

Tuesday, September 11

- Homework due Tuesday, September 18th
- Outline:
 - Airmass
 - Magnitudes
 - Types of Spectra
 - Blackbody
 - Emission Line

Photometry Basics:

- **Vega magnitudes:**

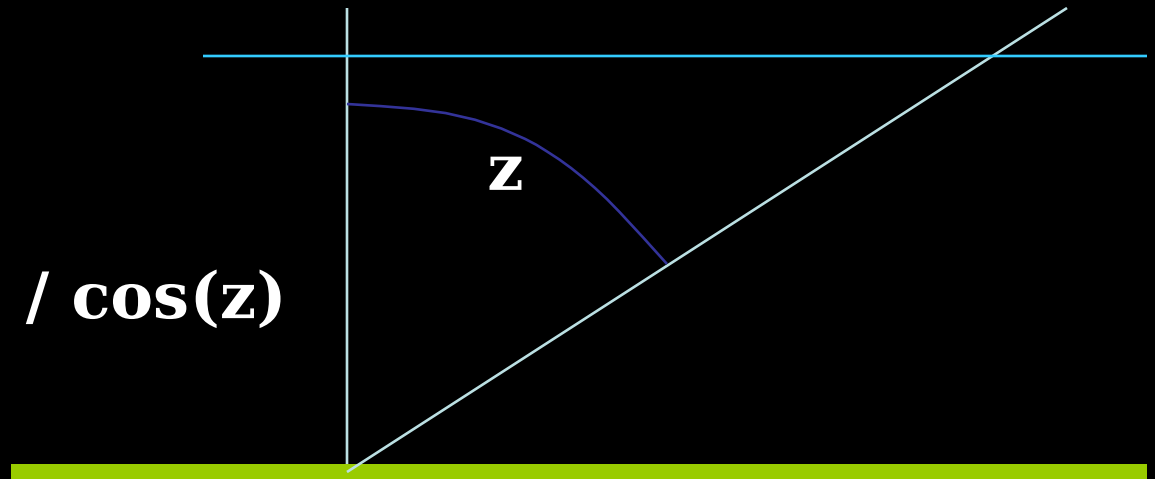
$$m(\lambda) = -2.5 \log [F(\lambda) / F_{\text{Vega}}(\lambda)]$$

$F(\lambda)$ = Counts on source

$F_{\text{Vega}}(\lambda)$ = Counts on Vega

Airmass:

$$A = \sec(z) = 1 / \cos(z)$$

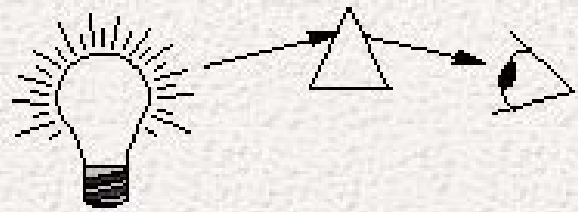


Type of Spectra

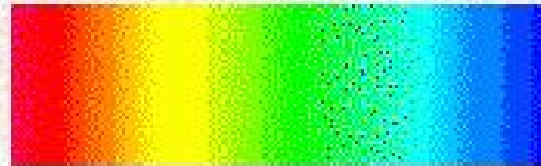
- **Continuum:**
 - **Blackbody:** $B_\nu(T)$
 - **free-free, free-bound**
 - **Non-thermal: Synchrotron radiation**
 - **Compton scattering**
- **Line & Band**
 - **E dipole, B dipole, E quadrupole**
 - **fine structure, hyperfine structure**
 - **electronic transitions**

Types of Spectra:

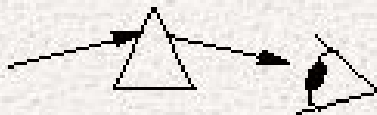
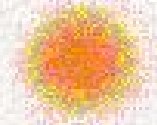
Nah, this slide is boring, let's try the next...



Continuum Spectrum



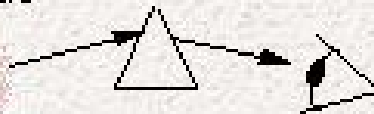
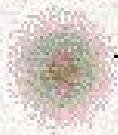
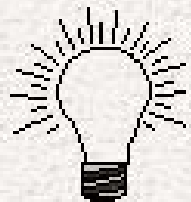
Hot Gas



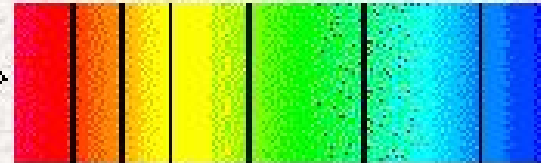
Emission Line Spectrum



Cold Gas



Absorption Line Spectrum



Hot,
Opaque
media

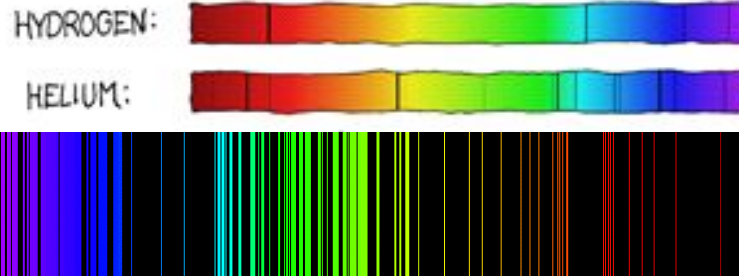
Nebulae

Stars

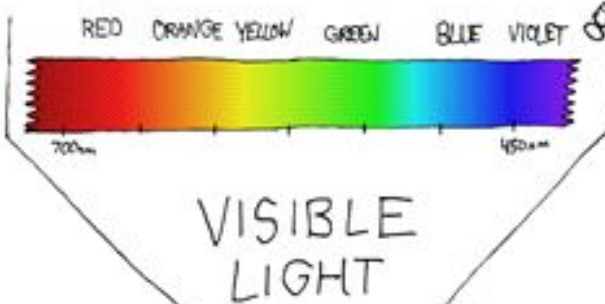
THE ELECTROMAGNETIC SPECTRUM

THESE WAVES TRAVEL THROUGH THE ELECTROMAGNETIC FIELD. THEY WERE FORMERLY CARRIED BY THE AETHER, WHICH WAS DECOMMISSIONED IN 1897 DUE TO BUDGET CUTS.

