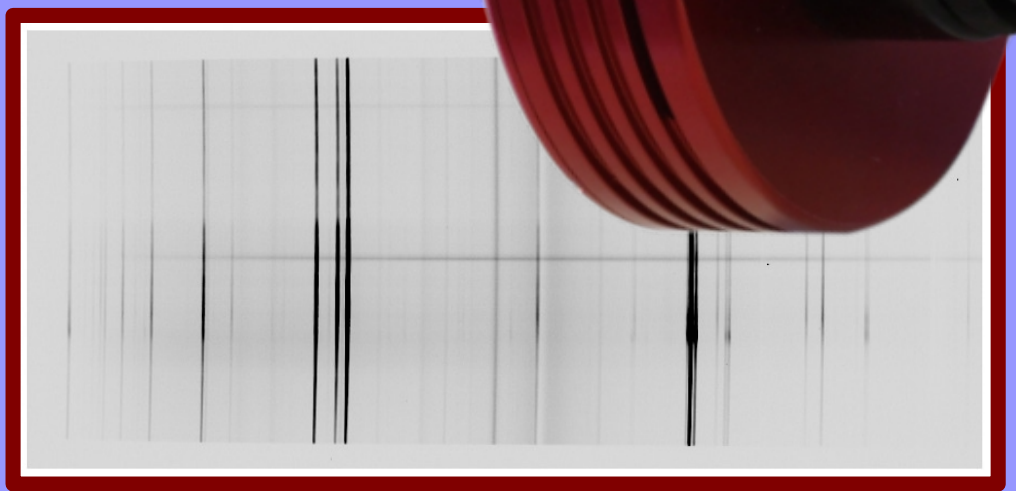
Cat's eye nebula / no slit Vs slit



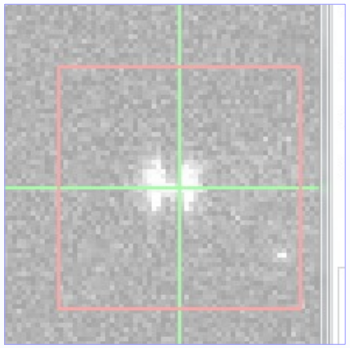
Mirror slit

- *Centering*
- *(auto)Guiding*





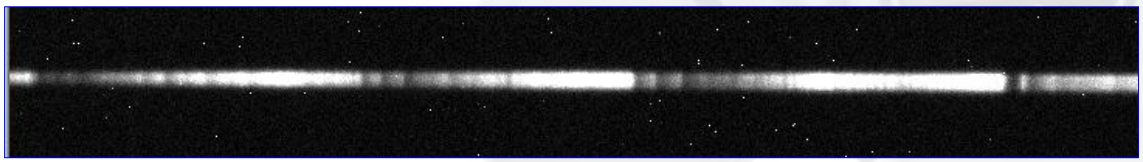
Using a spectroscope



Guiding camera

A spectrum is an image which can be displayed as a profile

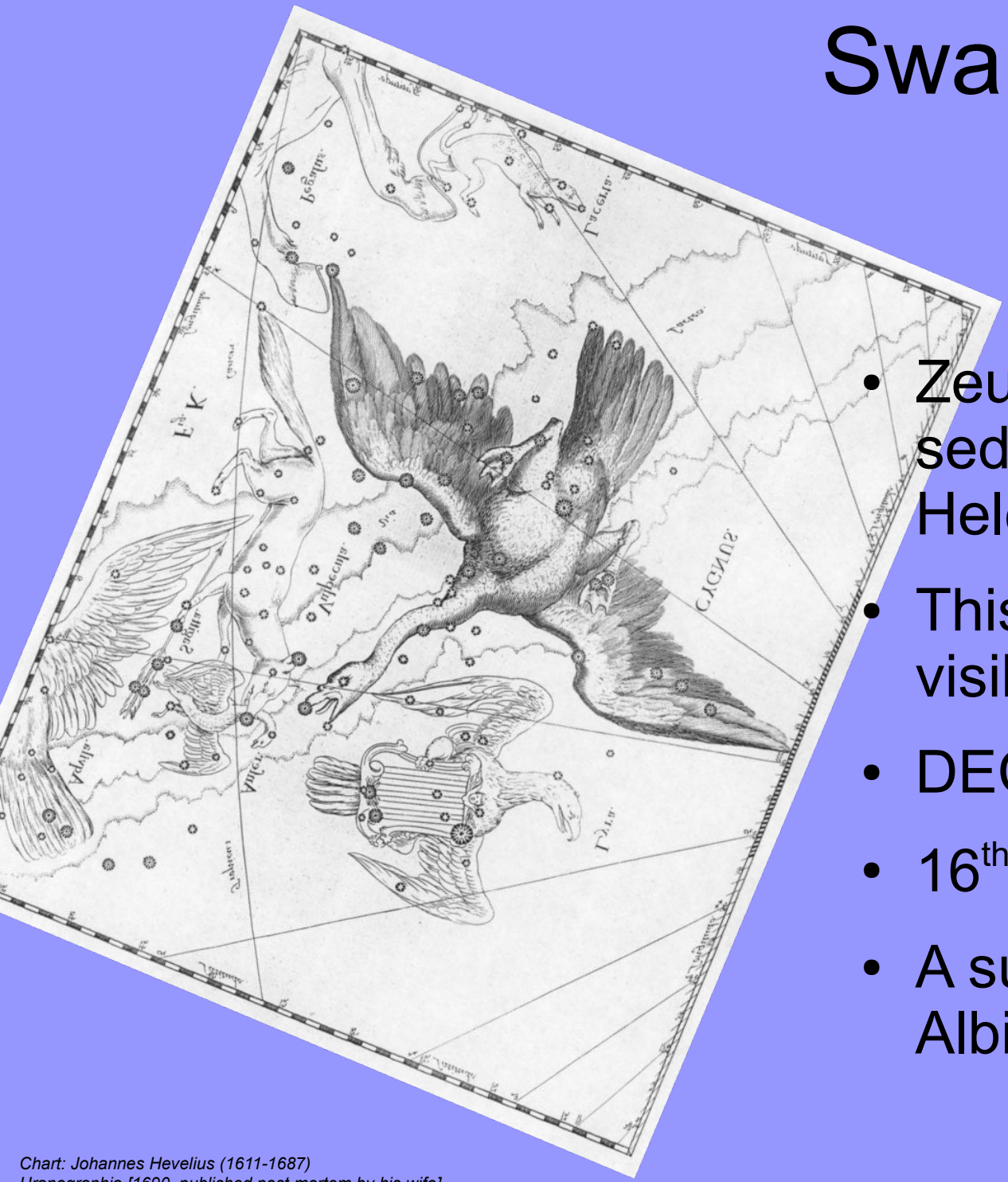
Alpy 600 spectrograph



Acquisition camera


The Swan
Photos: Jim Edlin

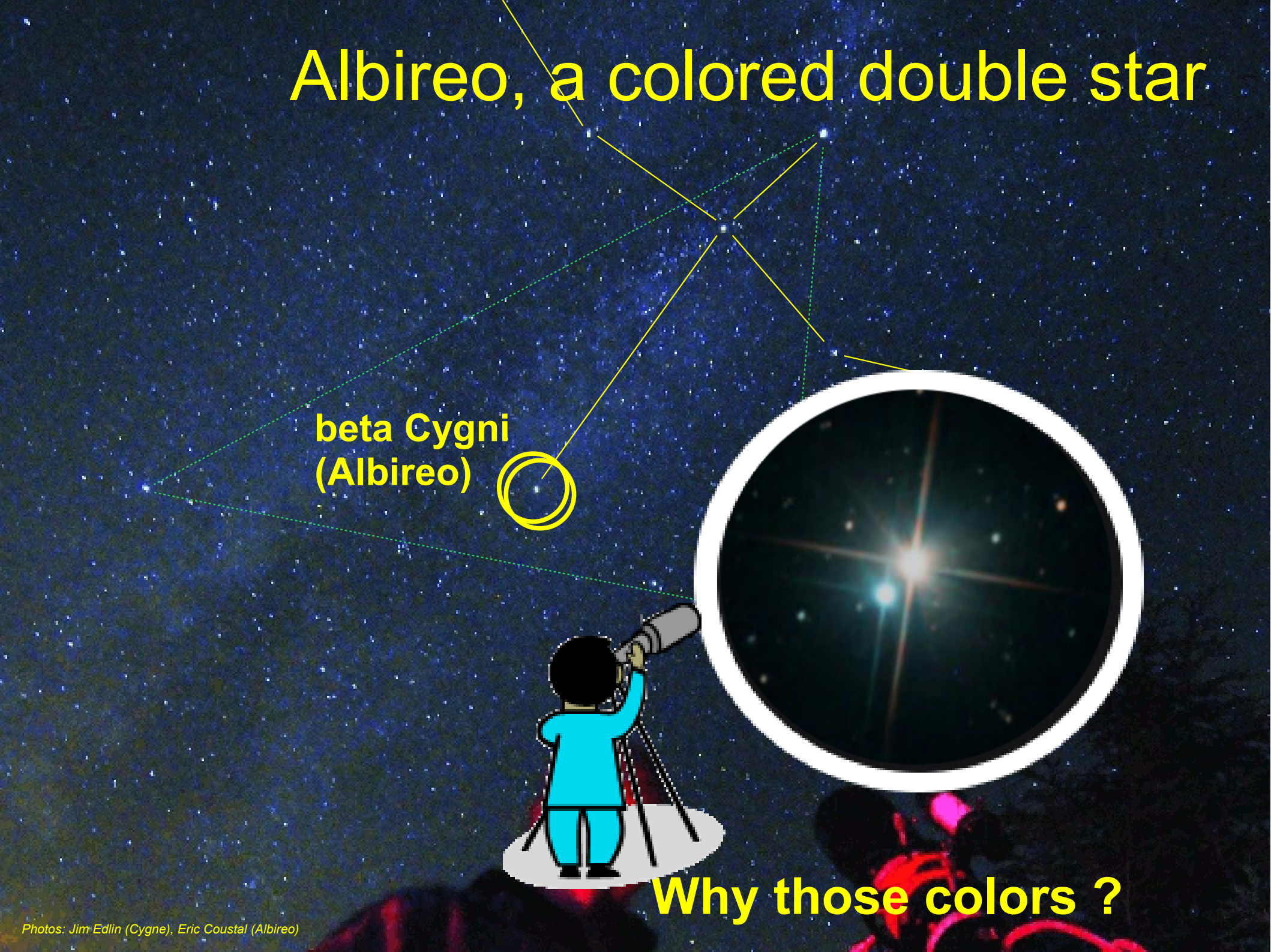
Swan constellation



- Zeus took its shape to seduce Léda... Pollux & Helena are their children !
- This "North cross" is well visible in summer & fall
- DEC +27° --> +60°
- 16th constellation in size
- A superb double star: Albireo

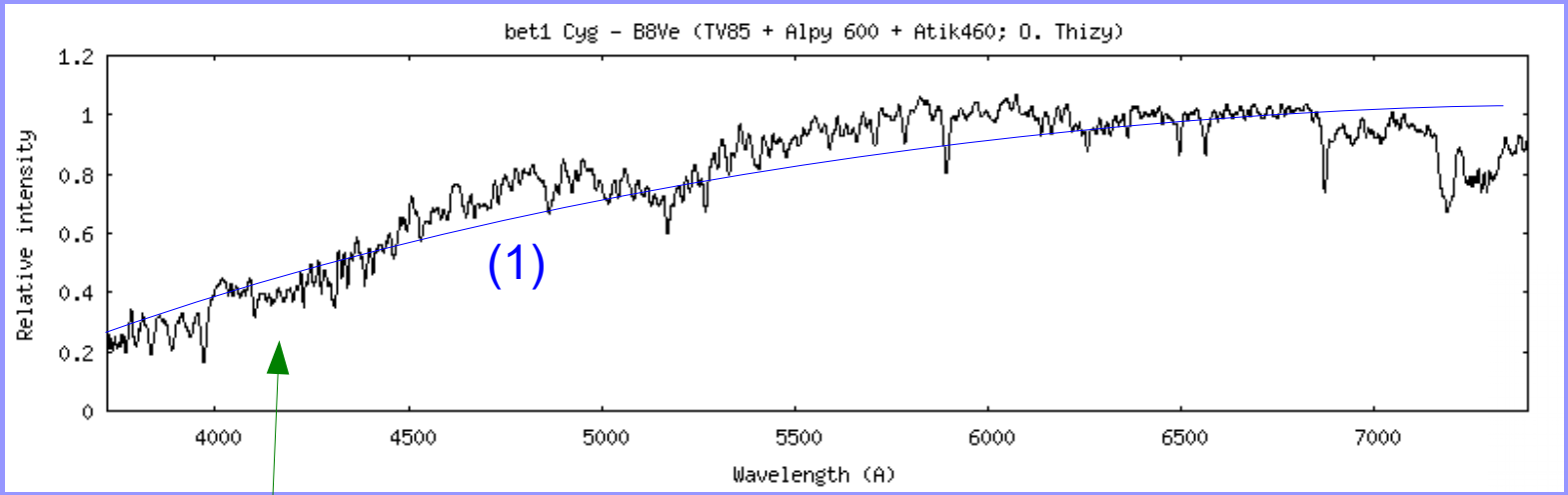
Chart: Johannes Hevelius (1611-1687)
Uranographia [1690, published post mortem by his wife]

Albireo, a colored double star



Photos: Jim Edlin (Cygne), Eric Coustal (Albireo)

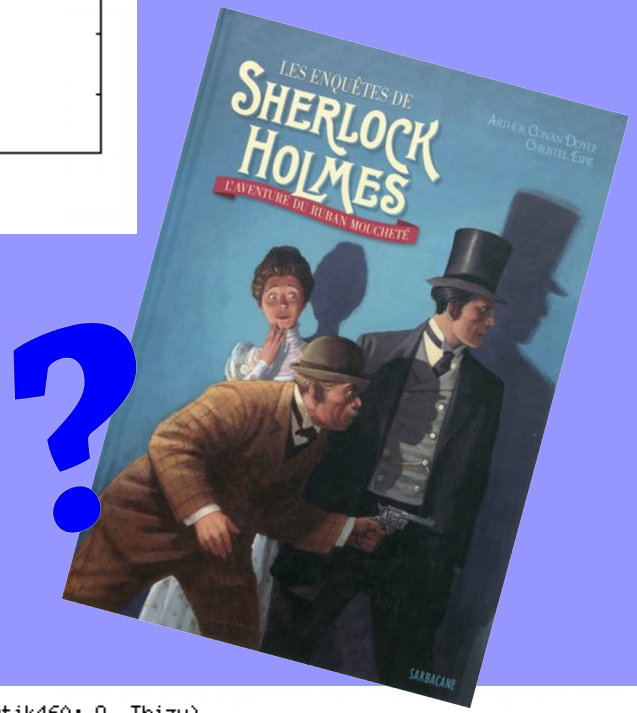
Albireo

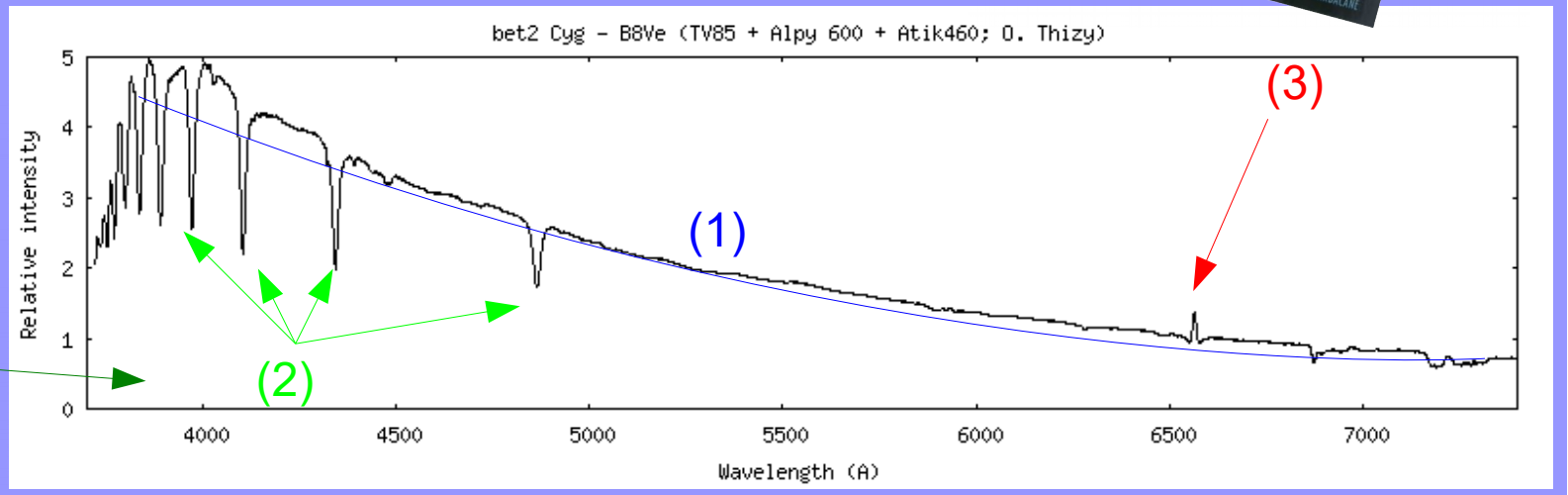


(1) Different shape for the profiles ?

(2) Absorption lines ?

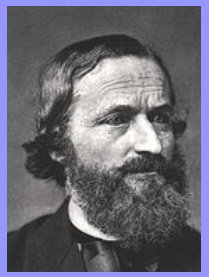
(3) Emission line (beta Cyg B) ?



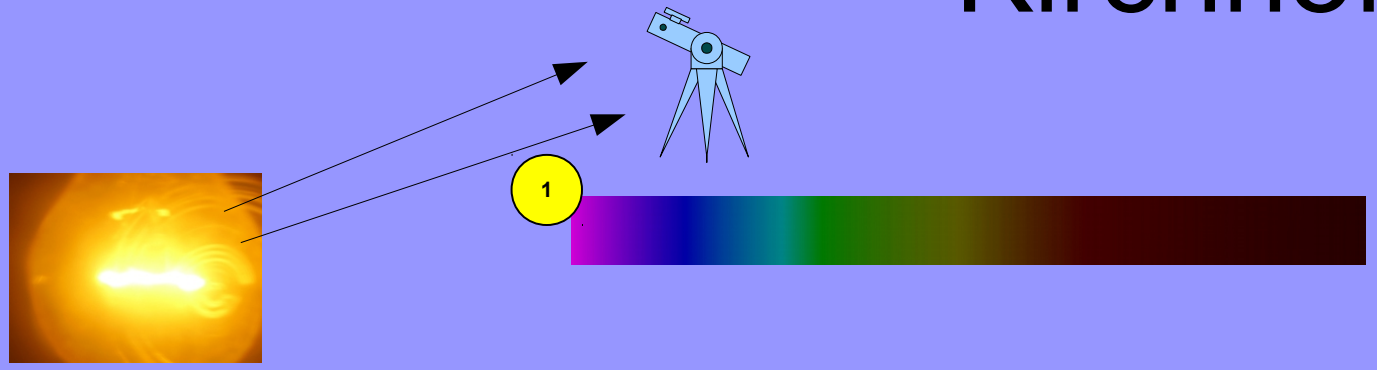


Elementary my dear Watson...

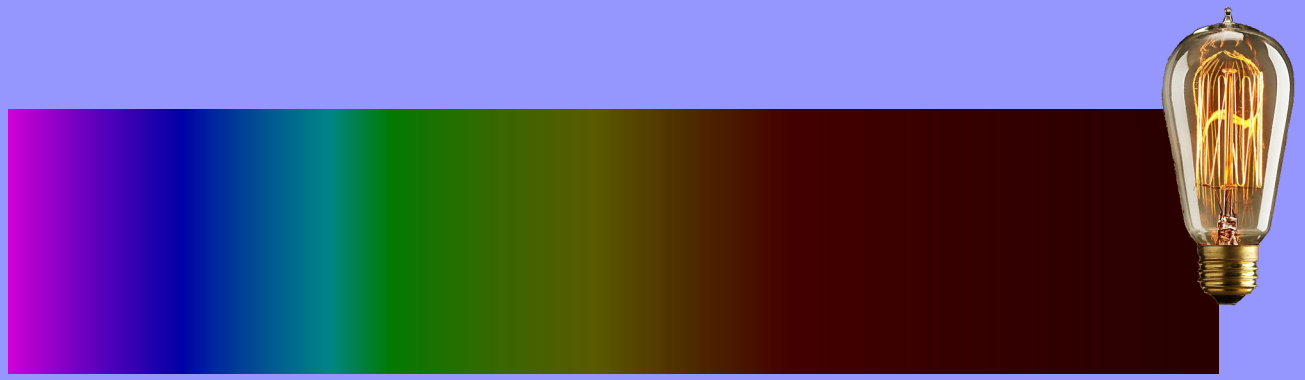
Photos: Eric Coustal (Albireo) & Wikipedia



