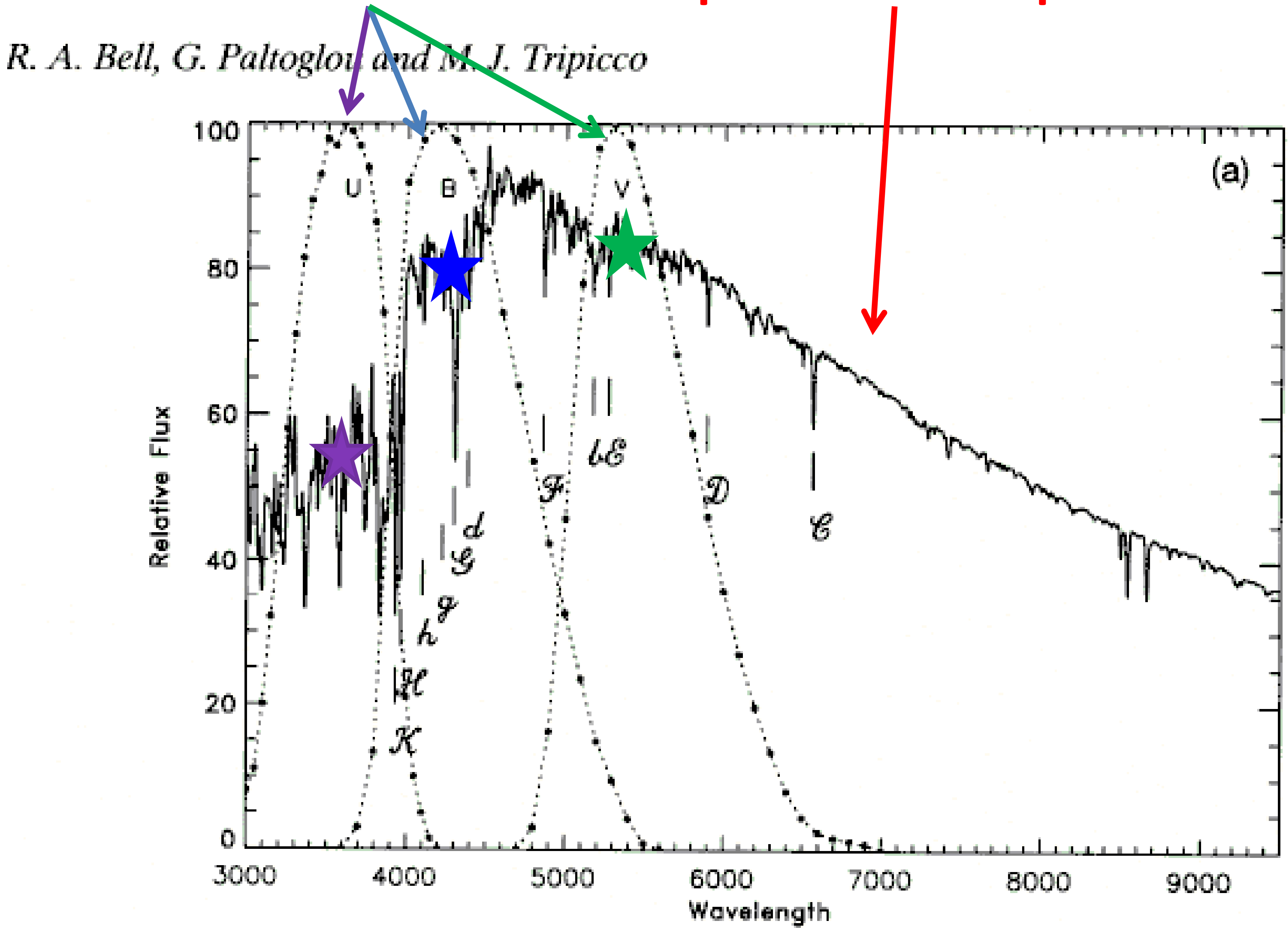
AGA414
Espectroscopia I

- Introduction
- Basic information about different type of spectrographs
- *Prism*
- *Applications*

Prof. Jorge Meléndez

Fotometria vs. Espectroscopia

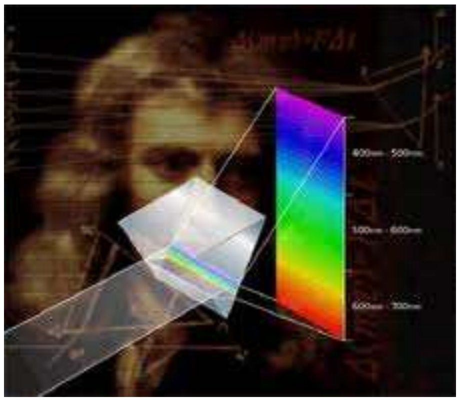


Segundo o filósofo August Comte (1798 – 1857) alguns conhecimentos nunca seriam acessíveis:

[1835-1840?] On the subject of stars, all investigations which are not ultimately reducible to simple visual observations are … necessarily denied to us … **We shall never be able by any means to study their chemical composition**

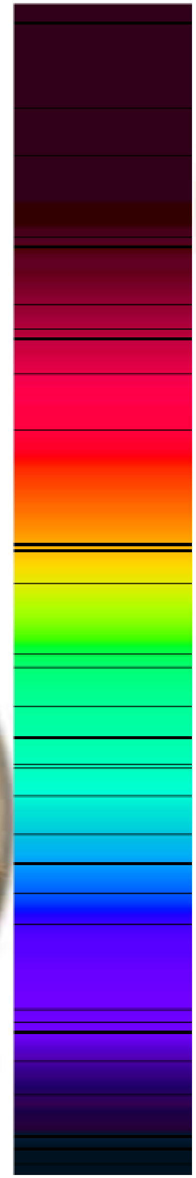
1859: Gustav Kirchhoff shows the presence of sodium in the solar atmosphere

Continuous (optical) spectrum



Newton (1666)

Line spectrum



Fraunhofer
(1817)
574 lines

Wollaston
(1802)
7 lines

Infrared spectrum

William Herschel (1800)

Emission spectrum

John Herschel (son of William)
and W.H. Fox Talbot (1826)

A Method of Examining Refractive and Dispersive Powers, by Prismatic Reflection

William Hyde Wollaston

PHILOSOPHICAL TRANSACTIONS:

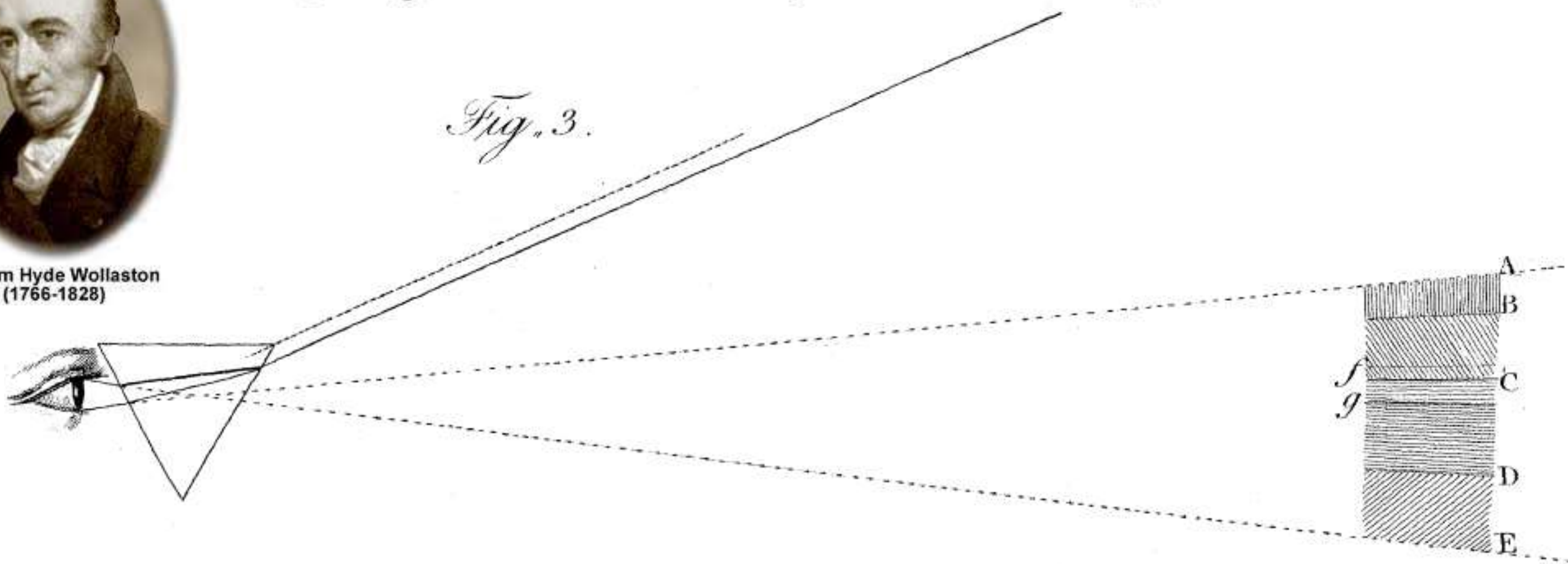
Phil. Trans. R. Soc. Lond. 1802 **92**, doi: 10.1098/rstl.1802.0014, published 1 January 1802

I cannot conclude these observations on dispersion, without remarking that the colours into which a beam of white light is separable by refraction, appear to me to be neither 7, as they usually are seen in the rainbow, nor reducible by any means (that I can find) to 3, as some persons have conceived; but that, by employing a very narrow pencil of light, 4 primary divisions of the prismatic spectrum may be seen, with a degree of distinctness that, I believe, has not been described nor observed before.

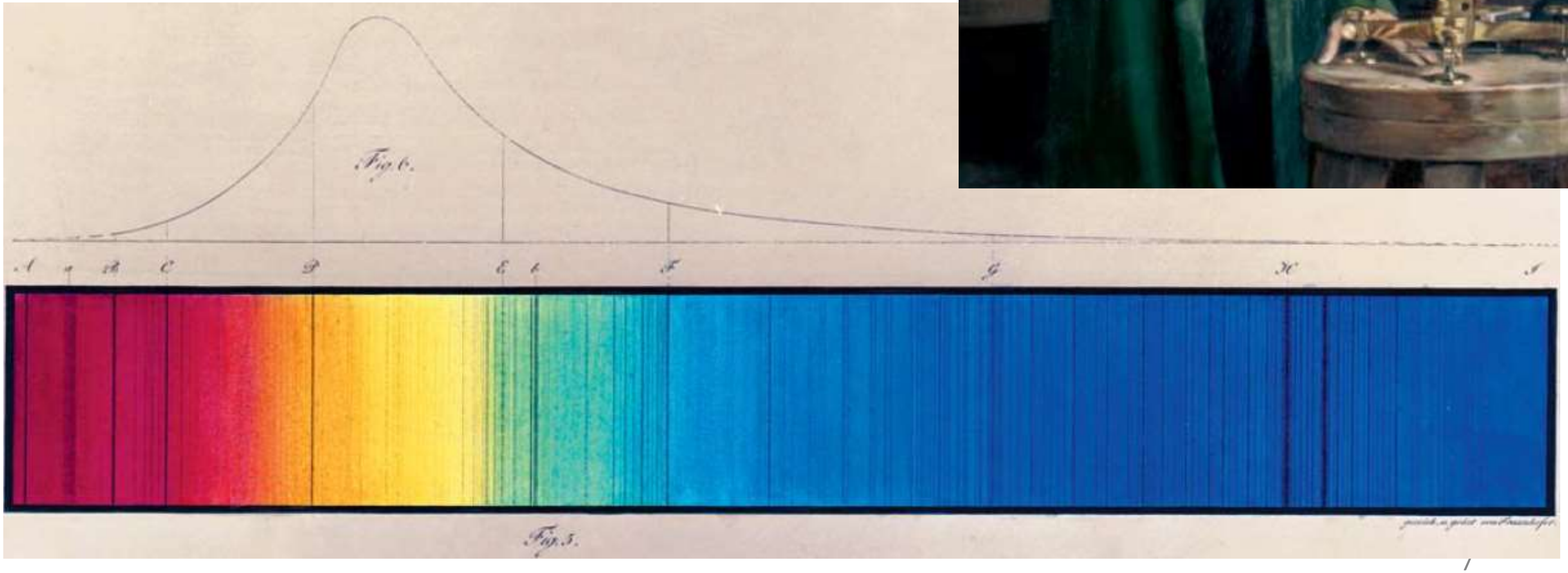
The line A that bounds the red side of the spectrum is somewhat confused, which seems in part owing to want of power in the eye to converge red light. The line B, between red and green, in a certain position of the prism, is perfectly distinct; so also are D and E, the two limits of violet. But C, the limit of green and blue, is not so clearly marked as the rest; and there are also, on each side of this limit, other distinct dark lines, *f* and *g*, either of which, in an imperfect experiment, might be mistaken for the boundary of these colours.

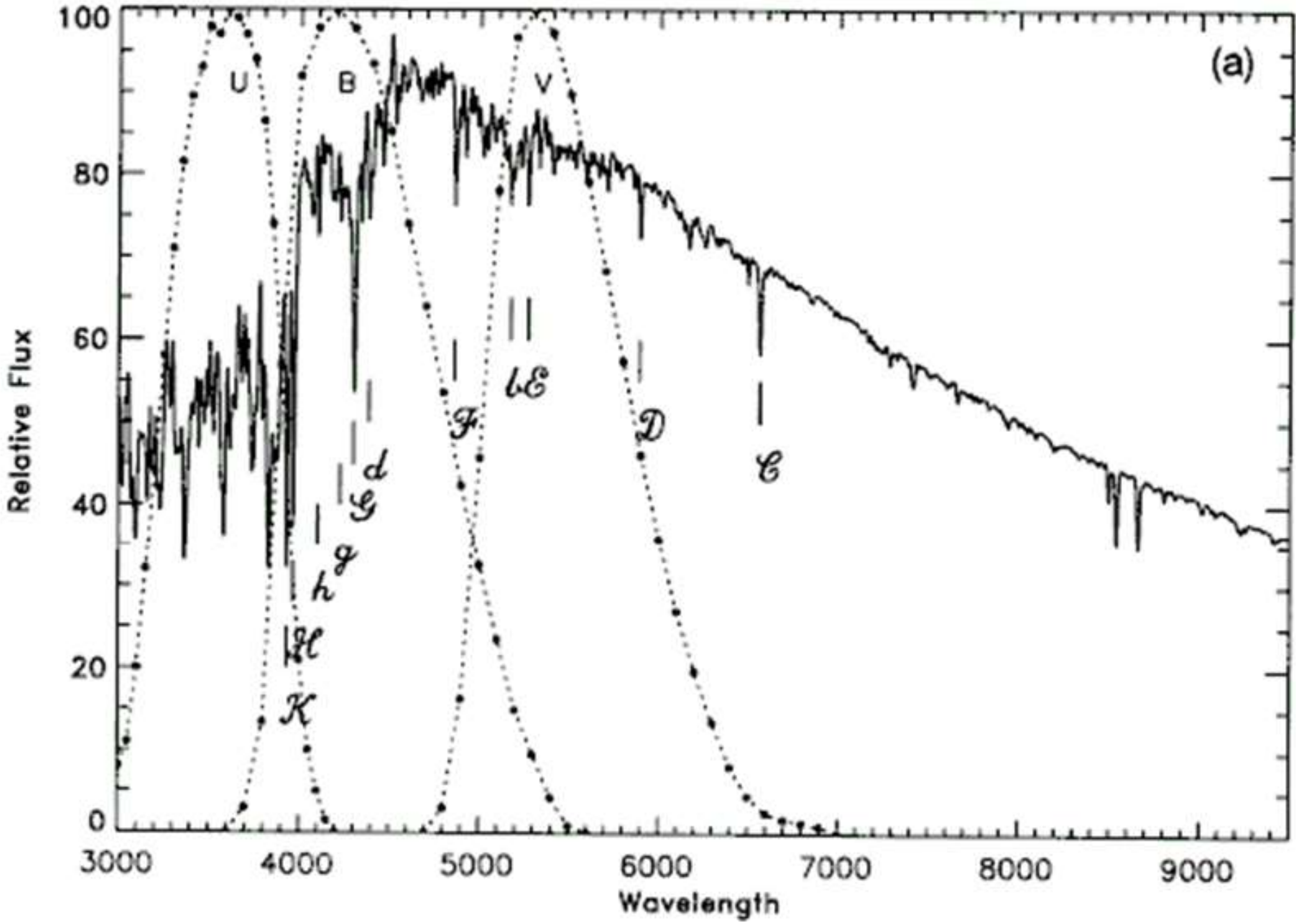
William Hyde Wollaston
(1766-1828)

Fig. 3.

