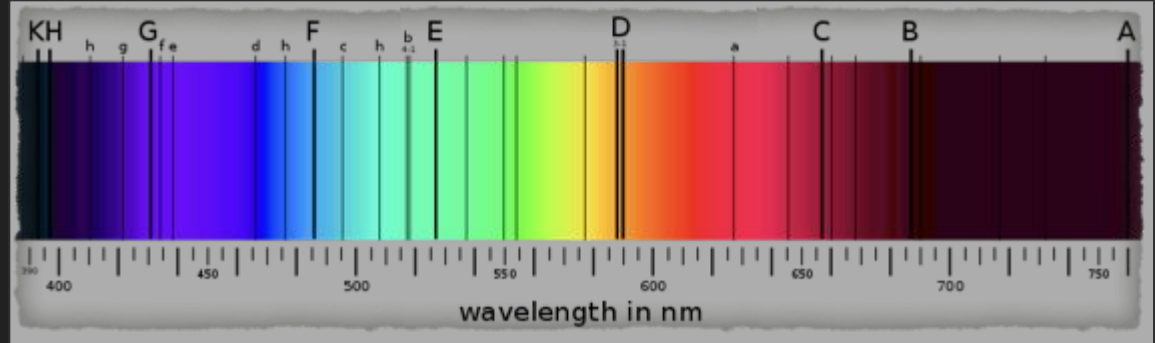# AGA0414 Spectroscopy

Prof. Alessandro Ederoclite

Fraunhofer: the Sun has "dark lines"

1787 - 1826

Kirkhoff Laws (Gustav Kirchhoff , 1824 - 1887)

1. A solid, liquid, or dense gas excited to emit light will radiate at all wavelengths and thus produce a continuous spectrum.
2. A low-density gas excited to emit light will do so at specific wavelengths and this produces an emission spectrum.
3. If light composing a continuous spectrum passes through a cool, low-density gas, the result will be an absorption spectrum.
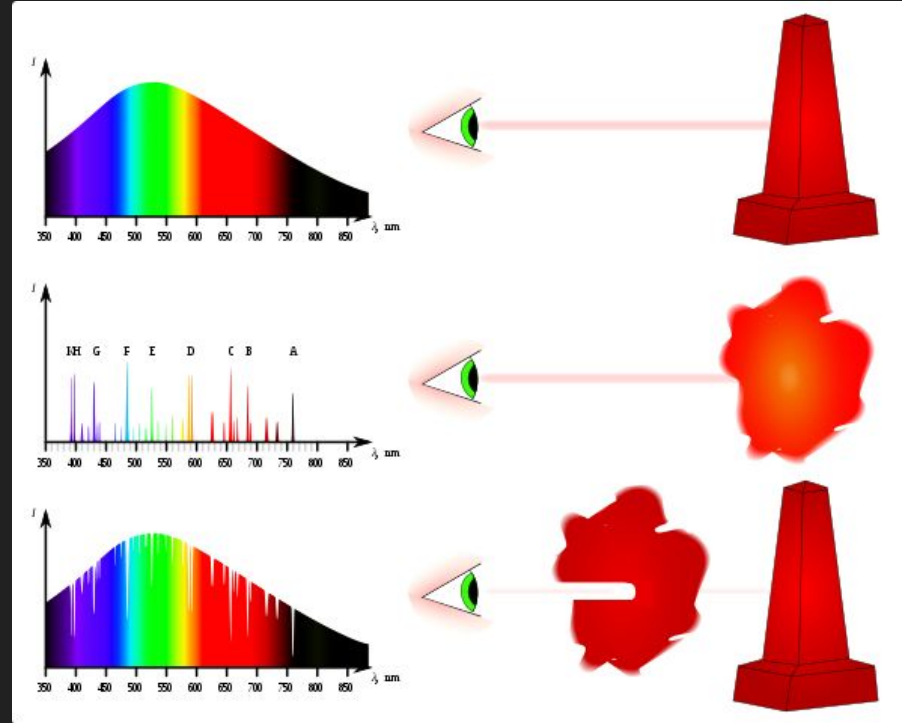
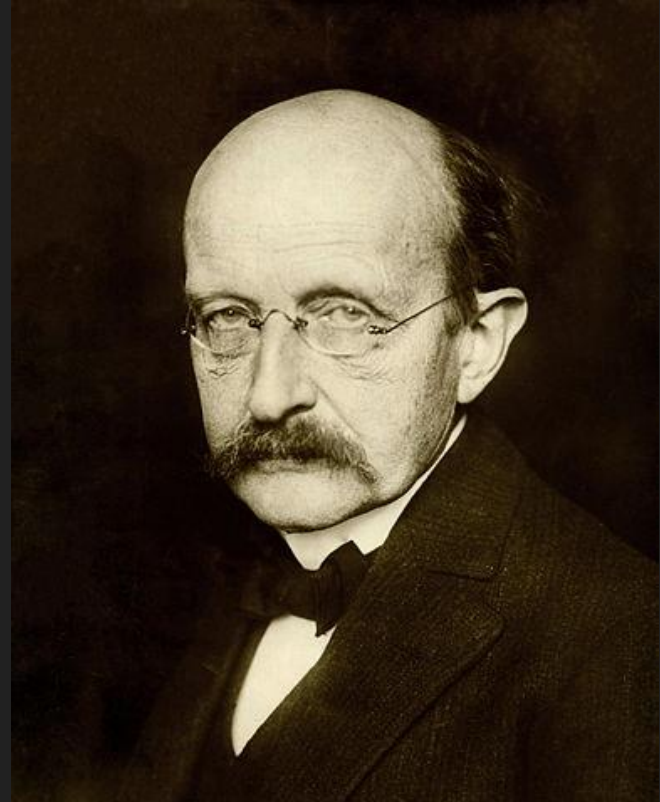Continua