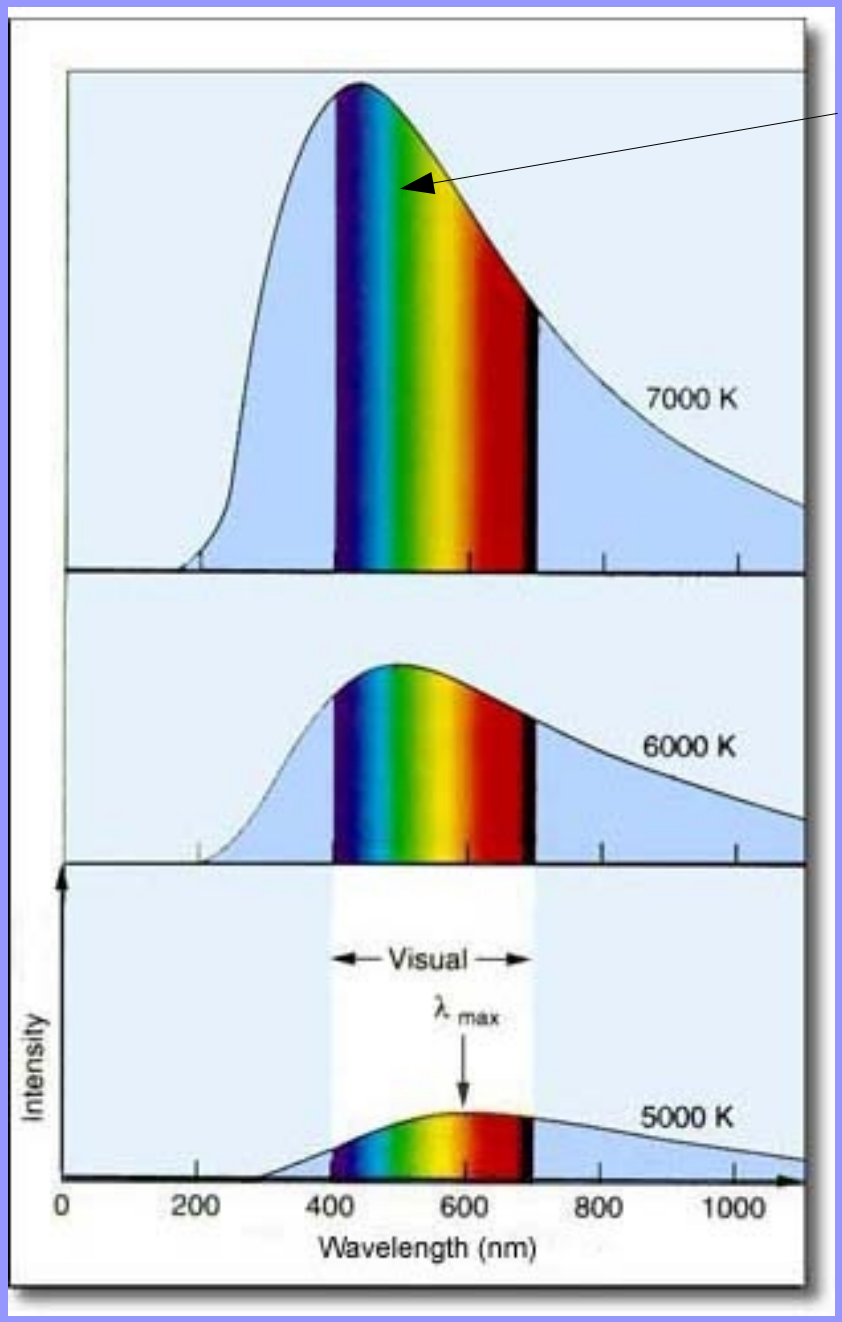
Kirchhoff law #1



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



Planck's Profile



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

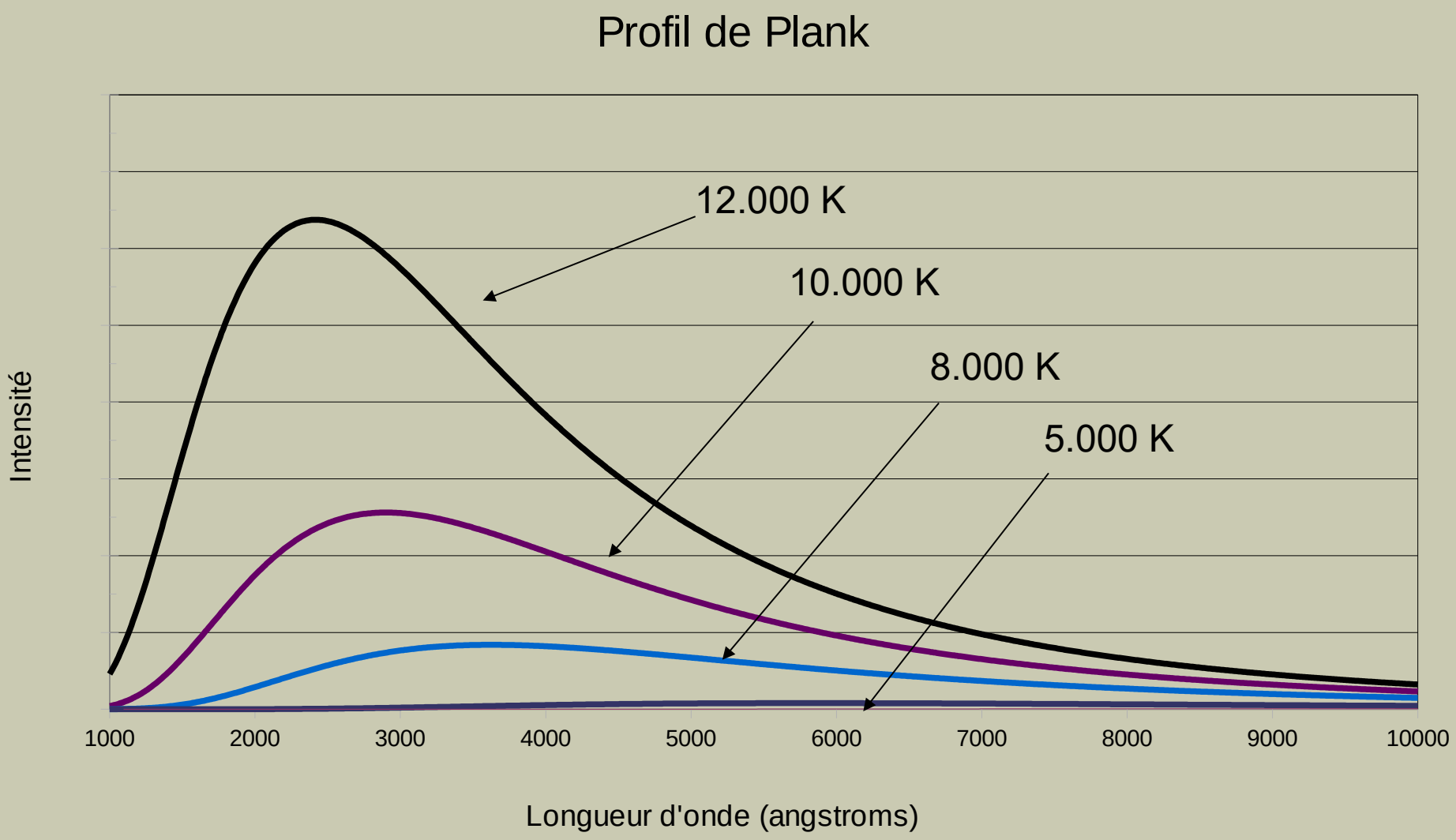
- **Stefan's law:**
  Intensity (area under the curve)
  = Constant * T^4

- **Wien's law:**
  λ max * Temperature
  = 2900 µm.K

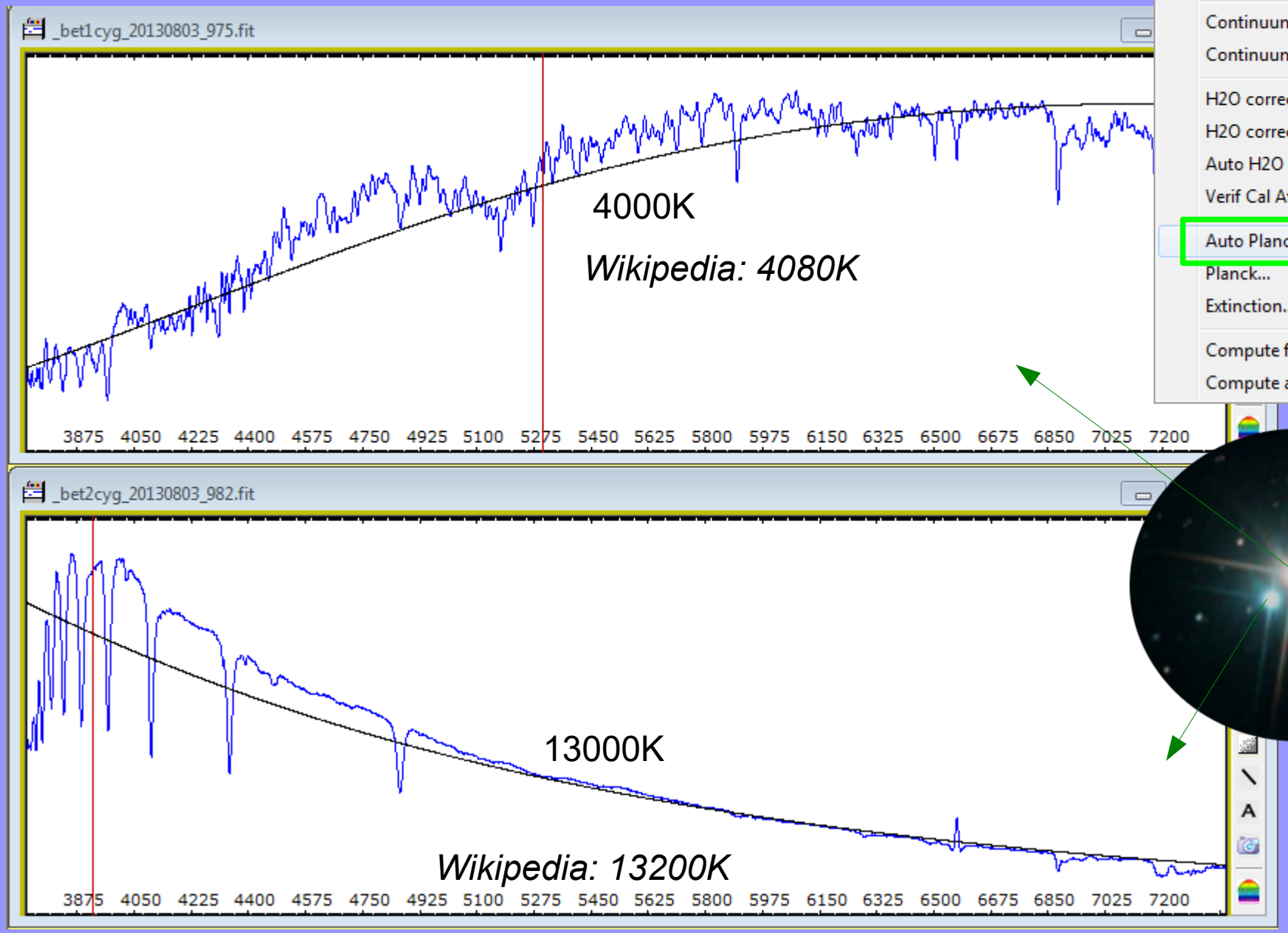
  ==>Temperature ⟷ Color !!!

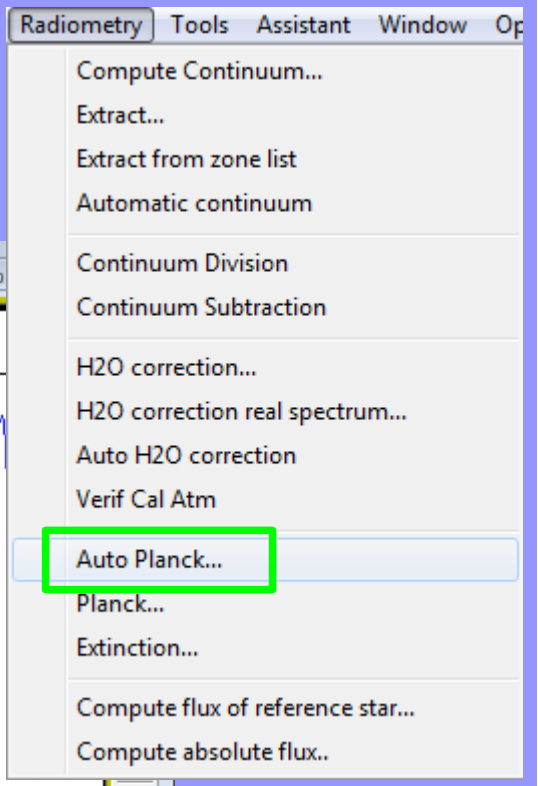
Photos : Wikipedia

profile vs. effective temperature



VisualSpec "autoPlanck"





Analyse: VisualSpec; photo Aliréo: Eric Coustal

Careful: this is an approximation !

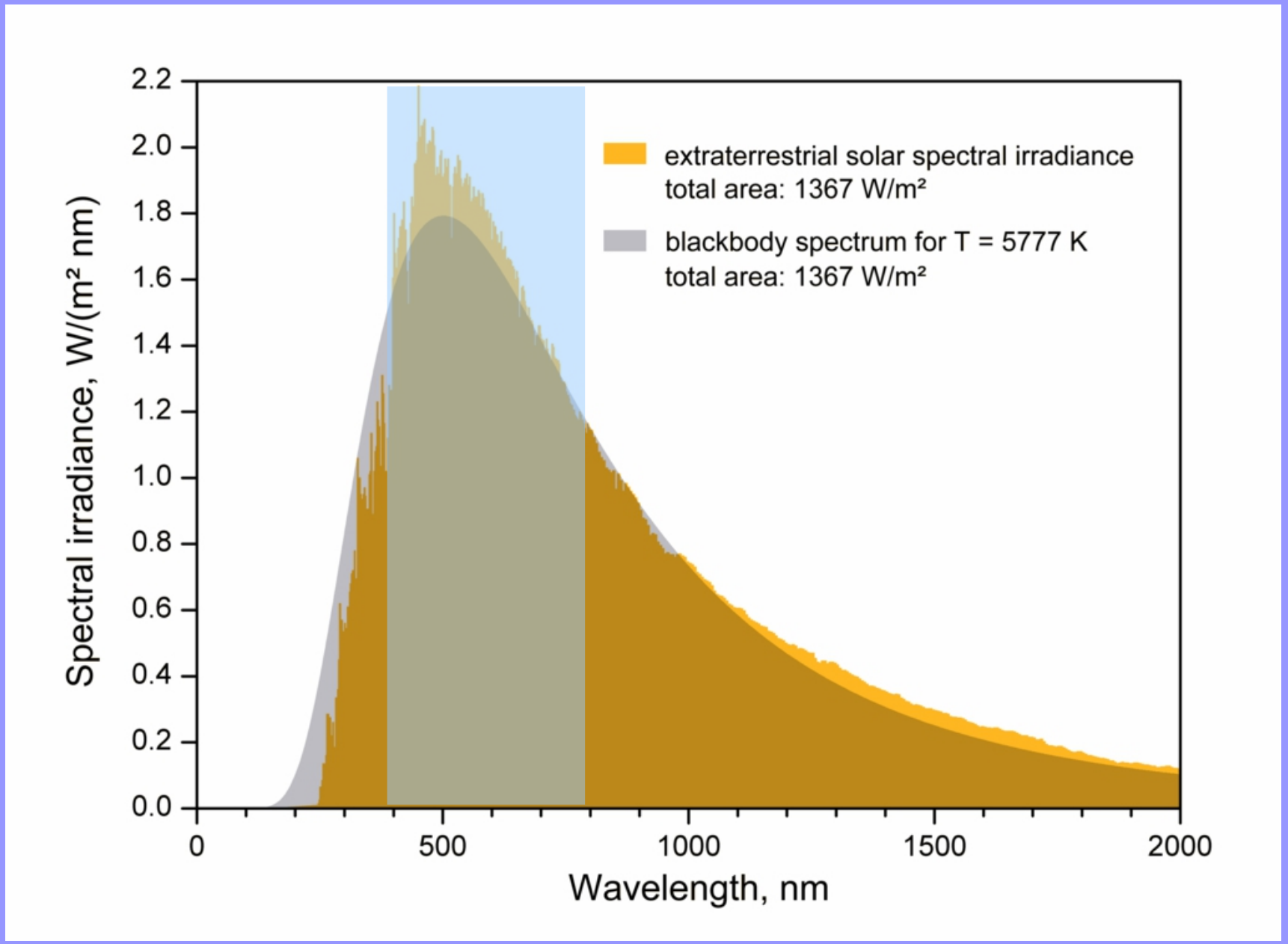
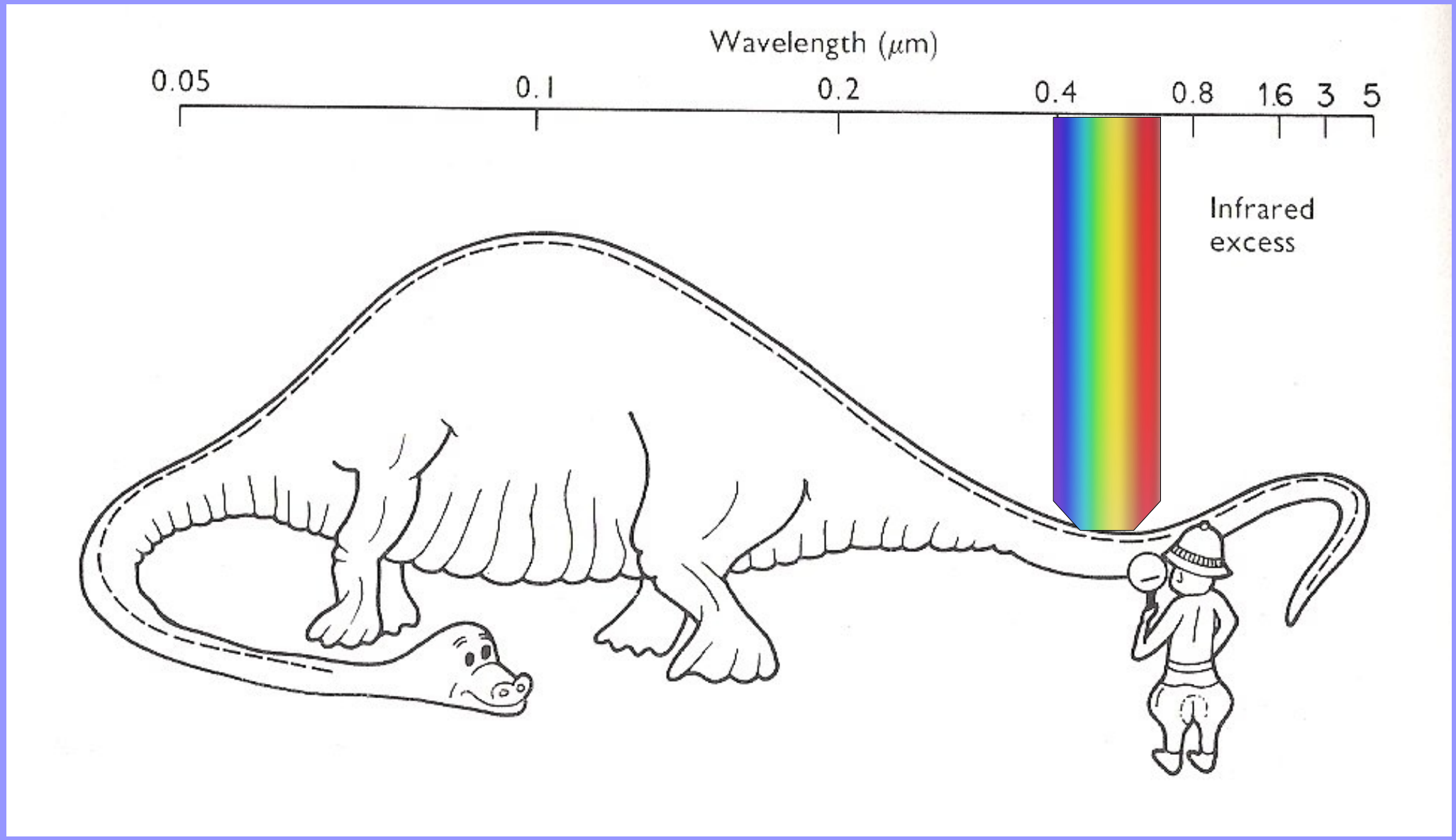
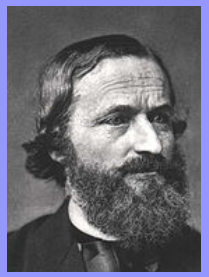


Photo : Wikipedia

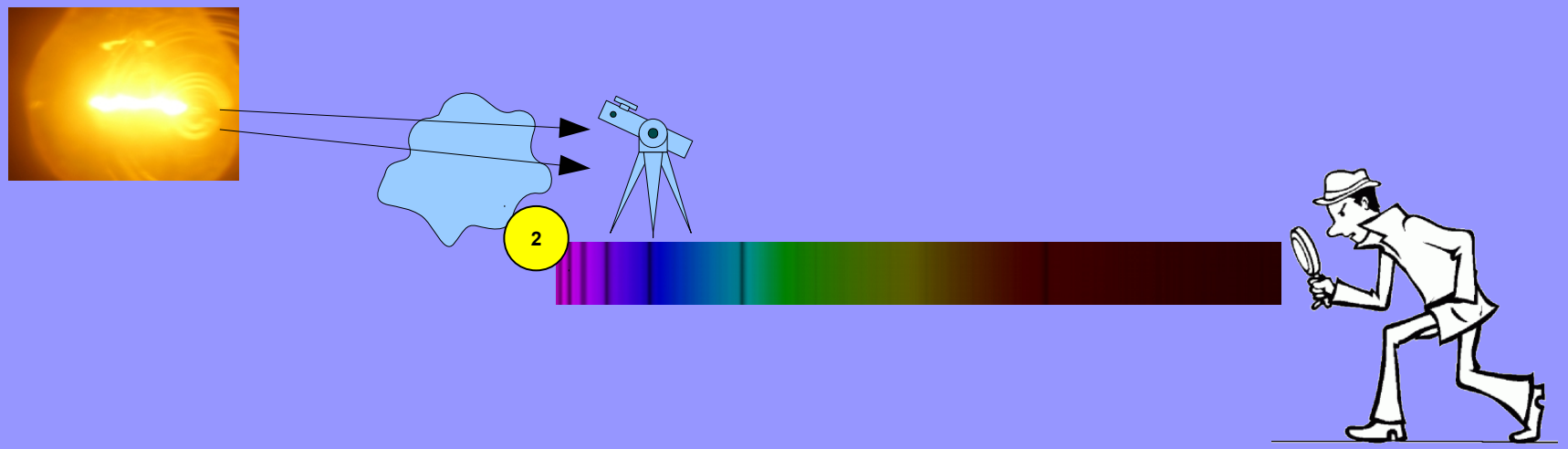
Careful: a very partial view !



