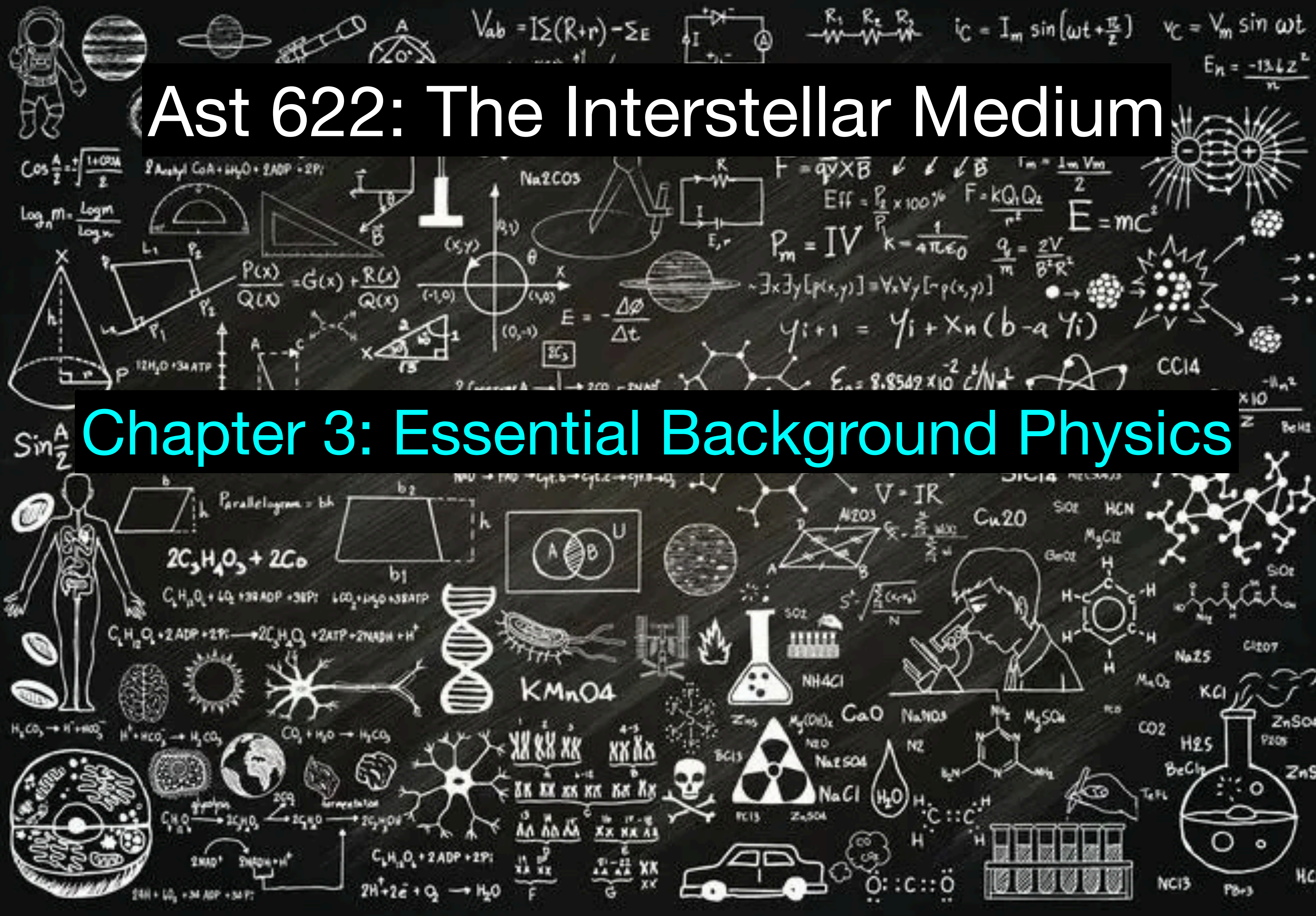
Ast 622: The Interstellar Medium

Chapter 3: Essential Background Physics



https://www.timeshighereducation.com/student/subjects/what-can-you-do-physics-degree

Lecture plan

The following slides are snippets from Chapter 3. **They are not intended to replace reading this Chapter.** We will discuss the concepts and I want to assess your understanding.

We can take as much time as necessary to go through this material. Let me know where you want to go fast and where to go slow. Its essential that you have some familiarity with each of the following topics before we move on to the astrophysics.