Max Karl Ernst Ludwig Plank

1858 - 1947

14 Dec 1900: Plank Postulate
"electromagnetic energy can only be
emitted in quantised form" (i.e. E=hv)

Nobel Prize in Physics: 1918

https://en.wikipedia.org/wiki/Max_Planck

The Black Body

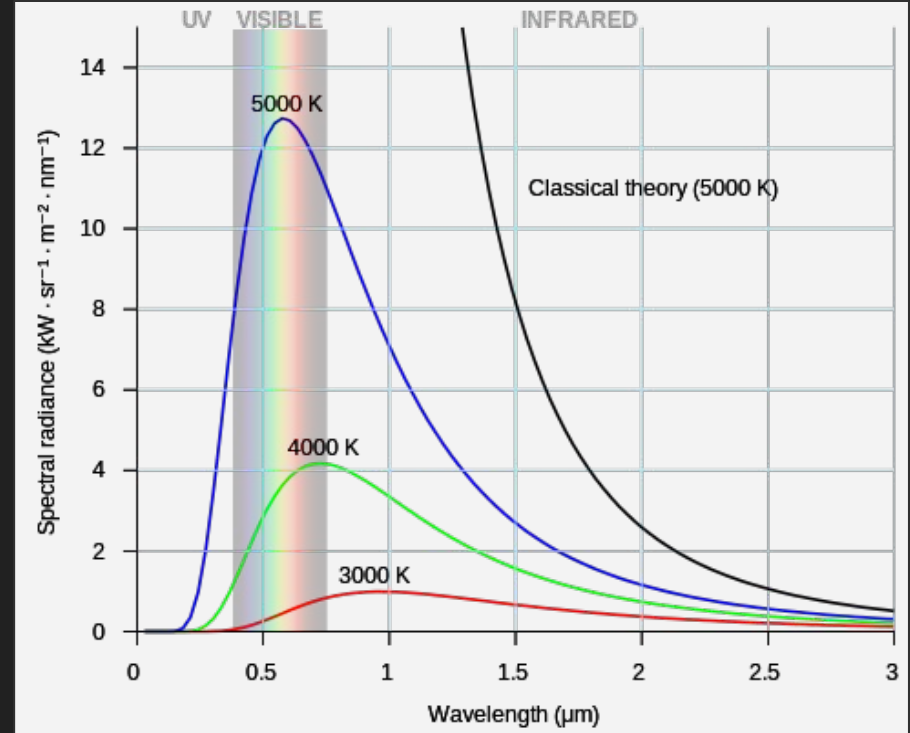$$B_\nu(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1},$$

Wien's Displacement Law

$$\lambda_{\max} = \frac{b}{T},$$

Stefan-Boltzmann Law

$$L = \sigma T^4$$

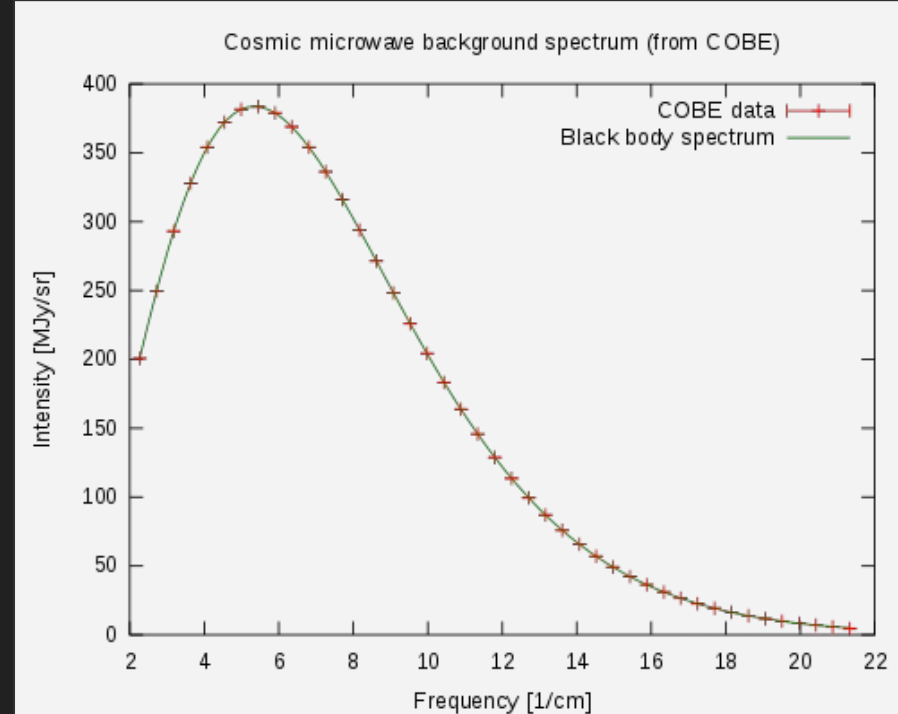https://en.wikipedia.org/wiki/Black-body_radiation