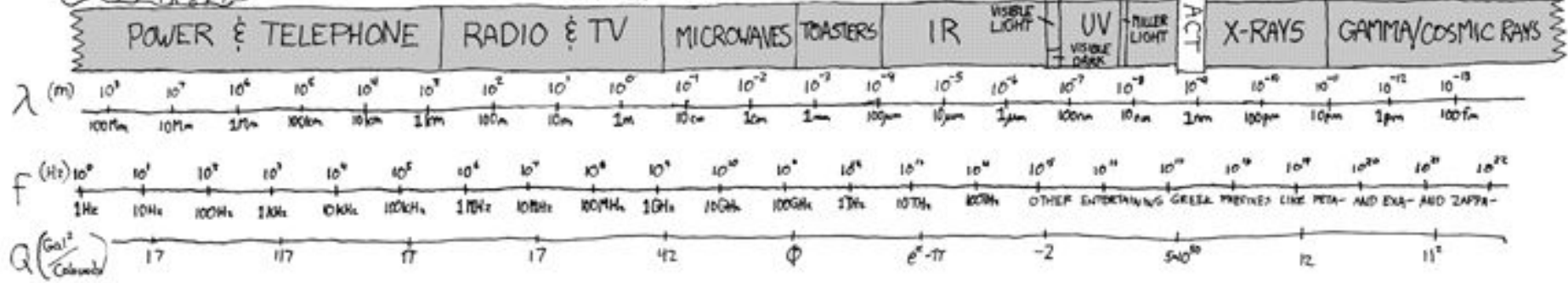
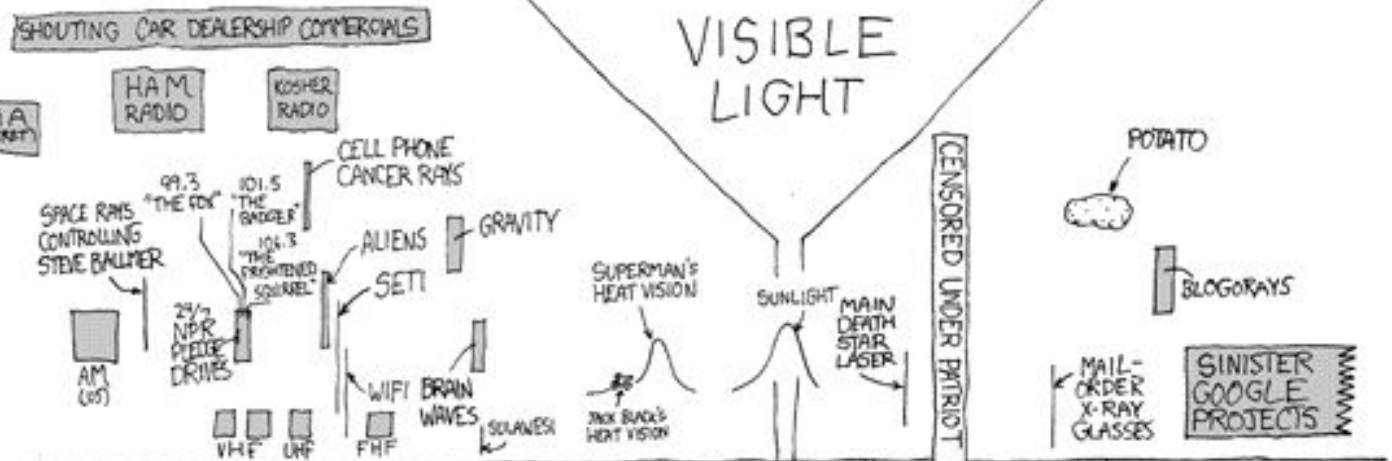
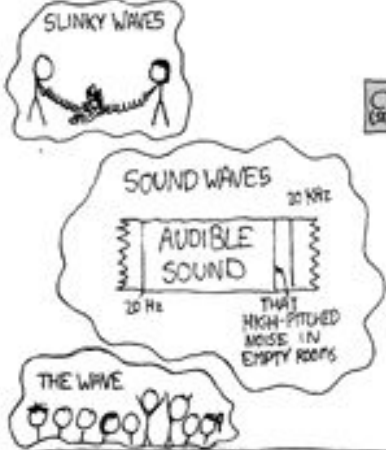
ABSORPTION SPECTRA:



Stars
Nebulae
Hot,
Opaque
media



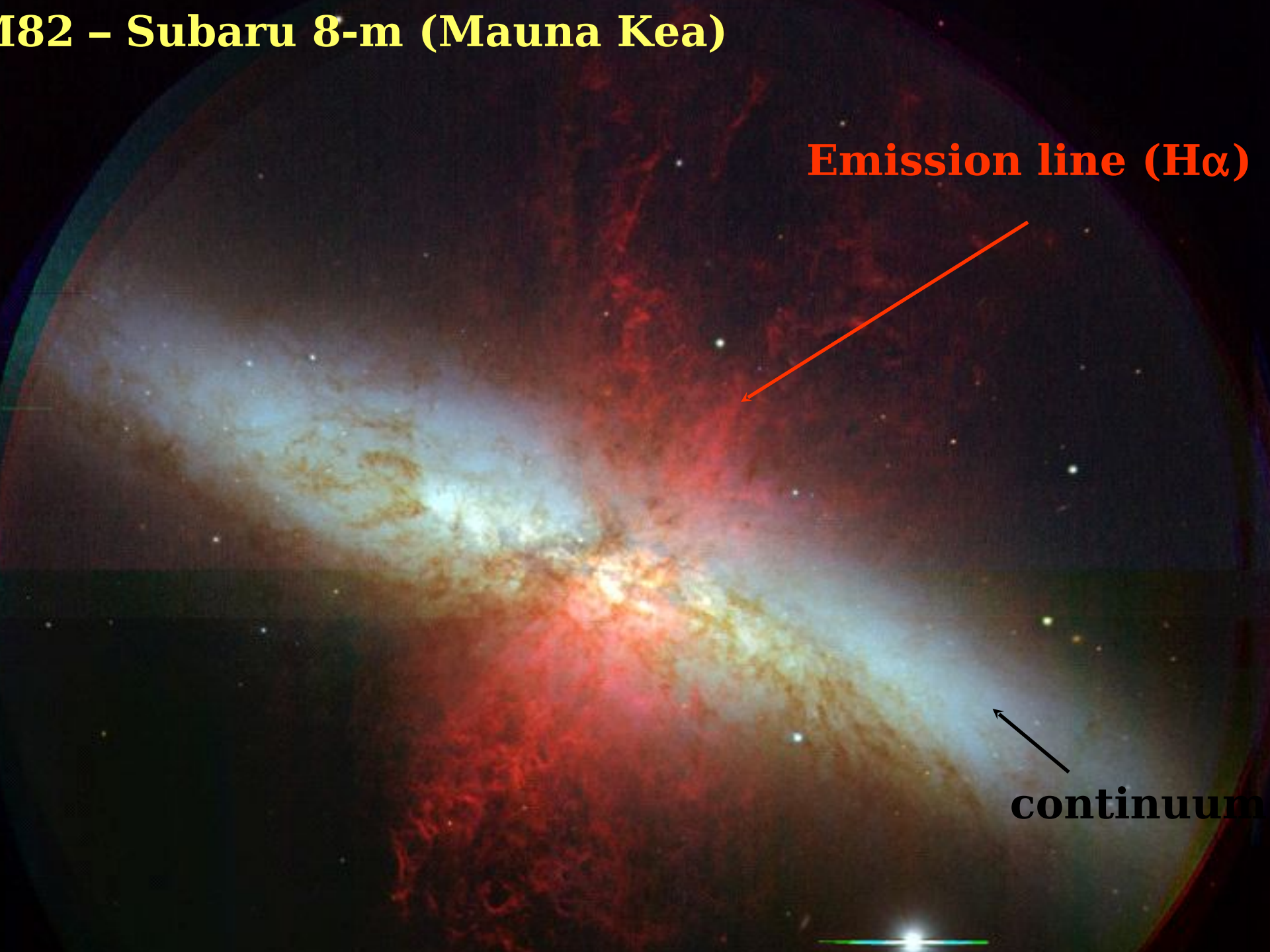
OTHER WAVES:



182 - Subaru 8-m (Mauna Kea)

Emission line ($H\alpha$)

continuum



The Planck Function: Black-body radiation

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

(erg s⁻¹ cm⁻² Hz⁻¹ 2 π sr⁻¹)

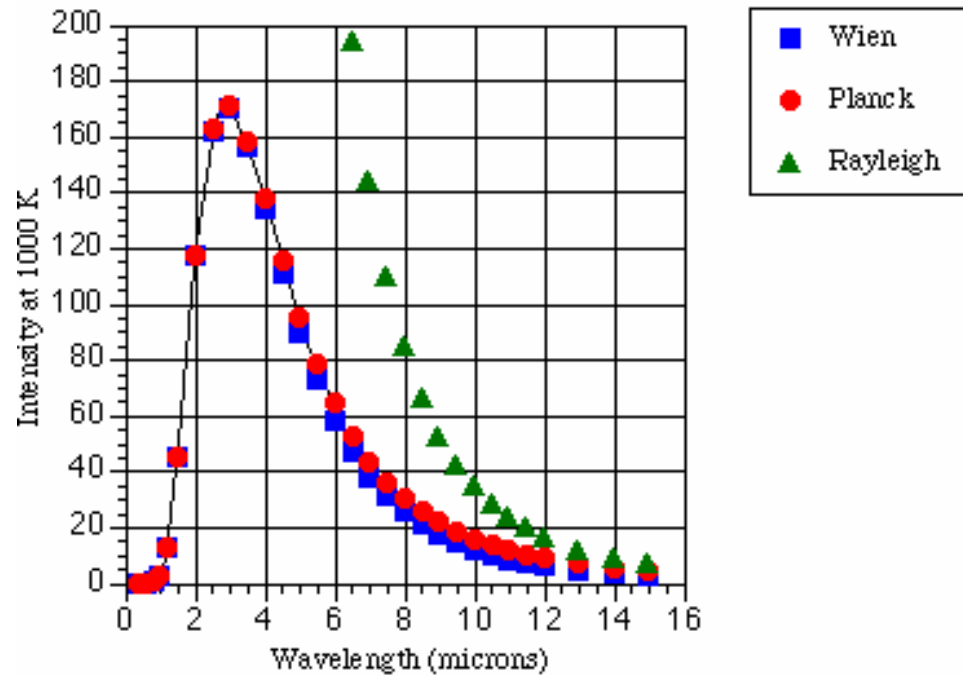
Wien:

$$B(\nu, T) = (2 \pi h \nu^3 / c^2) e^{-h\nu/kT}$$

Rayleigh-Jeans:

$$B(\nu, T) = 2kT/\lambda^2$$

Blackbody Radiation

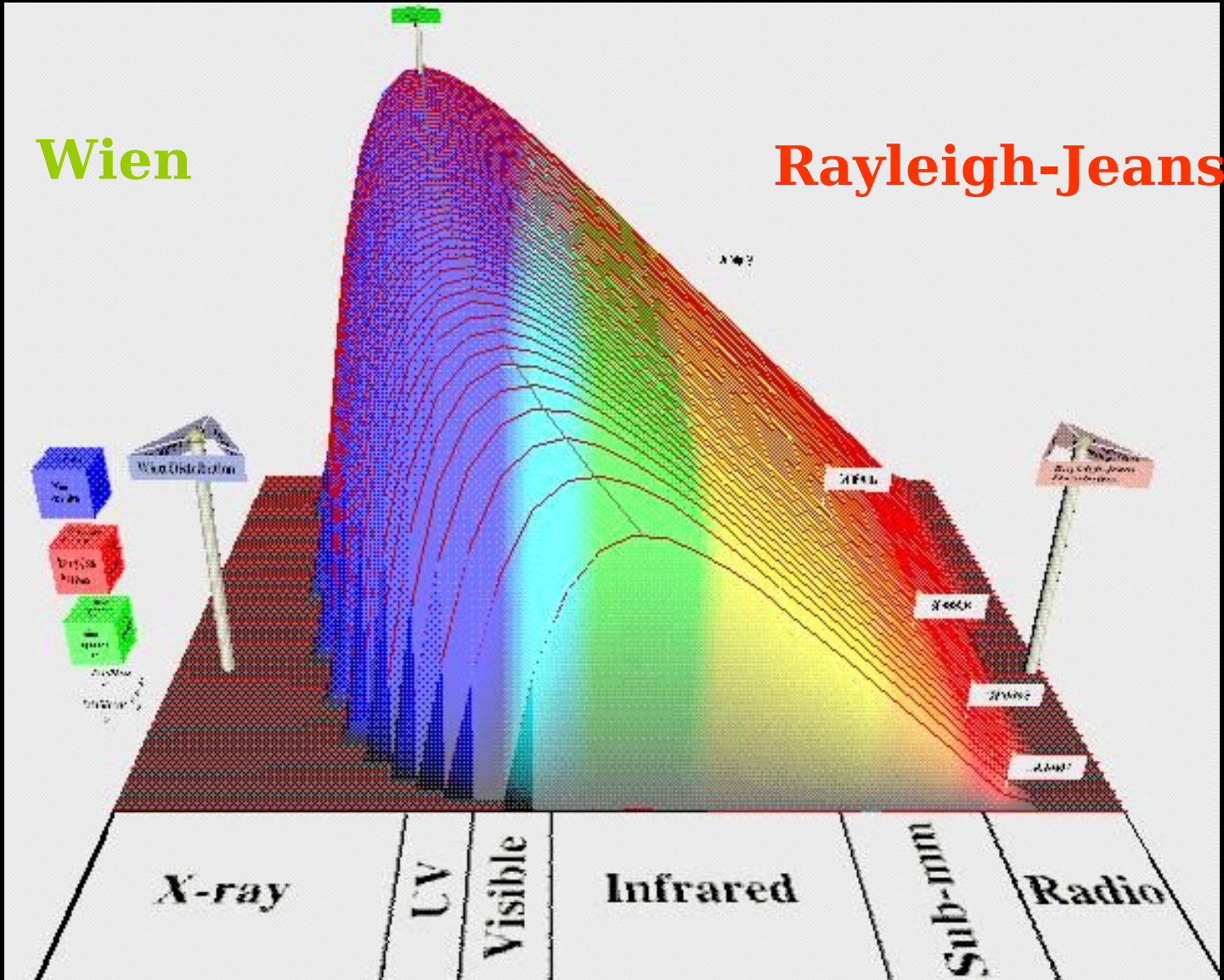


Wien: $I = \frac{c_1 \lambda^{-5}}{e^{c_2/\lambda T}}$

Planck: $I = \frac{8\pi hc \lambda^{-5}}{e^{hc/\lambda T} - 1}$

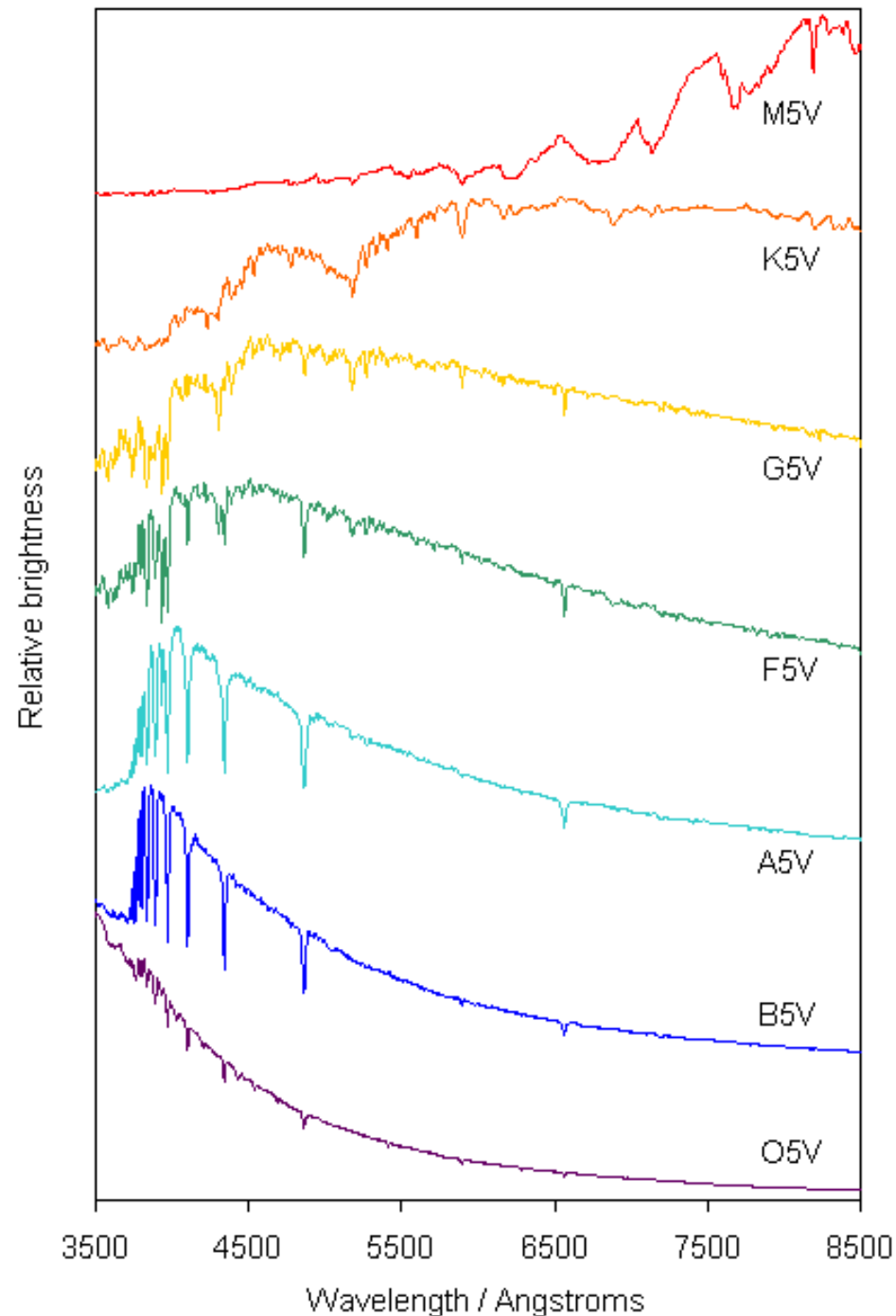
Rayleigh: $I = 8\pi k T \lambda^{-4}$

The Planck Function: Black-body radiation



Stellar Spectra

- Blackbody continuum
- Absorption Lines
- Balmer jump (bound-free transitions)
- Hottest stars (O stars) have ionized helium, coolest stars have molecular transitions



Spectrum of Hydrogen (& H-like ions)

$$E_n = \frac{-2\pi^2 m e^4 Z^2}{n^2 h^2}$$

Ionization (n to infinity):

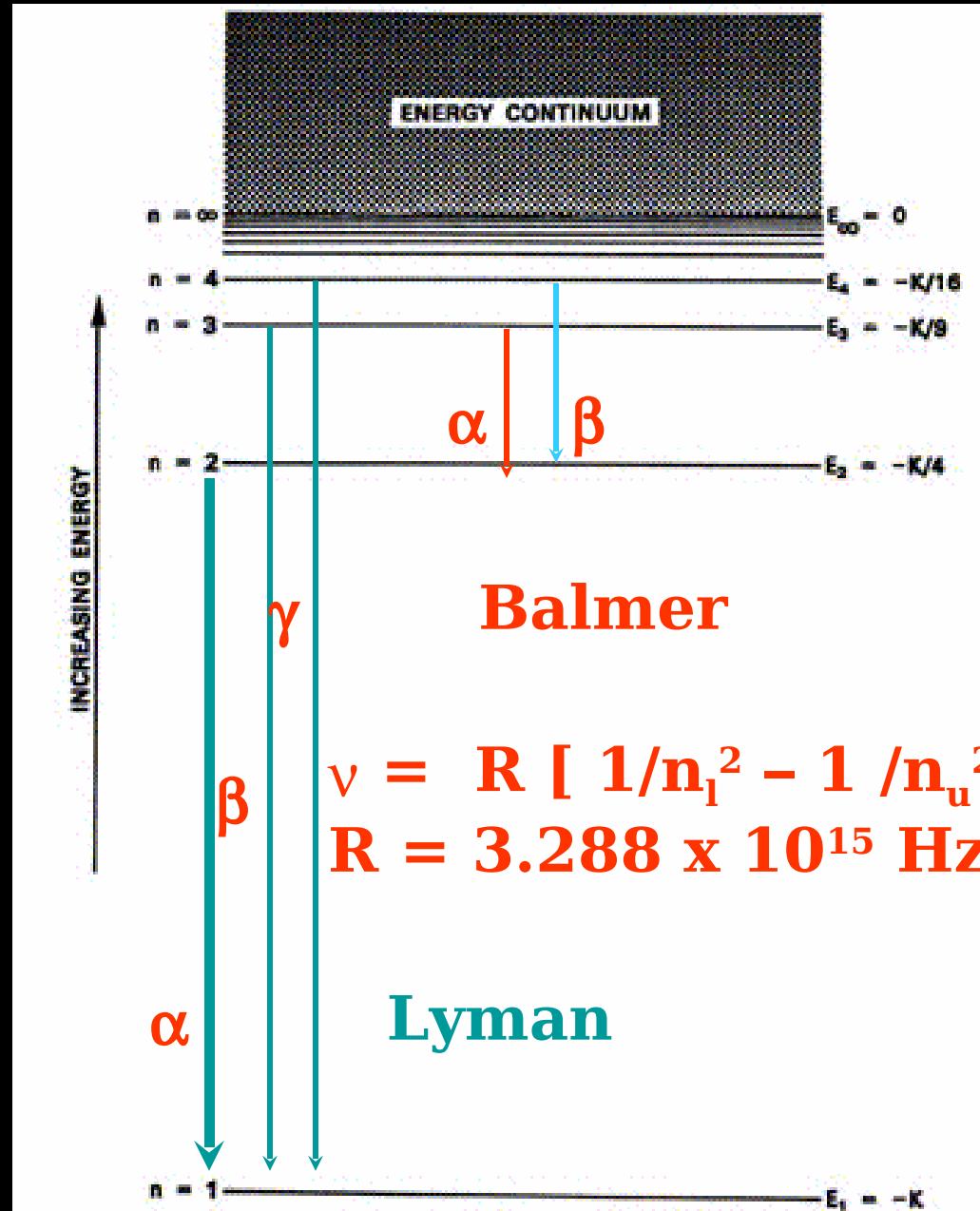
$$E = 13.6 \text{ eV}$$

$$\lambda \leq 912 \text{ Angstroms}$$

Transitions:

$$E = h\nu = E_u - E_l$$

$$\nu = \frac{E}{h} = \frac{E_{n'} - E_n}{h}$$



**Bohr model:
Allowed orbits**

$$mvr = nh / 2\pi$$

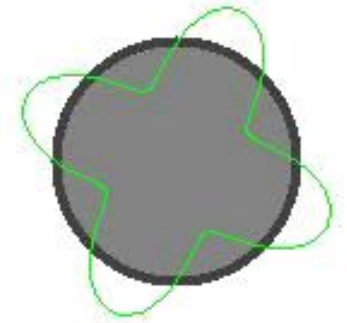
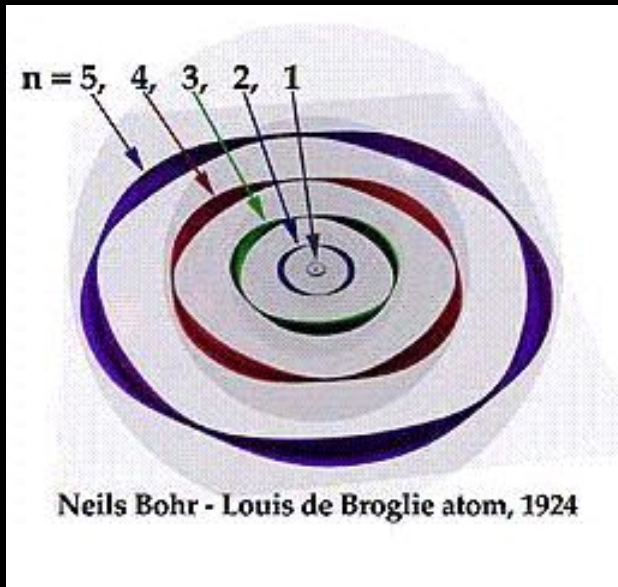
Coulomb Force:

$$Ze^2 / r^2 = mv^2/r$$

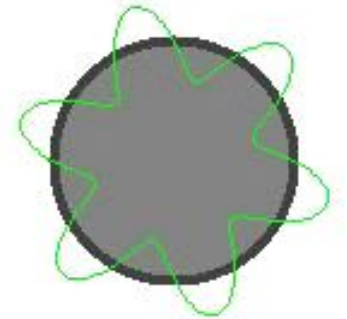
Thus, (eliminate v)