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

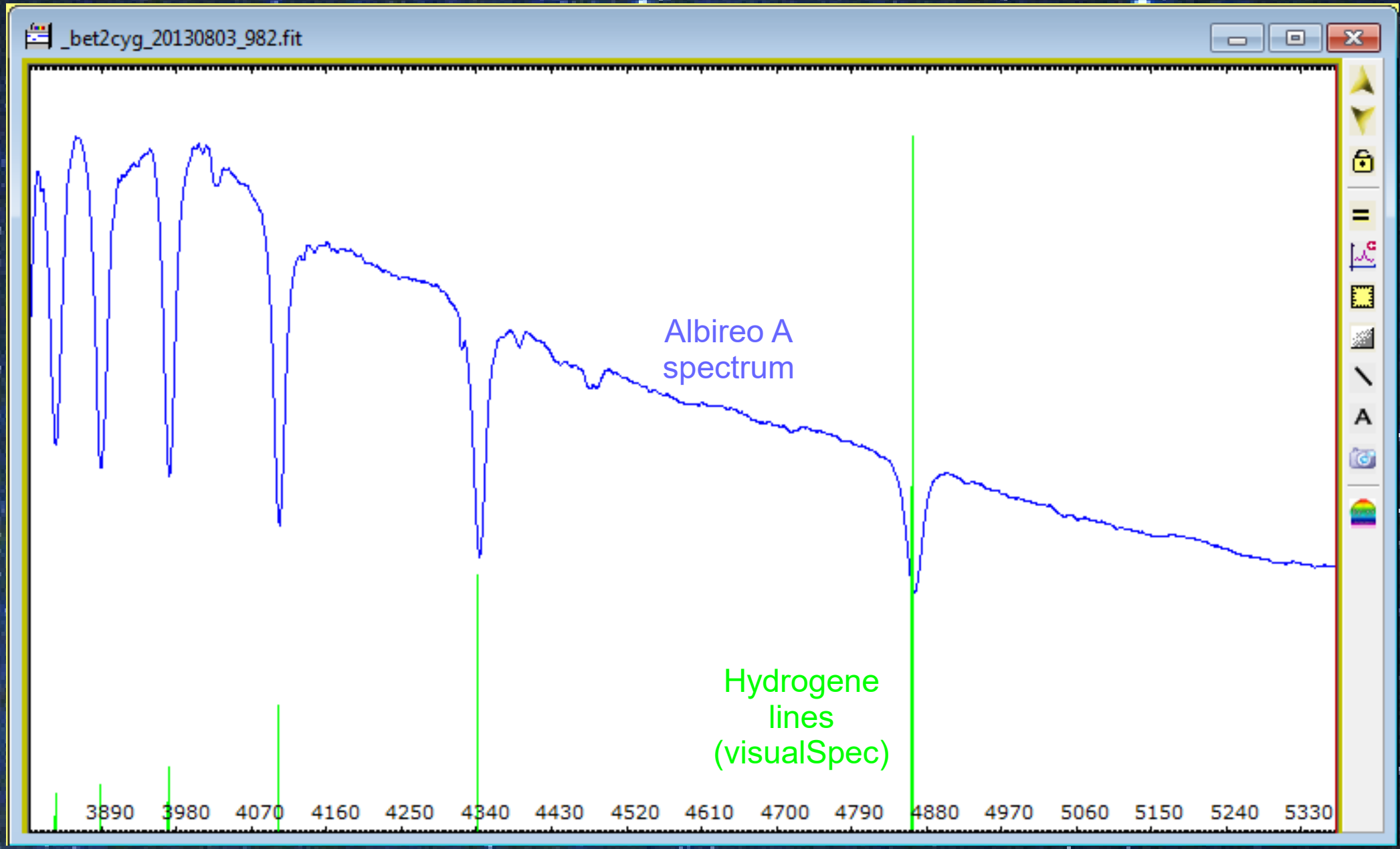


Kirchhoff law #2

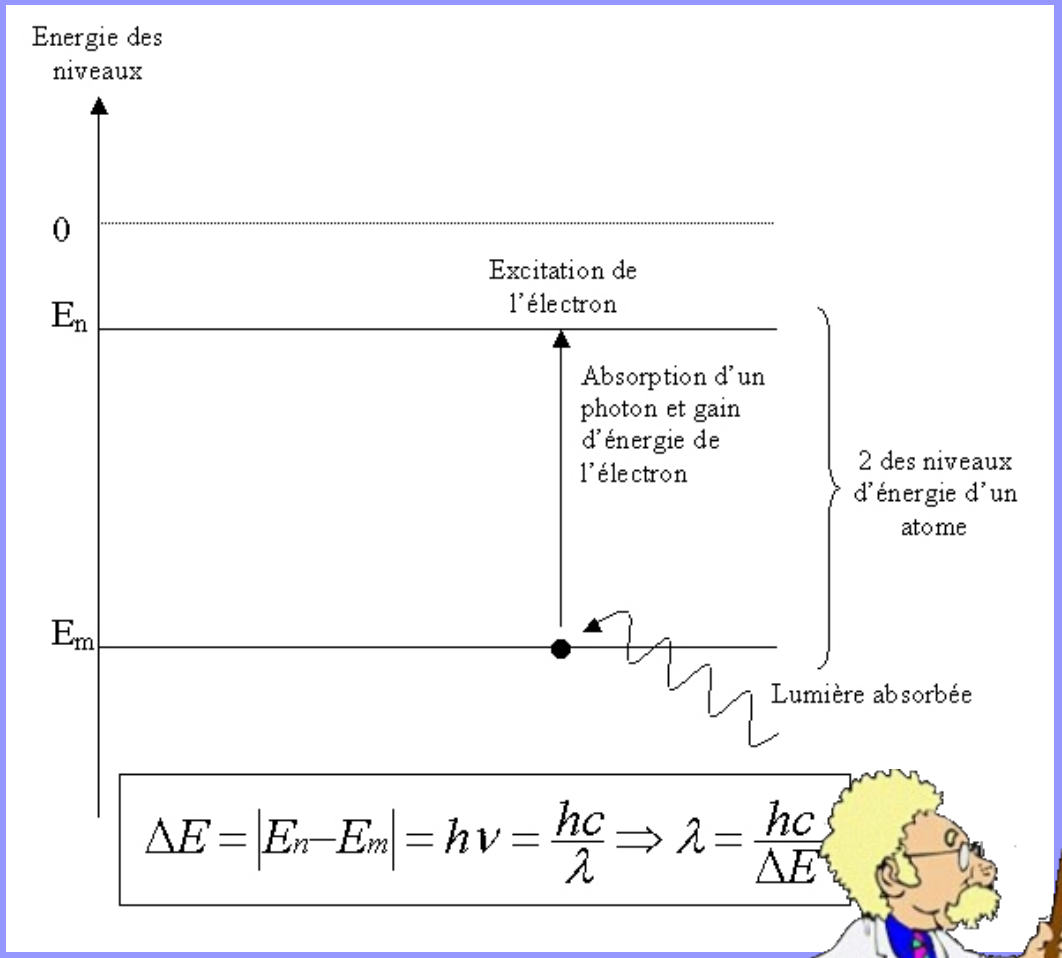


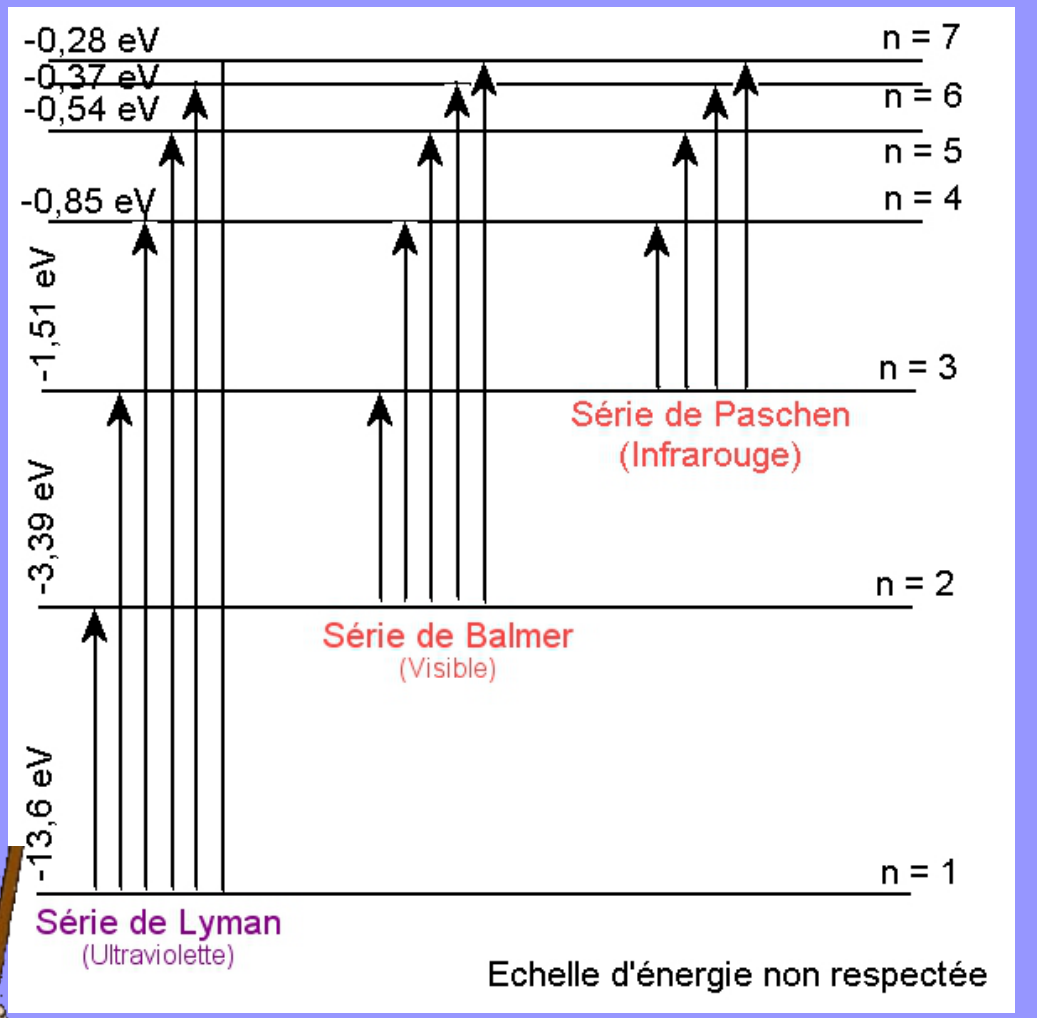
2 **Absorption line spectra**: a low pressure low temperature gaz crossed by a continuous light absorbs some photons. Spectra then shows dark lines in front of the continuous spectra;

Stellar Atmosphere



Absorption lines physics





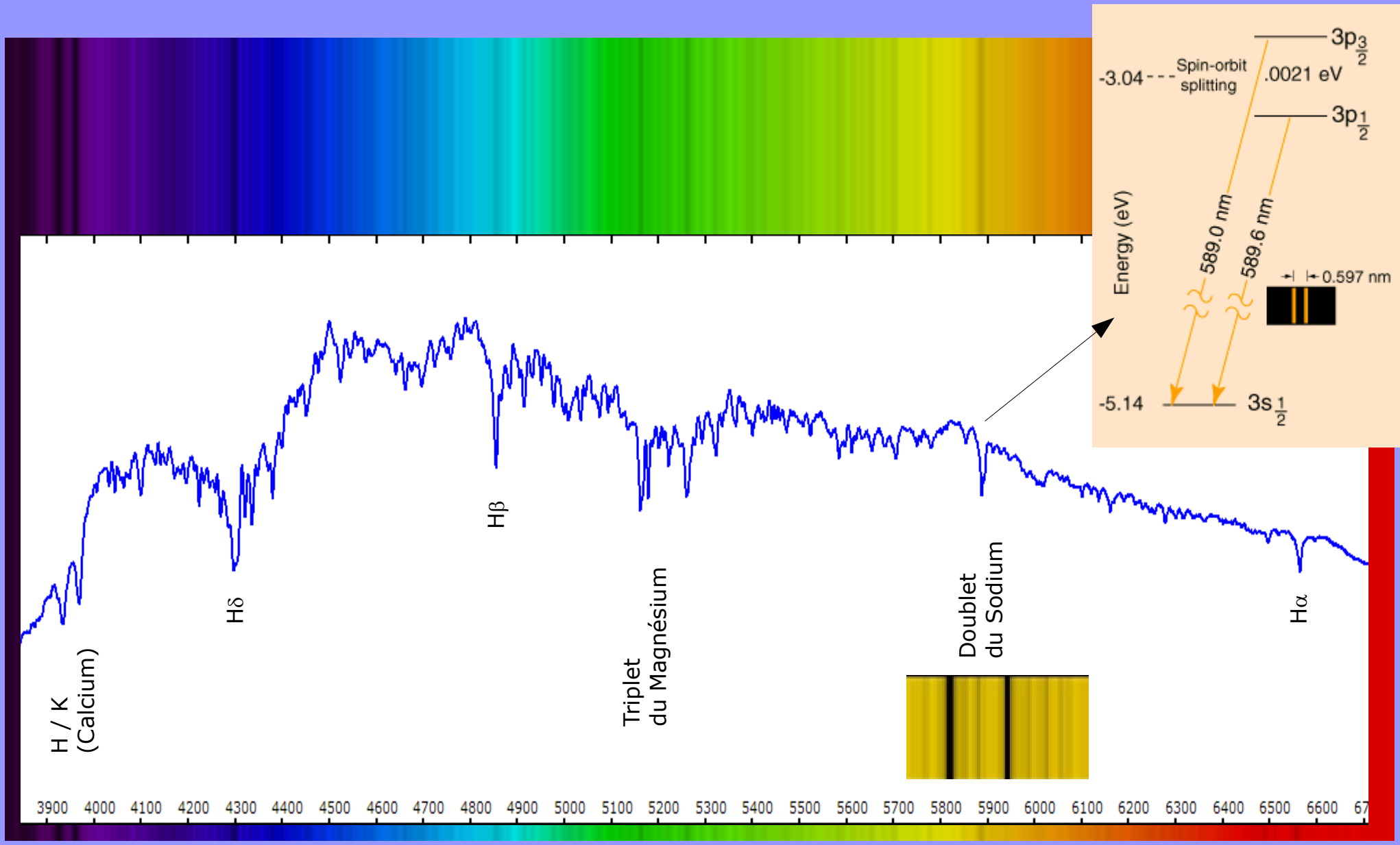
Exemple for the hydrogen atom

Sources: http://culturesciencesphysique.ens-lyon.fr/ressource/Quantique.xml
&: http://e.m.c.2.free.fr/niveaux-energie-hydrogene-emission-absorption.htm

Visual solar spectrum

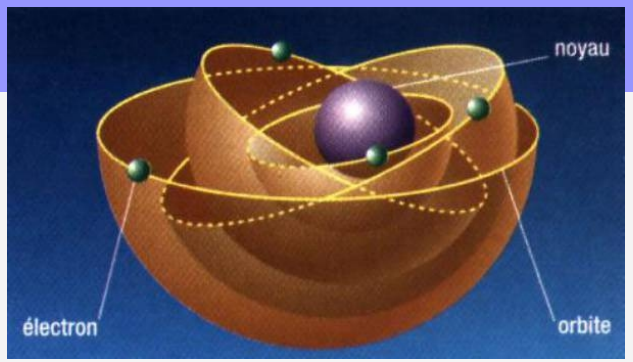
Crédit: O. Garde, O. Thizy

Solar spectrum



Profil spectral : O. Thizy, janvier 2007 ; Lhires III – 300tt/mm; Digital Rebel / EOS300D

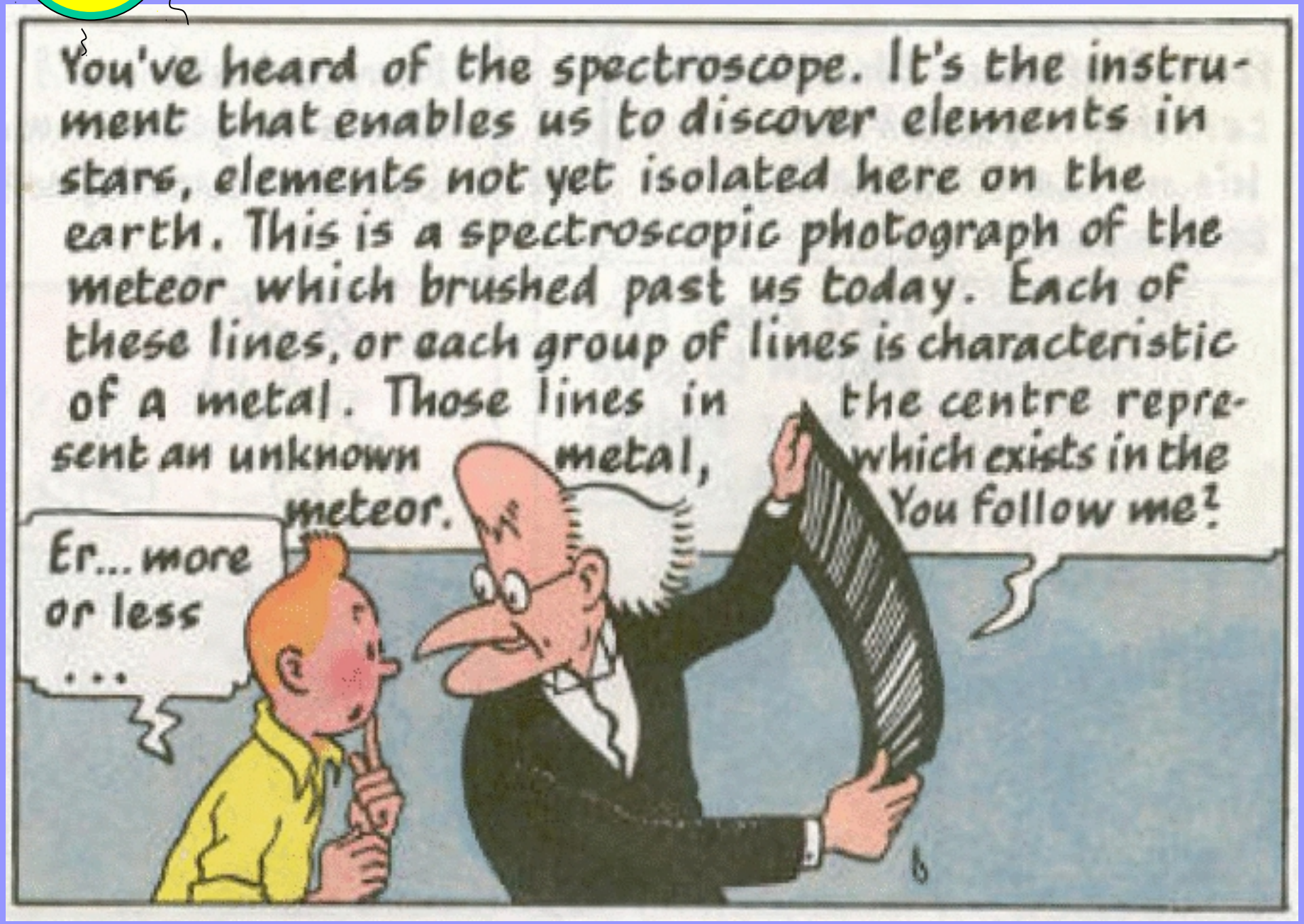
Table of elements



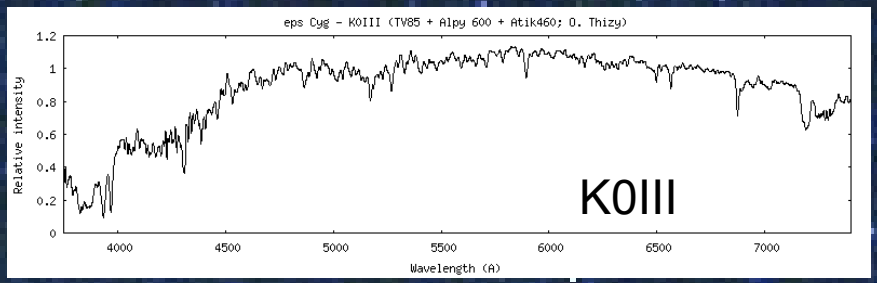
	IA												IIIA	IVA	VA	VIA	VIIA	0
1	1 H	IIA																2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg	IIIB	IVB	VB	VIB	VIIB	—— VII ——		IB	IIB		13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

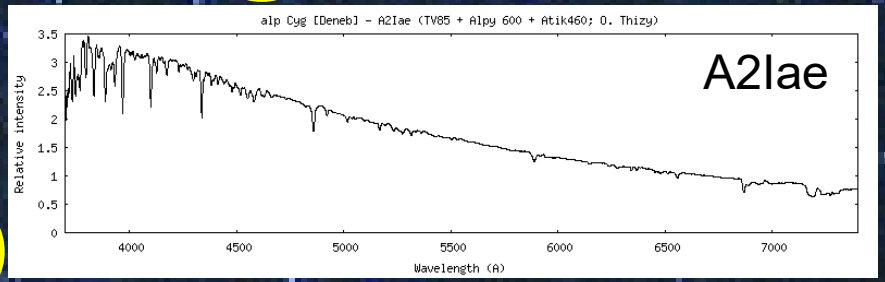
*Lanthanide	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+Actinide	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

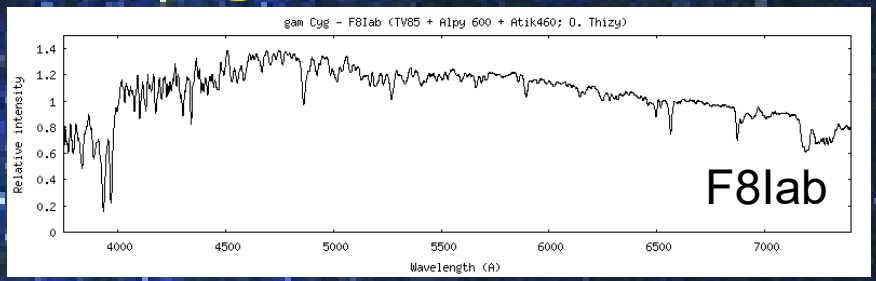
New elements?

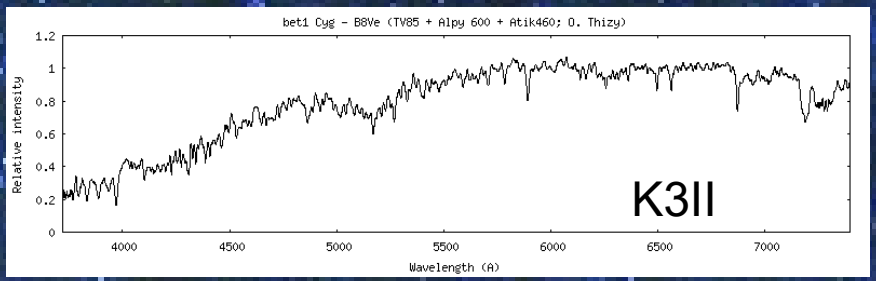


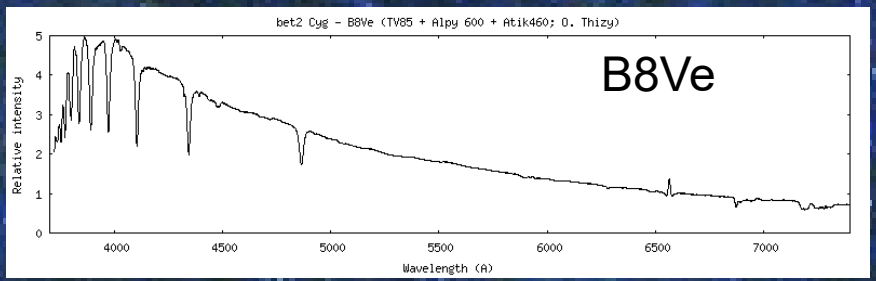
Swan top 5

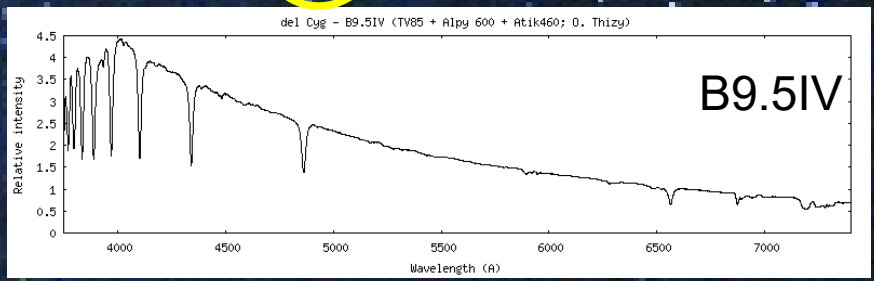

eps Cyg - K0III (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
K0III


alp Cyg [Deneb] - A2Iae (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
A2Iae


gam Cyg - F8Iab (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
F8Iab


bet1 Cyg - B8Ve (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
K3II


bet2 Cyg - B8Ve (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
B8Ve

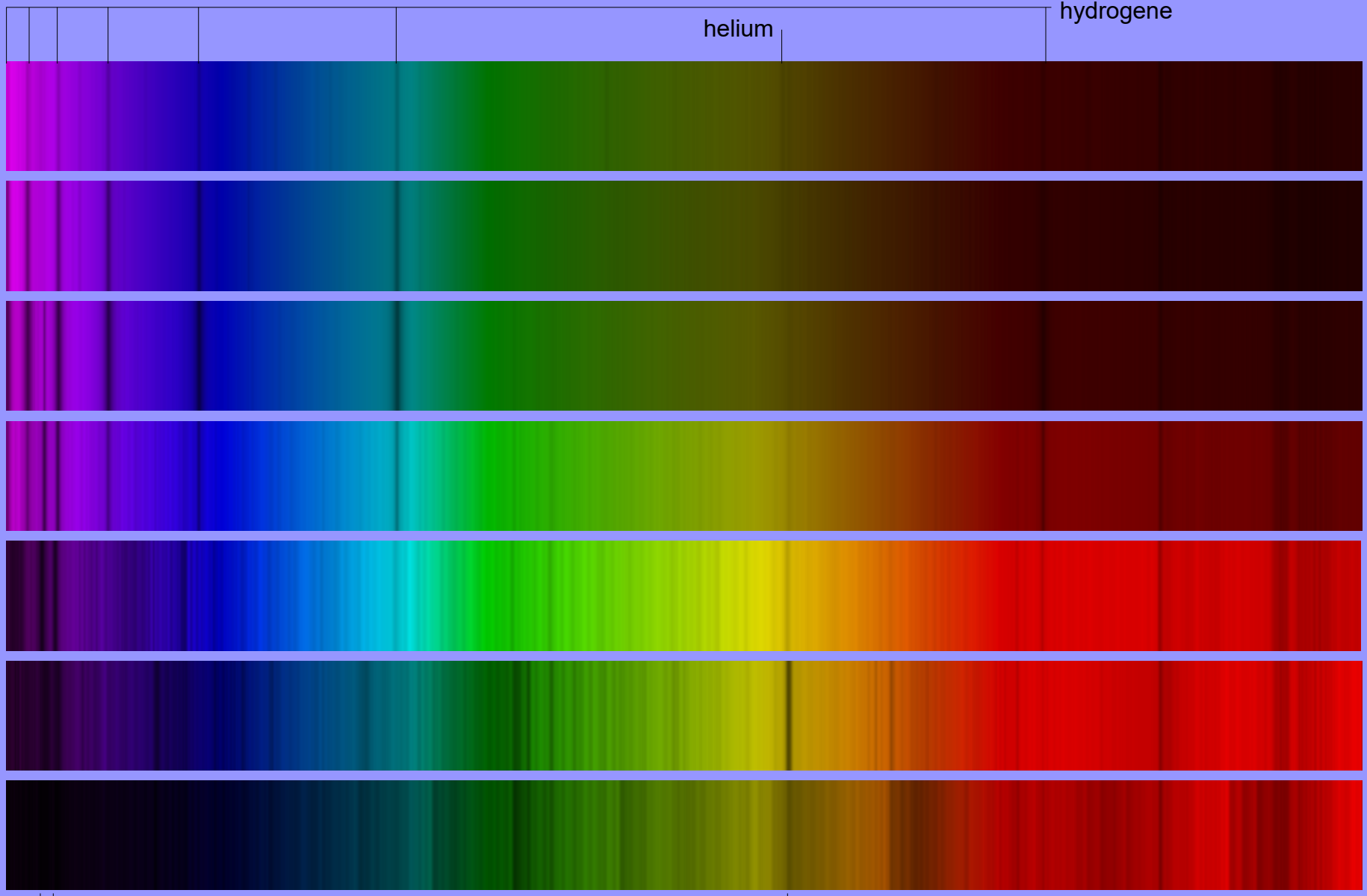

del Cyg - B9.5IV (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
B9.5IV

Spectral 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 classication
  - Annie Jump Cannon (1863-1941)
    - "OBAFGKM" types
    - sub-divisions (B0..9)
    - ~400000 spectra of her own !!!
- **1943: "Atlas of Stellar Spectra" by William Morgan, Philip Keenan, & Edith Kellman [MKK]**
  - Spectral type from HD catalog (Temperature): OBAFGKM
  - Introduced class of luminosity I...V