The Best Black Body Known So Far

The cosmic microwave background.

Discovered by Penzias & Wilson.

COBE measured that it is a perfect black body.

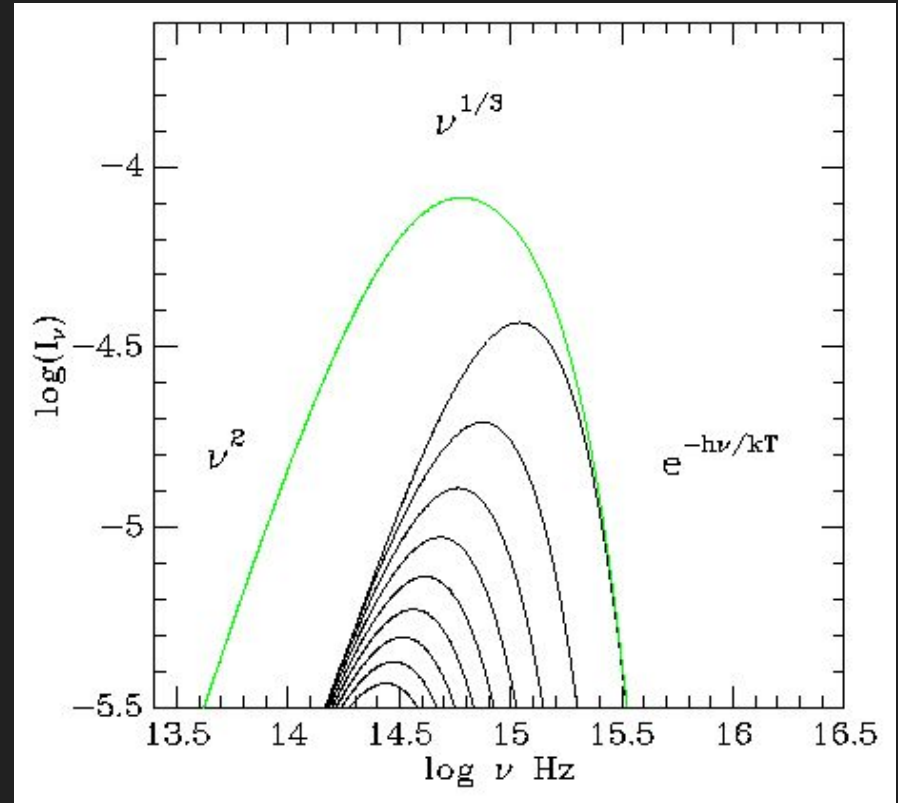https://en.wikipedia.org/wiki/Cosmic_Background_Explorer

Cosmic microwave background spectrum (from COBE)

Accretion discs

Shakura & Sunyaev (1972)

$f \sim \lambda^n$

Accretion at all scales (Scaringi 2012)

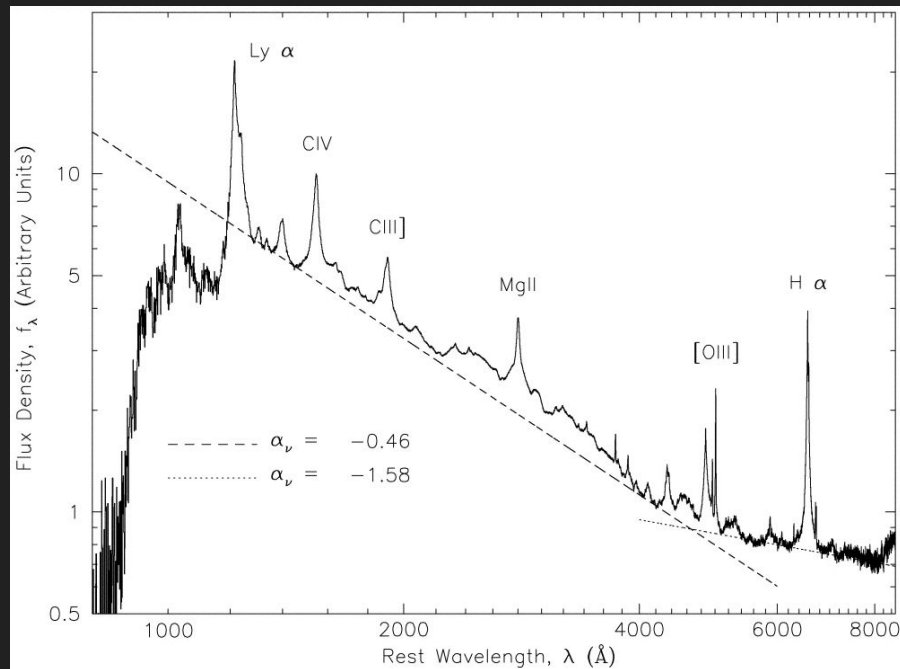http://www.astro.utu.fi/~cflynn/astroII/l6.html