$$r = Ze^2 / mv^2 = n^2 h^2 / 4 \pi^2 Ze^2 m$$

Energy $E = - (1/2) Ze^2 / r = - 2 \pi^2 Z^2 e^4 m / n^2 h^2$

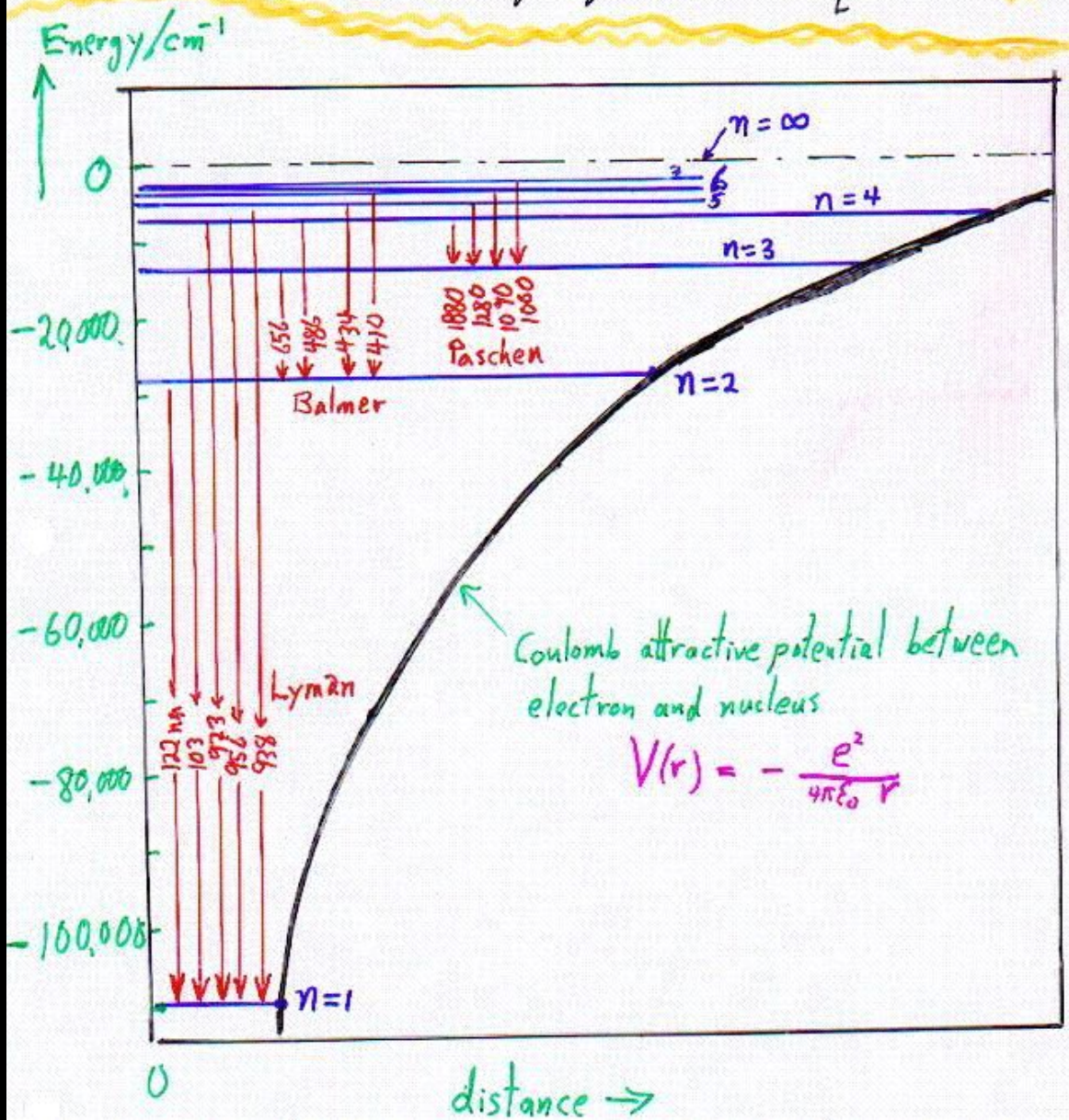


n=4 orbit

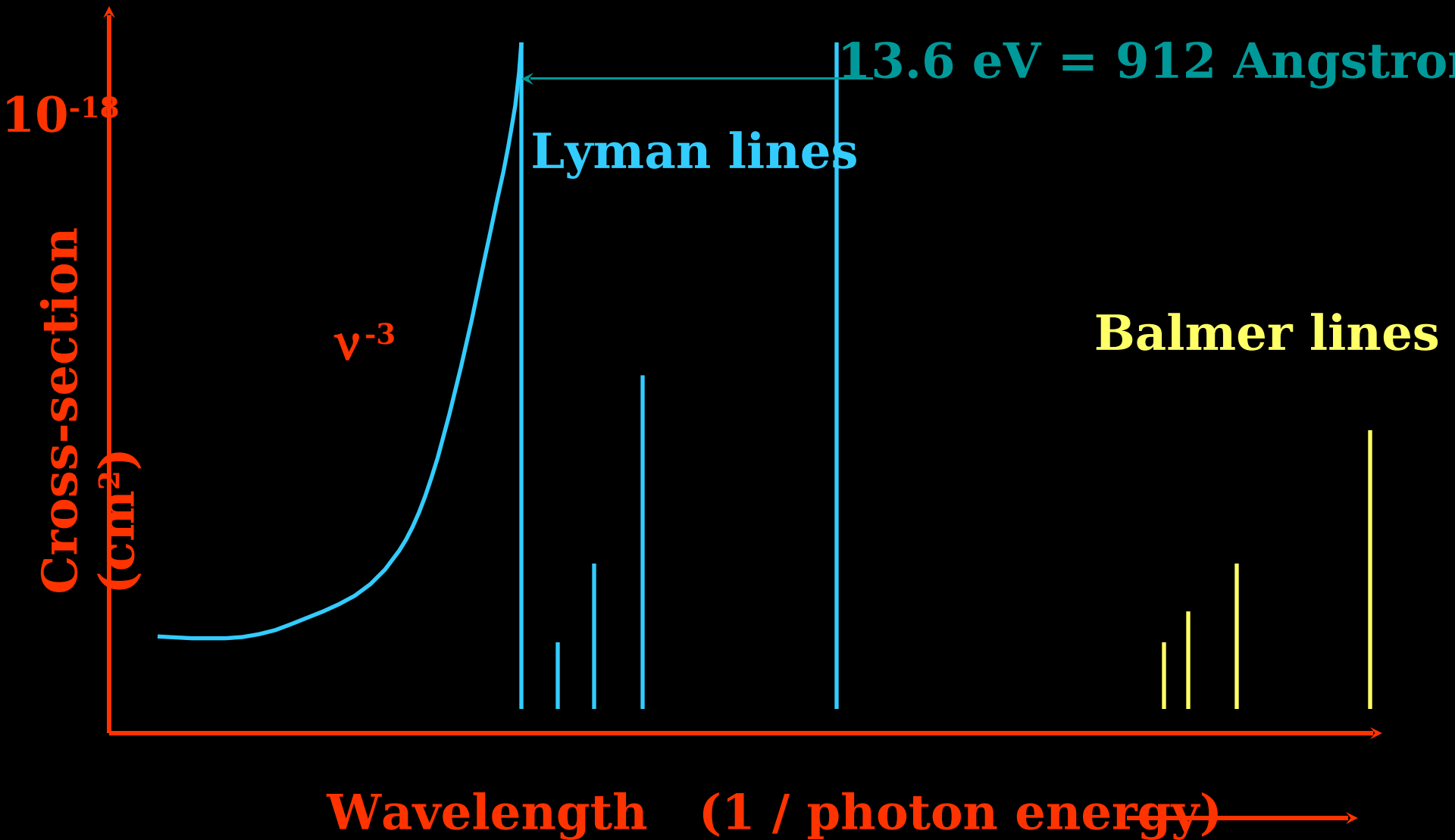


n=6 orbit

Conservation of energy means that energy $\Delta E = h\nu$ of the observed light quanta must exactly match spacing between allowed energy levels
 * \Rightarrow Level energies of the atom are "quantized" *



Ionization cross-section of hydrogen



Atomic Structure

- **Refinements to Bohr:**

- Elliptical e-orbits**

- Integral of P in r and $\theta = lh \quad l = 0, 1, 2, \dots, n-1$

- Relativistic effects \Rightarrow l makes small

- correction to E-levels

- Space quantization: Orientation of orbits

- m**

- Electron spin**

Atomic Structure

- **Atomic quantum numbers:**
n, l, m, s - completely specify state, E

n	=	1, 2, 3, 4
shell	=	K L M N
max n_e	=	2 8
l	=	0 1 2 3 4
		s p d f g

Atomic Structure

- **Refinements to Bohr:**
 - n**
 - Elliptical e-orbits:** **k**
 - Space quantization: Orientation of orbits**
 - w.r.t. magnetic field:** **m**
 - Electron spin:** **s**
- **Pauli: Fermions:**
 - No 2 e- in same state:** **$[n,k,m,s]$**
- **Schrodinger Wave function:**
 - $n \Rightarrow$ principle quantum number (radial)**
 - $l \Rightarrow$ orbital angular momentum 0, 1, ... n**
 - $m \Rightarrow$ magnetic sublevels (degenerate if $B = 0$)**

Atomic Structure

Multi-electron atoms/ions

- Atomic quantum numbers:

n, l, m, s - completely specify state, E

n = 1, 2, 3, 4

shell = K L M N

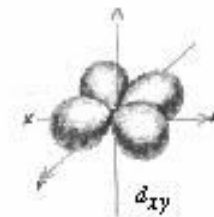
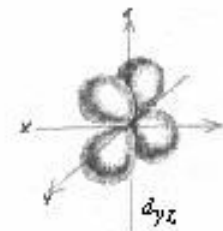
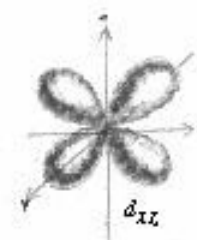
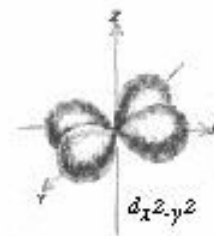
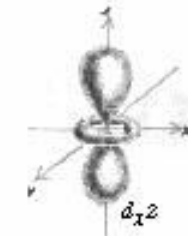
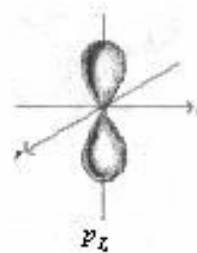
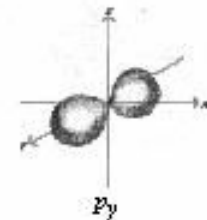
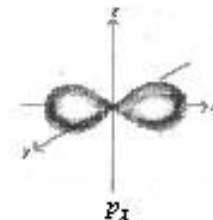
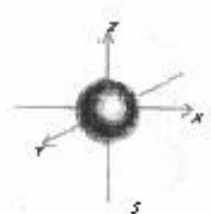
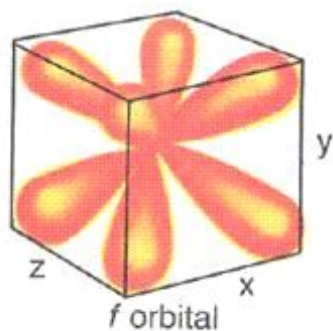
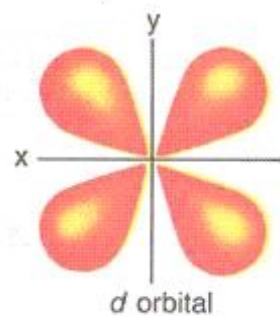
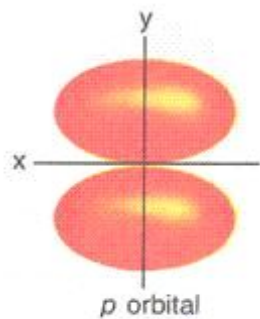
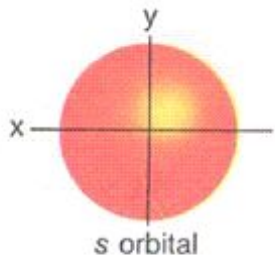
max n_e = 2 8