A personal perspective

old passport photo for arrival into the US (1989)

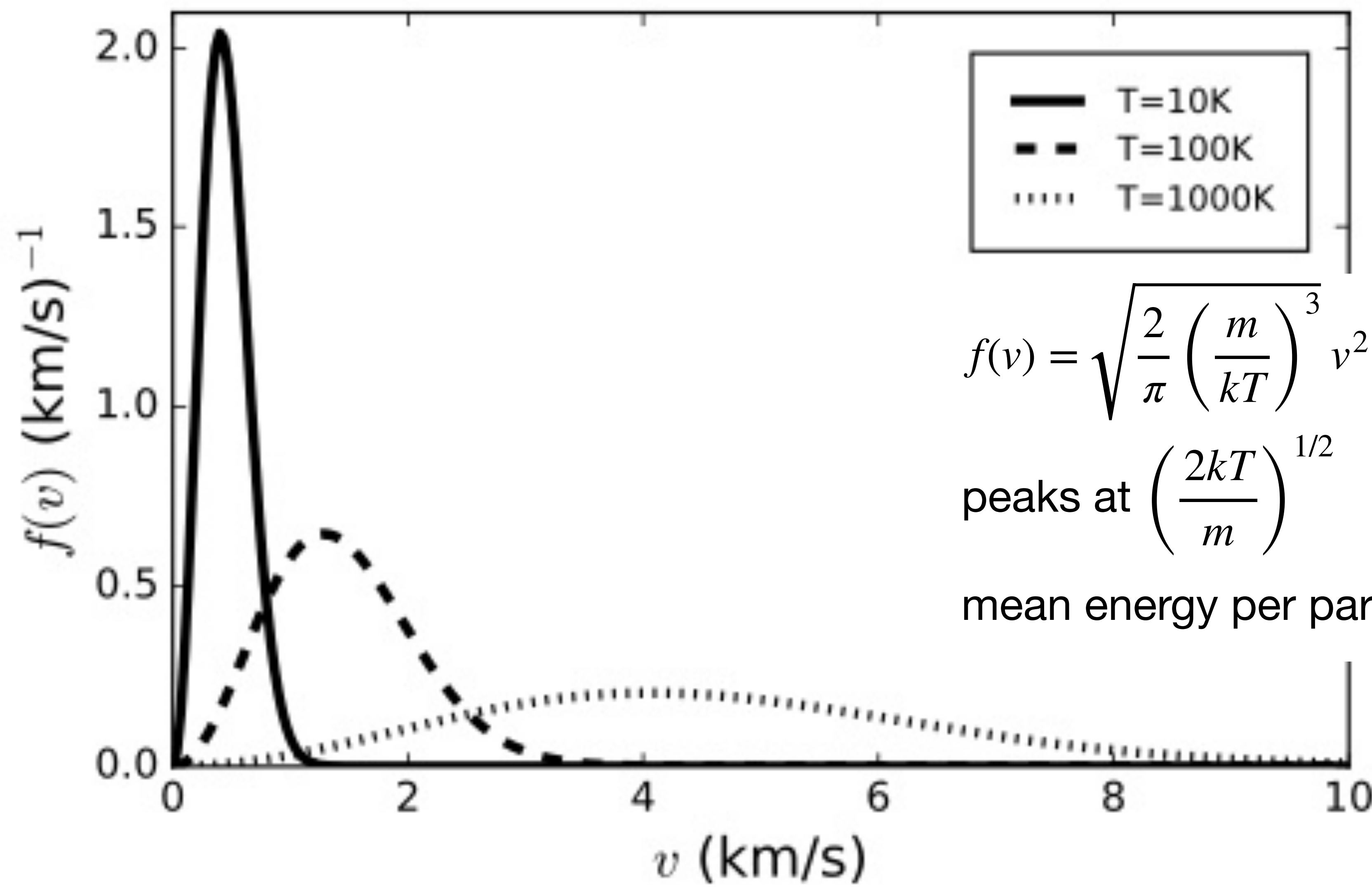
I came to astro grad school with a BA in Maths from the UK. That's a 3 year intensive program (think number theory, etc), with very little physics. My first year was a struggle (and there was no wikipedia!) so it meant a lot of catching up in the library and talking to other students / teachers.