Quasars

Active Galactic Nuclei

Accretion on a supermassive black hole.

Vanden Berk et al. (2001) ->

Lines

The Hydrogen Atom

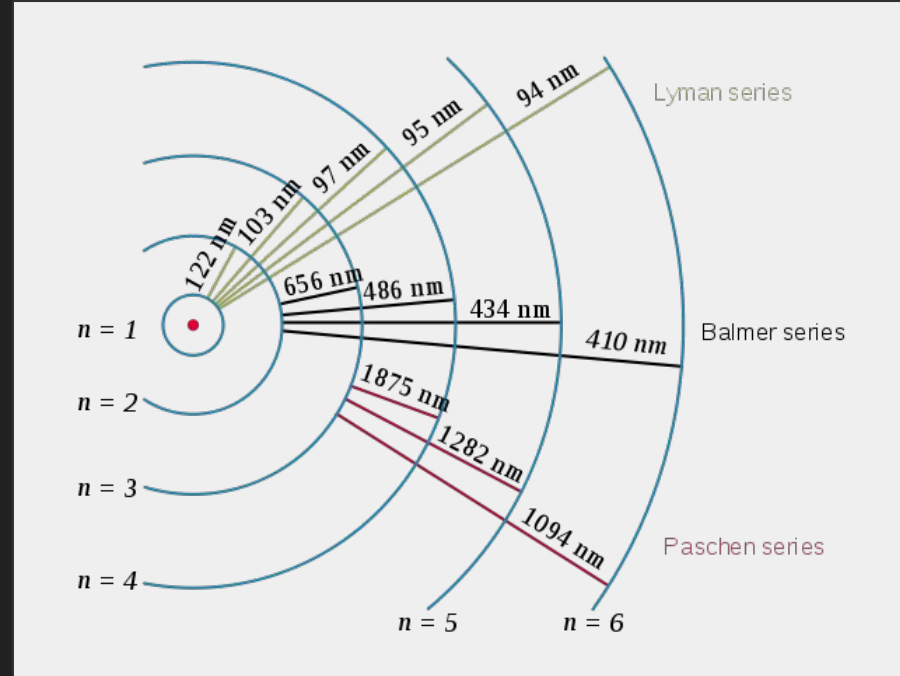Bohr

One proton and one electron.

The electron can orbit only in given energy states ("orbitals")

$$\frac{1}{\lambda} = Z^2 R_\infty \left(\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2} \right)$$

Rydberg formula Rinf ~ 10^7 m^{-1}

Rydberg

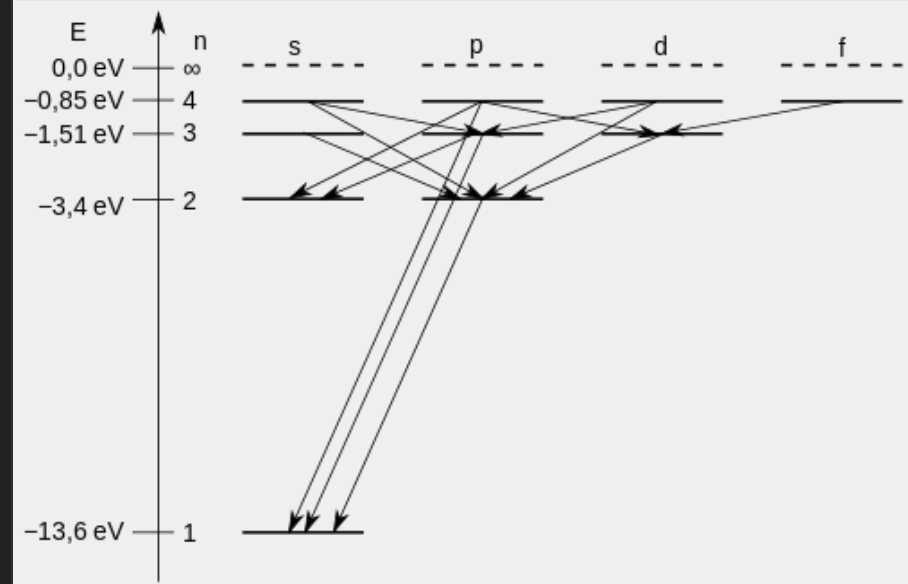$$R_\infty = \frac{m_\text{e}e^4}{8\varepsilon_0^2 h^3 c} = 10\ 973\ 731.568\ 508\ (65)\ \text{m}^{-1}$$

$$1\ \text{Ry} \equiv hcR_\infty = \frac{m_\text{e}e^4}{8\varepsilon_0^2 h^2} = 13.605\ 693\ 009(84)\ \text{eV} \approx 2.179 \times 10^{-18}\,\text{J}.$$