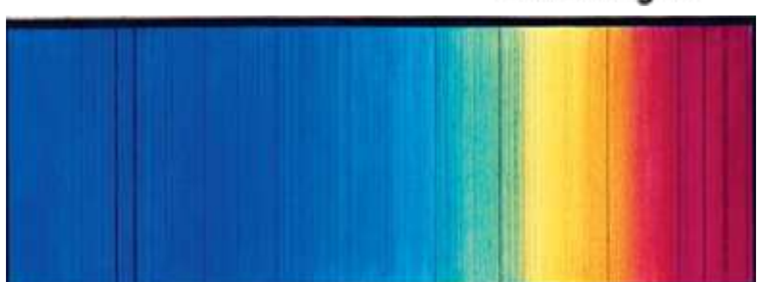


Fraunhofer found 574 lines in the solar spectrum (1817)





(a)
U
B
V
Relative Flux
Wavelength
0
20
40
60
80
100
3000
4000
5000
6000
7000
8000
9000
K
H
h
g
G
d
F
bE
D
C



DENKSCHRIFTEN

DER

KÖNIGLICHEN

AKADEMIE DER WISSENSCHAFTEN

ZU MÜNCHEN

FÜR DIE JAHRE

1814 UND 1815.

Bestimmung

des

Brechungs- und Farbenzerstreuungs-Vermögens

verschiedener Glasarten,

in

Bezug auf die Vervollkommnung achromatischer

Fernröhre.

Von

Joseph Fraunhofer,

Joseph von Fraunhofer
(1787-1826)

Fraunhofer, father of astronomical spectroscopy

Joseph Fraunhofer (1814 - 1815), in *Denkschriften der Königlichen Akademie der Wissenschaften zu München*

Ich habe auch mit derselben Vorrichtung Versuche mit dem Lichte einiger Fixsterne erster Gröſse gemacht. Da aber das Licht dieser Sterne noch vielmal schwächer ist, als das der Venus, so ist natürlich auch die Helligkeit des Farbenbildes vielmal geringer. Demohngeachtet habe ich, ohne Täuschung, im Farbenbilde vom Lichte des Sirius drey breite Streifen gesehen, die mit jenen vom Sonnenlichte keine Aehnlichkeit zu haben scheinen; einer dieser Streifen ist im Grünen, und zwey im Blauen. Auch im Farbenbilde vom Lichte anderer Fixsterne erster Gröſse erkennt man Streifen; doch scheinen diese Sterne, in Beziehung auf die Streifen, unter sich verschieden zu seyn.

With the same device [i.e., spectroscope], I've also made some experiments on the light of some stars of the first magnitude. Since the light of these stars is many times weaker than that of Venus, so naturally the brightness of the spectrum is also many times less. Notwithstanding, I have seen -- without any illusion -- **three broad stripes in the spectrum of Sirius, which seem to have no similarity to those of sunlight; one of these stripes is in the green, and two in the blue. Also, in the spectrum of the light of other fixed stars of the first magnitude, one detects stripes; yet these stars, in regard to the stripes, seem to differ among themselves.**

Caraterísticas dos espectros

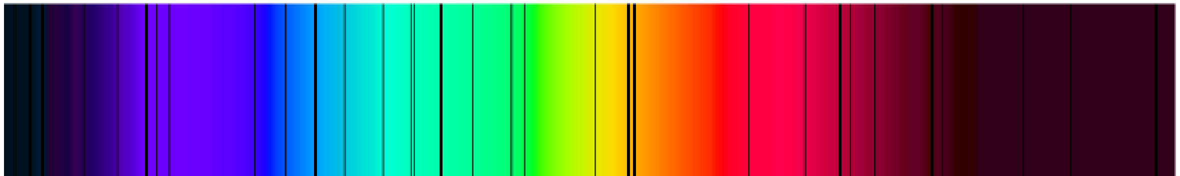
- Comprimento de onda λ ,frequência ν ou velocidade **v**
- Spectral resolution: $\Delta\lambda$, $\Delta\nu$, Δv

$\Delta\lambda$, $\Delta\nu$, Δv : elemento de resolução espectral em comprimento de onda, frequência ou velocidade

- Poder resolvente: R

$R = \lambda/\Delta\lambda$, $R = \nu/\Delta\nu$, $R = c/\Delta v$

- Spectral coverage : $\lambda_{min} - \lambda_{max}$

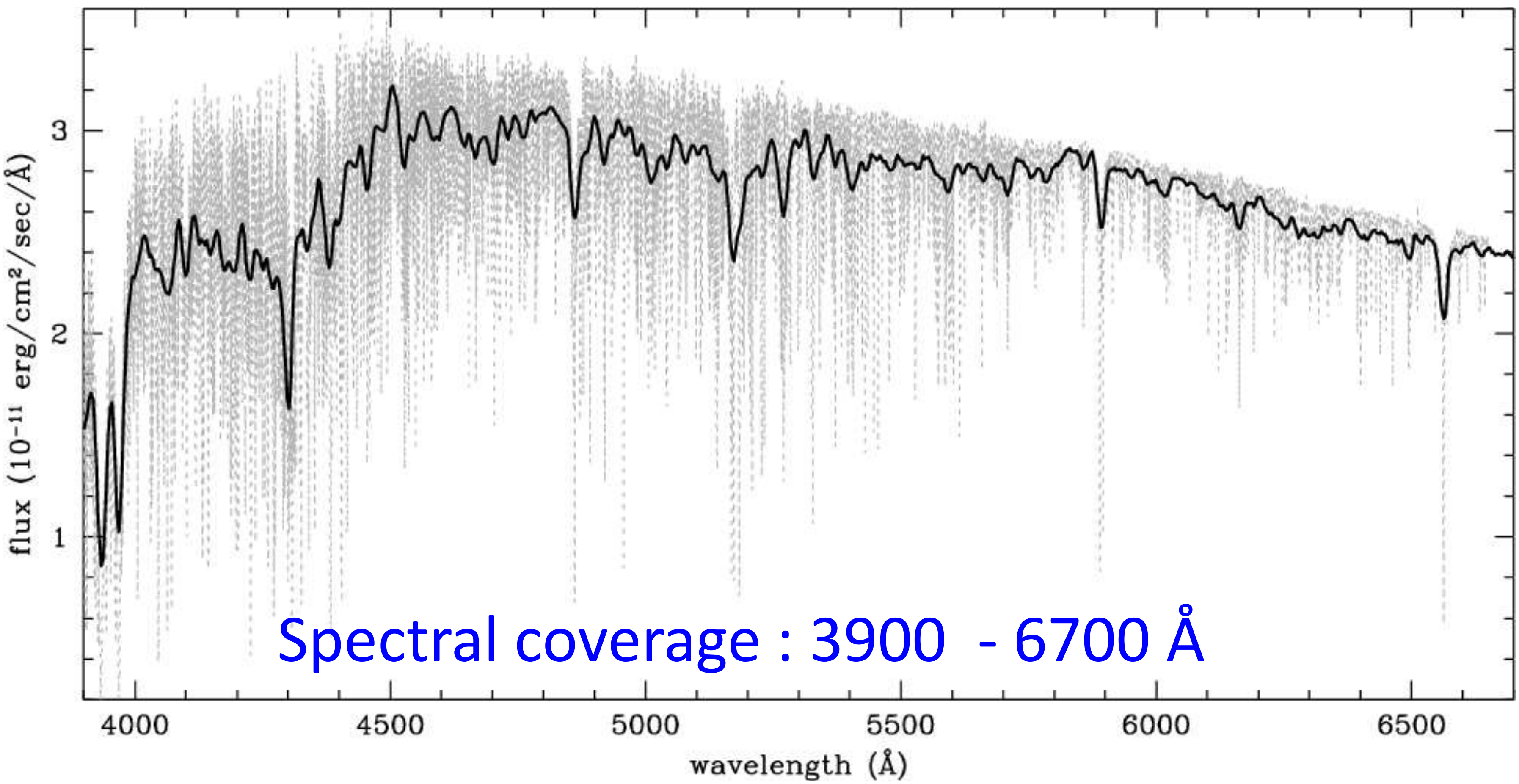


Exemplos

- λ = 500 nm, resolução $\Delta\lambda$ = 0,5 nm
- Qual o poder resolvente R?
- R = $\lambda/\Delta\lambda = 1000$ (baixa resolução)

- Podemos resolver um elemento de velocidade de Δv= 6 km/s, qual o poder resolvente?
- R = c / Δv = 50 000 (alta resolução)

Low spectral resolution ($\Delta\lambda \geq 1$ Å) vs.
High spectral resolution ($\Delta\lambda \sim 0{,}1$ Å)



Nature Vol. 290 5 March 1981

A water vapour maser in the Large Magellanic Cloud

E. Scalise Jr

CRAAM/INPE: Instituto de Pesquisas Espaciais, Conselho Nacional de Desenvolvimento, Cientifico e Tecnológico-CNPq, CP 515, 12200-São José dos Campos, SP, Brasil

M. A. Braz

CNPq-Observatório Nacional, Rua Pará, 277, 01243-São Paulo, SP, Brasil

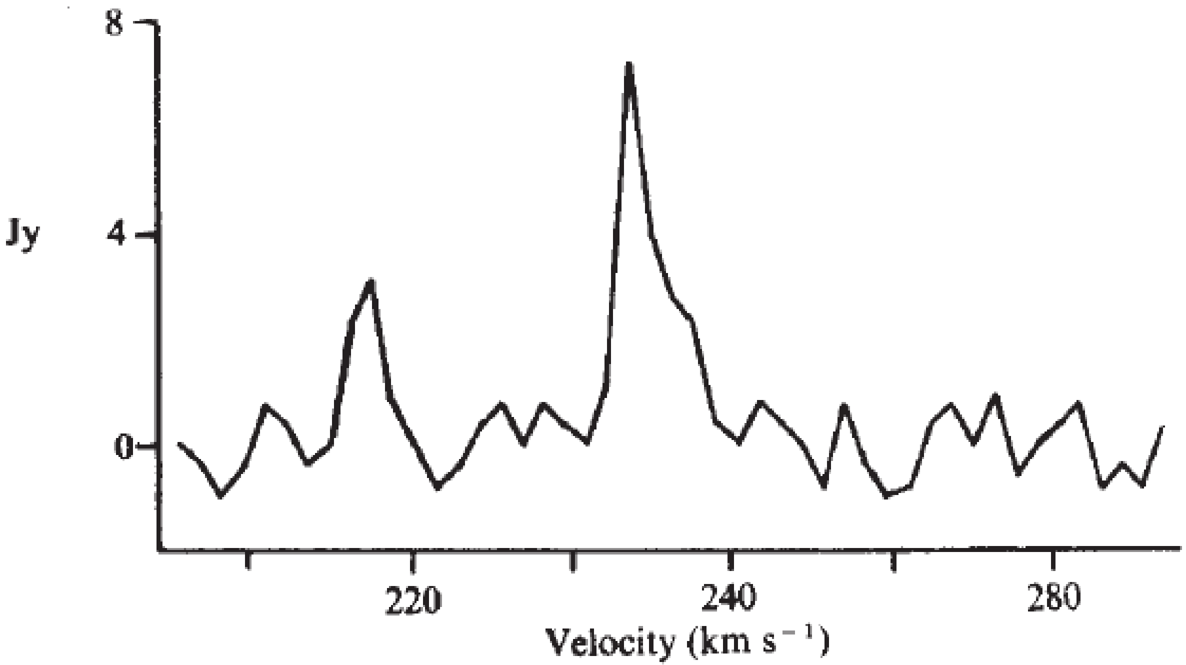


Fig. 1 Water vapour spectrum of N159 (RA 05 h 40 min 24 s DEC. −69°46ʹ.0,1950.0). The main feature appears at 233.6 km s^{-1} with respect to the Local Standard of Rest.

The survey was carried out in 1979–80. Upper detection limits of about 1.2 Jy were attained with the use of long integration times and a maser amplifier front-end, the total system temperature ranging from 250 to 400 K. Spectral information was provided by a 47-channel spectrometer, 100-kHz bandwidth filter bank, giving a velocity resolution of 1.35 km s^{-1}. Two vertically polarized feed horns were used in beam-

We concentrated our search for the $J = 6_{16}-5_{23}$ transition of the water maser line ($f = 22235.08$ MHz) in two of the strongest H(II) regions in the LMC[6]—N157 (ref. 7, 30 Doradus) and N159—and in two dark nebulae[8]—Hodge 47 and Hodge 52. Huggins *et al.*[9] studied these four regions in their carbon monoxide survey.

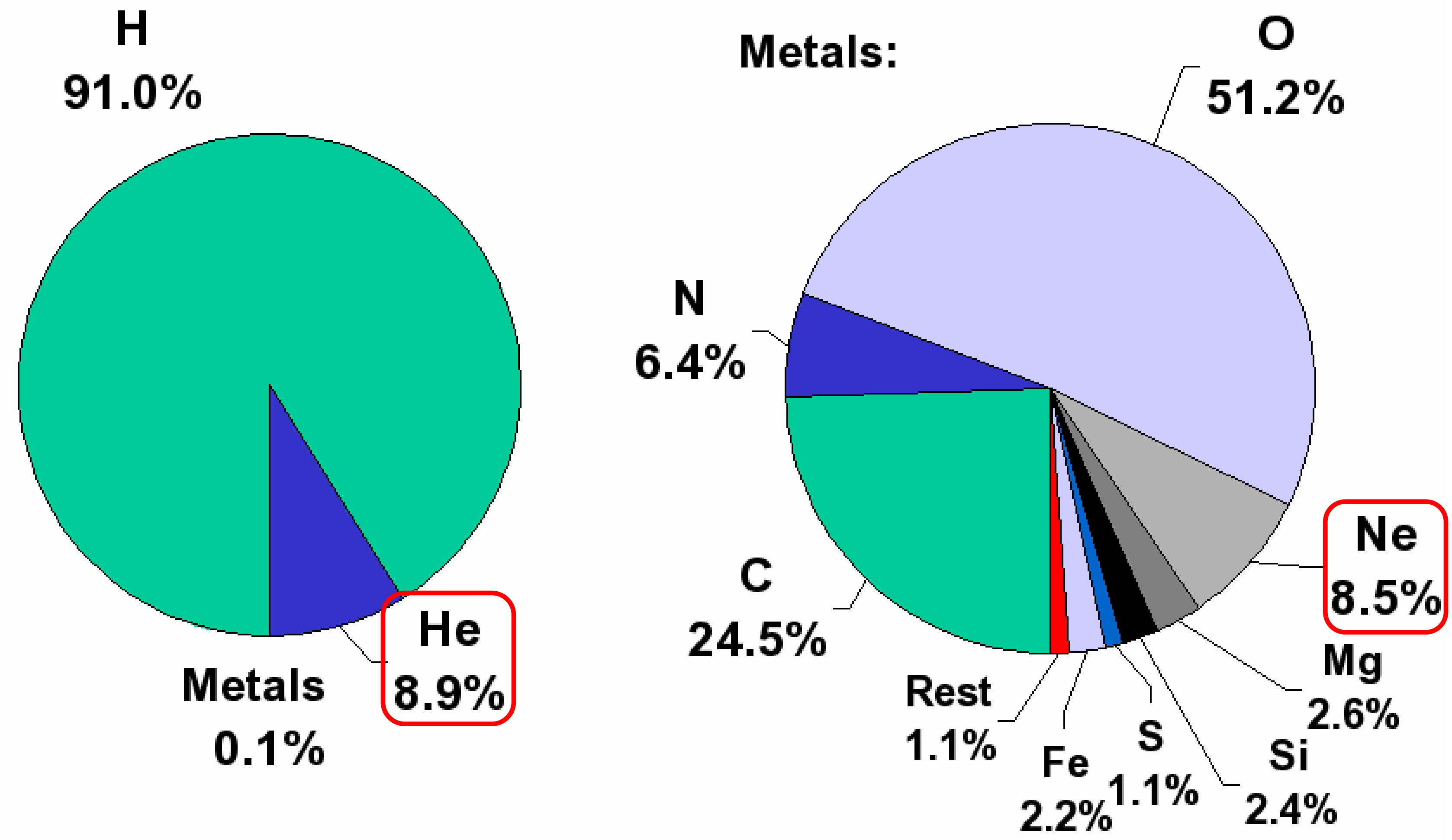
Exemplo de resolução em velocidade

Δv = 1,35km/s

R = 221 000

Alguns exemplos de espectroscopia

- Composição química do Sol



Notação em composição química

- Abundância química do elemento X em relação ao número de átomos de H:

  $A(X) = \log (N_X/N_H) + 12$

- Metalicidade [Fe/H]: abundância de ferro relativa ao Sol (em logaritmo)

[Fe/H] = 0 (metalicidade solar)

[Fe/H] = -2 (1/100 do Sol)

[Fe/H] = +0.3 (2 X do Sol)

The Astrophysical Journal, 751:86 (16pp), 2012 June 1 doi:10.1088/0004-637X/751/2/86

R ~ 60 000, HRS (HET/McDonald) – single-object

A DETECTION OF Hα IN AN EXOPLANETARY EXOSPHERE

Adam G. Jensen[1], Seth Redfield[1], Michael Endl[2], William D. Cochran[2], Lars Koesterke[2,3], and Travis Barman[4]
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[2] Department of Astr
[3] Texas

A few examples

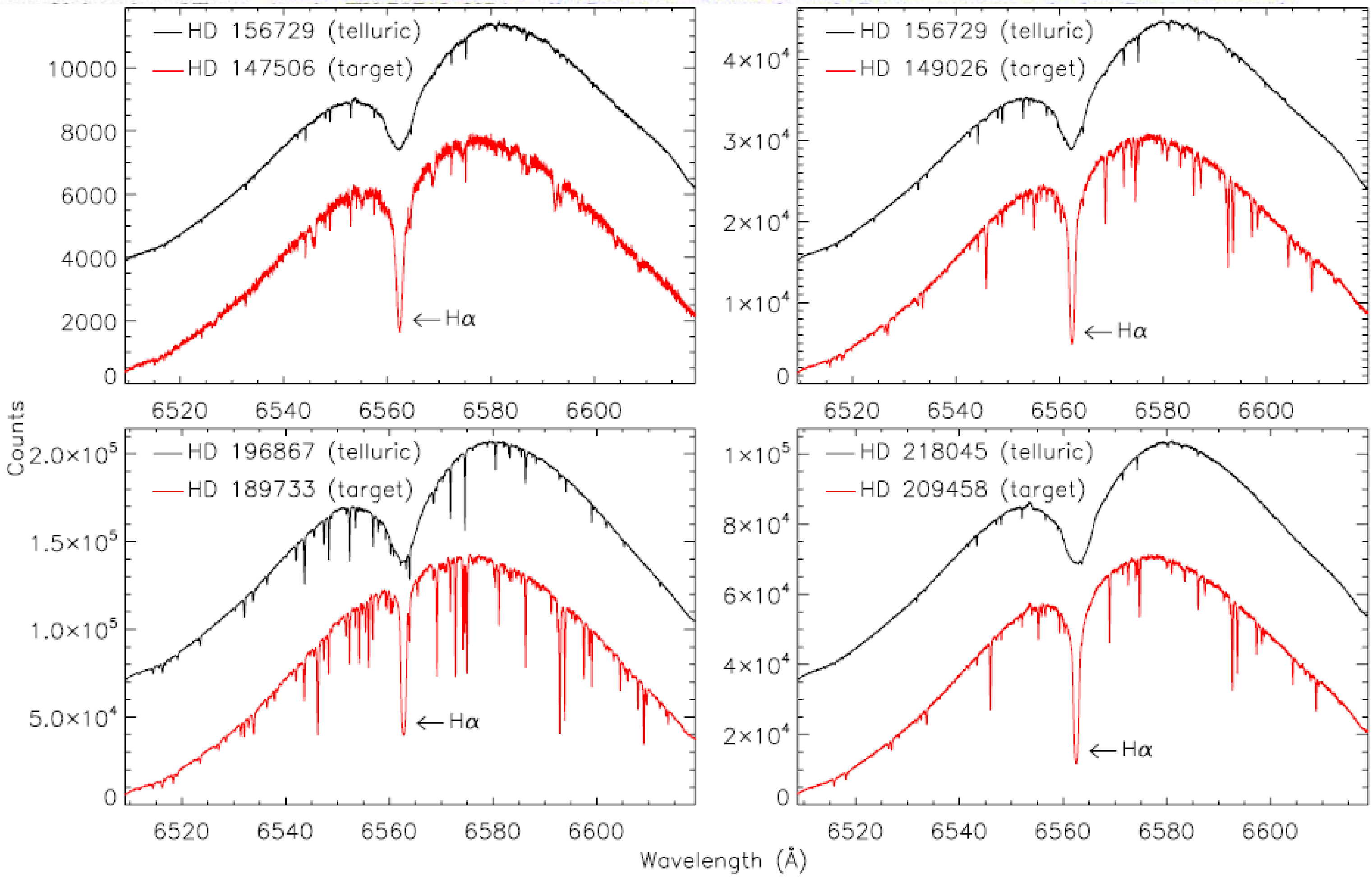

Figure 1. Examples of the spectra in the echelle order that contains H I λ6562 for all four targets, along with the spectra of their respective telluric standard stars from the same night of observation. All spectra are reduced from the raw echelle images but are not processed with the additional steps we discuss in Section 2.2 (including removal of the Hα feature from the telluric spectra, telluric correction from the primary target, and normalization). The target spectra are shown on the count scale of the y-axis, but the telluric spectra are scaled to have the same maximum as the corresponding target spectra and then arbitrarily shifted by 25% of that same maximum. The global shapes of the spectra are dominated by the blaze function of the echelle.

A few examples

The Astrophysical Journal, 751:86 (16pp), 2012 June 1 doi:10.1088/0004-637X/751/2/86

A DETECTION OF Hα IN AN EXOPLANETARY EXOSPHERE

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[2] Depa

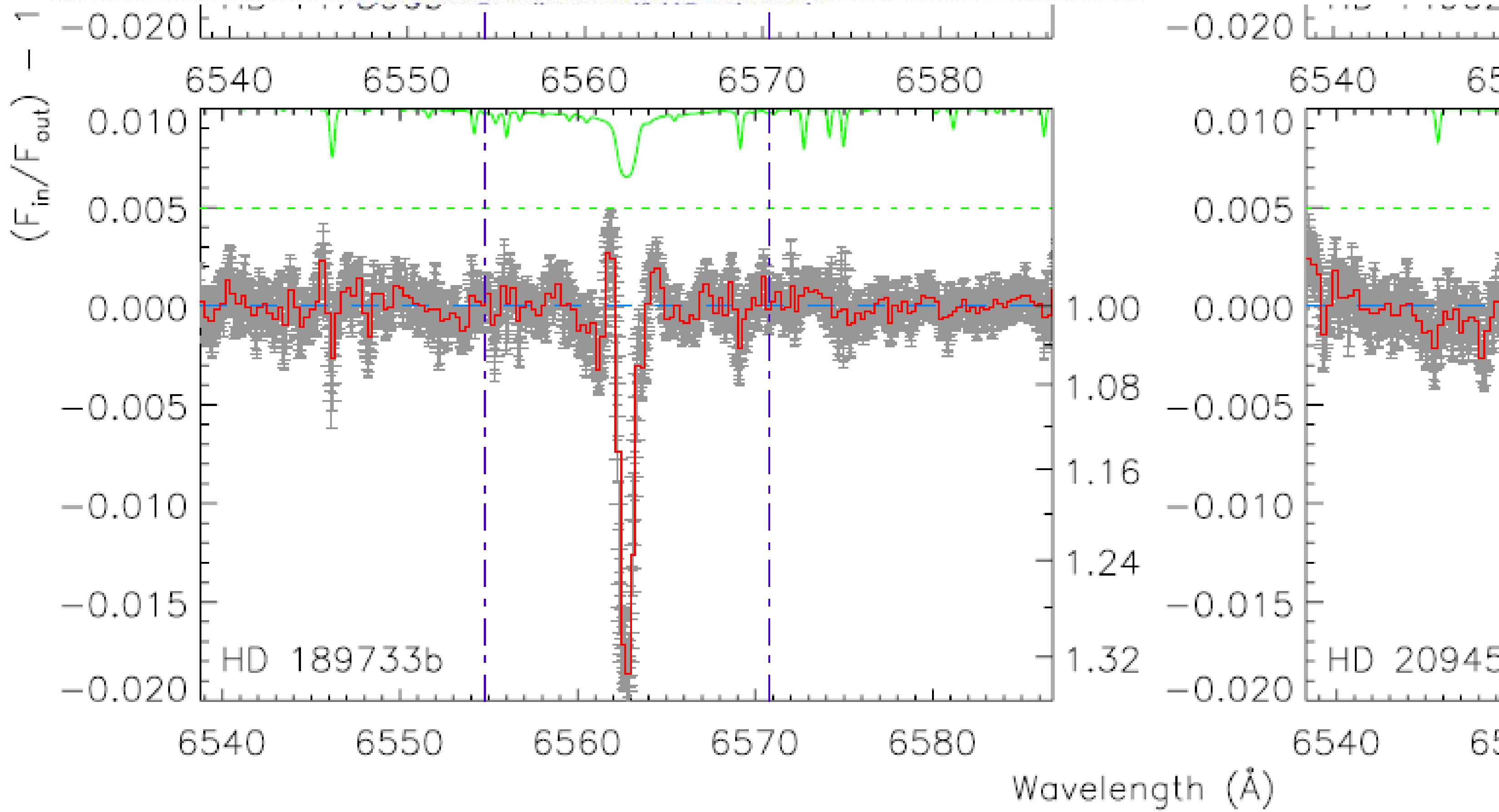


Figure 3. The Hα transmission spectra of our four targets. The binned transmission spectrum is shown in red. of the binned points). For reference, the master out-of-transit spectrum of the star is shown at the top with gr showing the zero level and the top of each plot being unity in the normalized spectrum. A blue dashed line s purple vertical dot-dashed lines define the bandpass that is integrated to make our absorption measurements; to the edges of the plot.

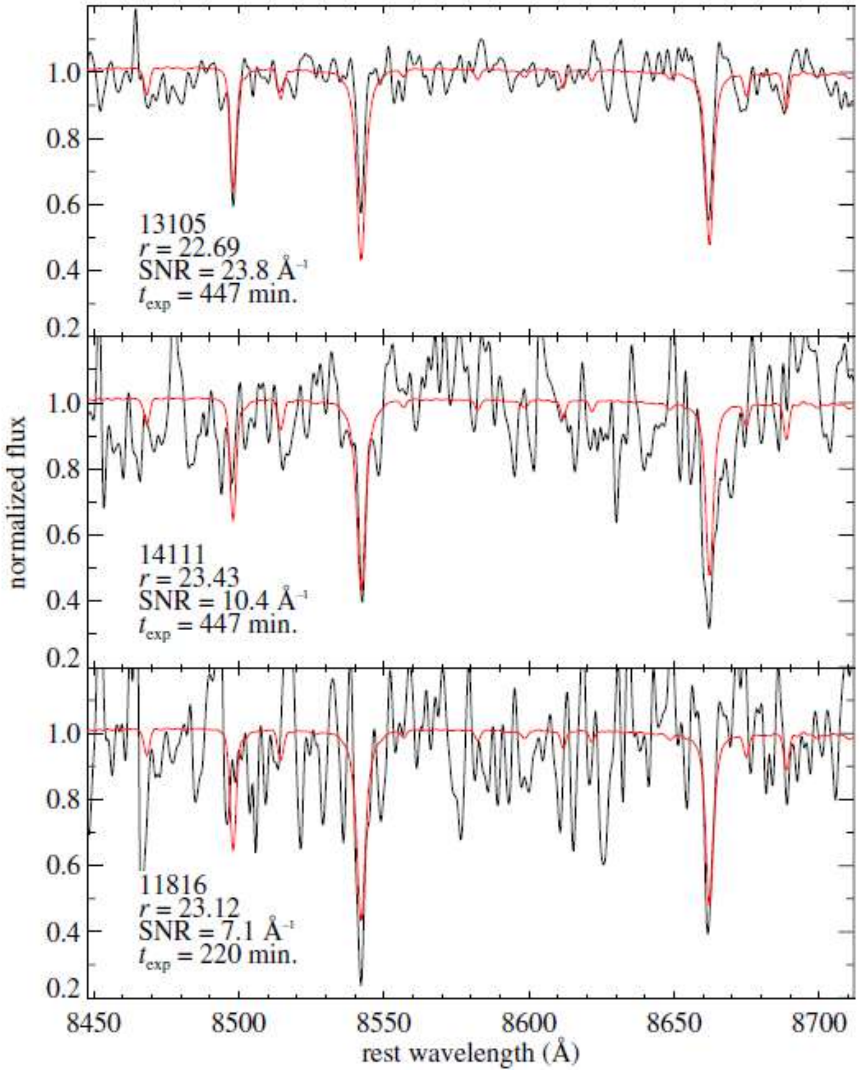
The Astrophysical Journal, 751:46 (15pp), 2012 May 20
doi:10.1088/0004-637X/75

R ~ 7000, DEIMOS (Keck) – multi-object

THE DYNAMICS AND METALLICITY DISTRIBUTION OF THE DISTANT DWARF GALAXY VV124*

1,1 Mpc

Evan N. Kirby[1,3], Judith G. Cohen[1], and Michele Bellazzini[2]
[1] California Institute of Technology, 1200 East California Boulevard, MC 249-17, Pasadena, CA 91125, USA