l = 0 1 2 3 4

s p d f g

Selection rules: $\Delta l = +/- 1$

Orbitals



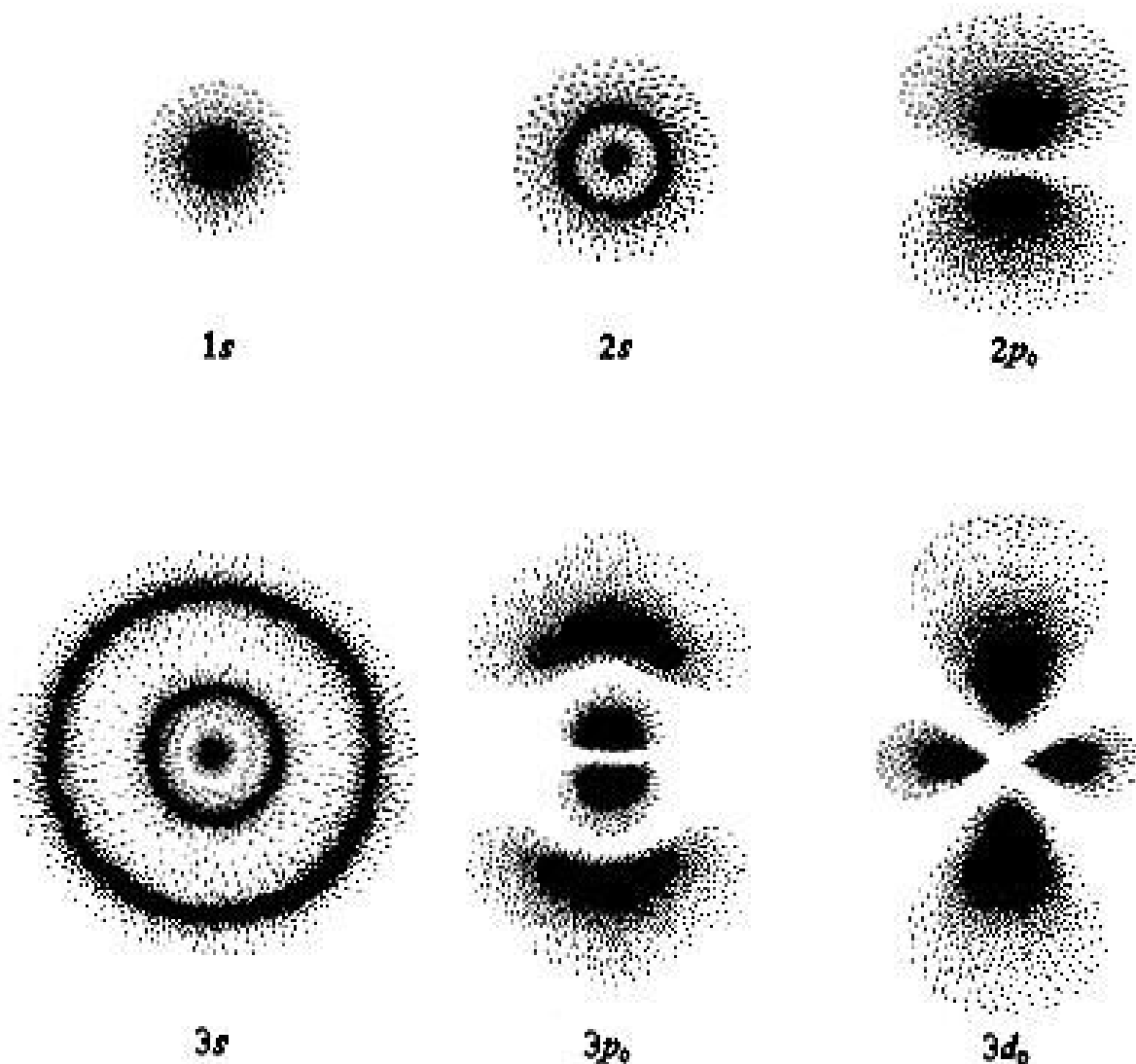
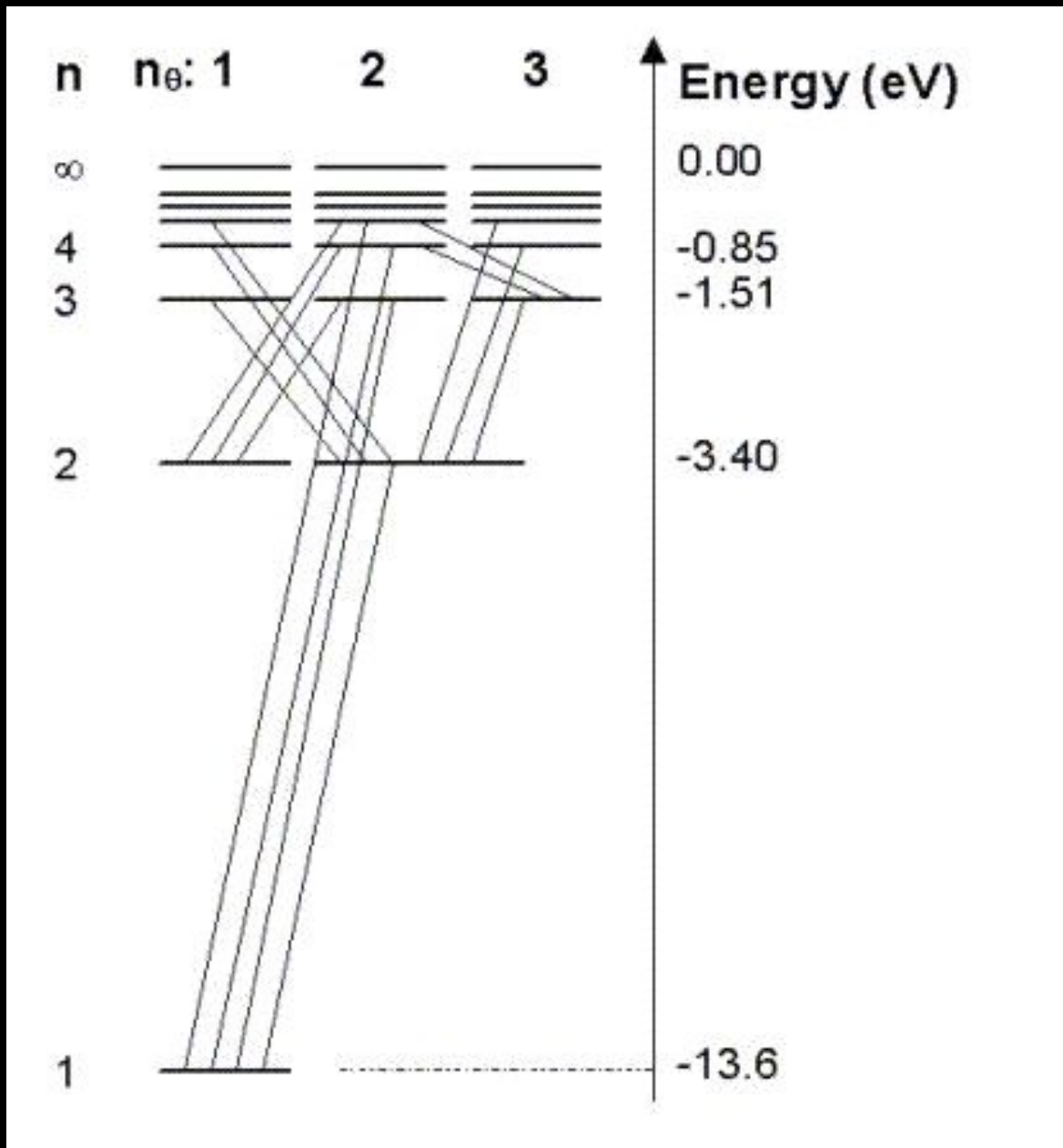
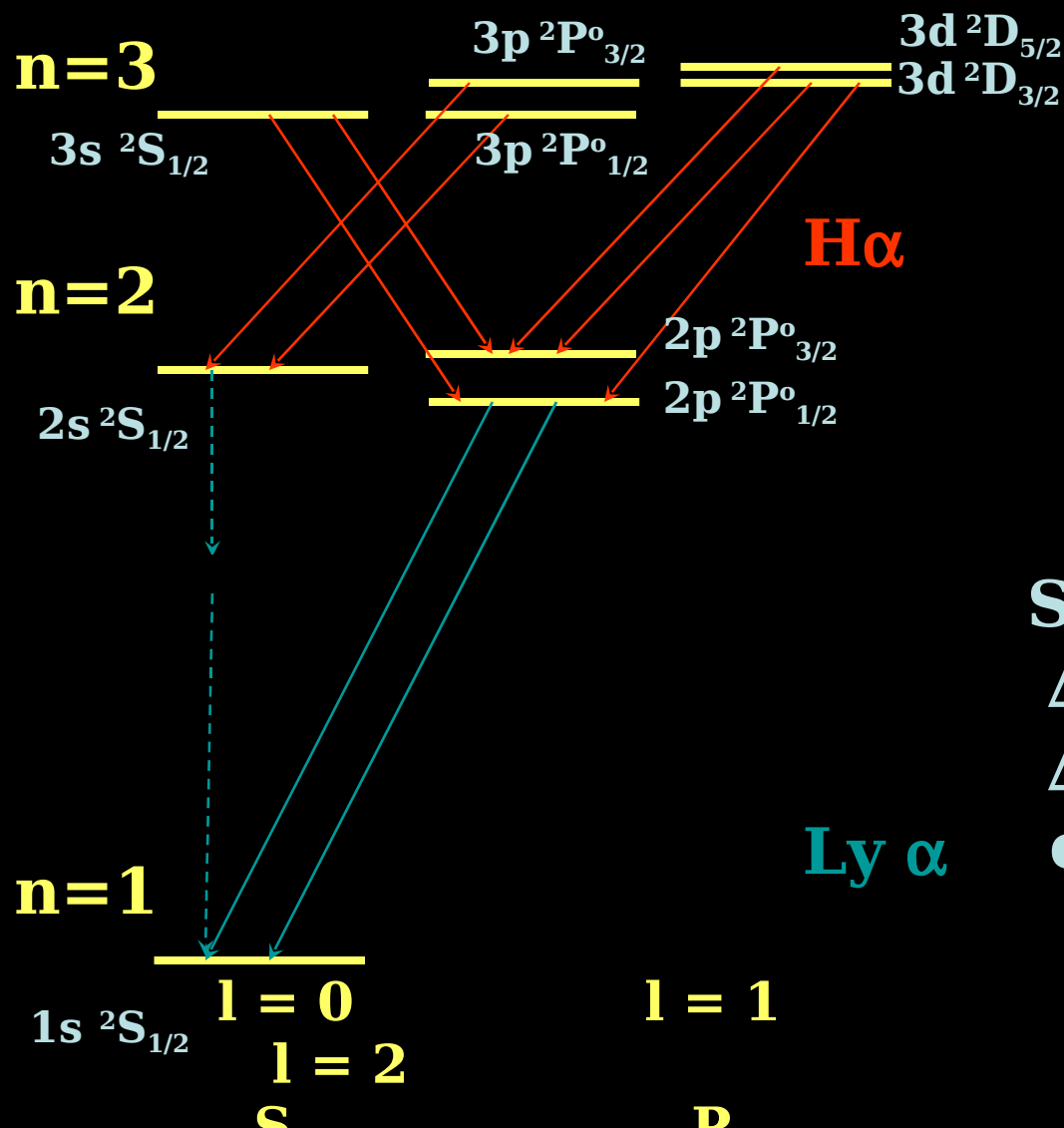