Grotrian Diagrams

Show the transitions that are possible in an atom
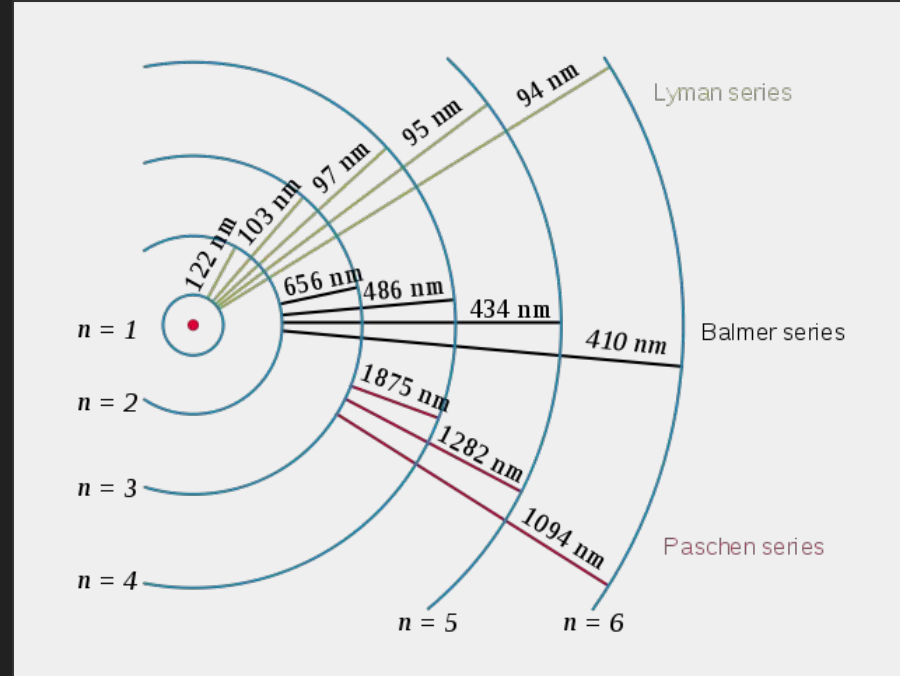
The best friend of a spectroscopist

The Balmer series

It would not be such a special one if it was not that it is the one with lines in the visible.

It is the series where the electrons are "falling" to the n=2 orbital.

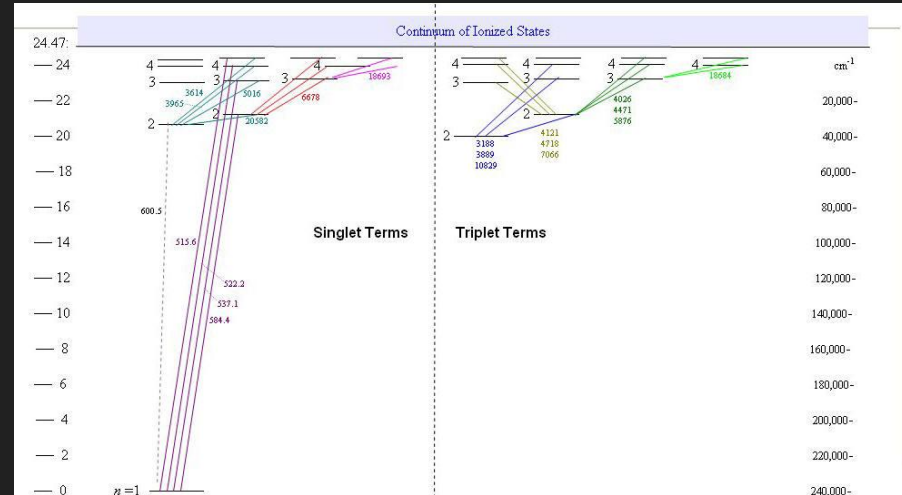It is denoted by H and a greek letter.

Any other atom (or molecule)

Are the energy level of He the same as H but double?