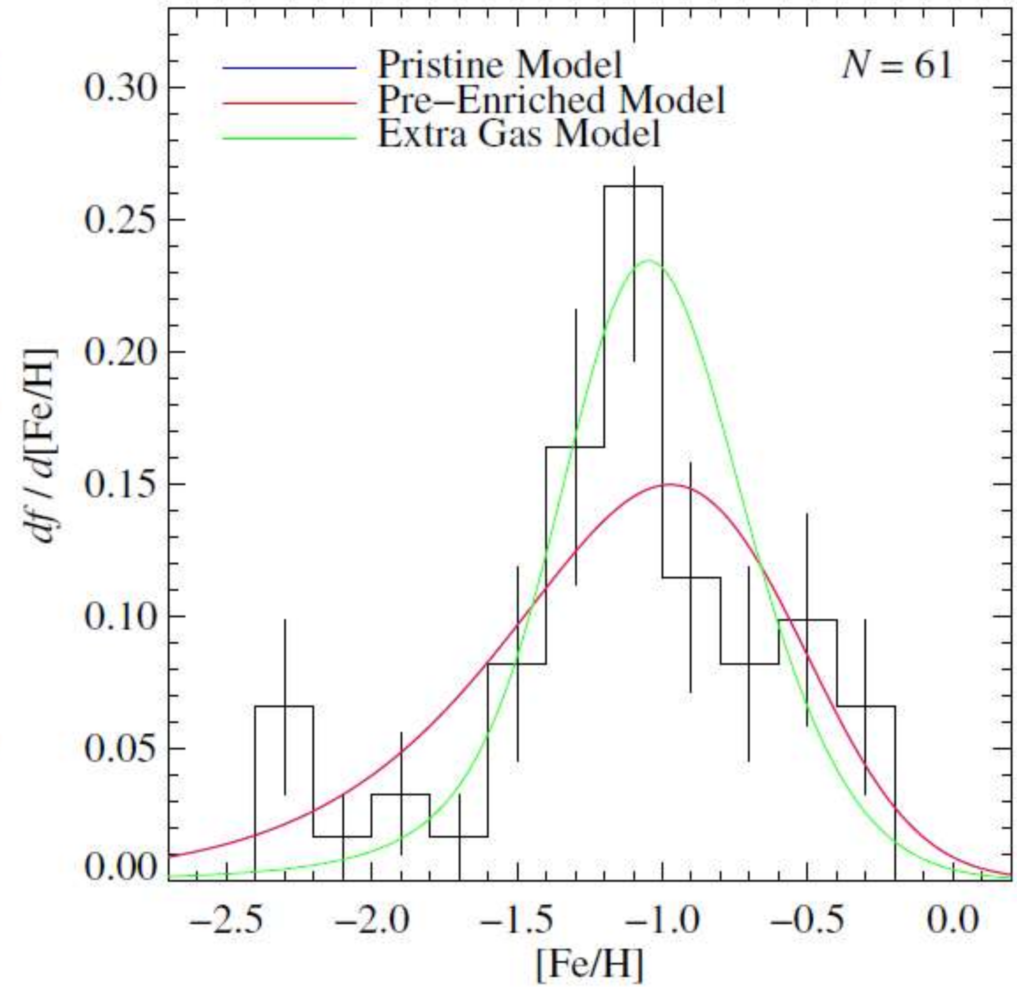


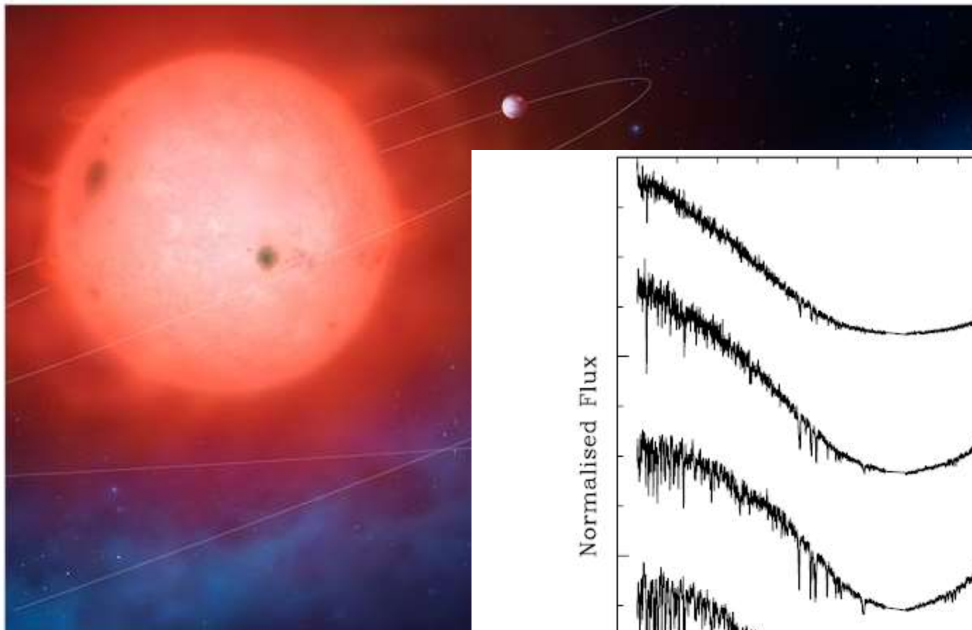
Figure 12. Metallicity distribution for member stars. Error bars are calculated with Poisson statistics. Best-fitting, analytic models of chemical evolution are shown as colored curves. The red and blue lines overlap almost exactly.

NATIONAL GEOGRAPHIC Daily News

Home Animals Ancient Energy Environment Travel/Cultures S

Four White Dwarfs Found Eating Earthlike Planets

Dusty dead stars hint at our solar system's fate, study says.



Planets shift their orbits and collide as they circle a

The chemical diversity of exo-terrestrial planetary debris around white dwarfs

B.T. Gänsicke[1], D. Koester[2], J. Farihi[3], J. Girven[1], S.G. Parsons[1], E. Breedt[1]
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[2] Institut für Theoretische Physik und Astrophysik, University of Kiel, 24098 Kiel, Germany
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arXiv:1205.0167v1

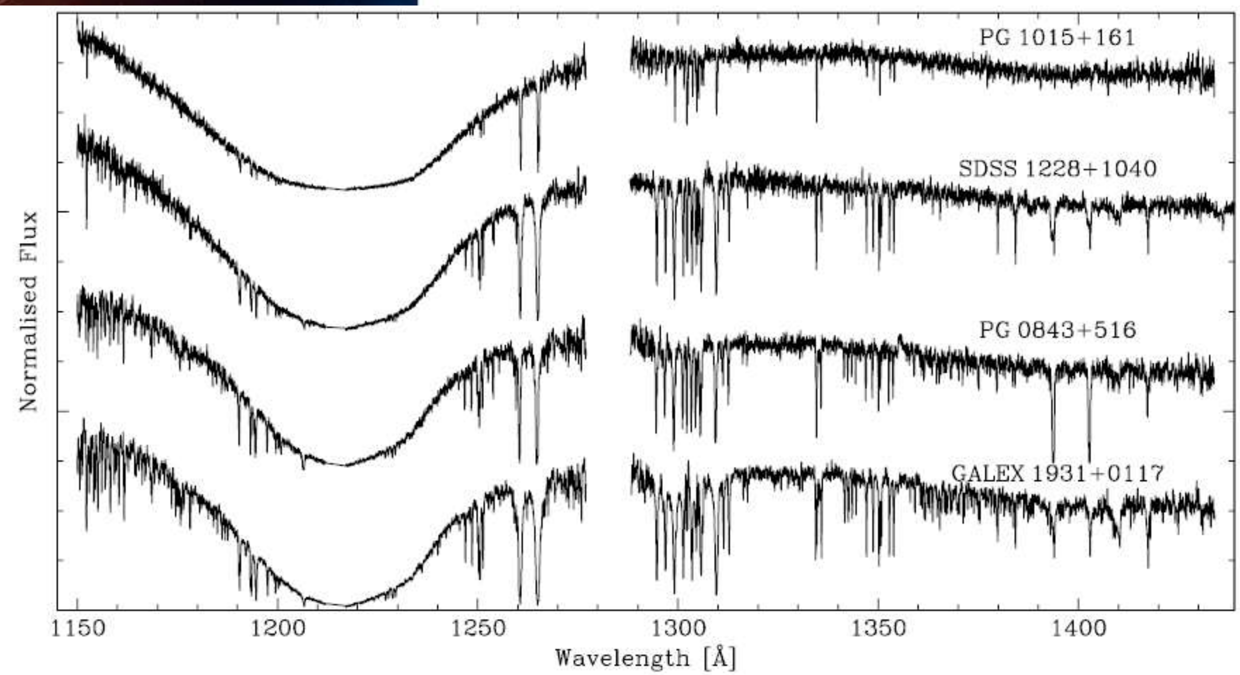
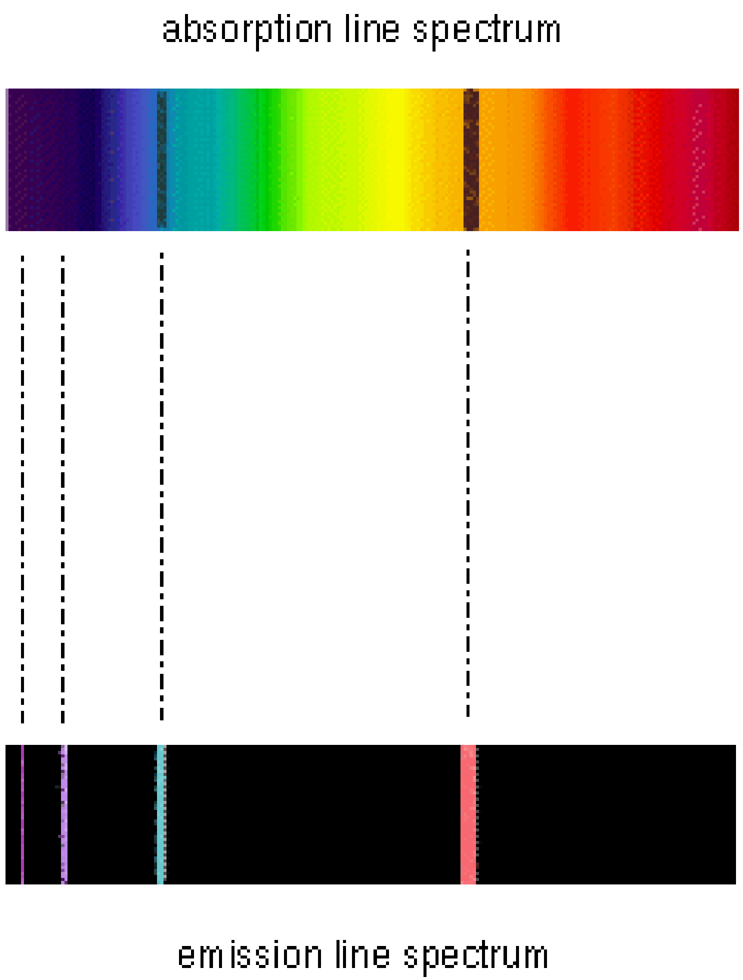
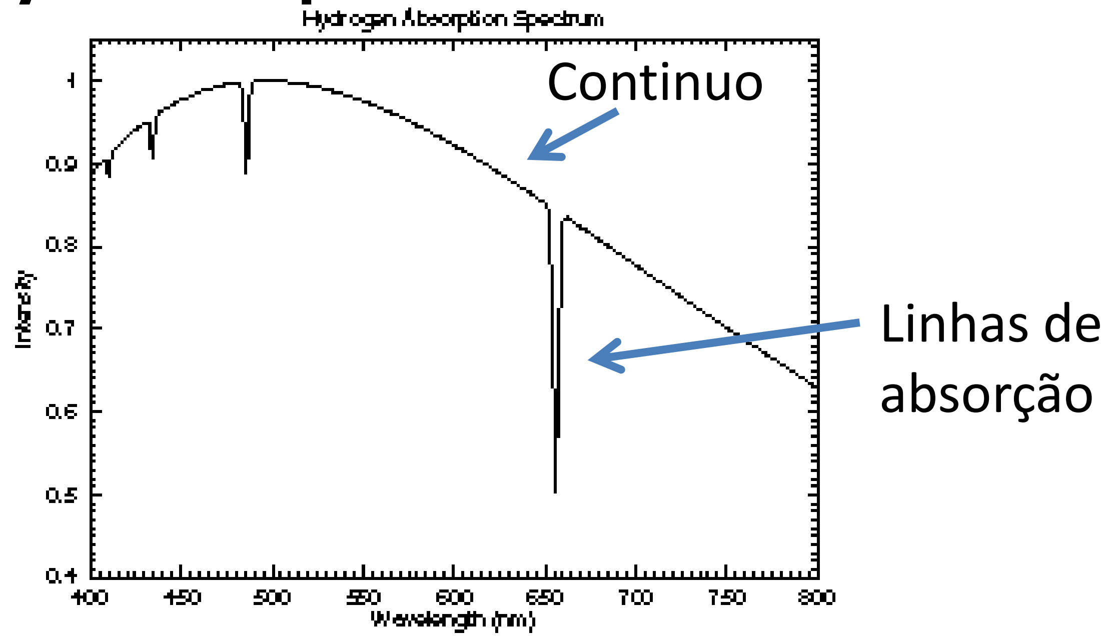
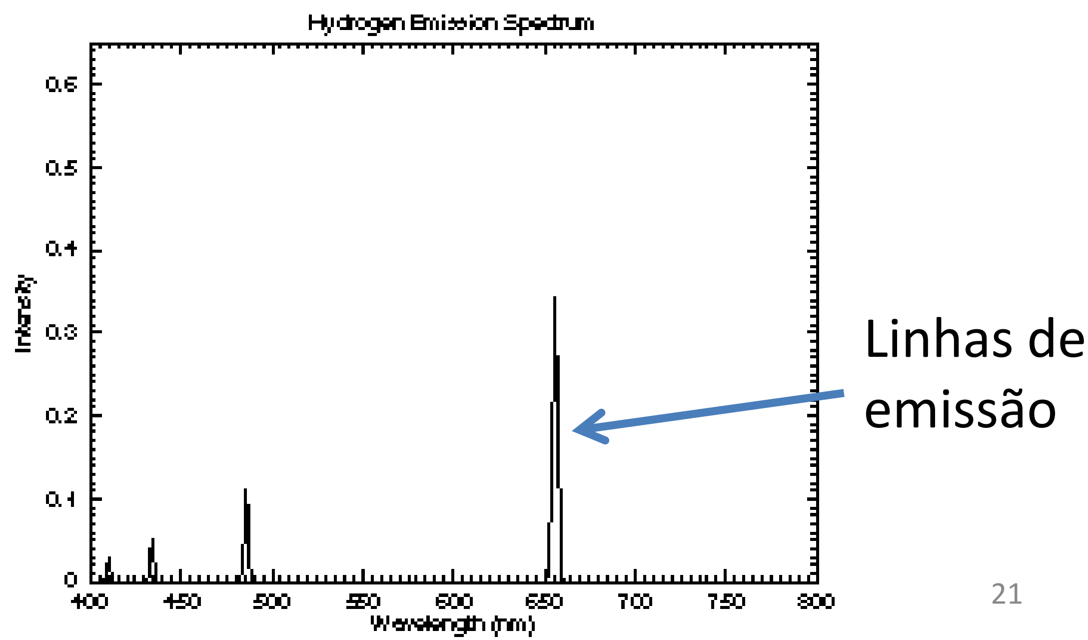


Figure 1. COS/G130M spectra of four white dwarfs known to have circumstellar discs, scaled to a peak flux of unity, offset by 1.4 units, and sorted from top to bottom by increasing metal abundances. For warm white dwarfs with pure hydrogen atmospheres, the broad Lyα line is the only spectral feature in this wavelength range. These four stars accrete from the circumstellar debris, and their spectra are riddled with absorption lines of C, O, Al, Si, P, S, Cr, Fe, and Ni. In addition, Mg and Ca can be detected in their optical spectra