Better to be temporarily embarrassed by asking "stupid" questions in class now than to be embarrassed in a job interview later…

Statistical mechanics

- distribution of gas particle speeds at a given temperature
- distribution of energy states in thermodynamic equilibrium
- Planck function (blackbody radiation)
- excitation temperature

Maxwell-Boltzmann distribution



$$f(v) = \sqrt{\frac{2}{\pi}\left(\frac{m}{kT}\right)^3}\, v^2\, e^{-mv^2/2kT}$$

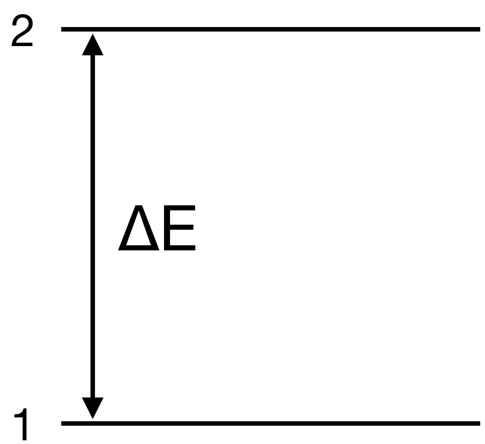
peaks at $\left(\frac{2kT}{m}\right)^{1/2}$

mean energy per particle = $\frac{3}{2}kT$

Figure 3.1 The Maxwell-Boltzmann distribution for three different temperatures, showing the range of thermal speeds in different ISM environments.

Boltzmann distribution of energy states

For a quantized system in thermodynamic equilibrium, the proportion of particles in different states is:



$$\frac{n_2}{n_1} = \frac{g_2}{g_1} e^{-\Delta E/kT}$$

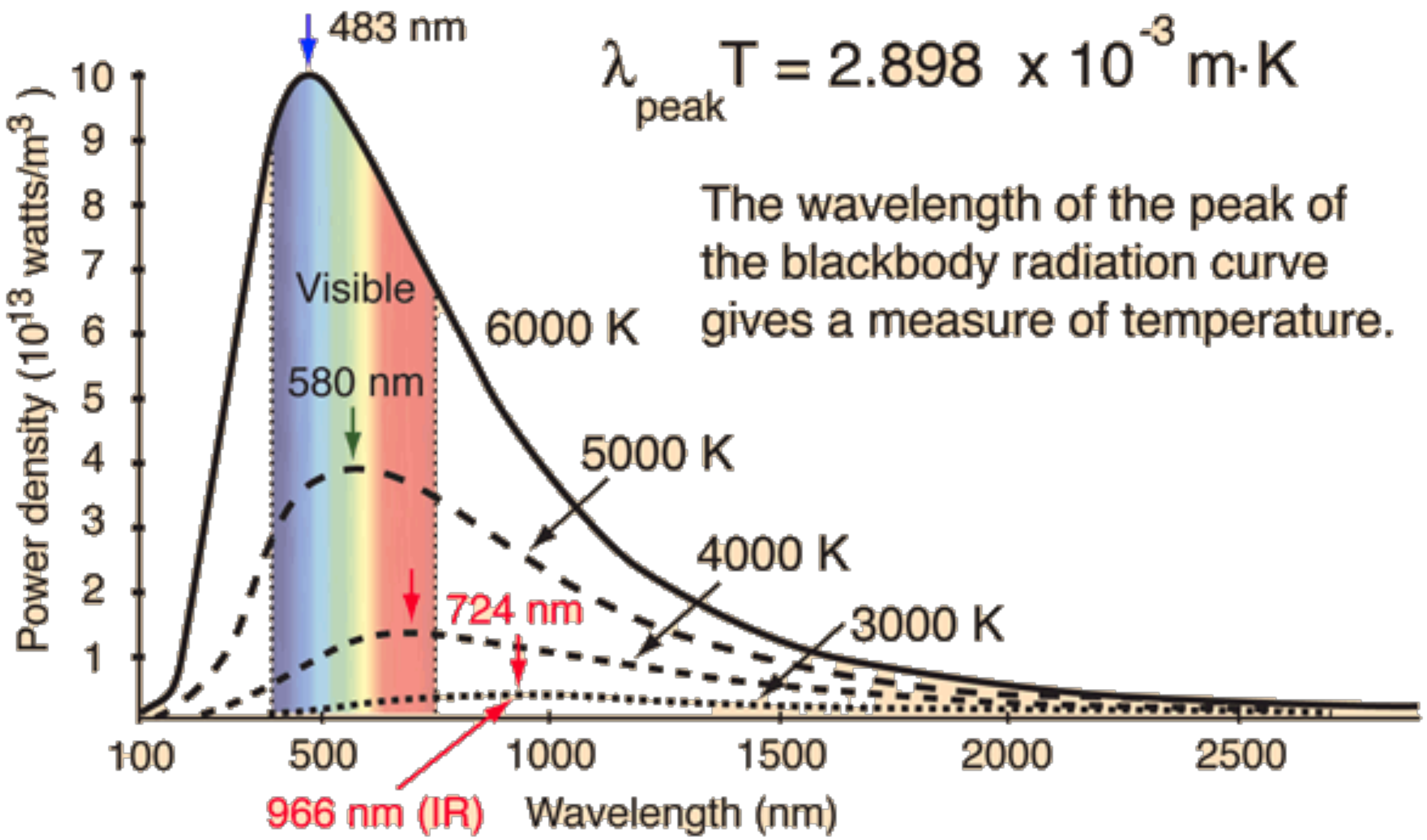
degeneracy

Boltzmann factor

Invert this to define an excitation temperature, $T_{\rm ex} = \dfrac{\Delta E}{k \ln(g_2 n_1 / g_1 n_2)}$

Planck function

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



http://hyperphysics.phy-astr.gsu.edu/hbase/wien.html

Radiative transfer

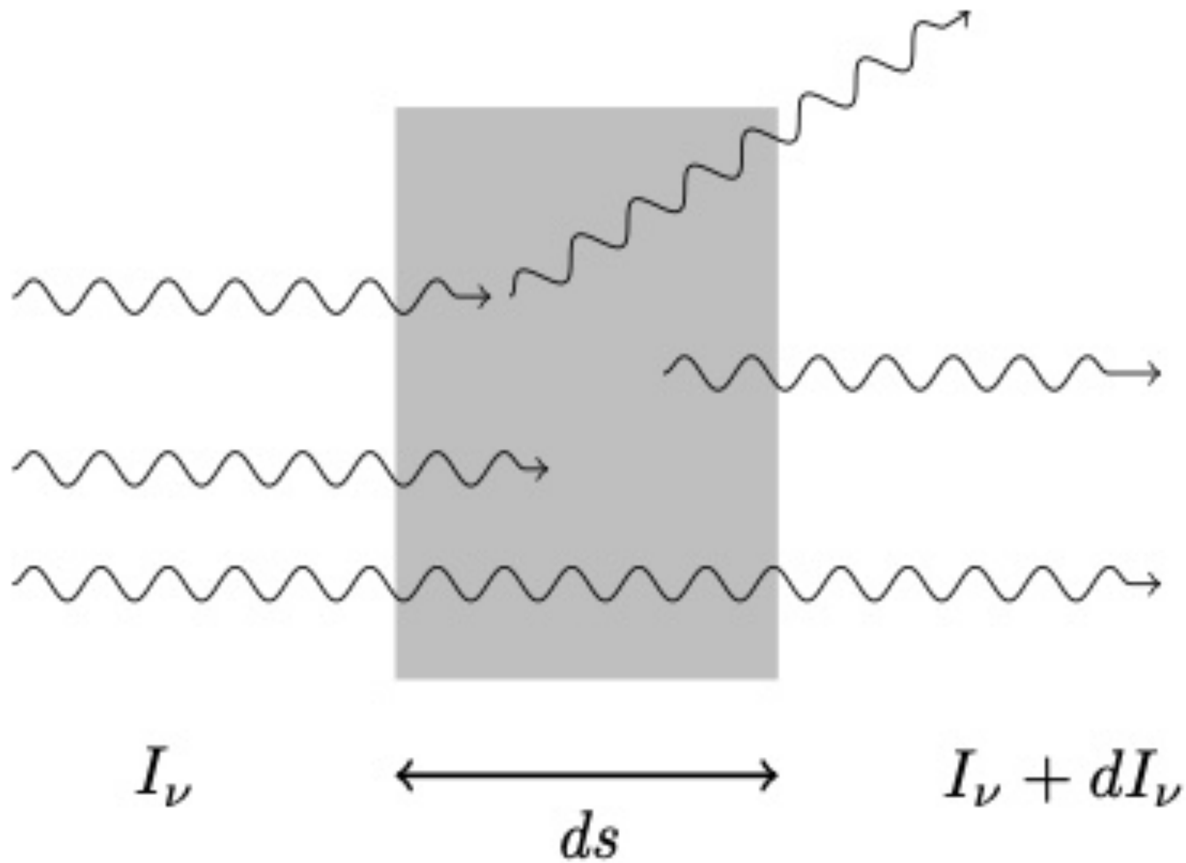


Figure 3.2 Schematic of the losses through scattering and absorption and gains through emission as radiation passes through a material, changing the specific intensity by dI_ν over pathlength ds.