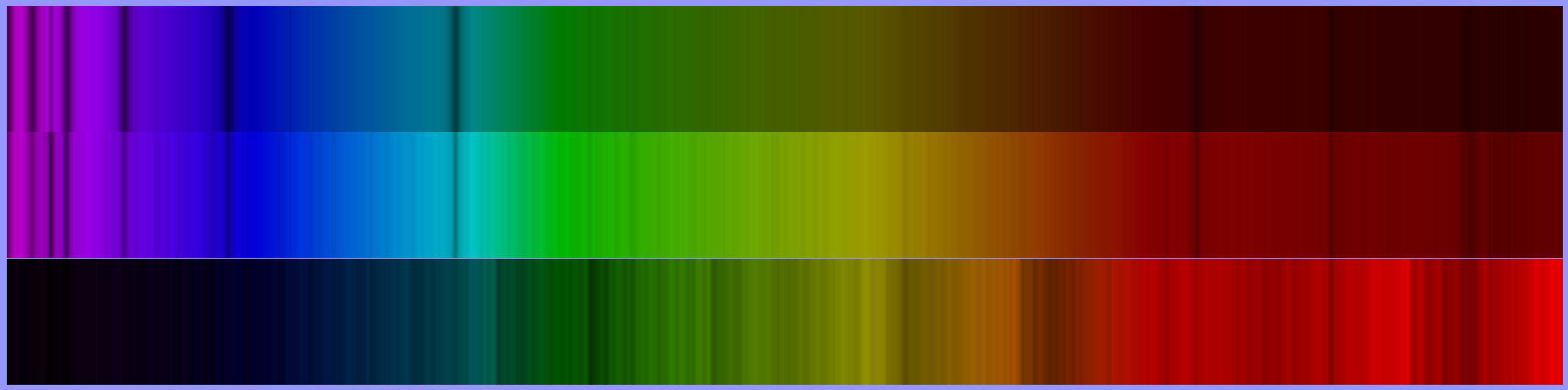
A.J. Cannon

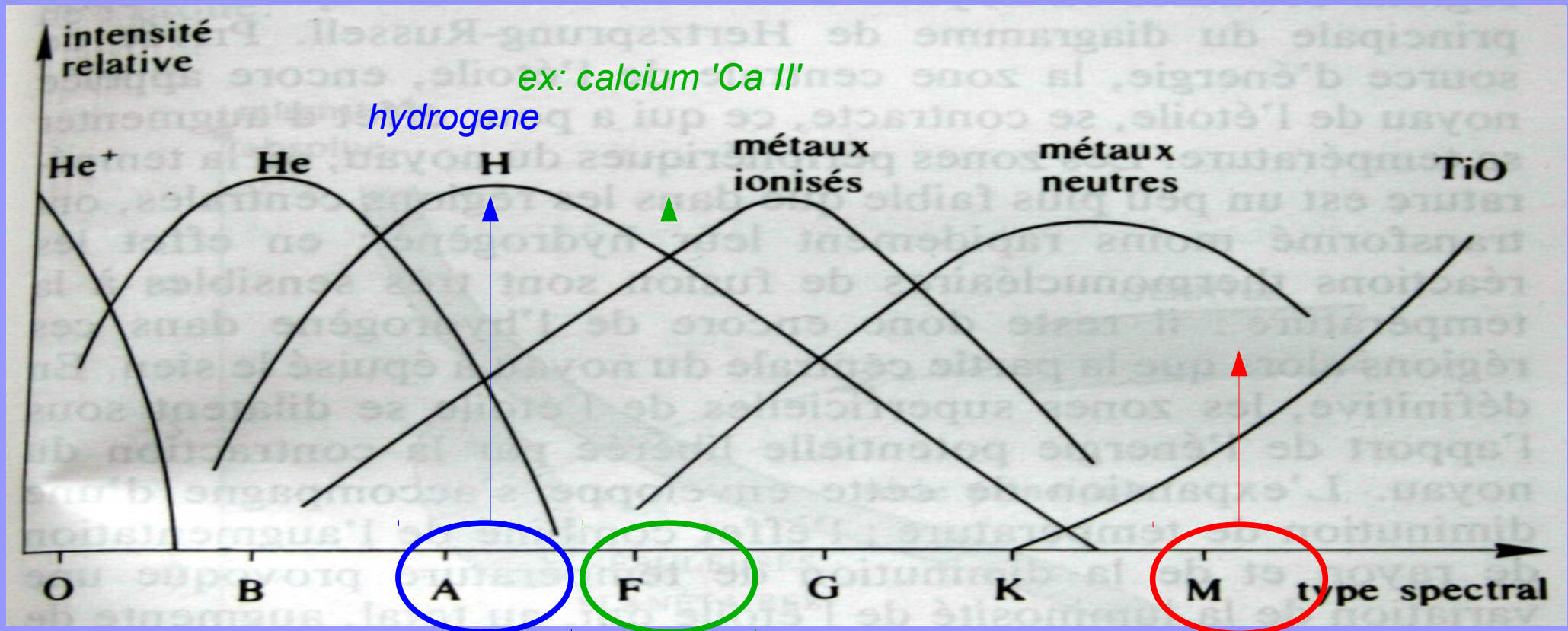
Spectral classification in the Swan



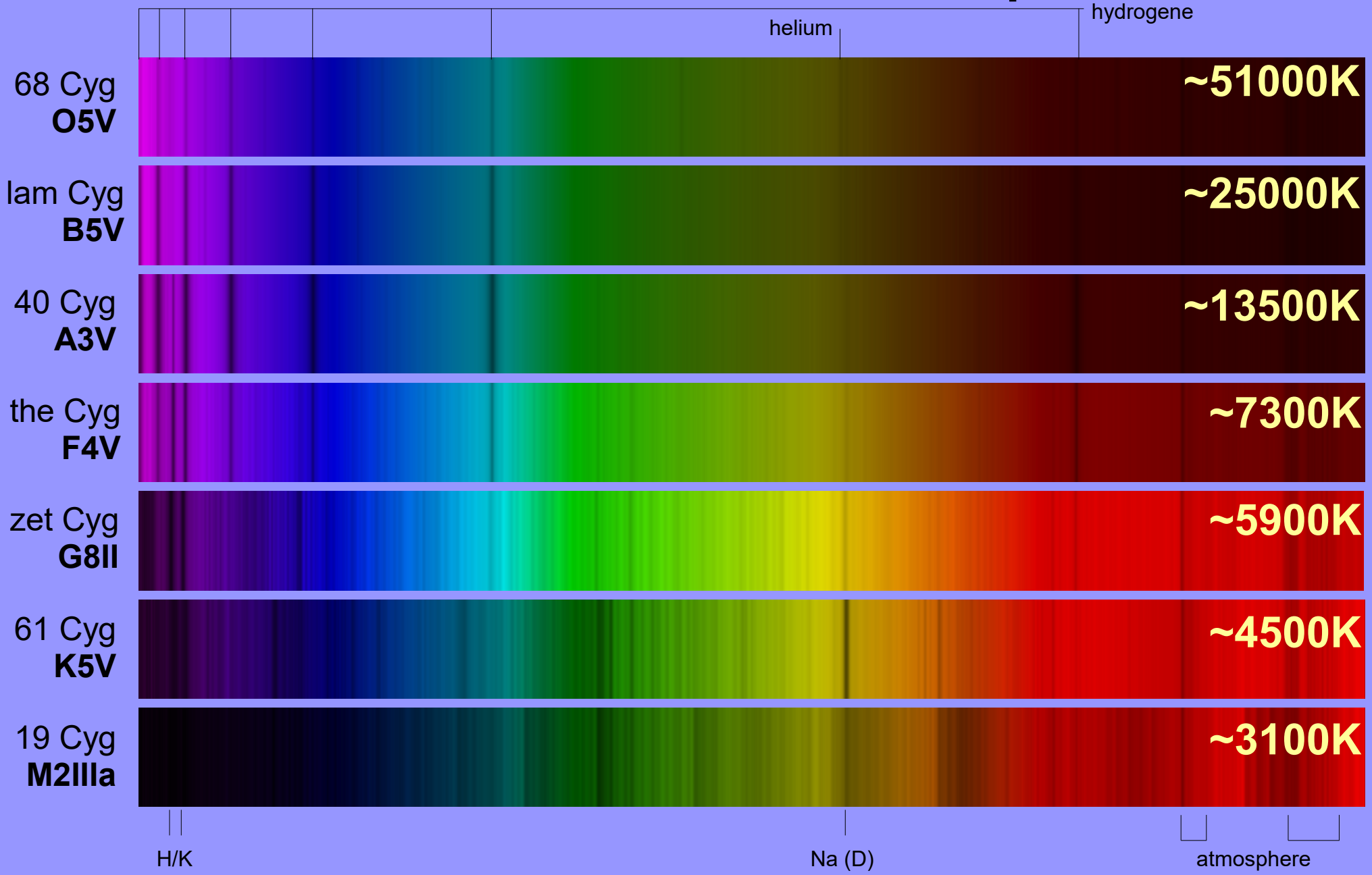
Oh, **B**e **A** **F**ine **G**irl/Guy... **K**iss **M**e !

Line "Visibility" vs. Temperature

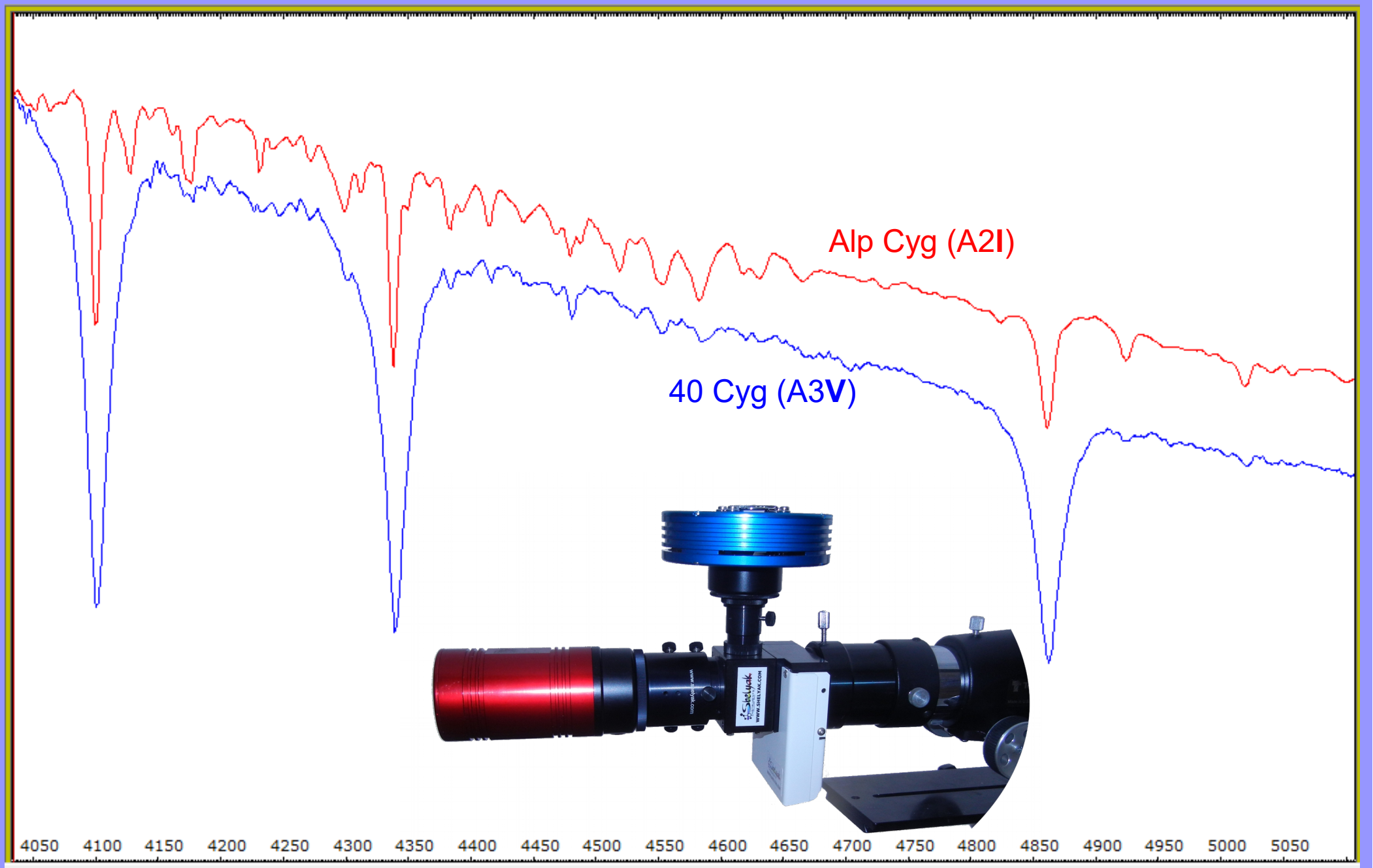




Temperatures

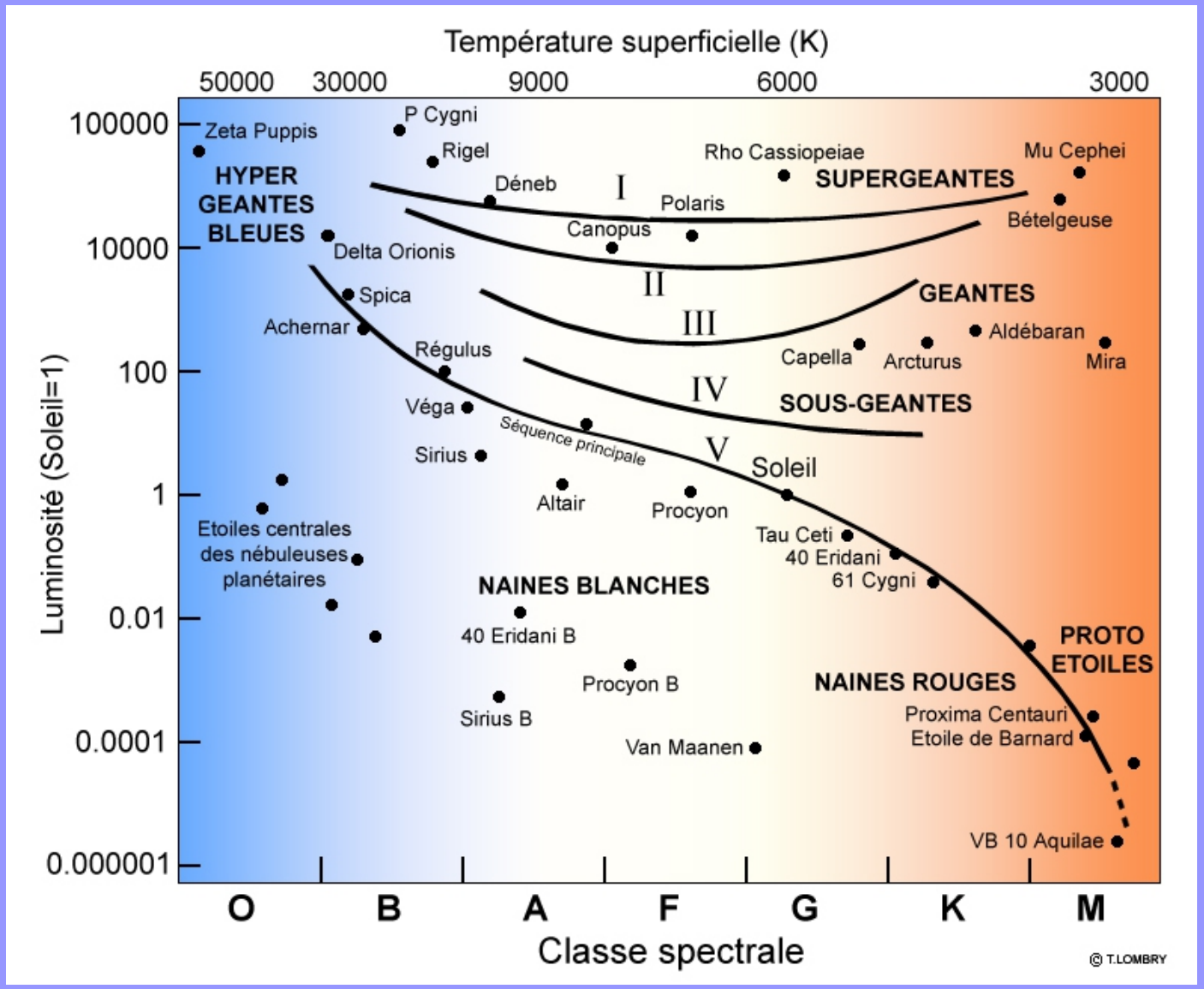


Luminosity class



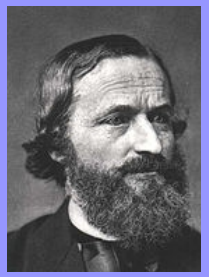
HR Diagram

- Ejnar *Hertzsprung* (1873-1967) & Henry *Russell* (1877-1957)
- Color/Luminosity diagram (first published in 1911)



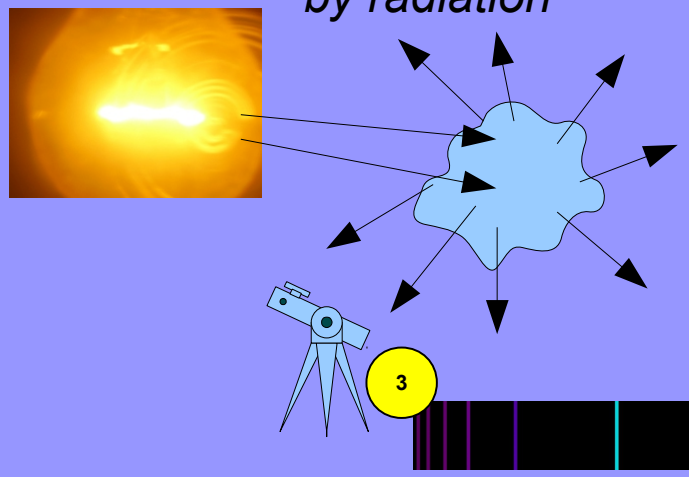
** There! I think I classified the humans based on their evolution.*