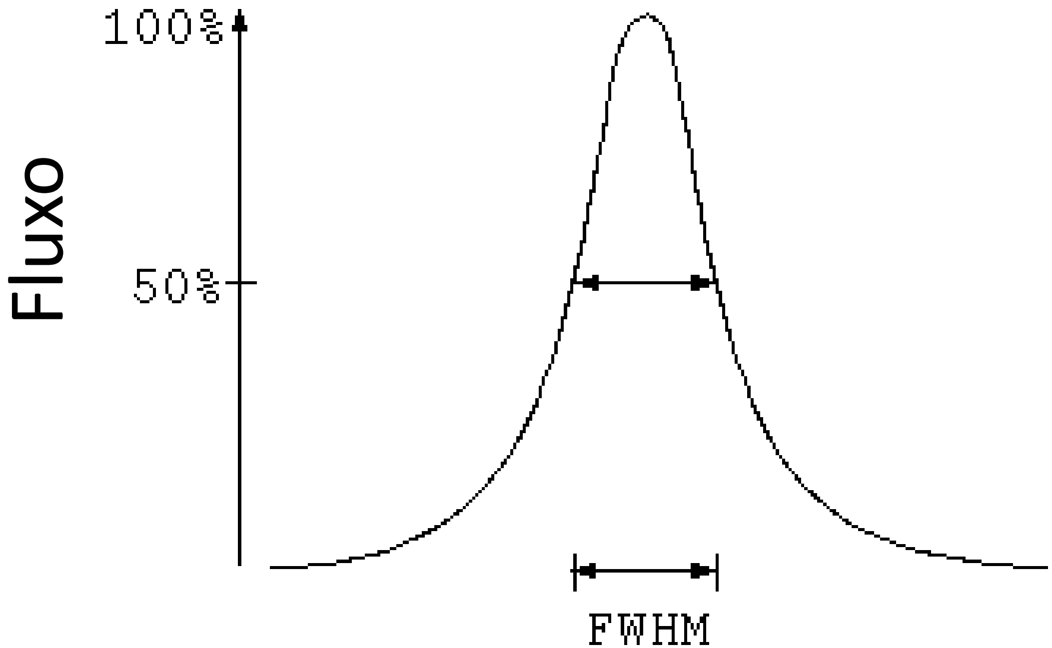
Terminology for spectral lines







FWHM
Largura a meia altura

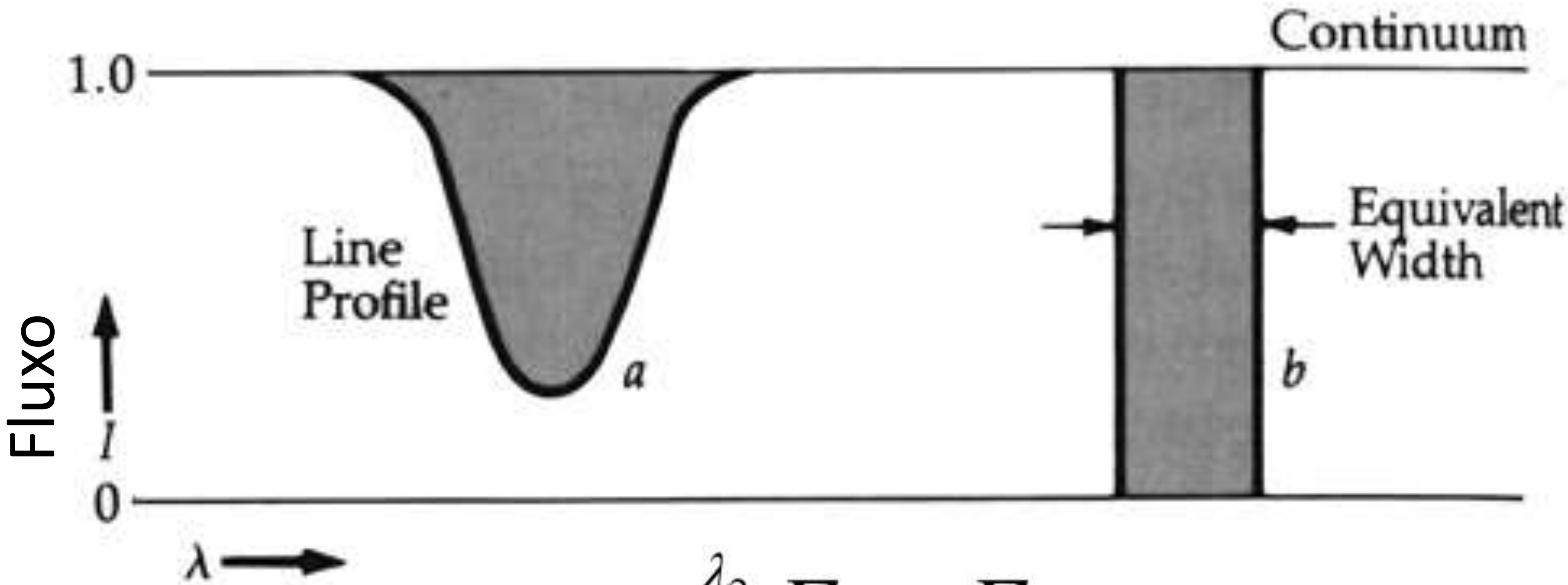


λ, ν ou $\mathbf{v}$

FWHM em

$\Delta\lambda$, $\Delta\nu$, $\Delta \mathbf{v}$

Largura equivalente (EW)



$$W = \int_{\lambda_1}^{\lambda_2} \frac{F_c - F_\lambda}{F_c} d\lambda$$

Slide adatado da Prof. Claudia (INPE)

As **linhas espectrais** carregam muitas informações dos processos e das condições físicas existentes na fonte (Processos Radiativos). Alguns exemplos:

Característica da linha	Informação
Posição	Elemento, transição
Intensidade ou largura equivalente	Abundância
	Temperatura, pressão, gravidade
Posição e perfil	Campo de velocidade macroscópico
Posição	Velocidade radial, planetas
Polarização	Campo magnético
Perfil, FWHM	Rotação
Fluxo relativo	Atividade estelar

Exemplos de linhas espectrais

Table 8.1 Examples of discrete transitions

Transition	Energy [eV]	Spectral Region	Example
Hyperfine structure	10^{-5}	Radiofrequencies	21 cm hydrogen line
Spin–orbit coupling	10^{-5}	Radiofrequencies	1667 MHz transitions of OH molecule
Molecular rotation	10^{-2}–10^{-4}	Millimetre and infrared	1–0 transition of CO molecule at 2.6 mm
Molecular rotation–vibration	1–10^{-1}	Infrared	H_2 lines near 2 μm
Atomic fine structure	1–10^{-3}	Infrared	Ne II line at 12.8 μm
Electronic transitions of atoms, molecules and ions	10^{-2}–10	Ultraviolet, visible, infrared	Lyman, Balmer series, etc., of H, resonance lines of C I, He I, and K, L shell electron lines (Fe XV, O VI)
Nuclear transitions	$> 10^4$	X and γ rays	^{12}C line at 15.11 keV
Annihilations	$\gtrsim 10^4$	γ rays	Positronium line at 511 keV

© Lena 3rd Ed or Table 5.1 2nd Ed.

Resolução espectral

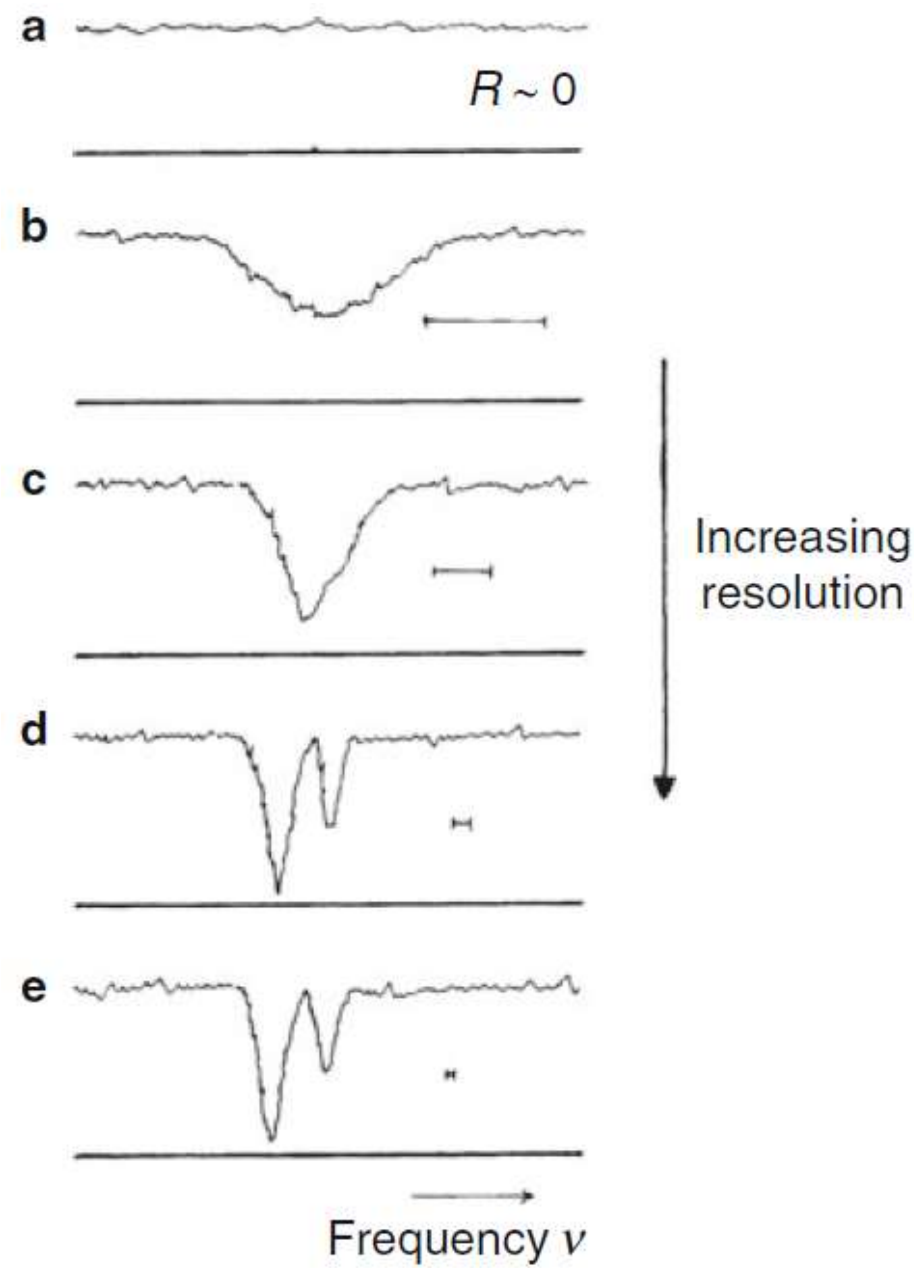


Fig. 8.4 Observation of a spectral line at increasing resolution. (**a**) $R \sim 0$. (**b**) The line appears. (**c**) The line appears double, but unresolved (*blended*). (**d**) The two lines are resolved. (**e**) The true width of the lines is attained, and line purity can be no further improved by increasing R. The *horizontal line* shows the instrumental spectral width $\Delta\nu = \nu_0/R$ used in each observation

Componentes básicos do Espectrógrafo

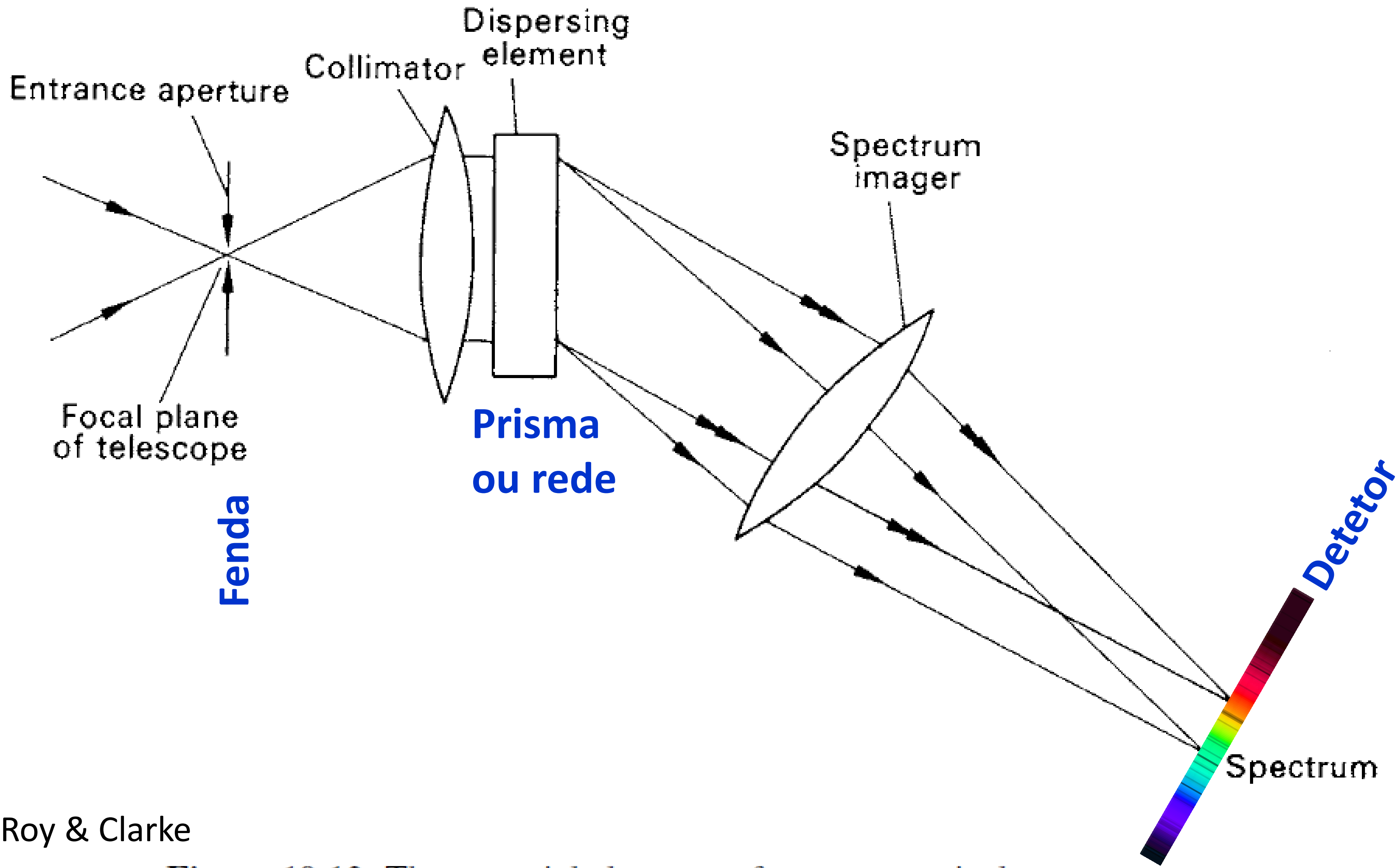
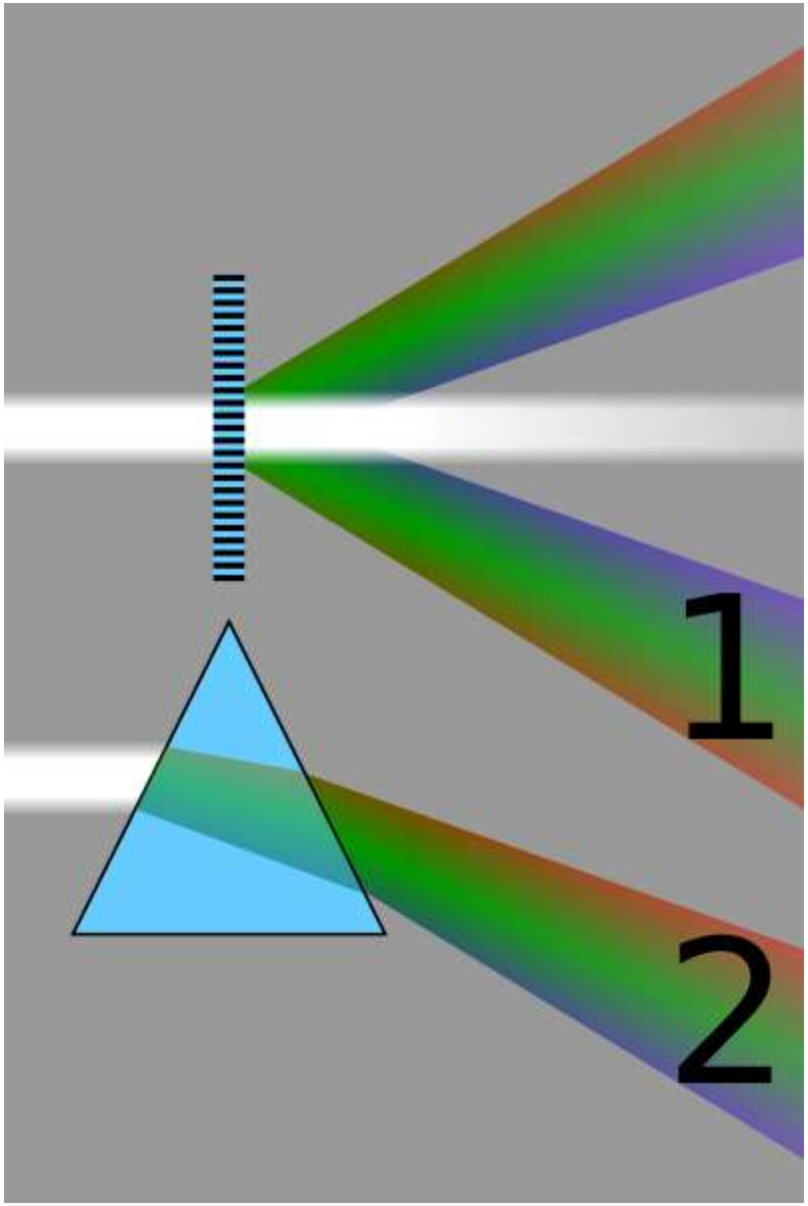


Figure 19.12. The essential elements of an astronomical spectrometer.