The "interaction factor" makes things more complicated.
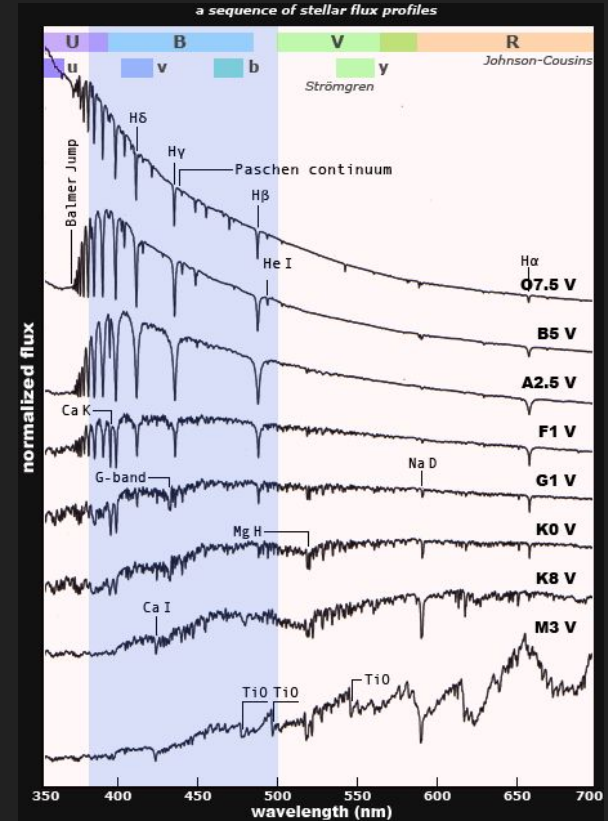
What about molecules?

Not only they have electrons to excite but a whole structure which can rotate or oscillate!

Stellar atmospheres

Radiative transfer equation

A stellar spectrum is the result of "seeing" a blackbody through the atmosphere of a star.

https://www.handprint.com/ASTRO/specclass.html

What makes lines large (Carrol & Ostlie, Section9.4)

- Natural broadening
    - Follows from Heisenberg's uncertainty principle: $\Delta E \sim h / \Delta t$
    - $\Delta \lambda = (\lambda^2 / 2\pi c) (1 / \Delta t_i + 1 / \Delta t_f)$
- Doppler broadening
    - In thermal equilibrium the atoms follow a Maxwell-Boltzmann distribution; the most probable speed is $v_{mp} = \sqrt{2kT / m}$
    - $\Delta \lambda = (2\lambda / c) \sqrt{2kT / m}$
- Pressure (and collisional) broadening
- Instrument
    - Similar to the psf for an image

The Voigt Profile and the Curve of Growth

- Lines tend to have Gaussian cores BUT Lorenzian "wings"

https://en.wikipedia.org/wiki/Spectral_line_shape

- The equivalent width vs. the electron density is called "curve of growth"

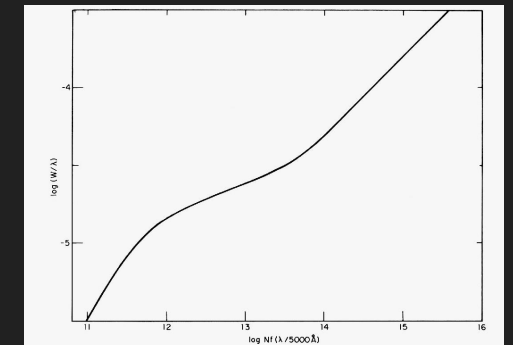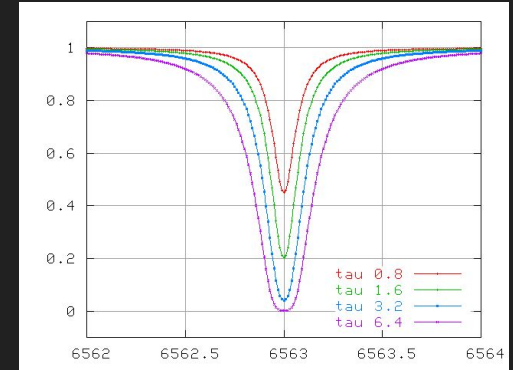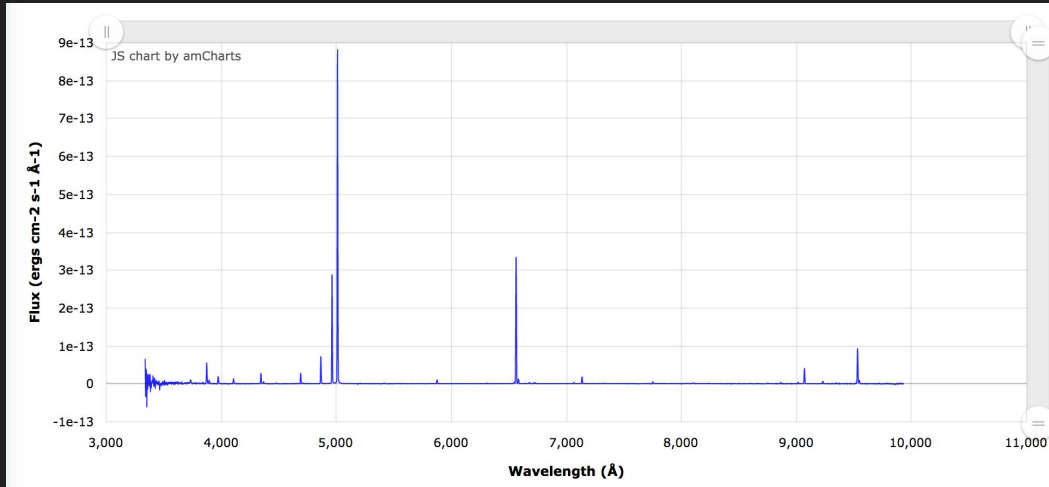http://spiff.rit.edu/classes/phys440/lectures/curve/curve.html