Dessin : CLEA

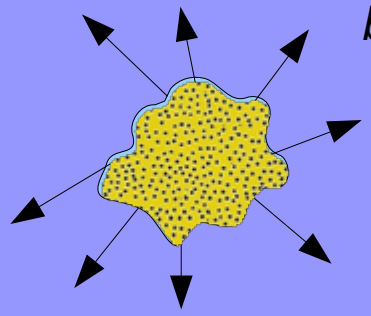


Kirchhoff law #3

excitation by radiation

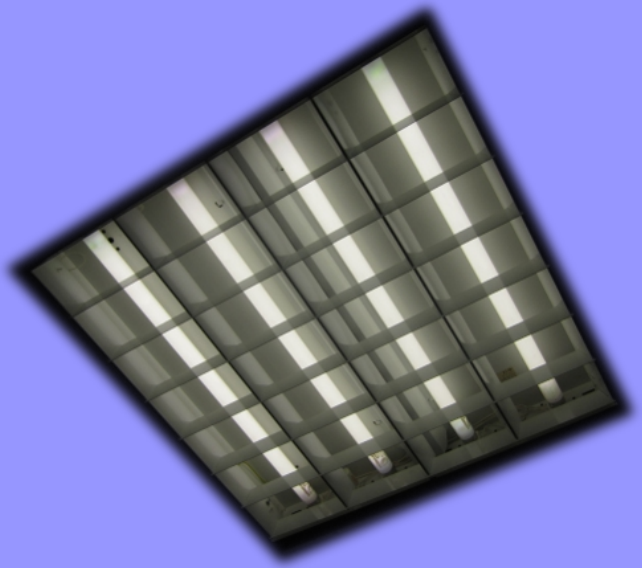


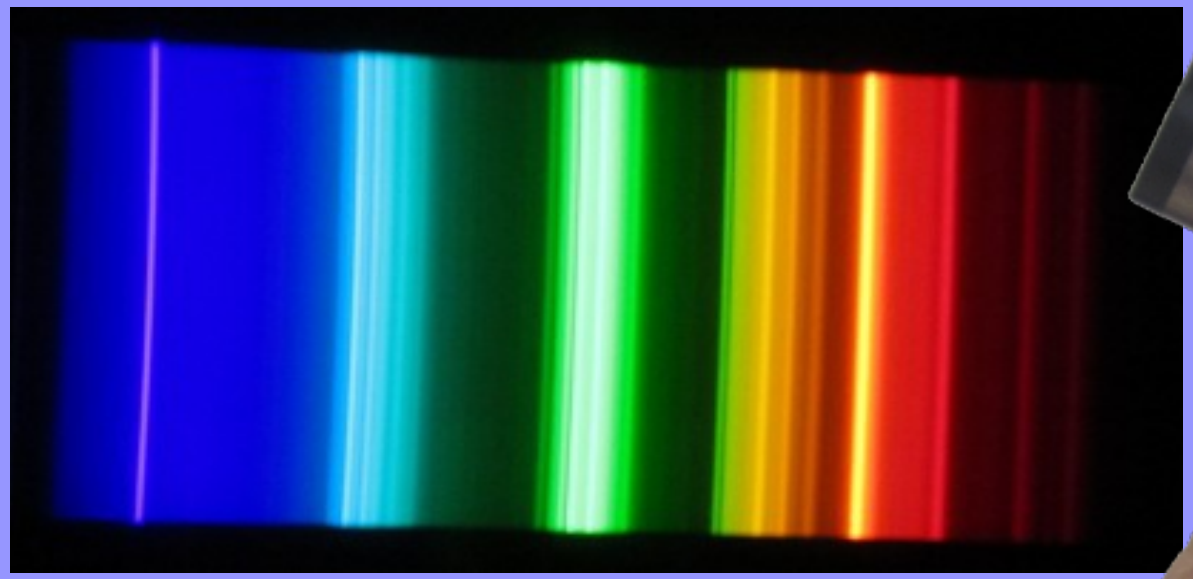
excitation by shocks



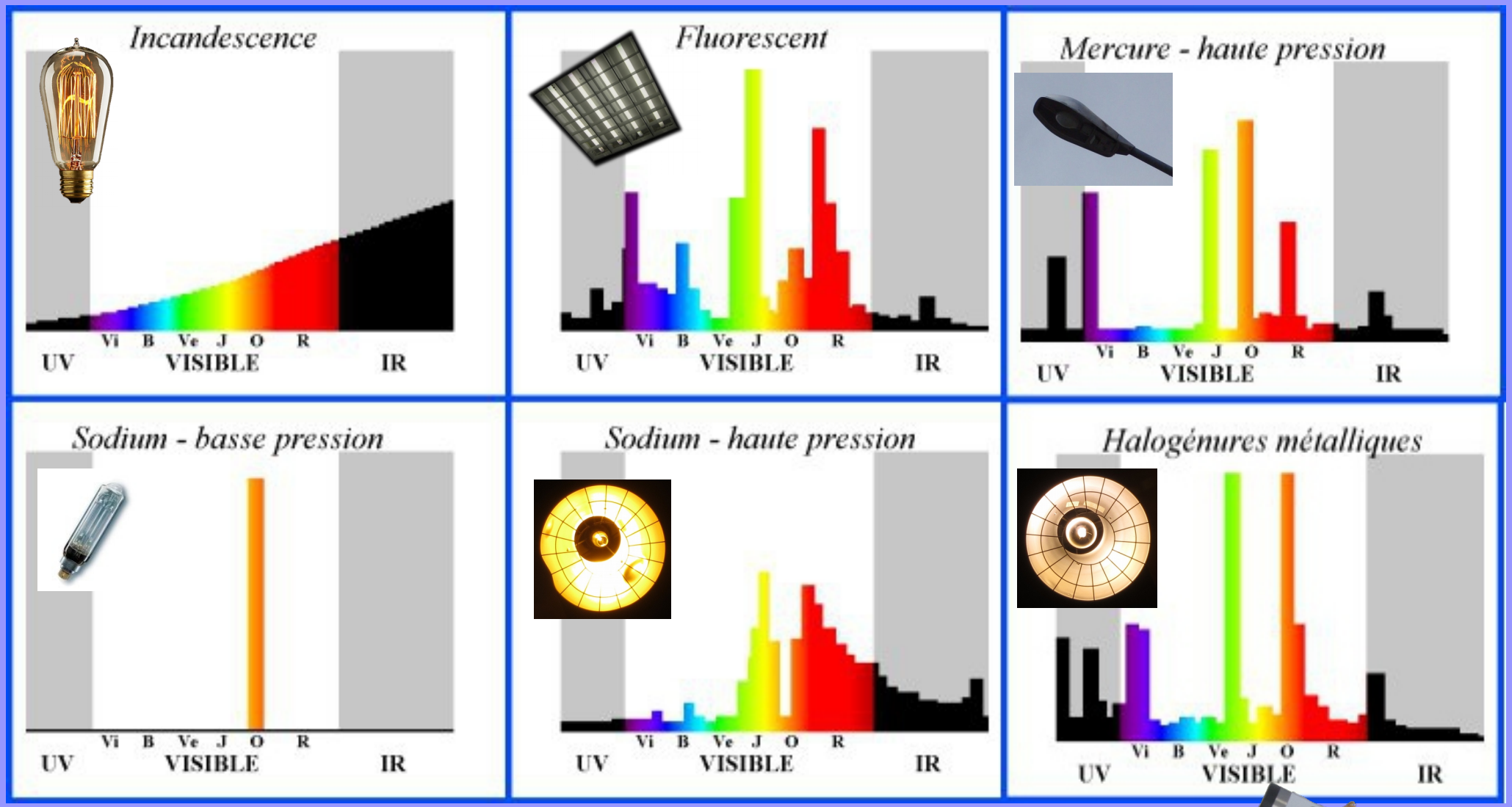
3 **Emission line spectra**: a low pressure high temperature gaz emits a light made of few radiations, characteristics of the atoms that constitutes this gaz. Each chemical element has its own line spectra, true identity card of its composition and state.

Educational Handheld Spectroscope



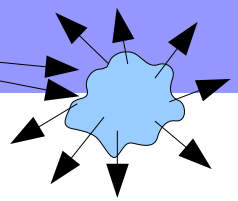


Educational Handheld Spectroscope

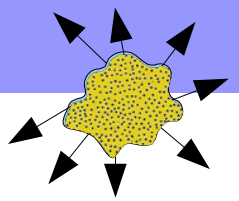


Images: Philippe Demoulin, O. Thizy

Emission lines physics

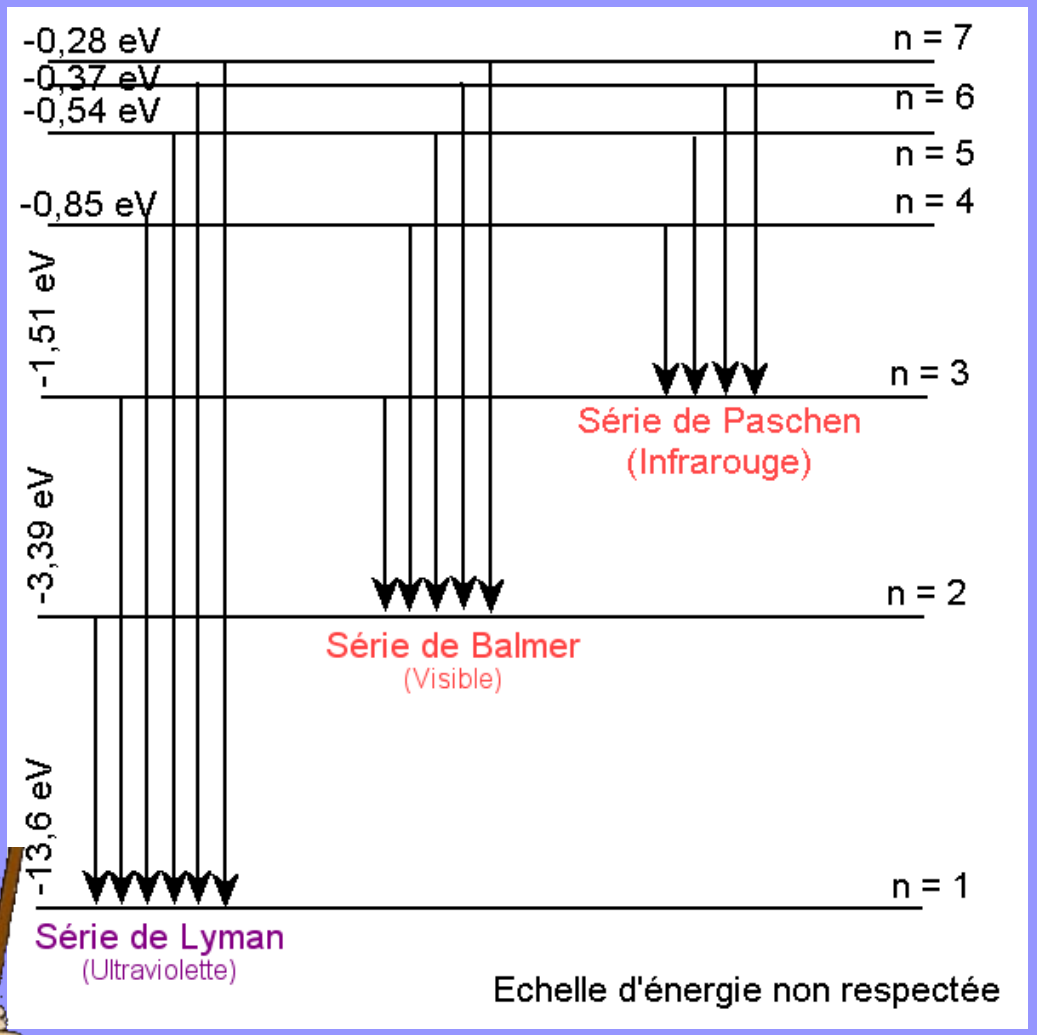


excitation by radiation



excitation by shocks

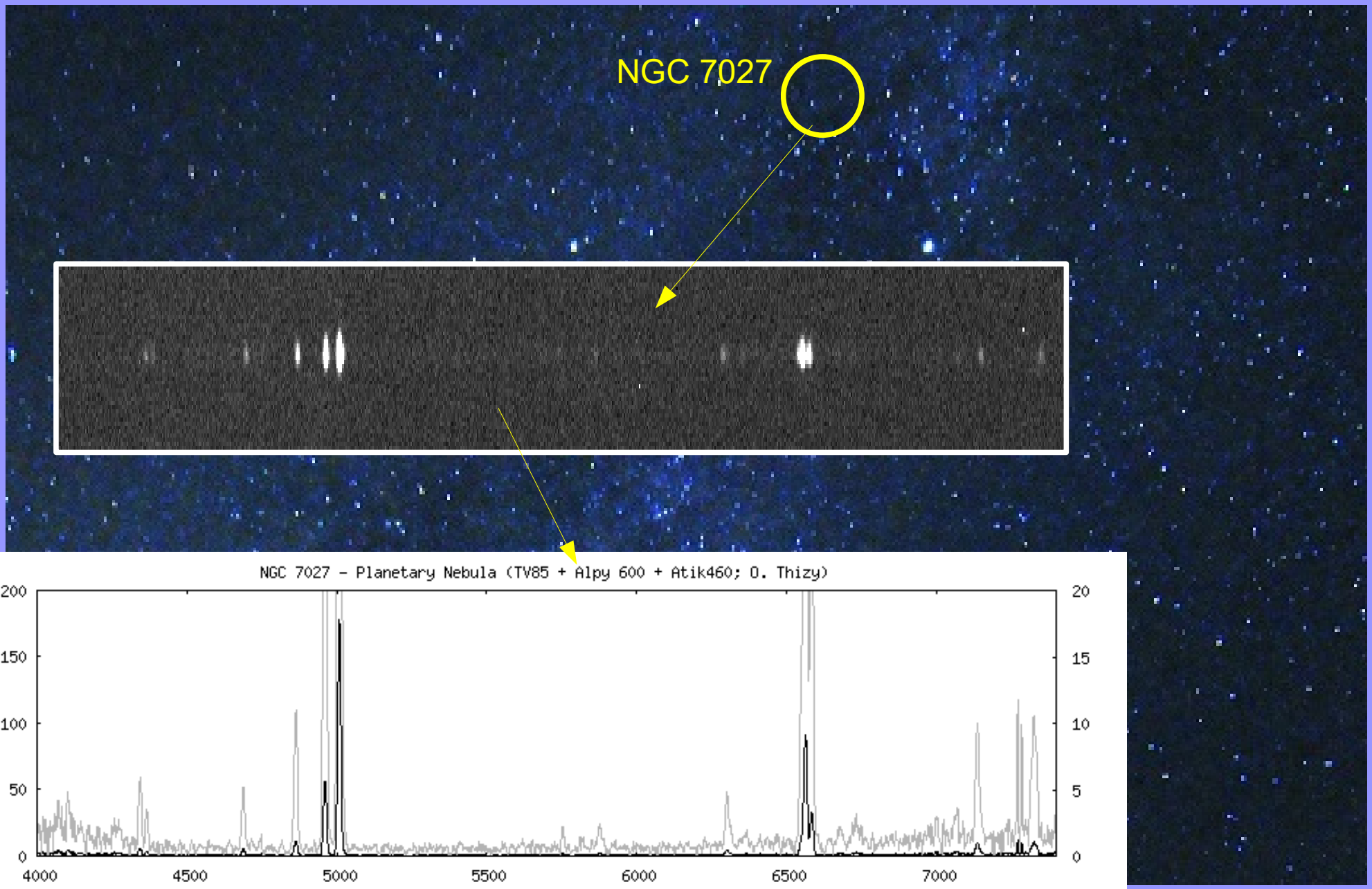
$$\Delta E = |E_n - E_m| = h\nu = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{\Delta E}$$



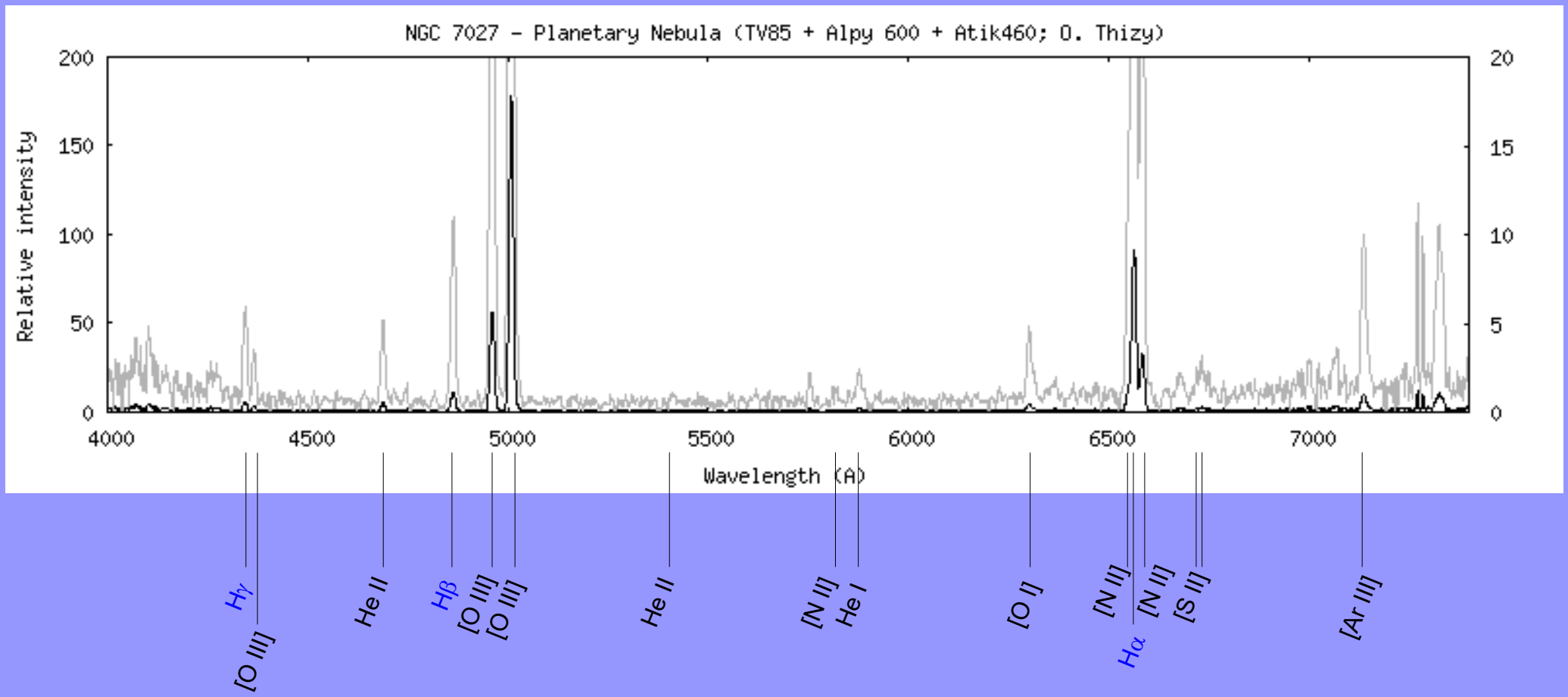
Exemple for the hydrogen atom

Sources: http://culturesciencesphysique.ens-lyon.fr/ressource/Quantique.xml &: http://e.m.c.2.free.fr/niveaux-energie-hydrogene-emission-absorption.htm

Planetary Nebula: NGC7027

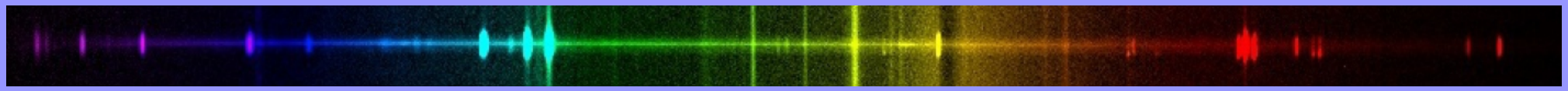


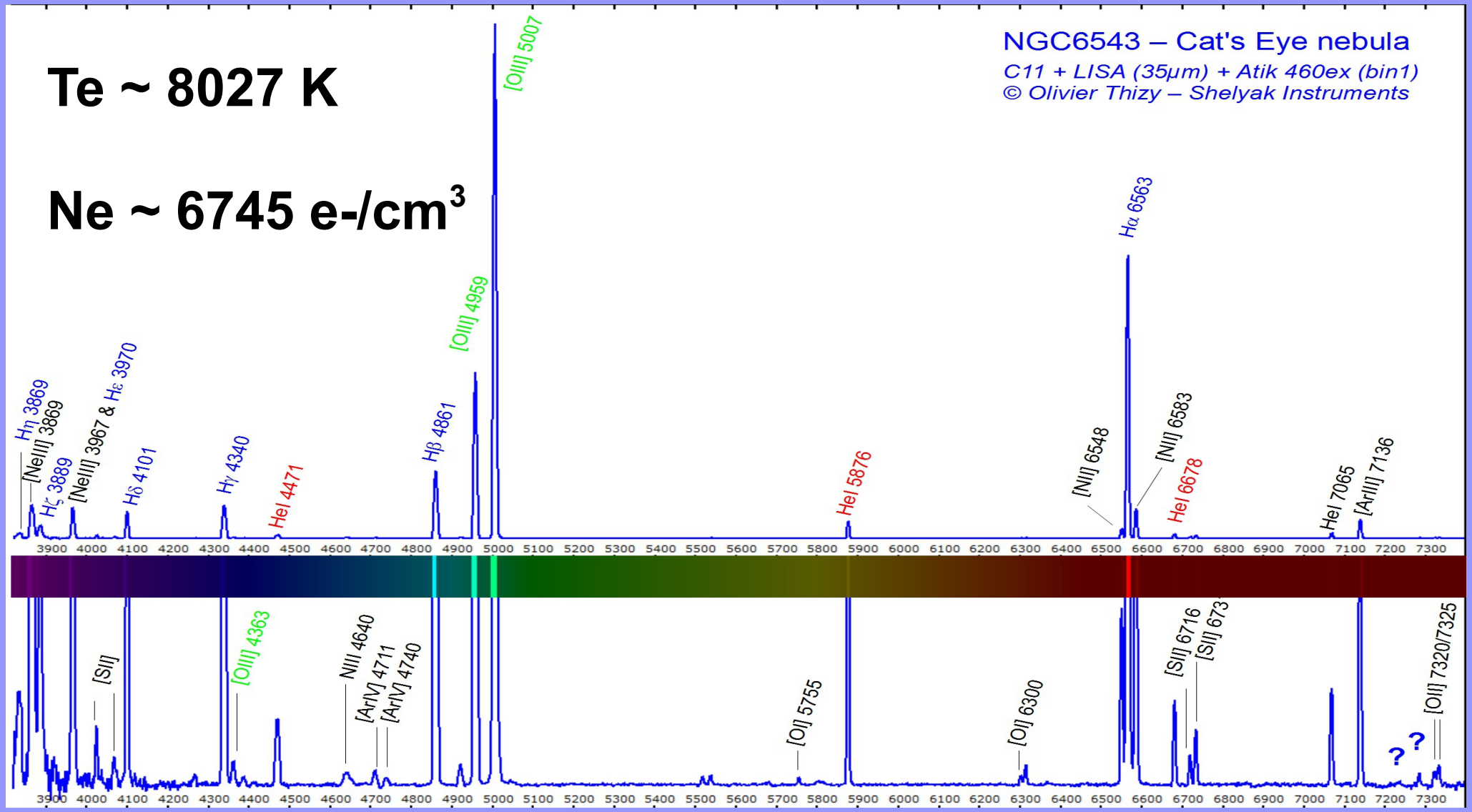
NGC7027: line identification



Cf the 'bible': http://www.astronomie-amateur.fr/feuilles/Spectroscopie/NGC2392.html

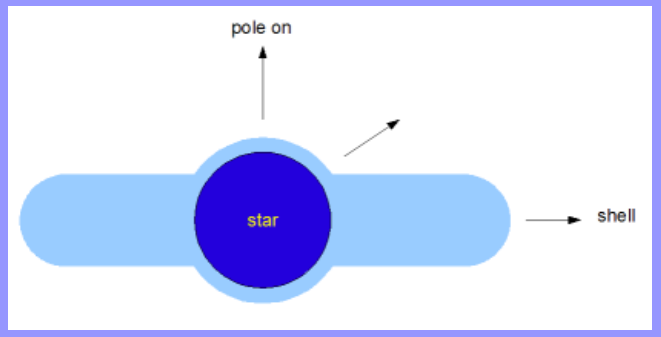
PN: temperature & density

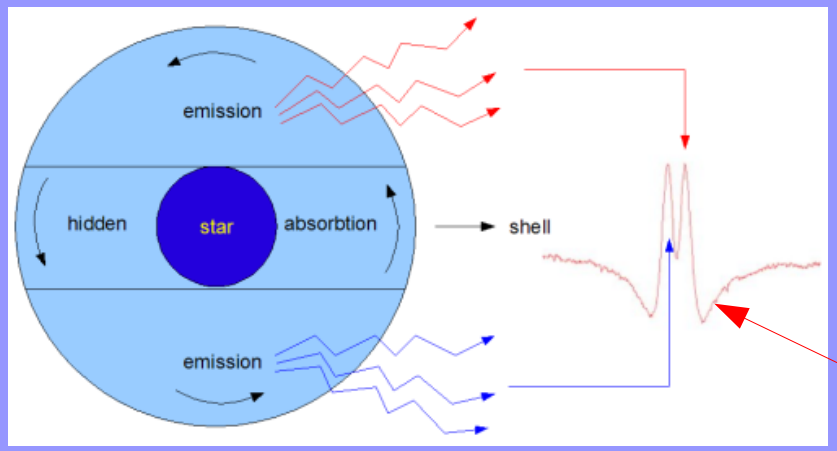




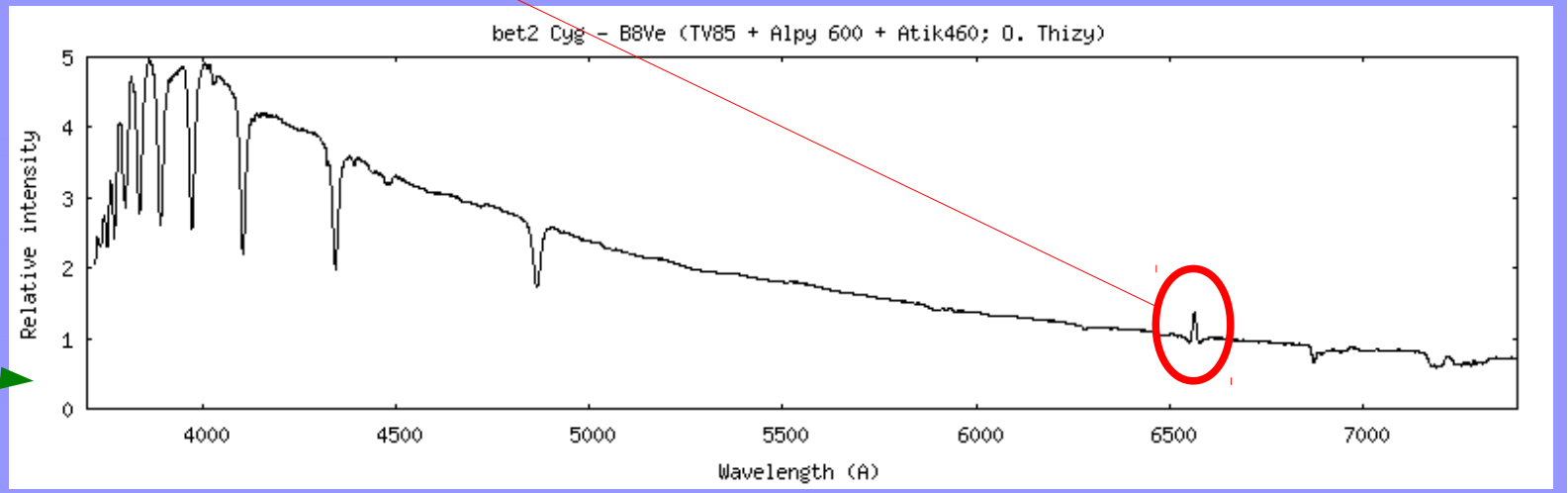
Cf: http://www.shelyak.com/dossier.php?id_dossier=77