Dispersing element

- Diffraction Grating: diffraction+interference

- Prism: differential refraction



Prism as a dispersing element

θ_{exit} ?

$$n_{air} \sin \theta_{air} = n_{glass} \sin \theta_{glass}$$

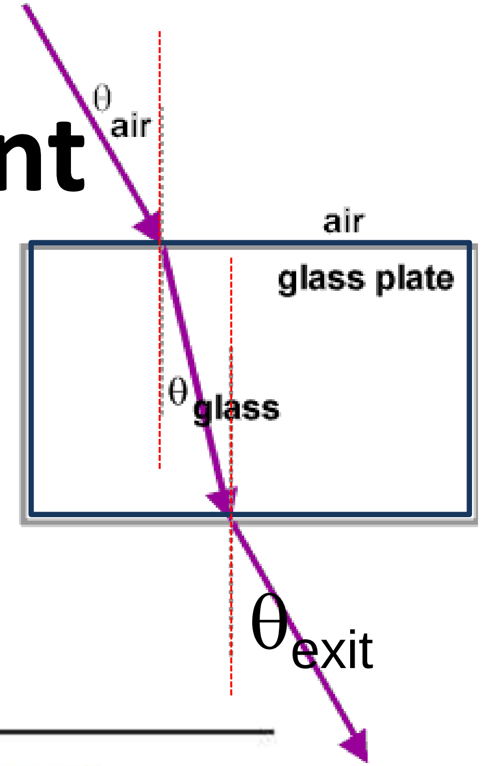
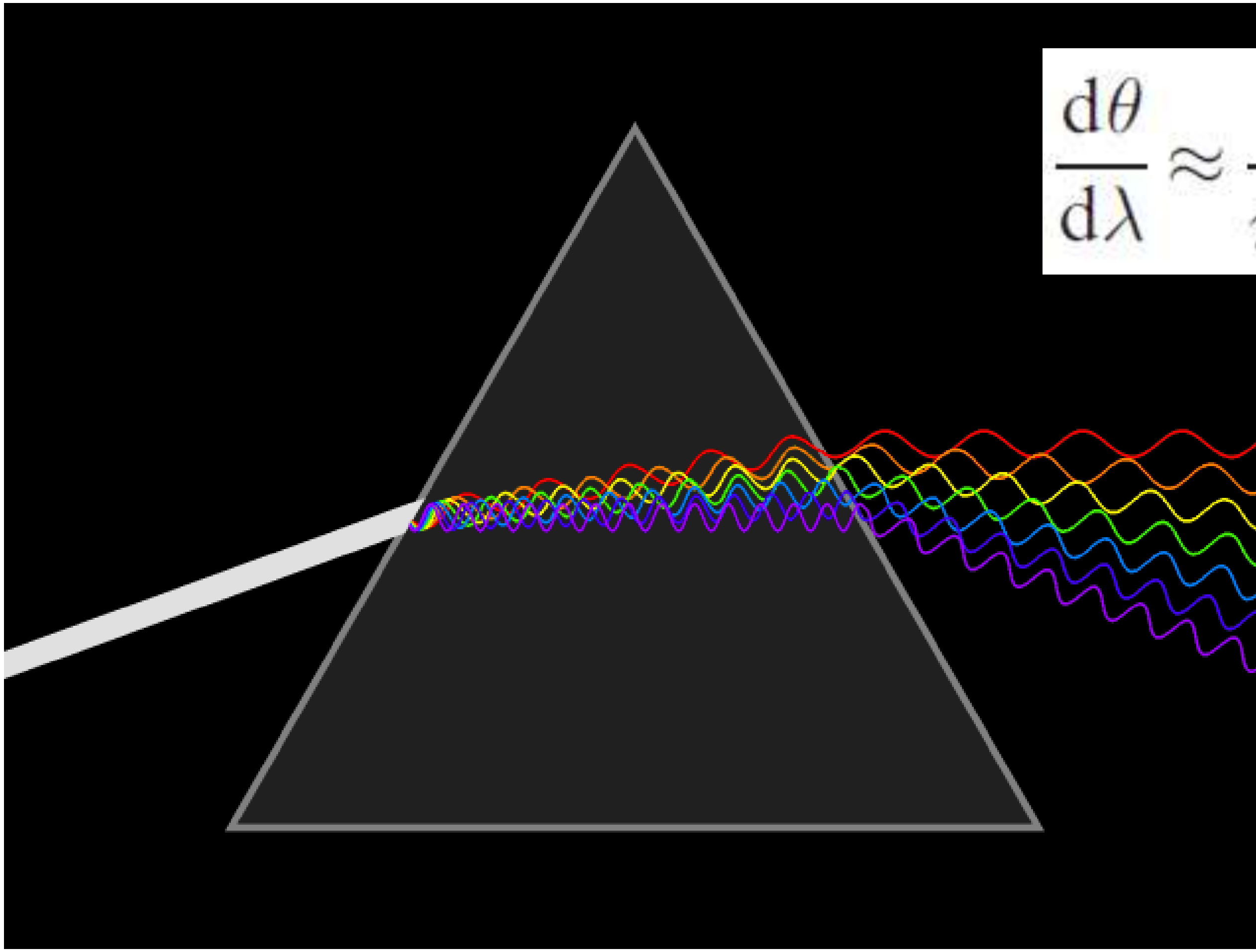


Table 1.1.5.

	Refractive index at the specified wavelengths (nm)				
Glass type	361	486	589	656	768
Crown	1.539	1.523	1.517	1.514	1.511
High dispersion crown	1.546	1.527	1.520	1.517	1.514
Light flint	1.614	1.585	1.575	1.571	1.567
Dense flint	1.705	1.664	1.650	1.644	1.638

n(air) = 1.0003

Elemento dispersor : prisma



$$\frac{d\theta}{d\lambda} \approx \frac{-180AB}{\pi(\lambda - C)^2} \quad {}^\circ\,\mathrm{m}^{-1}$$

dispersion of a prism increases rapidly towards shorter λ

Spectrograph based on prism

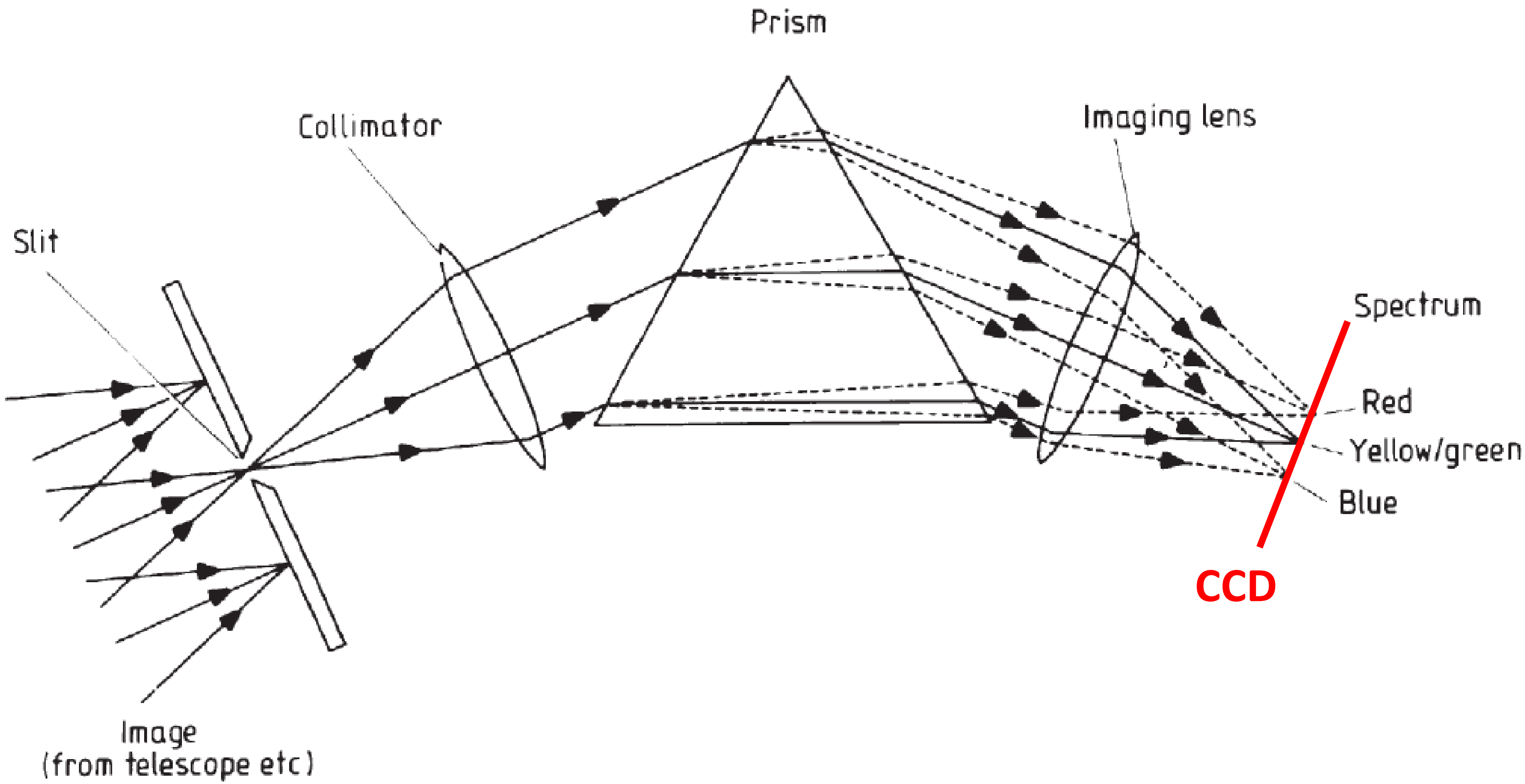


Figure 4.1.12. Basic optical arrangement of a prism spectroscope.

Objective prism spectrograph

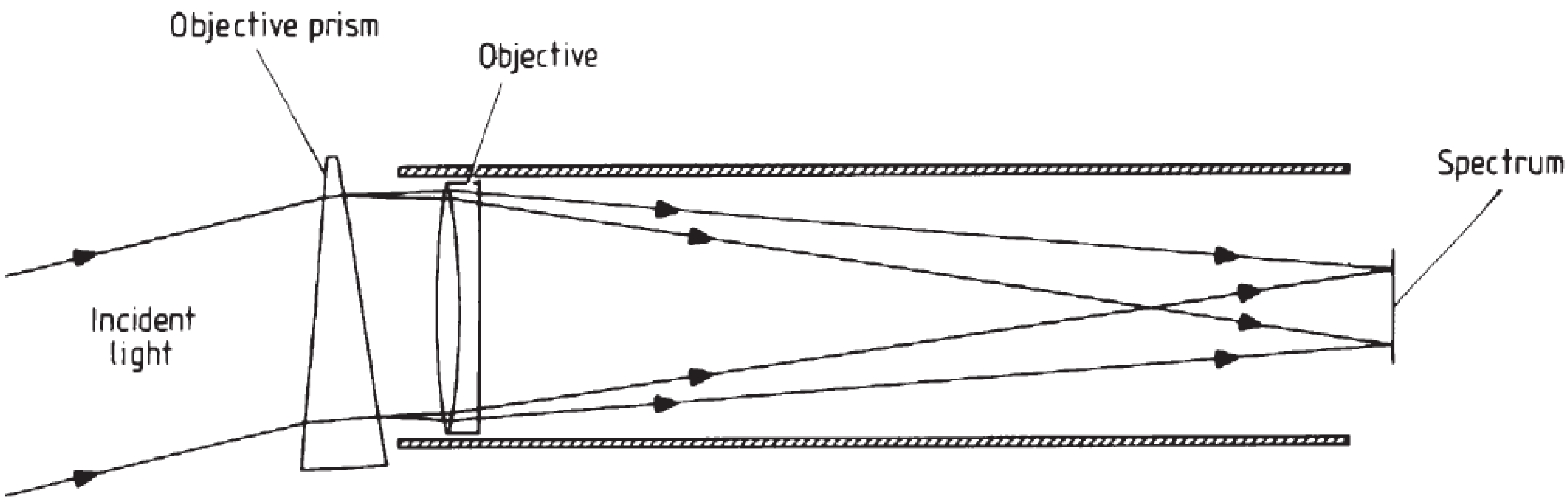


Figure 4.2.6. An objective prism spectroscope.

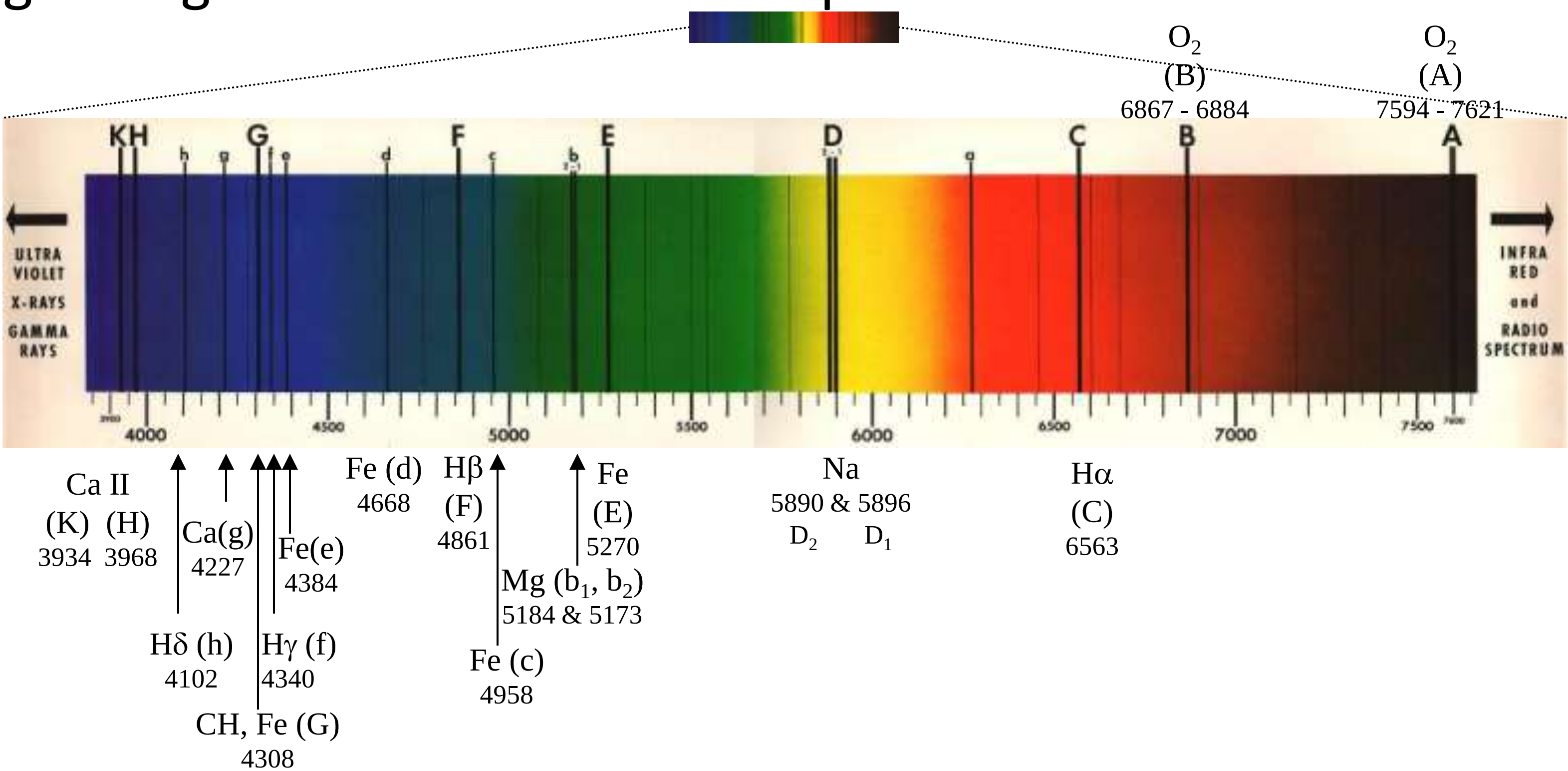
Aplicações clássicas de espectrógrafos (maiormente baseados em prisma)

The beginning of stellar spectroscopy

1802: William Wollaston first observed dark lines in the solar spectrum which he incorrectly interpreted as gaps separating the colors

1817: Joseph Fraunhofer (1817) observed a continuous color change without color discontinuities at the dark lines. He found 574 lines.

1836: Sir David Brewster found that certain lines had strengths that varied with the Sun's elevation. He correctly ascribed these as originating in the terrestrial atmosphere.