Figure 6-12. Probability density plots of some hydrogen atomic orbitals. The density of the dots represents the probability of finding the electron in that region.

Hydrogen energy levels showing allowed transitions

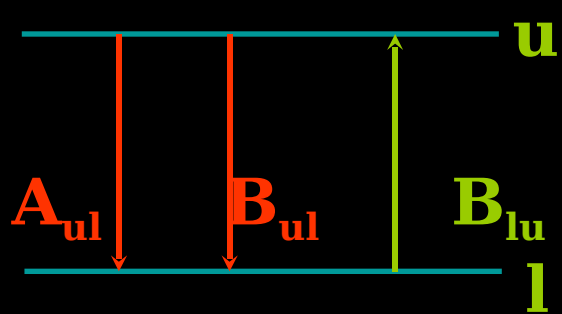


Hydrogen energy levels showing fine structure



Selection Rules:
 $\Delta l = 0, +/-1$
 $\Delta j = 0, +/-1$
 even \Leftrightarrow odd

Transition A & B coefficients: radiative process



A_{ul} Spontaneous decay

B_{ul} Stimulated decay (prop to Flux)

B_{lu} Absorption (prop to Flux)

$$A_{ul} = \frac{64\pi^4 \nu_{ul}^3}{3hc^3} \mu_{ul}^2$$

$\mu_{ul} = e x_0$ is the electrical dipole moment

$$A_{ul} = \frac{8\pi h \nu^3}{c^3} B_{ul}$$

H ground state, $\mu_{ul} \approx 2.5 \times 10^{-18}$ and $A_{ul} \approx 10^9 s^{-1}$

Ionization & Excitation

- **Radiation:** $R_r = \sigma I_{\text{rad}}$
 $\sigma = \text{cross section}$

- **Collisions:** $R_c = n \sigma_{\text{thermal}} \langle v_{\text{thermal}} \rangle \approx n \sigma_{\text{thermal}} \sqrt{3 kT / 2 m}$