Albireo B: a Be star





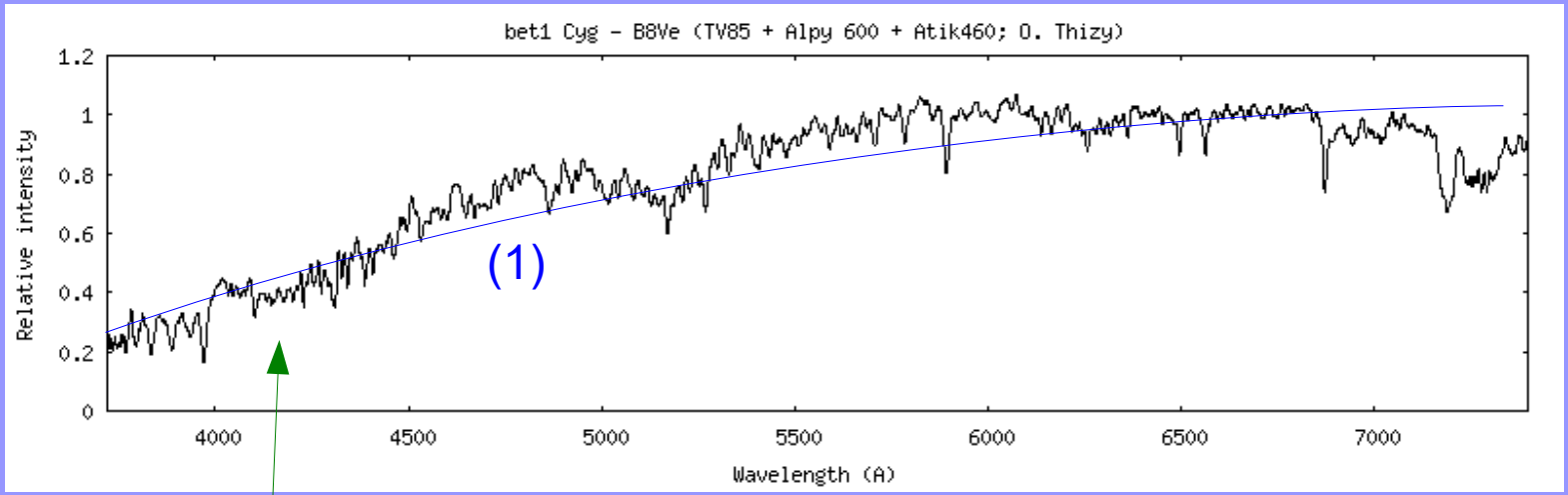
- Non super-giant, B-type star, showing or having shown a Balmer line in emission
- Discovered in 1866 by father Sechi: gamma Cas, beta Lyrae (Shelyak)...
- Disk of material ejected by the star (decretion disk), re-emitting energy absorbed from UV radiation of the hot star itself



Photos: Eric Coustal (Albireo) & Wikipedia

Cf: http://www.shelyak.com/dossier.php?id_dossier=24

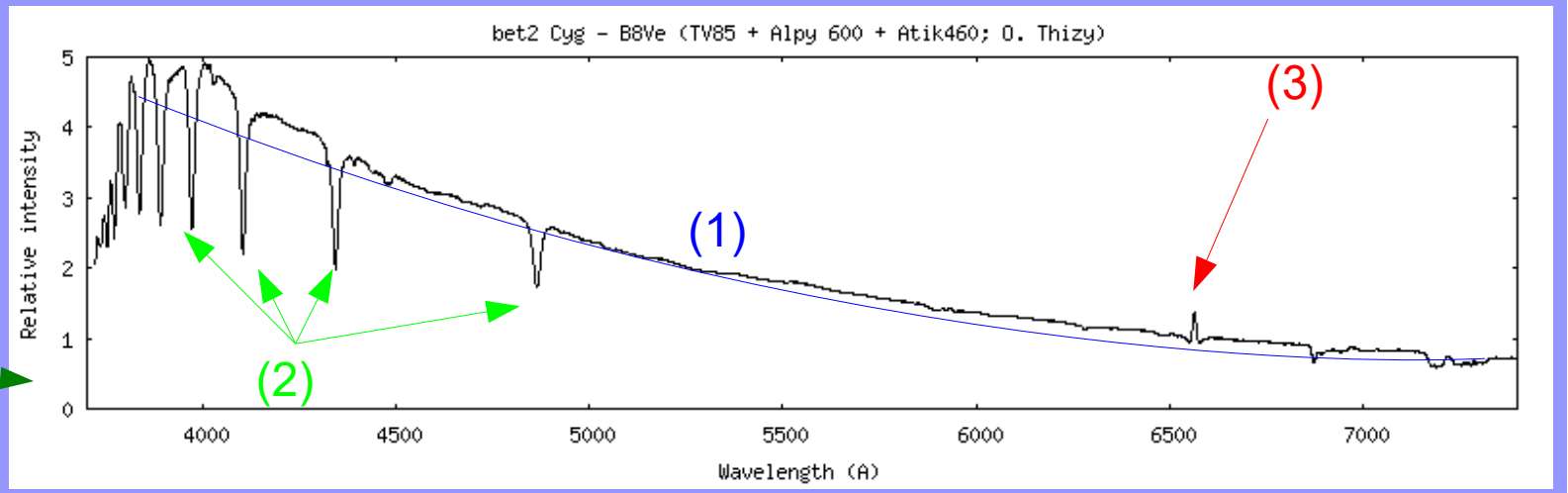
Albireo



(1) Overall profile= effective temperature (ie: Planck profile)

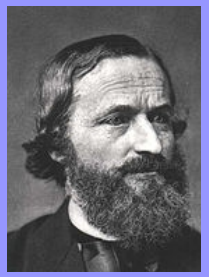
(2) Absorption lines = photons absorbed by stellar atmosphere

(3) Emission line = energy emitted by a disk around the star

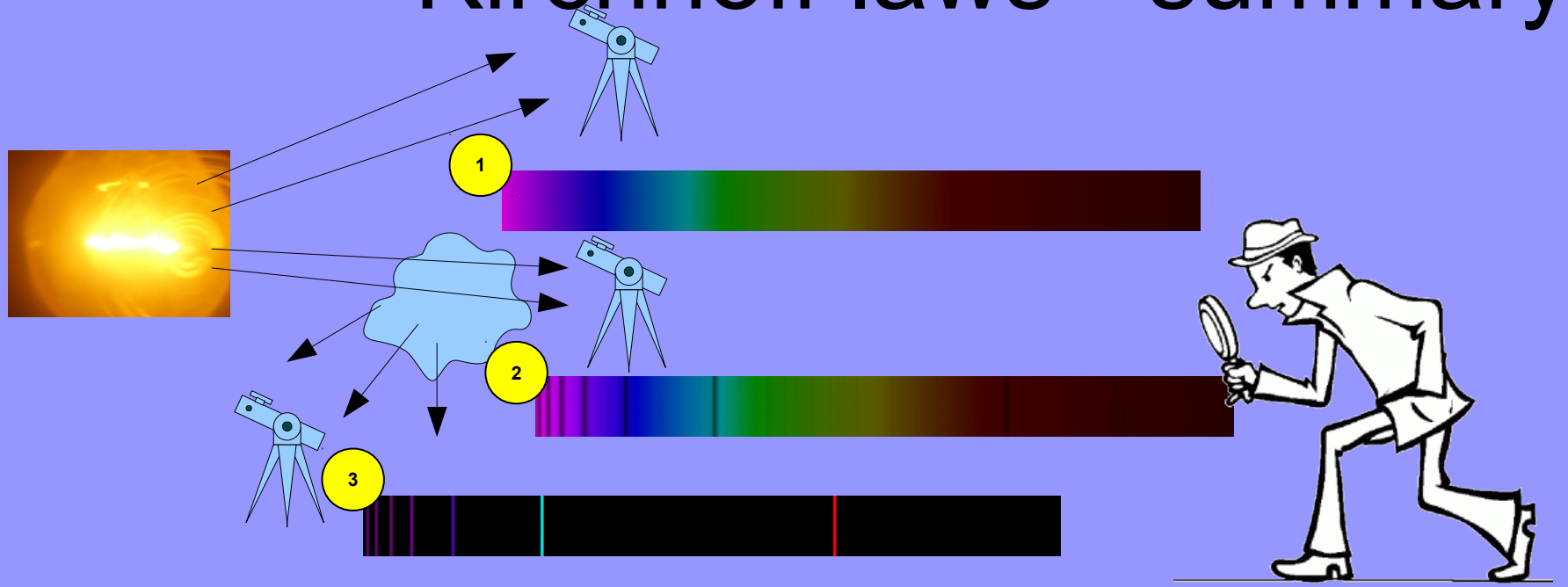


...Thank You Mr Kirchhoff !

Photos: Eric Coustal (Albireo) & Wikipedia



Kirchhoff laws - summary



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

2 **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;

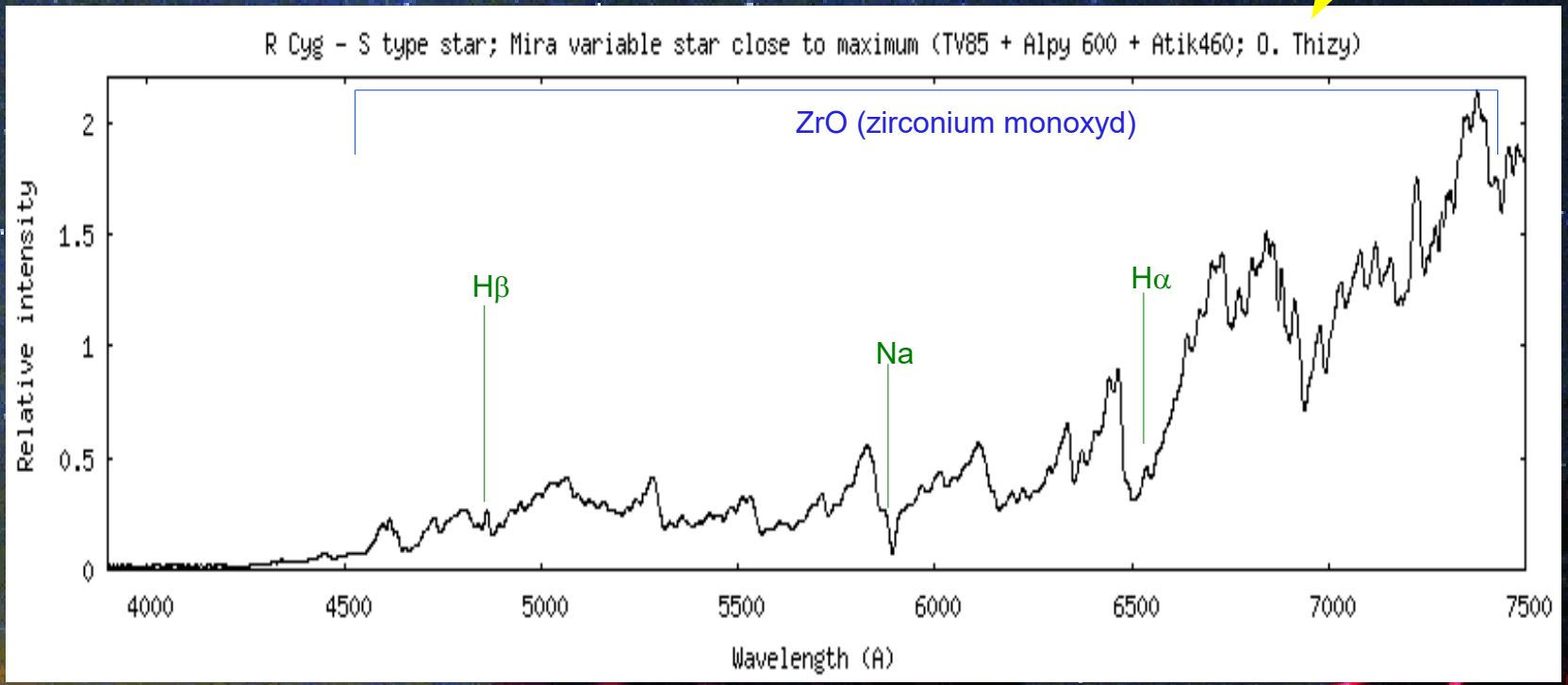
3 **Emission line spectra**: a low pressure high temperature gaz emits a light made of few radiations, characteristics of the atoms that constitutes this gaz. Each chemical element has its own line spectra, true identity card of its composition and state.

Where is Charly ?

Photo: Jim Edlin, OHP

R Cyg: type S, near maximum

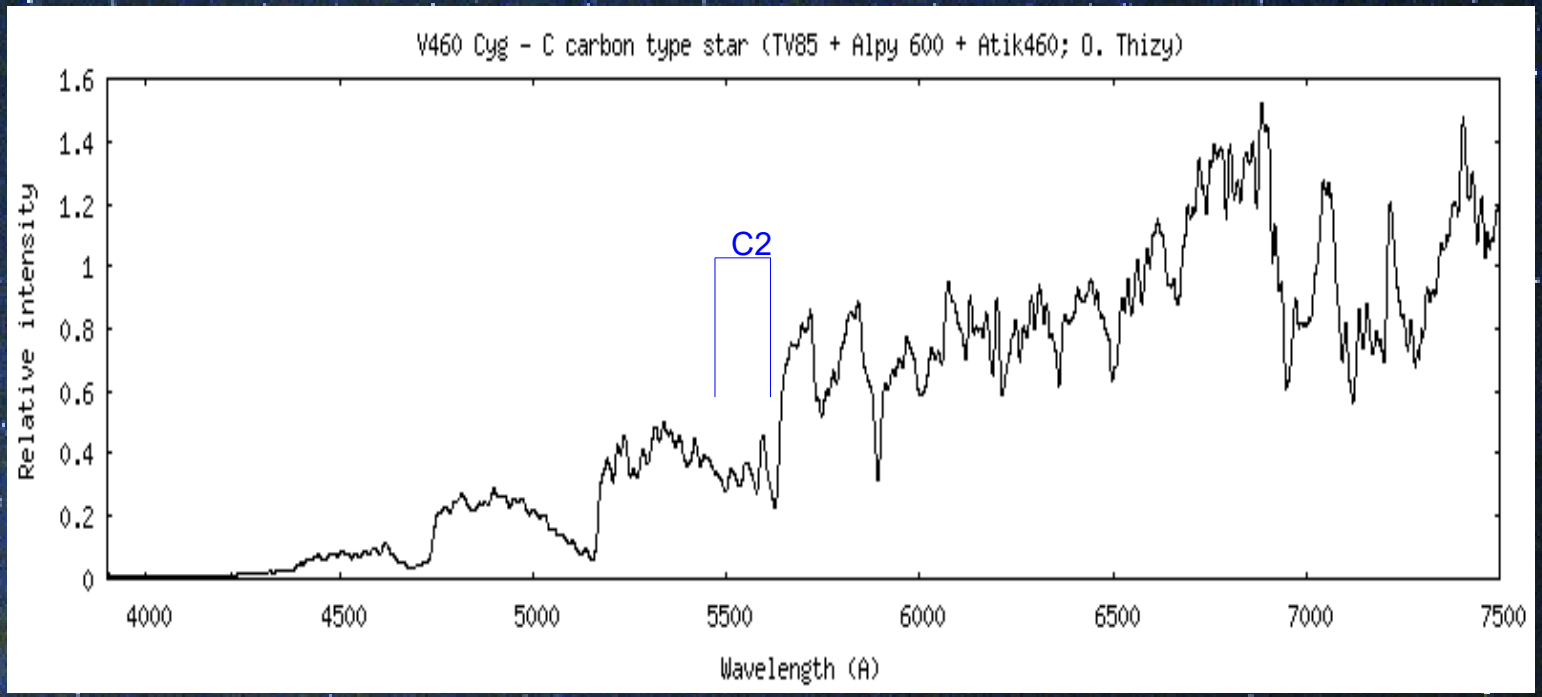
- Spectral Type S: red giant near end of life; between M type & Carbon stars
- Mira type variable



R Cyg

V460 Cyg

V460 Cyg: type C6,3

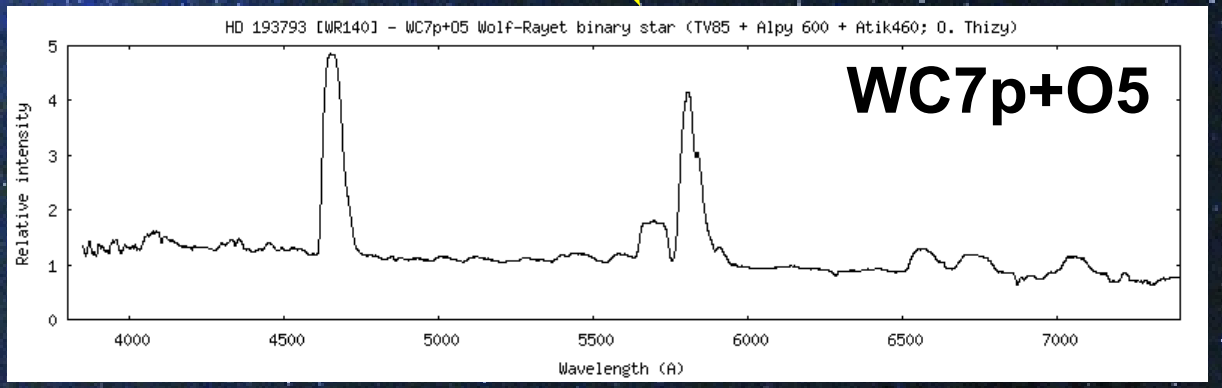


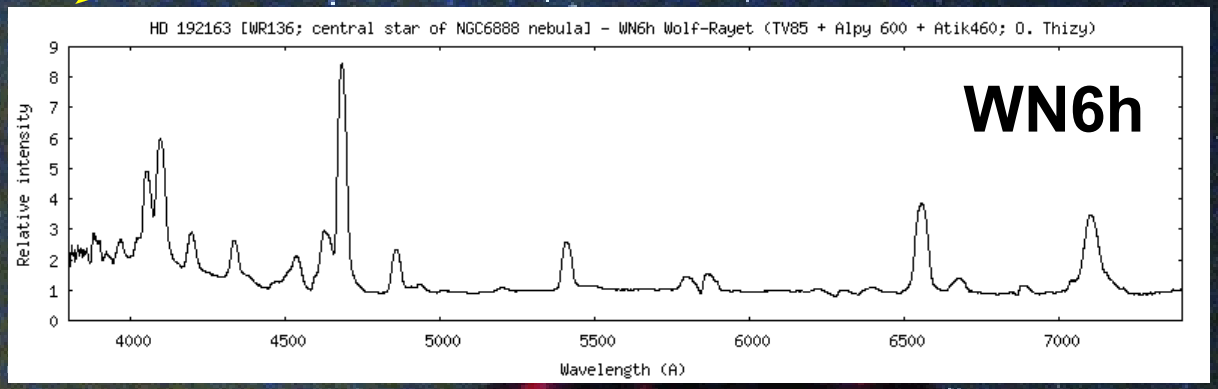
- Spectral type C6,3 : Carbon star
  - Teff ~3200K
  - low intensity of the C2 bands