Classificação de estrelas: 3, 4, 5 classes

Secchi's Classes of Stellar Spectra (1860-1870)

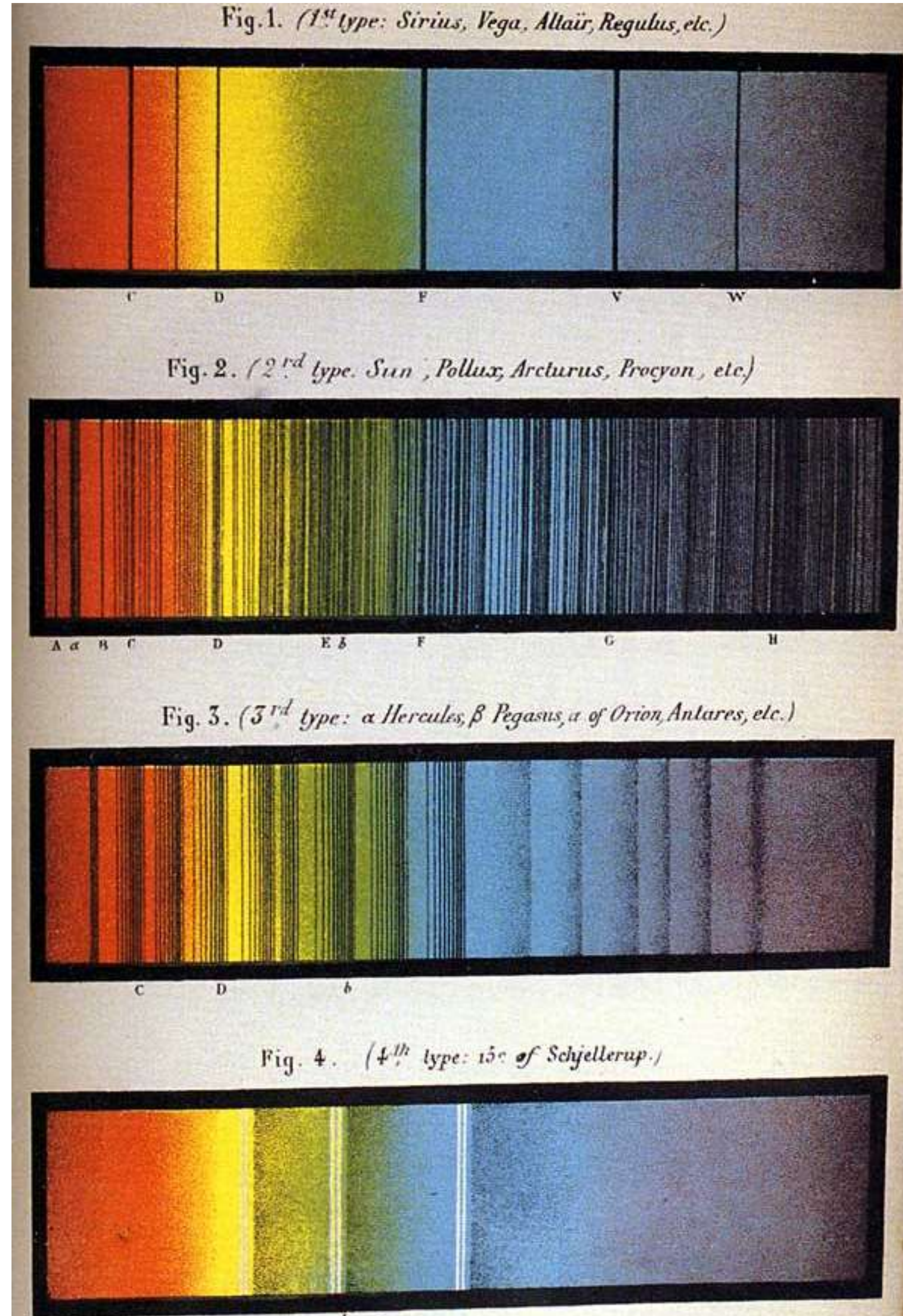
Secchi's four classes of stellar spectra, from a colored lithograph in a book published around 1870. The principal spectral lines are identified underneath by letters that Fraunhofer assigned.

Tipo I: **branco-azul; linhas fortes de H**. Atual classe A & F "cedo"

Tipo II: amarelas, de *tipo solar*. Numerous metallic lines (Na, Ca, Fe), with weaker H. Atual classe G, K, F tardio

Tipo III: **laranja-vermelho**; metallic lines and bands. atual classe M

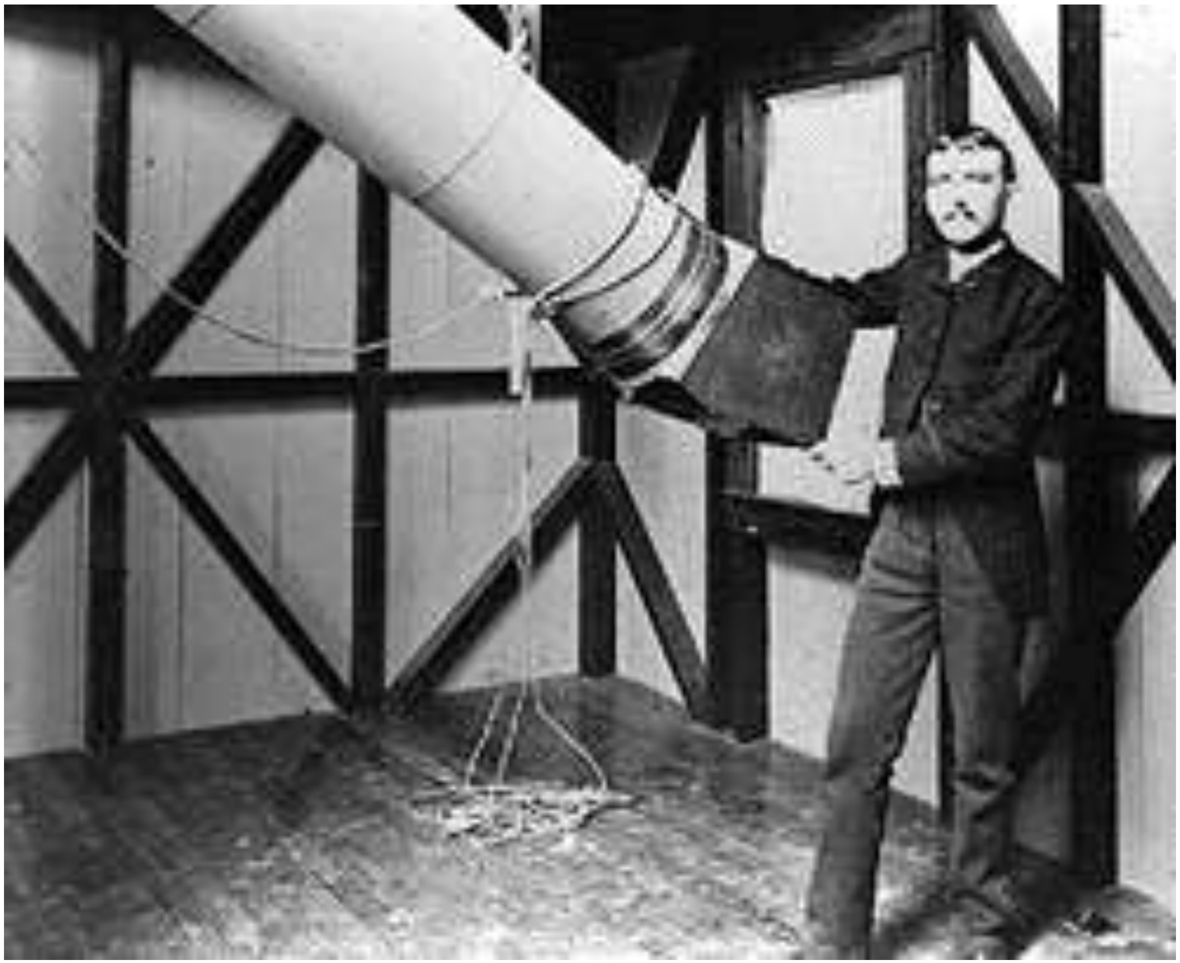
Tipo IV: estrelas com linhas de emissão



Henry Draper (Mar 7, 1837 – Nov 20, 1882)

pioneer of astrophotography

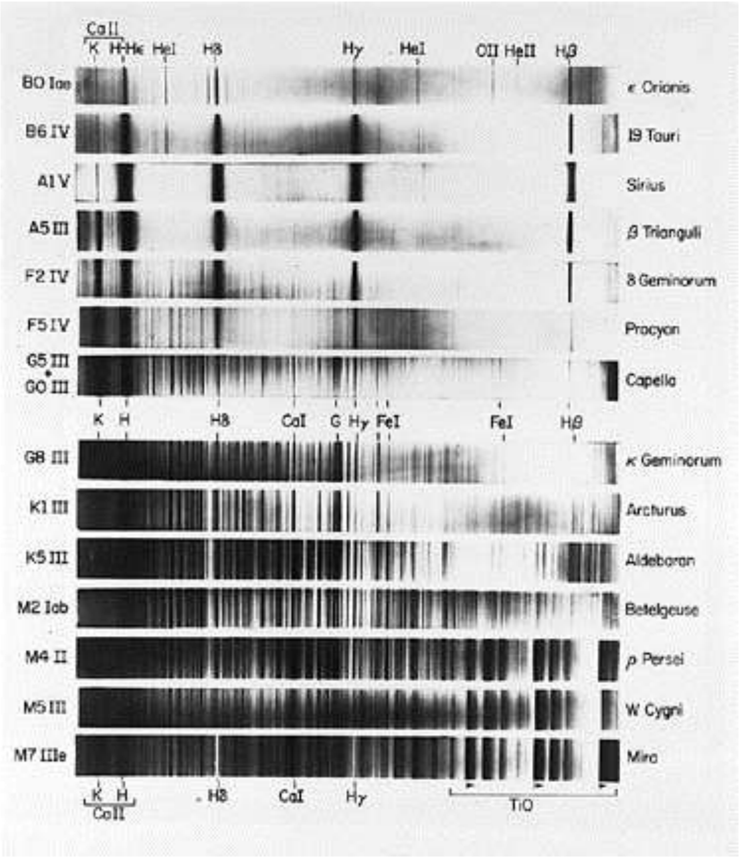
Mãe: Antonia Coetana de Paiva Pereira Gardner (filha do médico do Emperador do Brasil)



O sistema de classificação de Harvard

- 1890-1900s: classificação de Harvard (E.Pickering + Williamina Fleming + Antonia Maury + Annie J. Cannon):

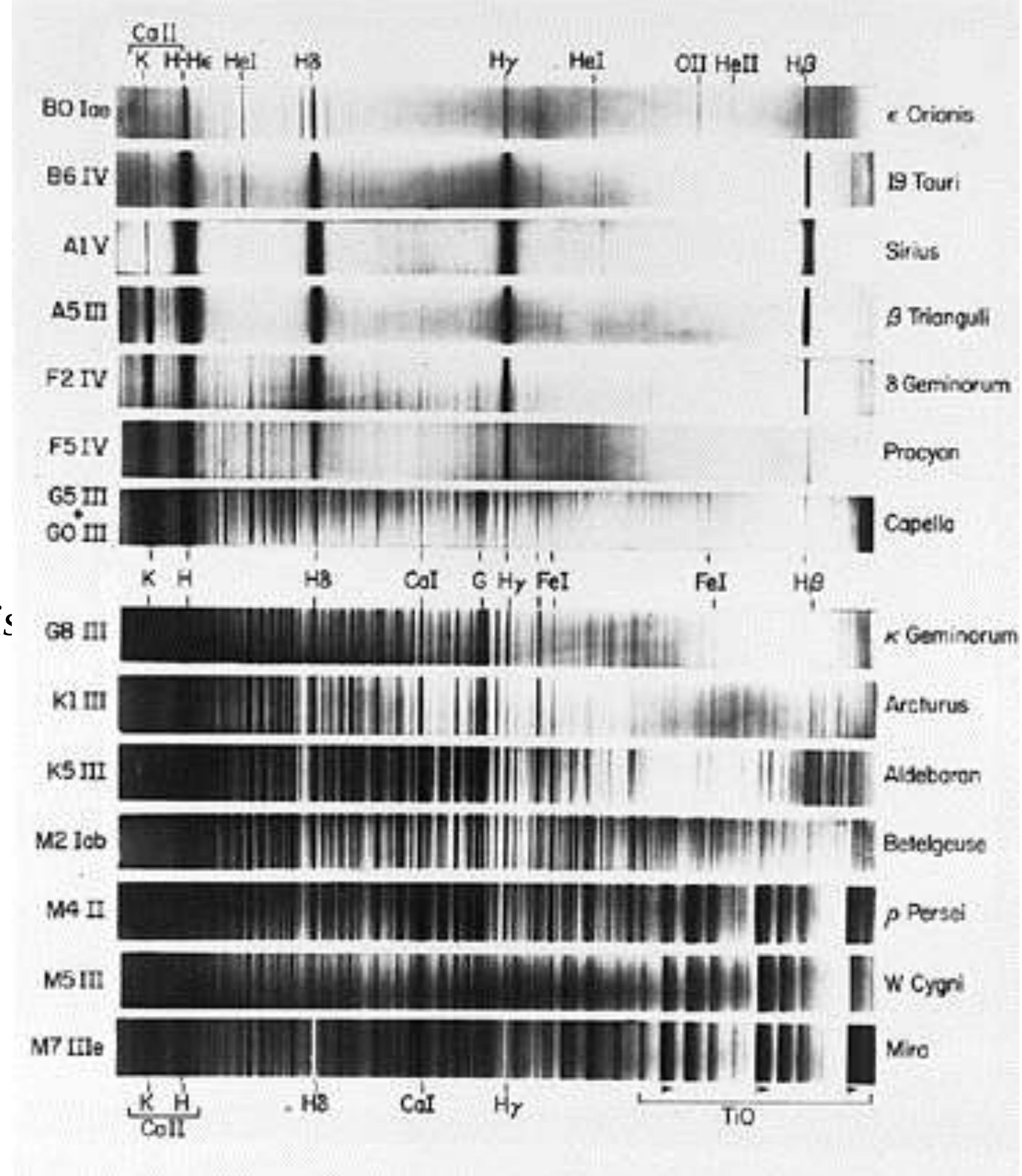
O, B, A, F, G, K, M



Classificação estelar:
O, B, A, F, G, K, M

Baseado em espectros das estações Harvard Norte (U.S.A.) & Sul (Arequipa, Peru)

Annie J. Cannon classificou mais de 250 000 espectros!