Figure 9.22 A general curve of growth for the Sun. (Figure from Aller, *Atoms, Stars, and Nebulae*, Revised Edition, Harvard University Press, Cambridge, MA, 1971.)
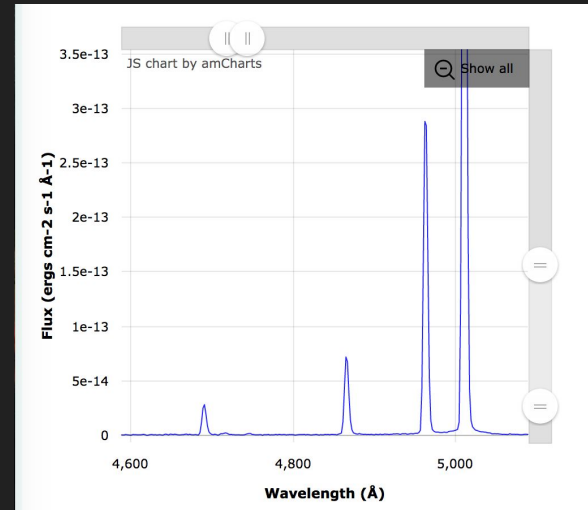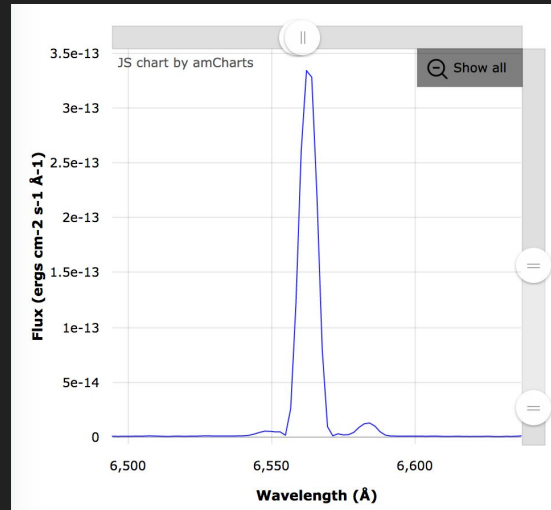
Emission lines (Planetary Nebulae)

NGC 1501

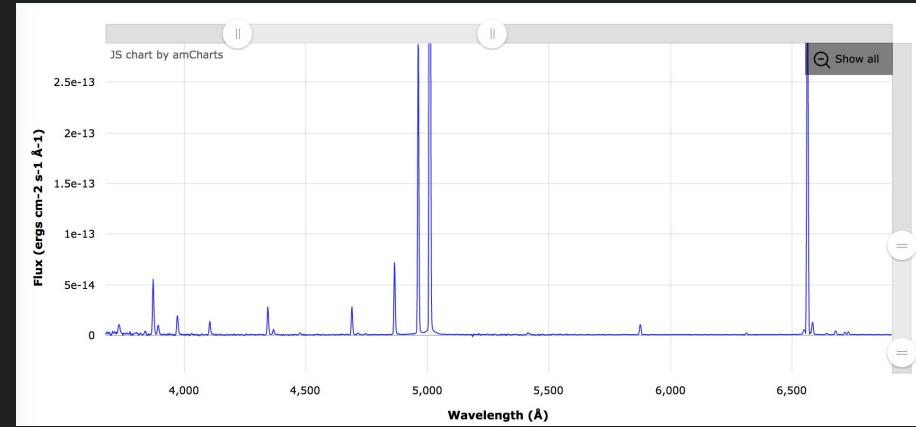https://web.williams.edu/Astronomy/research/PN/nebulae/