Wolf Rayet stars

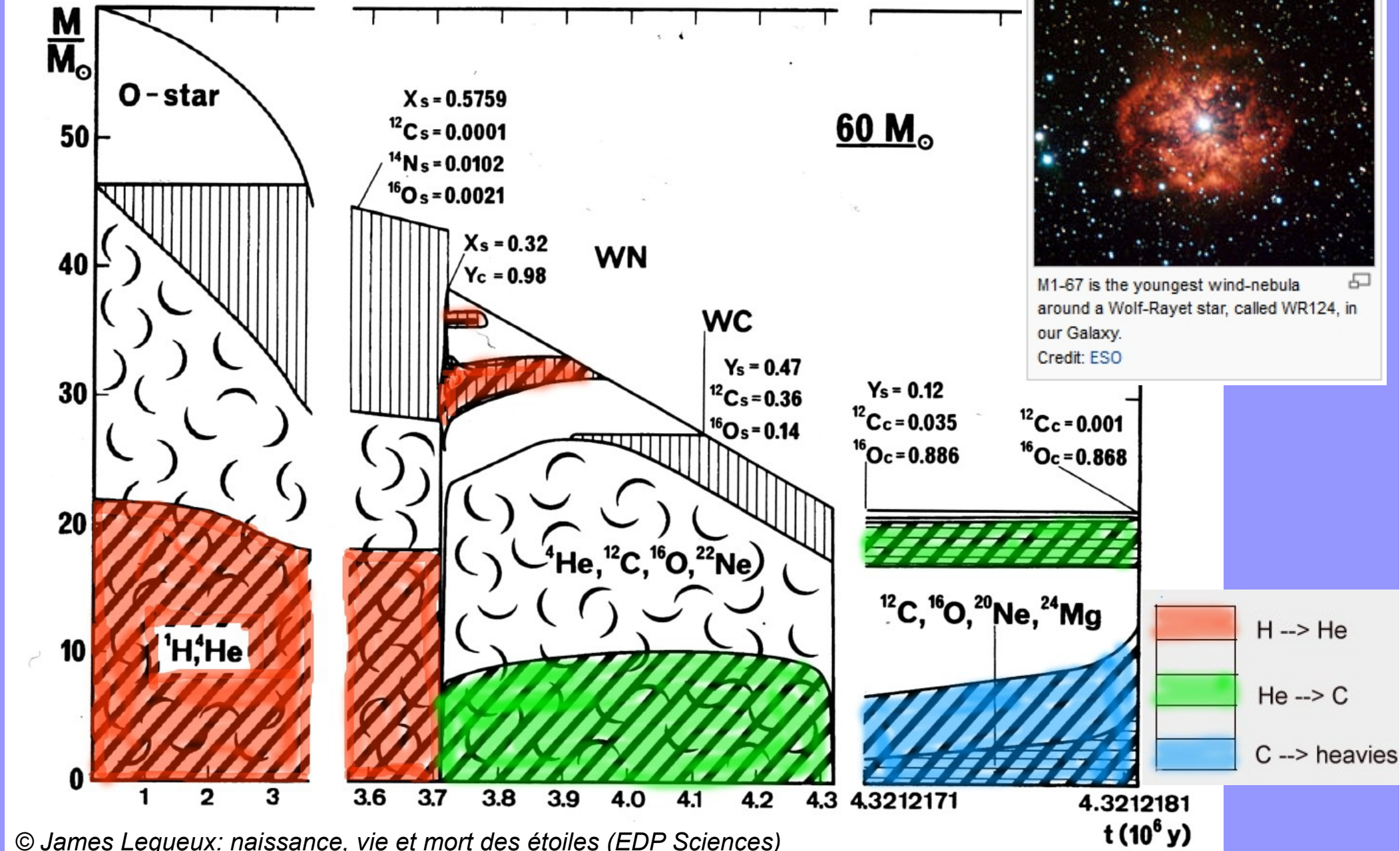
WR 136

WR 140





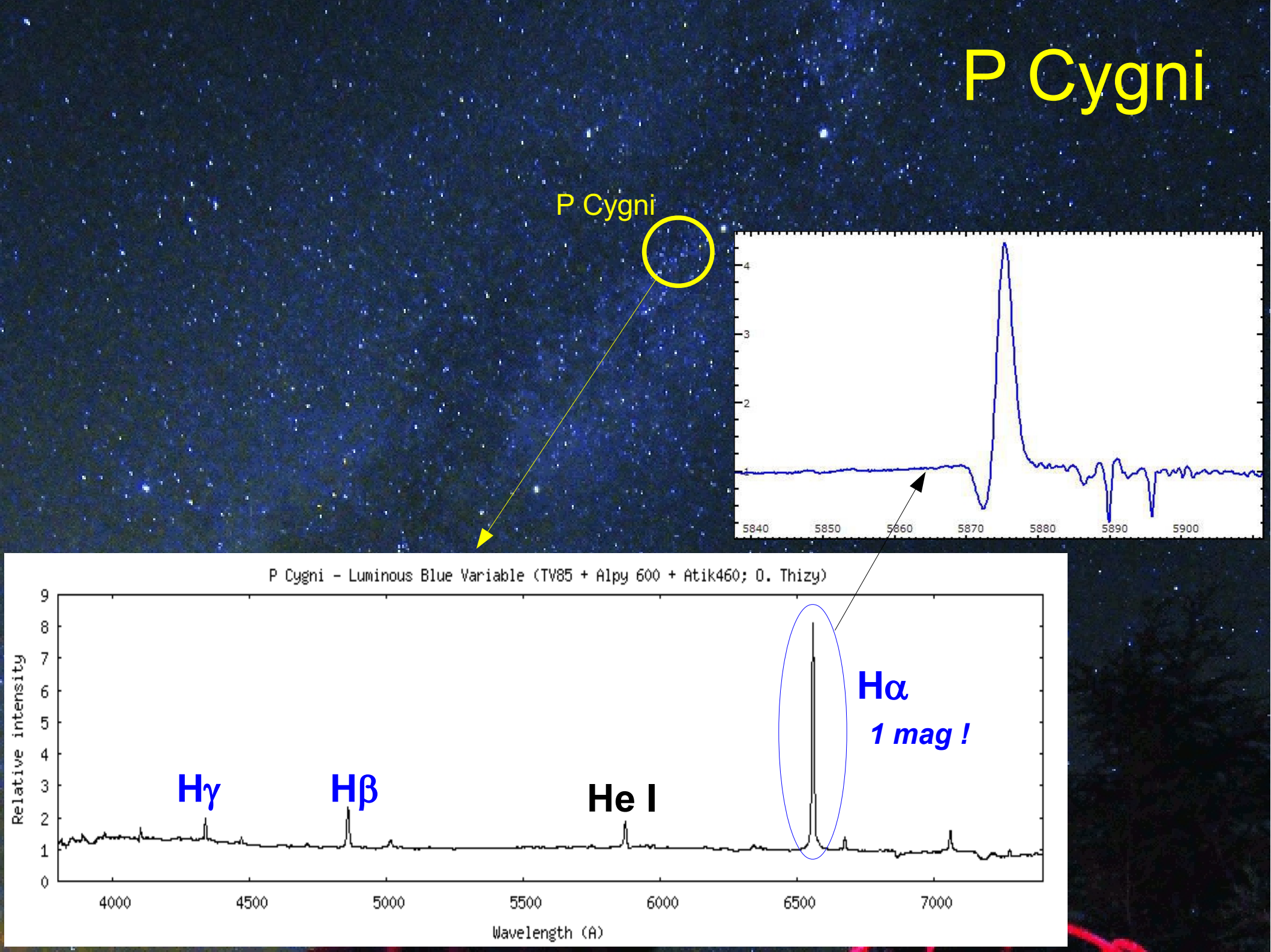
Wolf Rayet : massive stars evolution

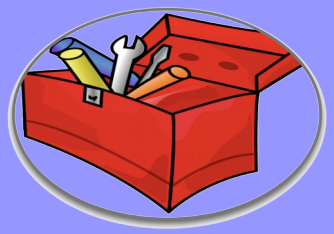


M1-67 is the youngest wind-nebula around a Wolf-Rayet star, called WR124, in our Galaxy.
Credit: ESO

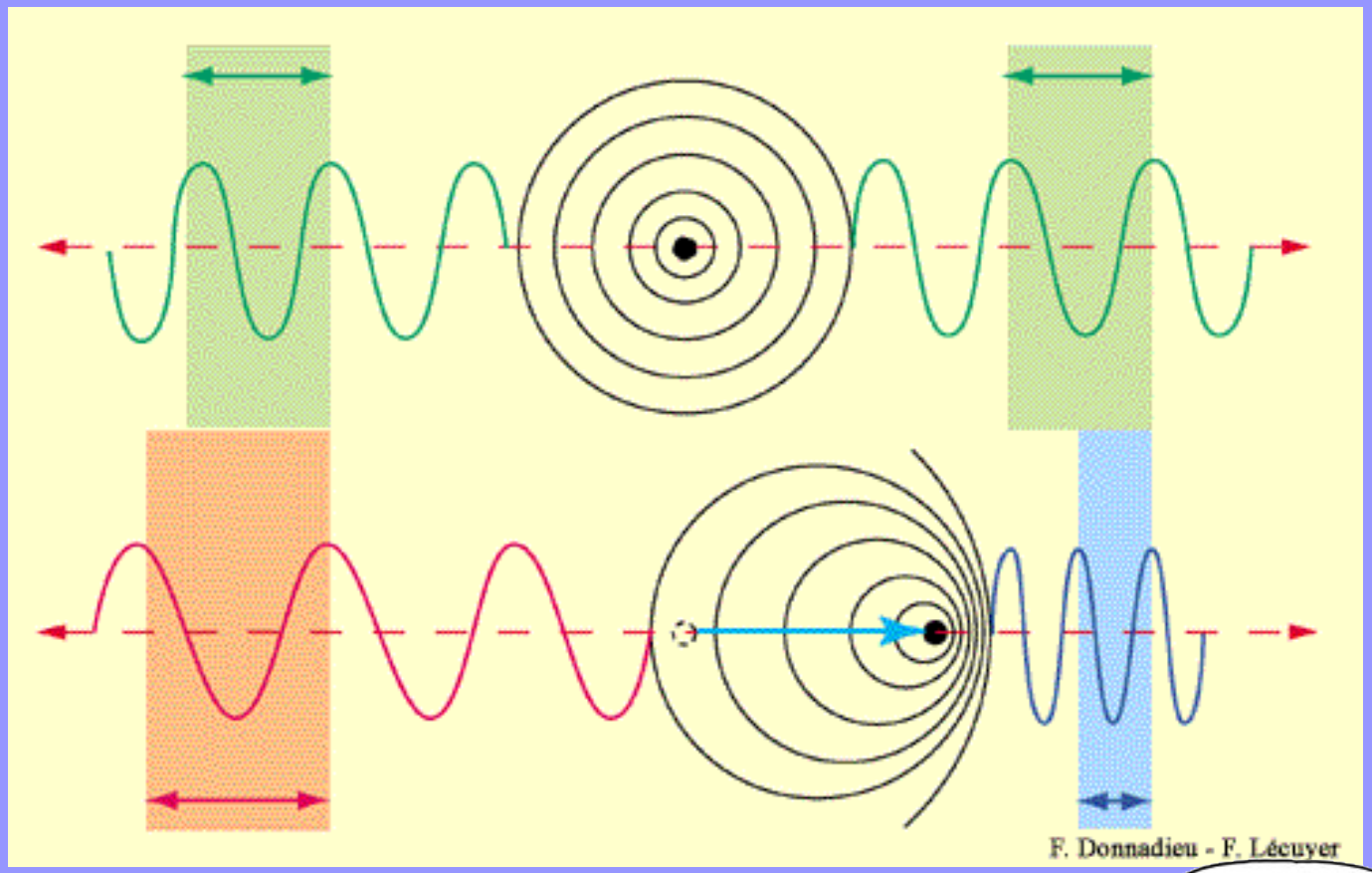
© James Lequeux: naissance, vie et mort des étoiles (EDP Sciences)

P Cygni


P Cygni
P Cygni - Luminous Blue Variable (TV85 + Alpy 600 + Atik460; O. Thizy)
Relative intensity
Wavelength (A)
Hγ
Hβ
He I
Hα
1 mag !