The Henry Draper (HD) catalogue

Harvard plate taken with **objective prism spectrograph** in Arequipa. Field of η Carinae. E. Dorrit Hoffleit, 2002, Phys. Perspect., 4, 370

The HD catalogue, which ultimately listed over 400 000 stars, is still very useful, and the main ID of most stars with V < 9 is its HD number

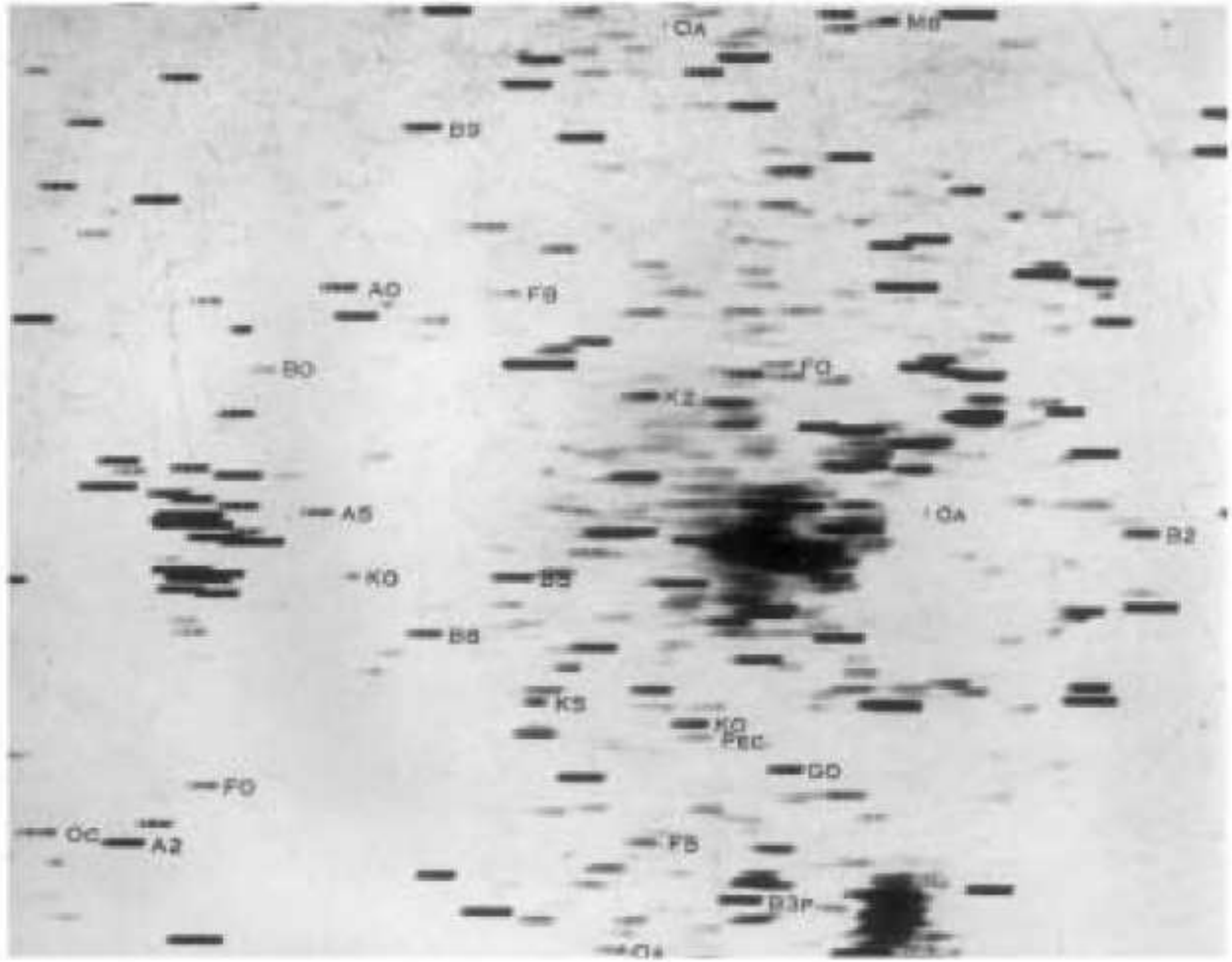
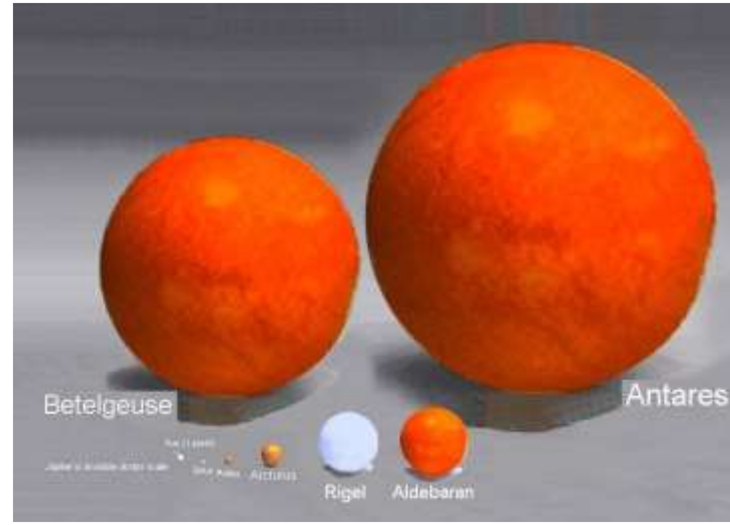


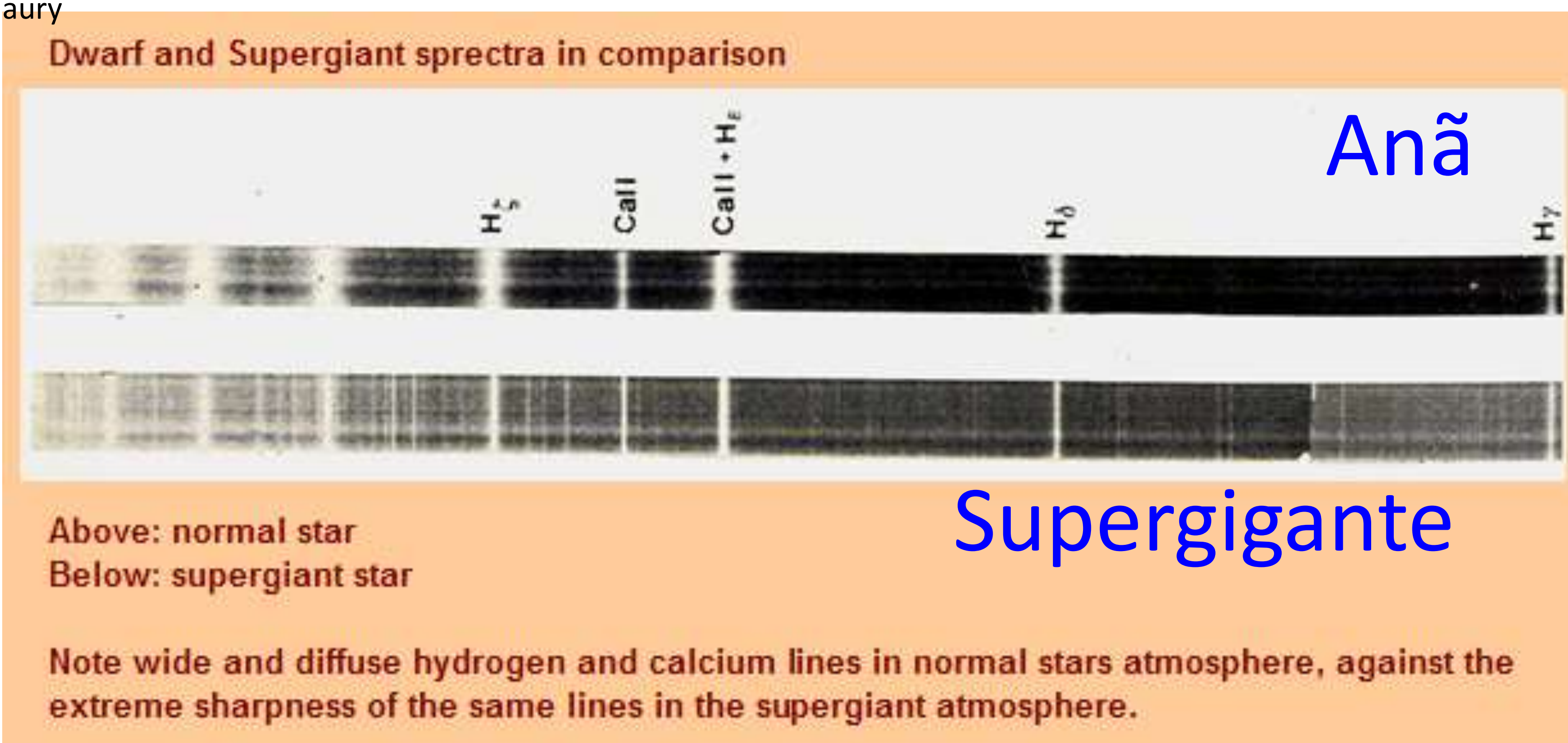
Fig. 4. A typical Harvard objective prism plate, taken at Harvard's southern station in Arequipa, Peru, on May 13, 1893, with the 8-inch Bache telescope covering 8 × 10 degrees in the sky. Field of η Carinae, exposure time 140 minutes. *Source*: *Annals of Harvard College Observatory* **99** (1924), frontispiece.

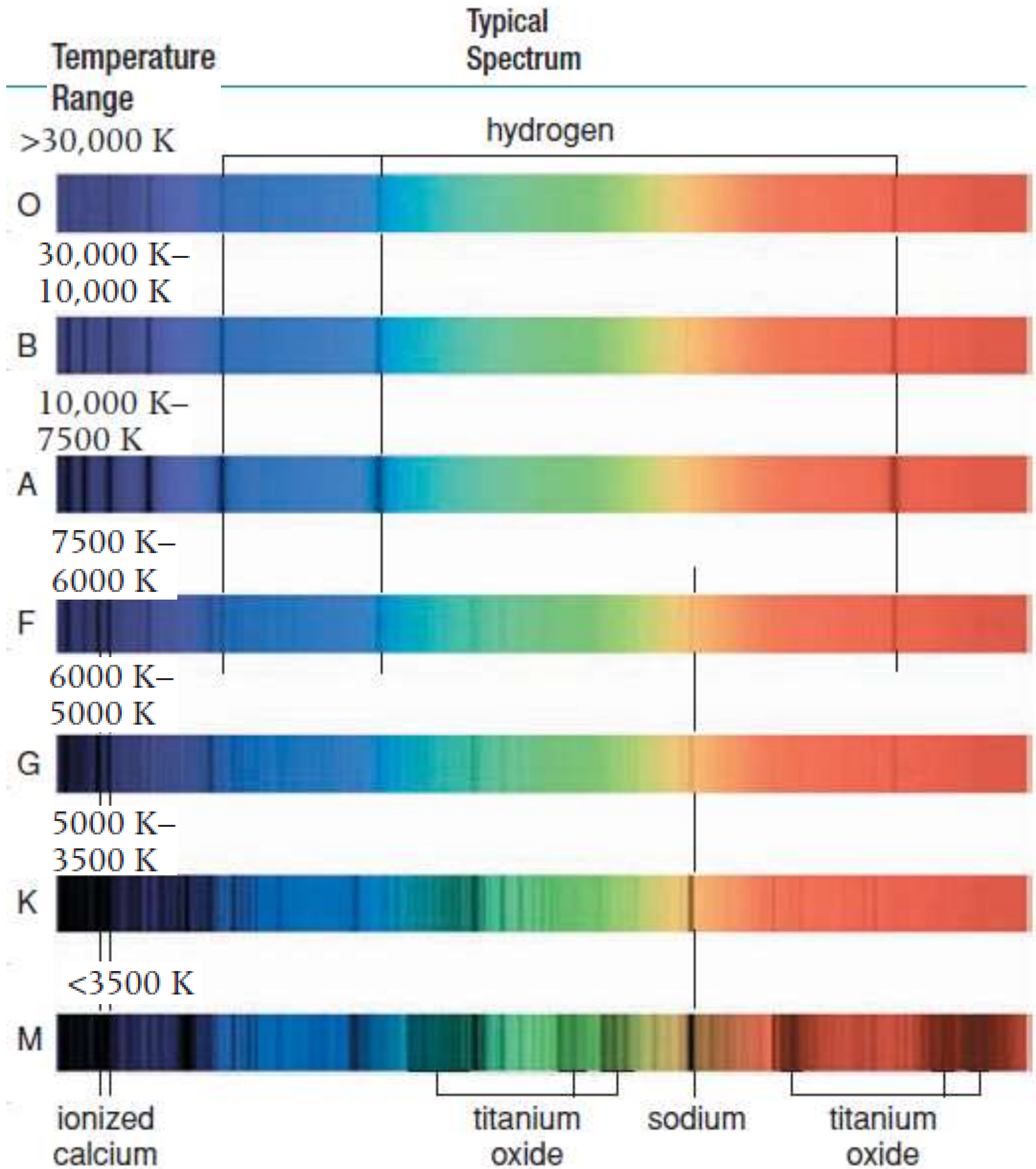
Classe de luminosidade

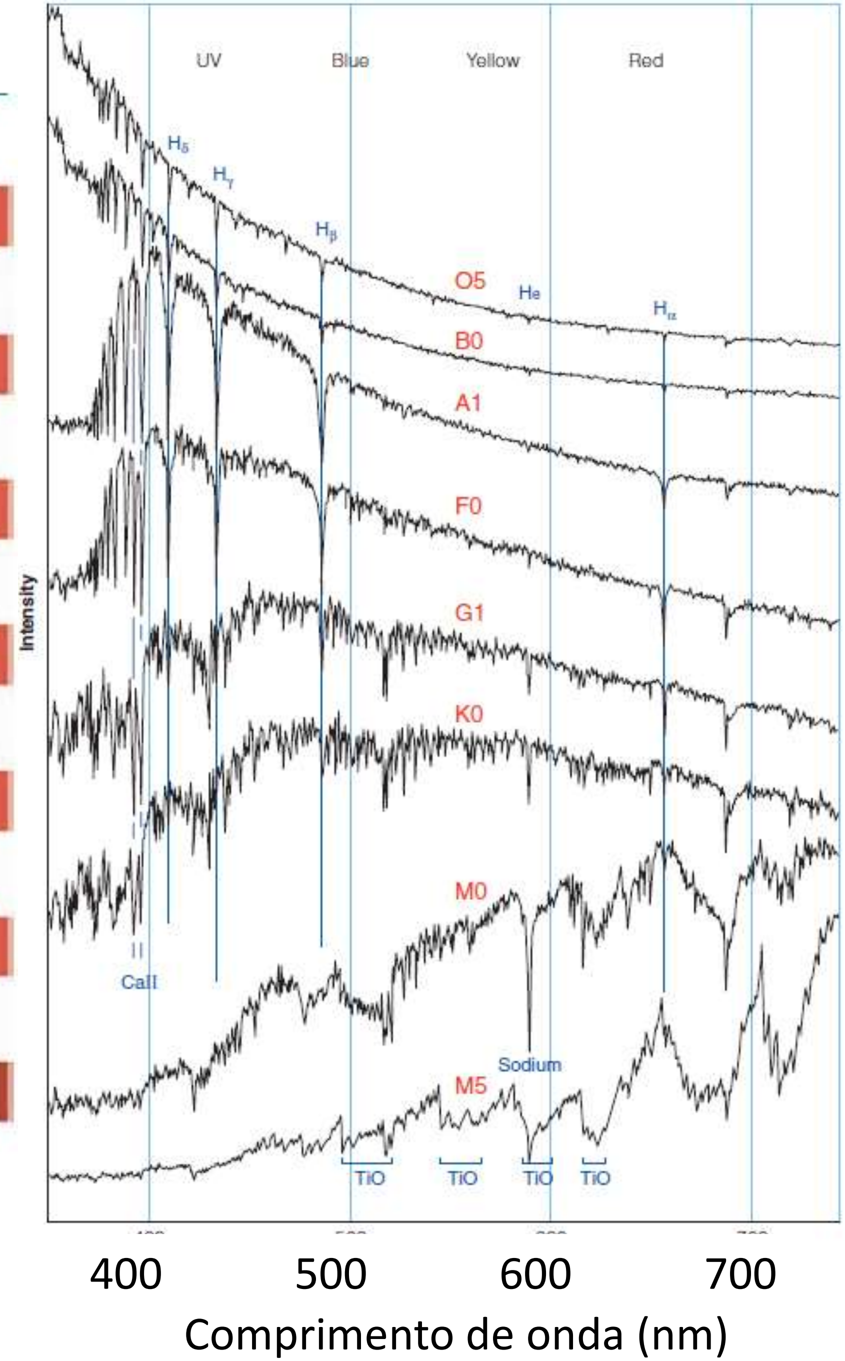
Antonia Caetana de Paiva Pereira Maury

Antonia Maury : foi contratada em 1888 por E. Pickering (Harvard) para classificar espectros. Ela propôs um novo sistema de classificação levando em conta tb a forma das linhas, mas foi ignorado por Pickering.






Temperature Range
Typical Spectrum
hydrogen
>30,000 K
O
30,000 K–
10,000 K
B
10,000 K–
7500 K
A
7500 K–
6000 K
F
6000 K–
5000 K
G
5000 K–
3500 K
K
<3500 K
M
ionized calcium
titanium oxide
sodium
titanium oxide


UV
Blue
Yellow
Red
H_δ
H_γ
H_β
O5
He
H_α
B0
A1
F0
Intensity
G1
K0
M0
CaII
Sodium
M5
TiO
TiO
TiO
TiO
400
500
600
700
Comprimento de onda (nm)