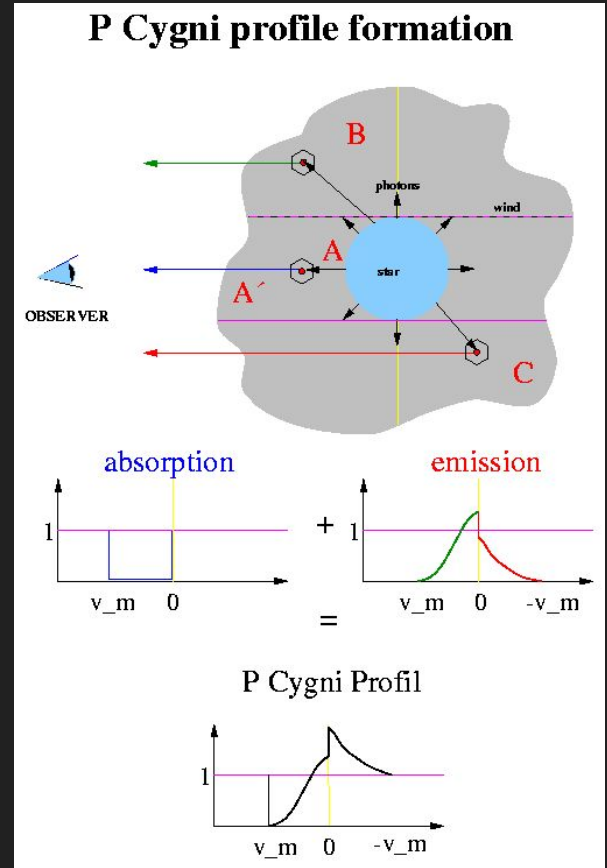# PNe lines

P Cyg

Emission and absorption playing together.

Present in all expanding atmospheres (LBVs, novae, supernovae,...)

Lyman Alpha Forest

https://youtu.be/6Bn7Ka0Tjjw

Measurables

Centroid

As easy as it may sound.

The centroid gives information on the nature of the line (well, in most cases, at least).

Series of observations may be used to see the centroid move.

Doing science with centroids

Planets (Mayor & Queloz 199?)

Quasars (Schmidt 1963)

A Jupiter-mass companion to a solar-type star

Michel Mayor & Didier Queloz

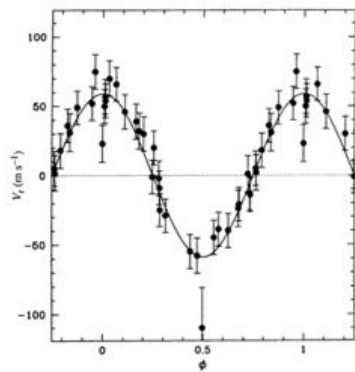Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.

3C 273 : A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By Dr. M. SCHMIDT

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena


Table 1.	WAVE-LENGTHS AND IDENTIFICATIONS		
λ	$\lambda/1\cdot158$	λ_0	
3239	2797	2798	Mg II
4595	3968	3970	H ε
4753	4104	4102	H δ
5032	4345	4340	H γ
5200–5415	4490–4675		
5632	4864	4861	H β
5792	5002	5007	[O III]
6005–6190	5186–5345		
6400–6510	5527–5622		

Equivalent Width

The EW is the width that a line **would** have if it was rectangular and its height was the height of the continuum.

$$W_\lambda = \int (1 - F_\lambda / F_0) d\lambda.$$

https://en.wikipedia.org/wiki/Equivalent_width
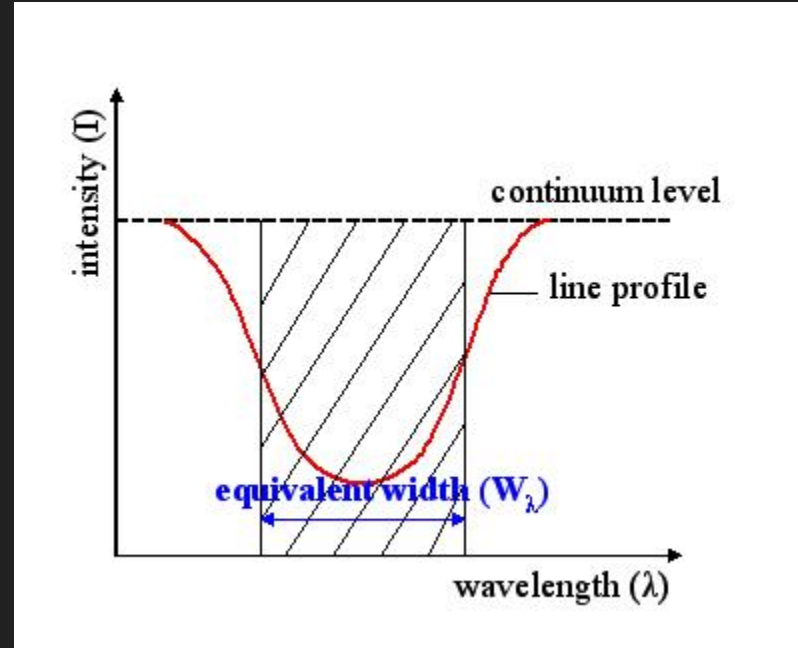
… next time

See you in the IT lab on Thursday at 14:00

Check the other courses you are taking: do they use spectra? How do they get information?