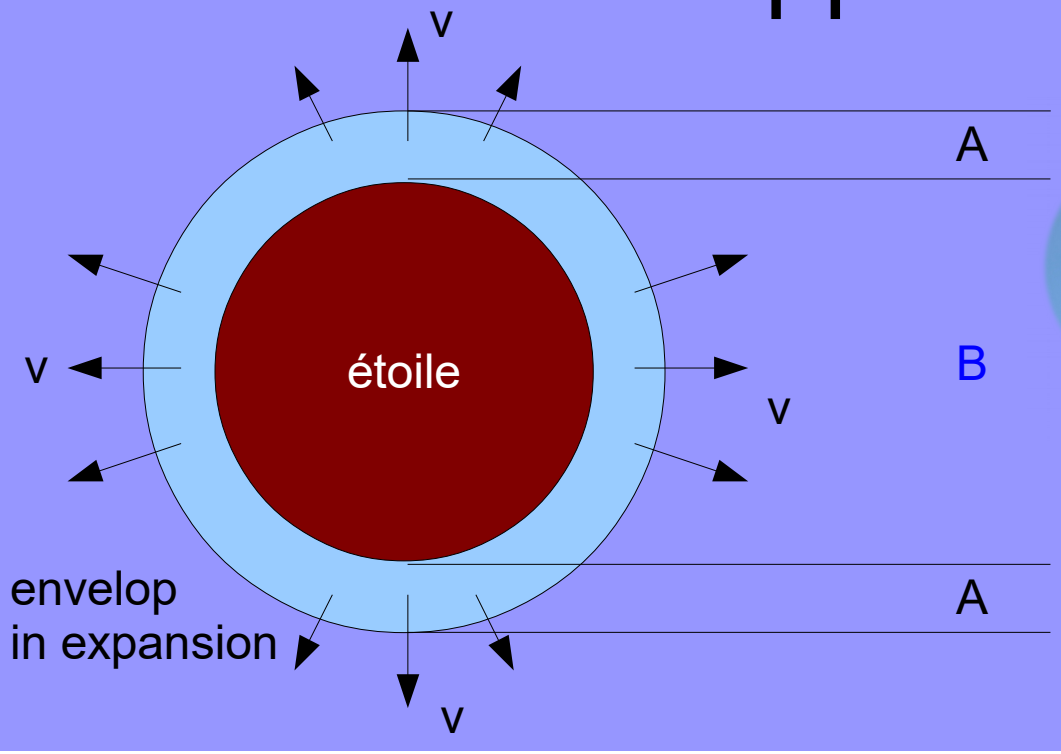
Doppler – Fizeau effect

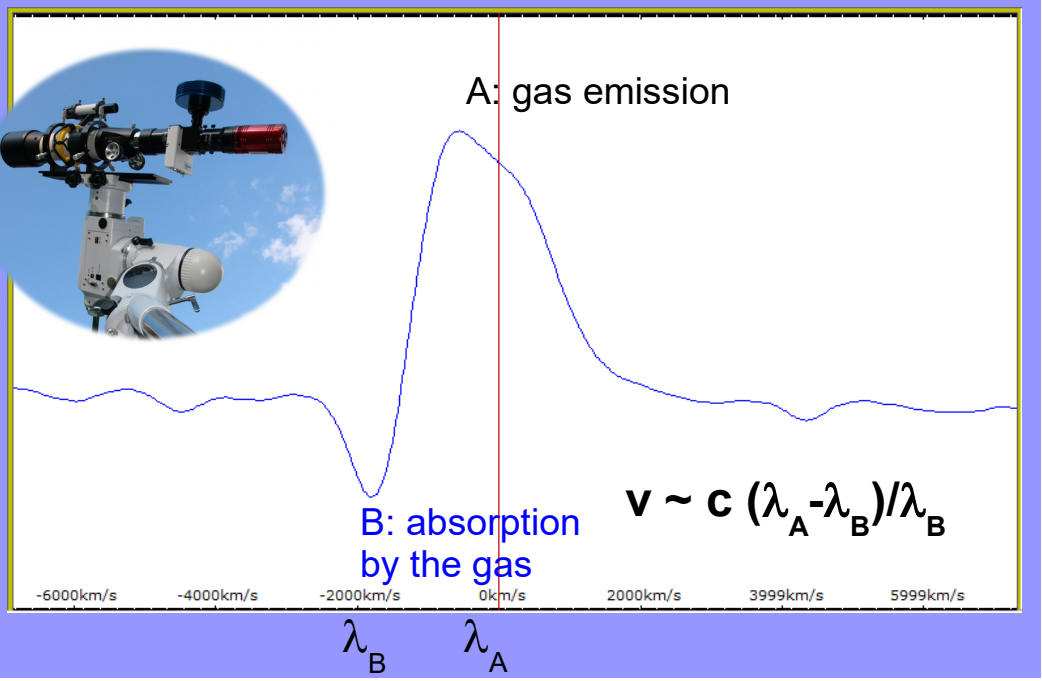


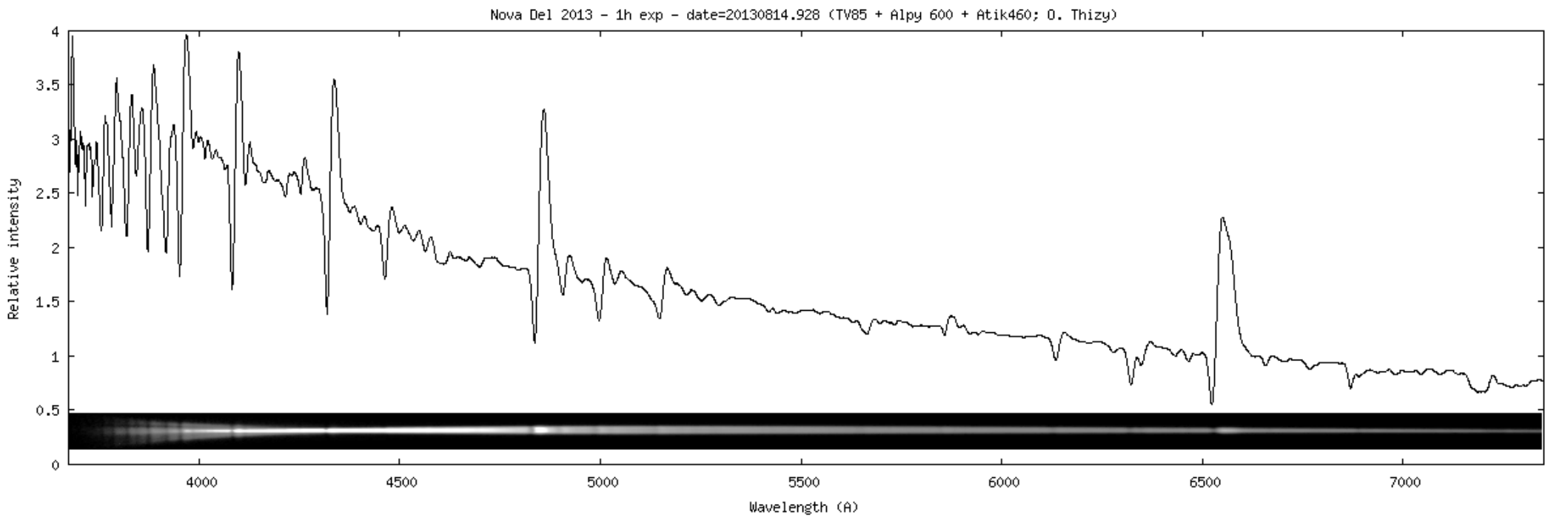
Expansion of the Universe = Red Shift

$$\frac{(\Delta\lambda)}{\lambda} = \frac{v}{c}$$

Ex. of Doppler effect : P Cygni profile

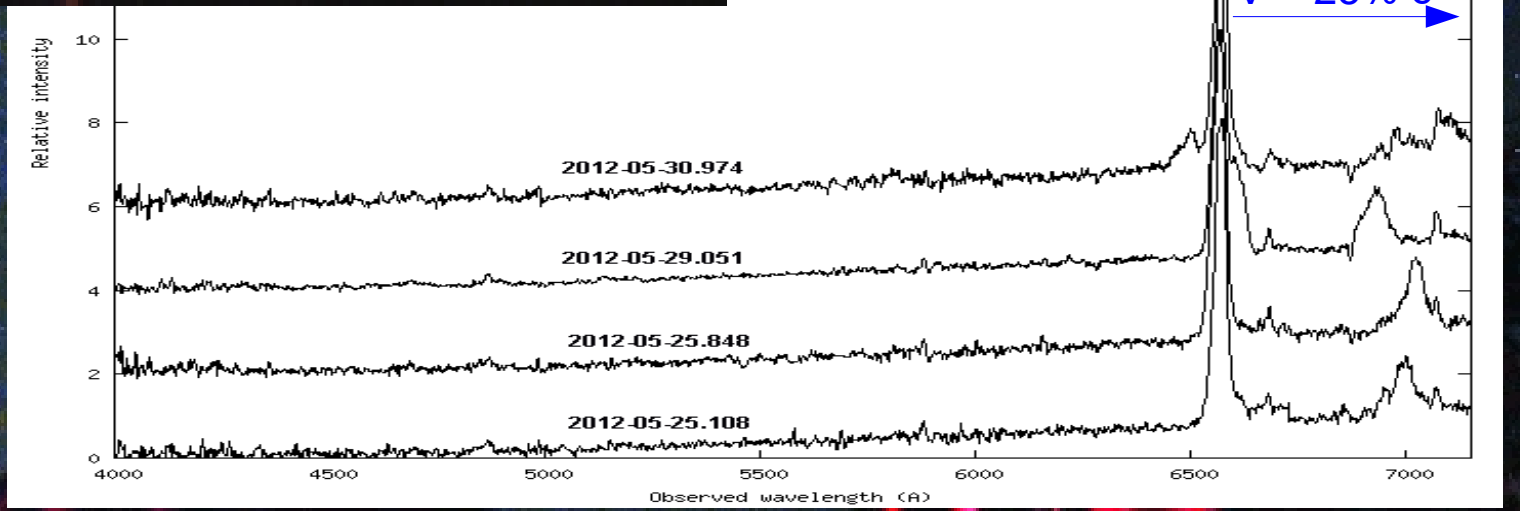






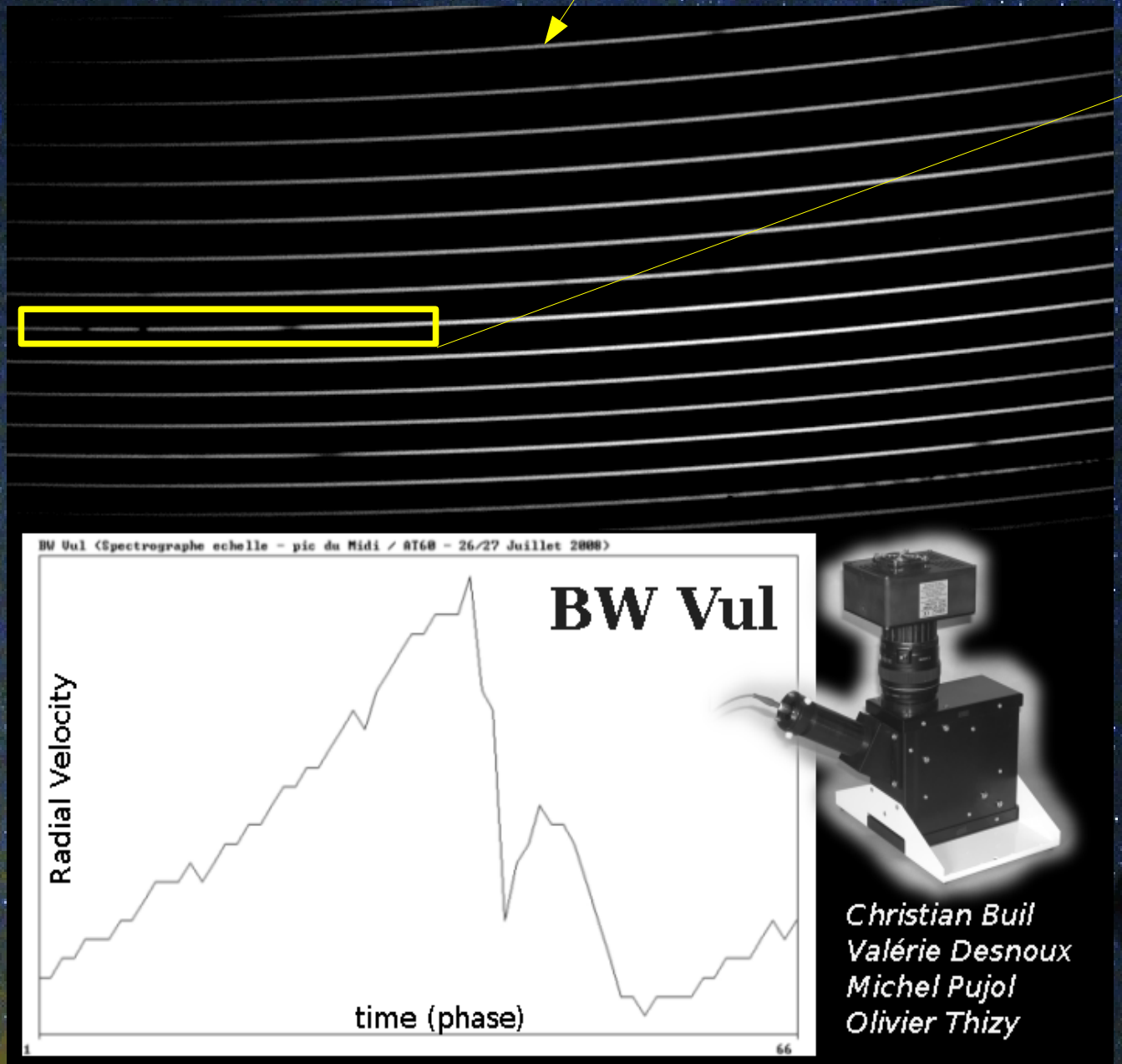
Microquasars

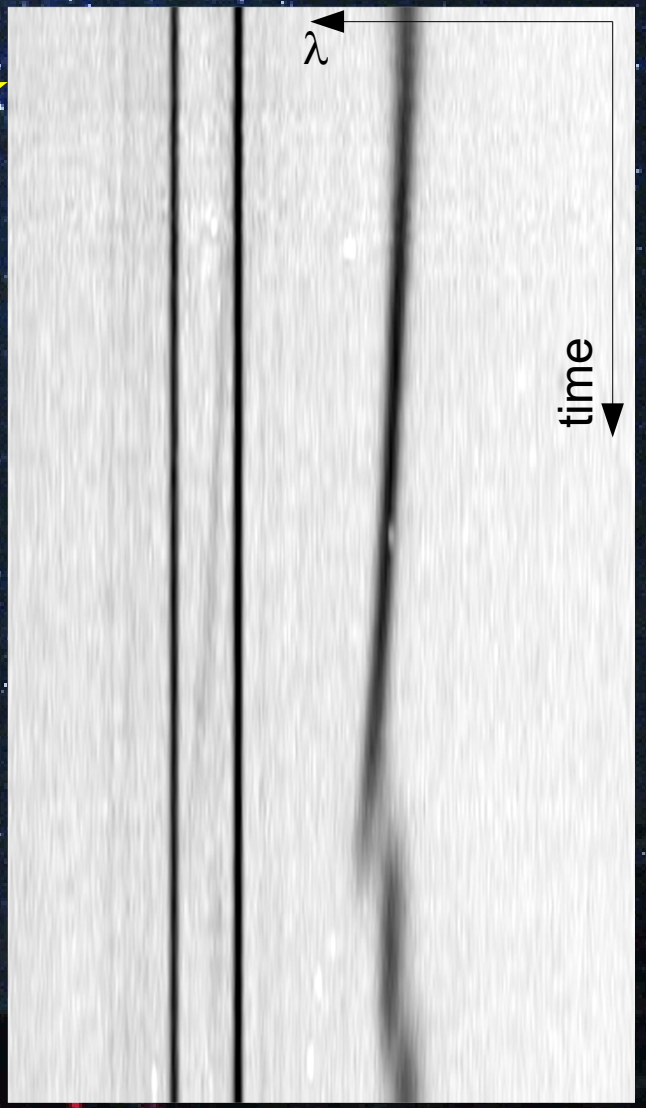
SS 433



Spectre: Christian Buil / Dessin: wikipedia

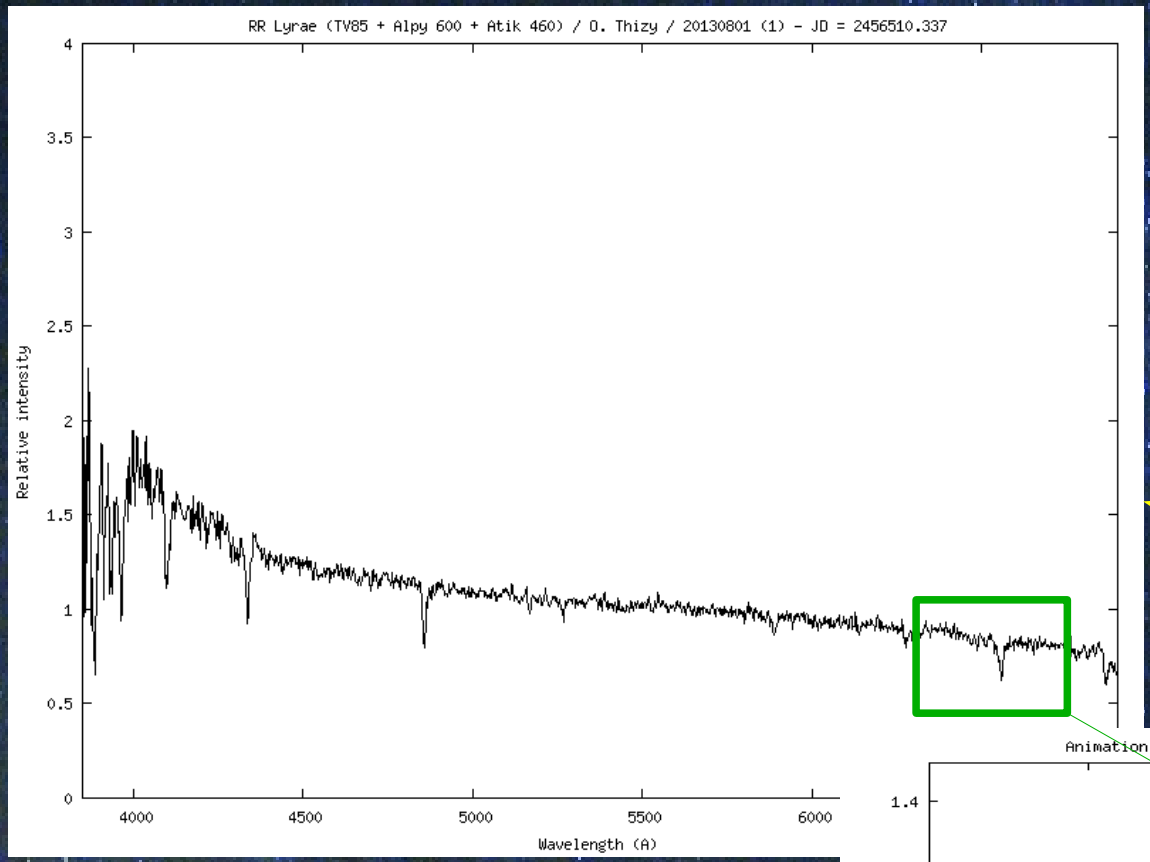
Pulsating stars



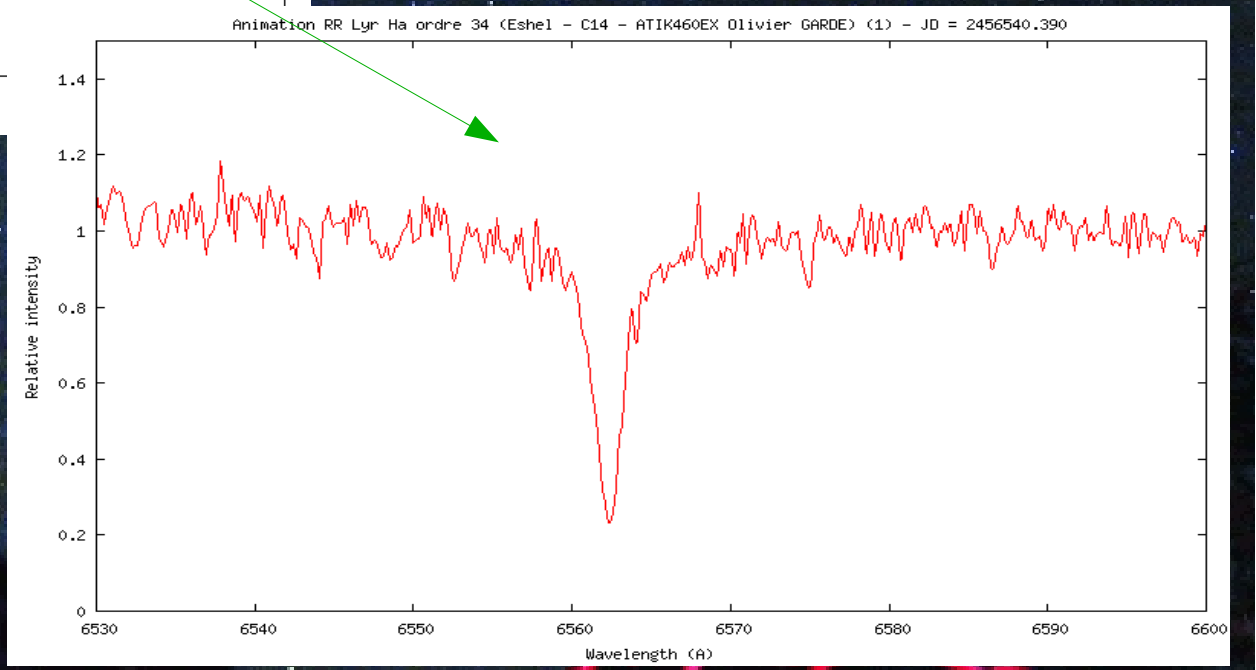


Christian Buil
Valérie Desnoux
Michel Pujol
Olivier Thizy

Pulsating stars : RR Lyrae



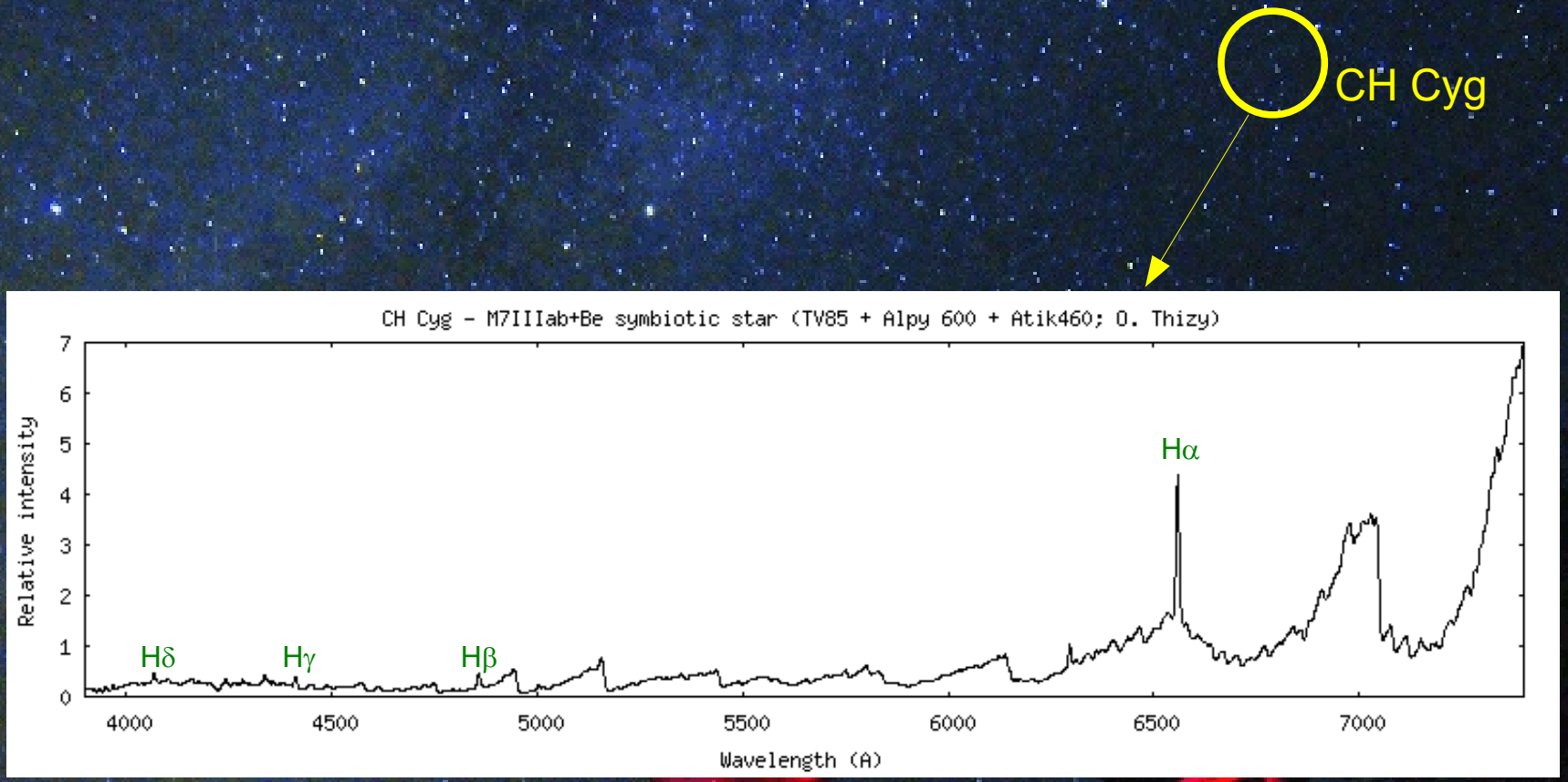
RR Lyr



Spectres: O. Thizy (LISA) / Olivier Garde (eShel)

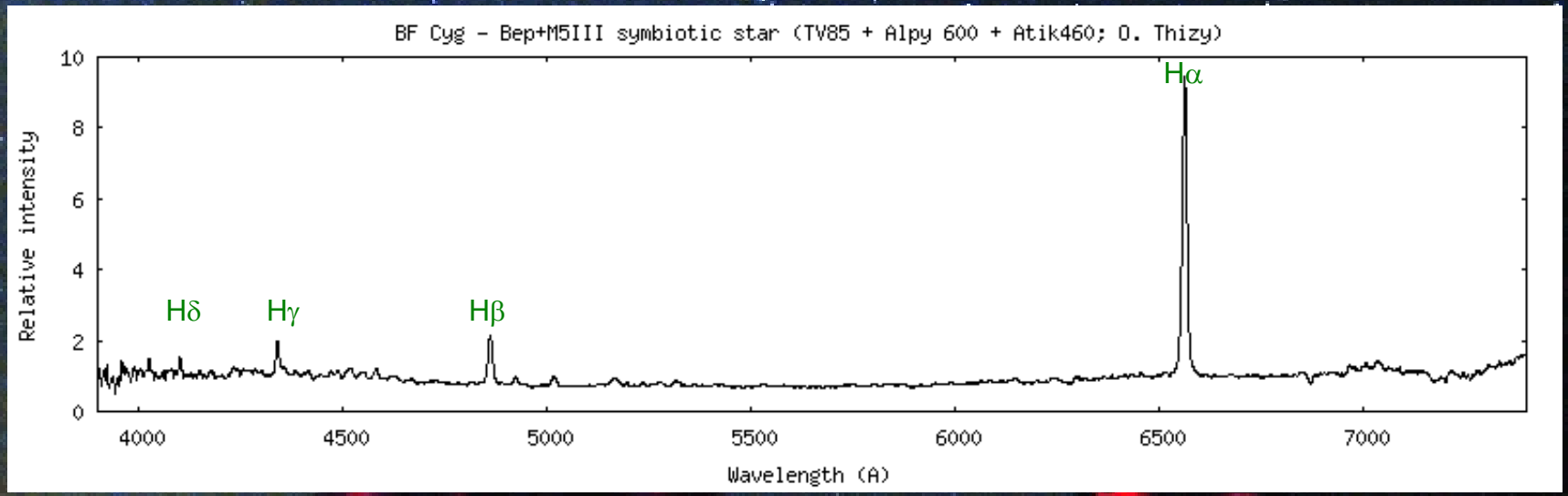
Symbiotic stars : CH Cyg

- Red Giant + White Dwarf
- Mass transfer

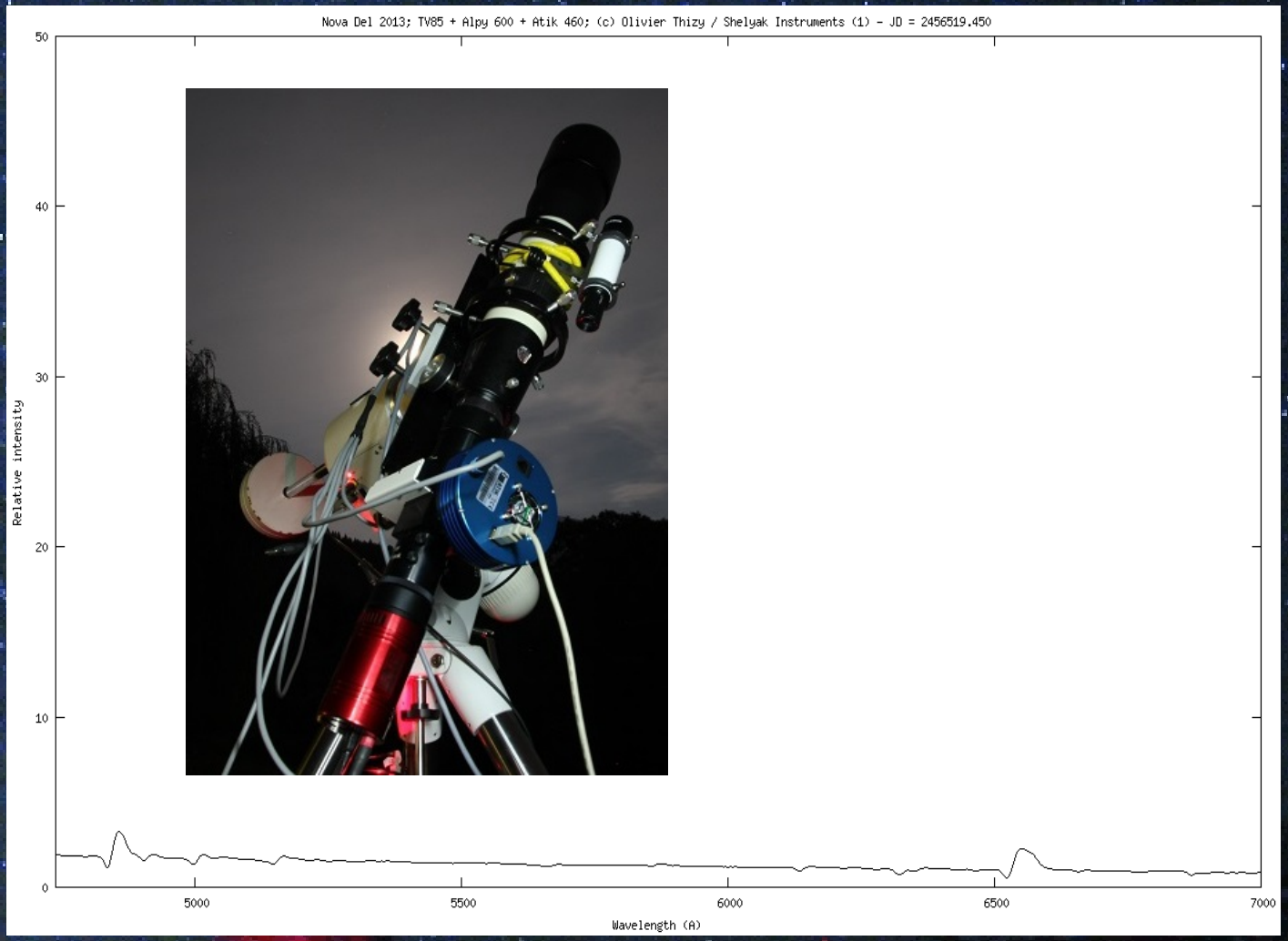


Another symbiotic star : BF Cyg

BF Cyg



Nova Delphinus 2013



Nova Del 2013

20130814.928

20130815.865

20130816.862

20130817.838

20130818.874

20130819.985

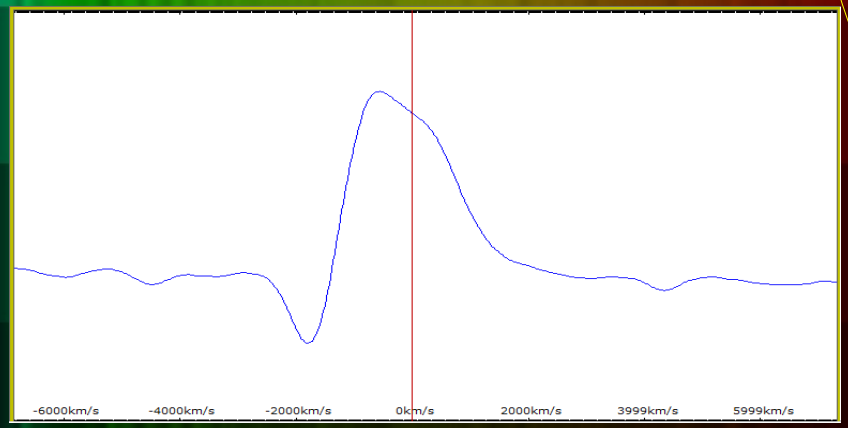
20130820.829

20130821.814

20130822.848

20130823.806

„P Cygni“ profile



Nova Del 2013 : Pro-Am collaboration

- Over 1100 spectra from 40 people for the nova Del 2013 spectroscopy follow up!
- A state of the art collaboration with a professional astronomer, Steve Shore
- A well structured campaign: http://www.astrosurf.com/aras/novae/Nova2013Del.html

Source: Google Map / O. Thizy

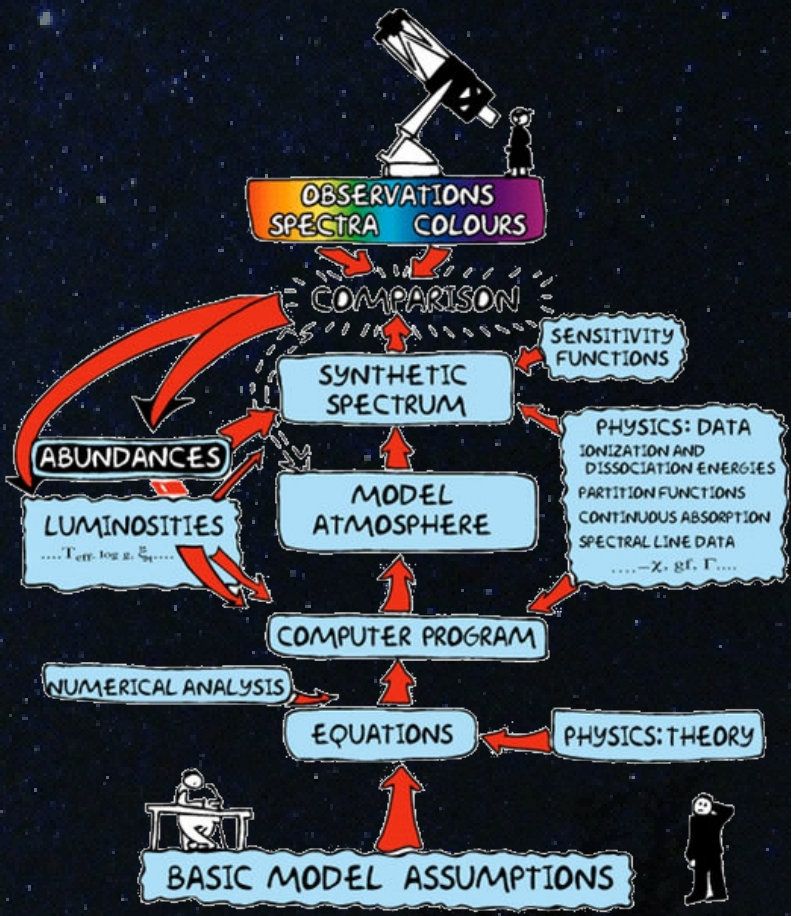
In summary...

Light from the stars teaches us about :

- their **temperature** [overall profile]
- their **composition** & **physical conditions** of excitation & ionisation (ie temperature)
- their chemical quantitative composition (**abundance**), **pressure**, **gravity**

...but also about :

- their **movements** [Doppler-Fizeau effect]
  - *radial velocity*
  - *rotation*
  - *expansion*



*Spectroscopy is a «**scientifical game**»*

- this technic is used all the time by professional astronomers;
- and more and more amateur astronomers are doing spectroscopy !

Schéma : Bengt Gustafsson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Merci ...
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