$$dE_\nu = I_\nu dA d\Omega d\nu dt$$

defines specific intensity

$$\frac{dI_\nu}{d\tau_\nu} = S_\nu - I_\nu$$

source function = emissivity/absorption

equation of radiative transfer

$$I_\nu(\tau_\nu) = I_\nu(0)e^{-\tau_\nu} + \int_0^{\tau_\nu} S_\nu \, e^{(\tau_\nu - \tau')} \, d\tau'$$

general solution

$$I_\nu = \underline{I_\nu(0)e^{-\tau_\nu}} + \underline{B_\nu(T_{\rm ex})(1 - e^{-\tau_\nu})}$$

What do these two terms physically signify?

solution for thermal radiation with constant T_{ex}

Line absorption and emission

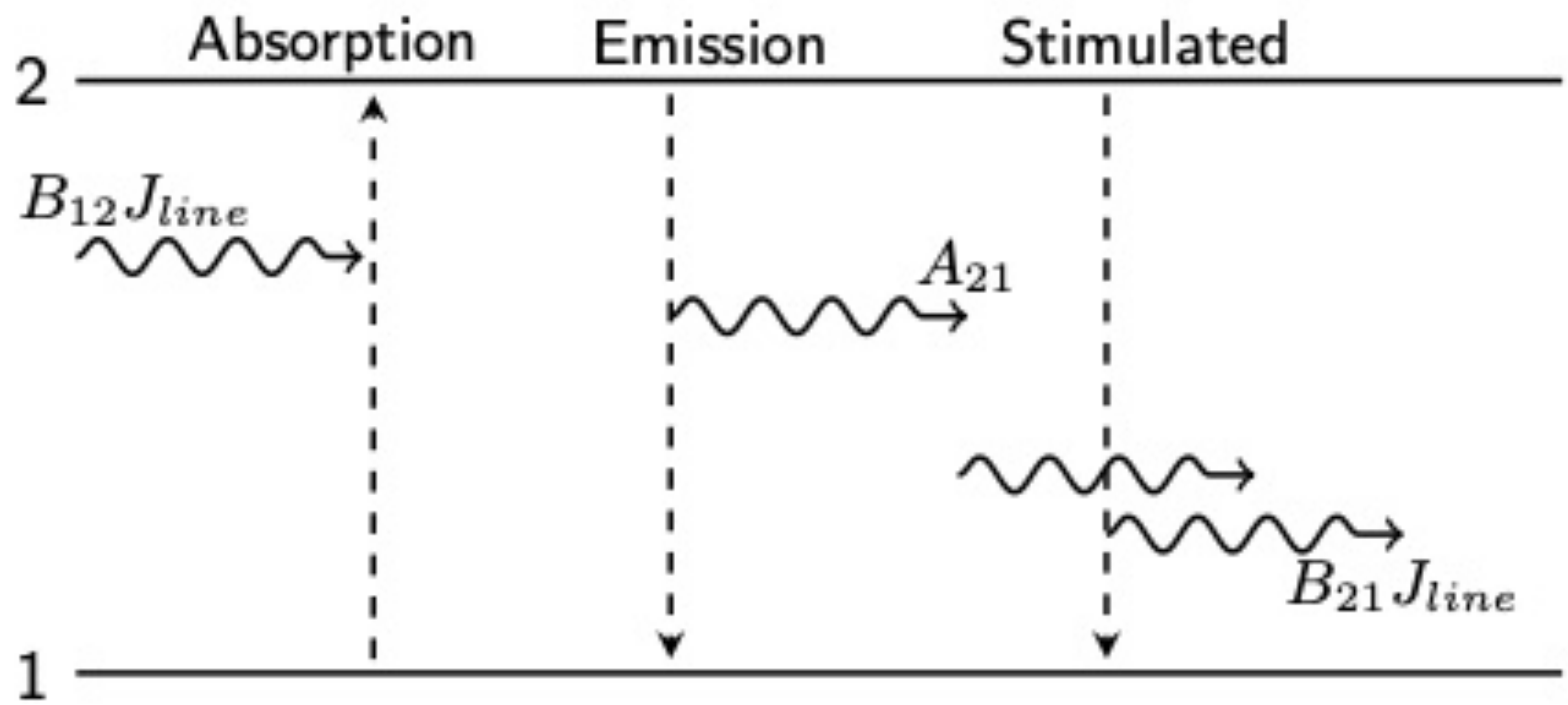


Figure 3.3 Visualization of the quantum processes described by the Einstein A and B coefficients.

In equilibrium, $n_1 B_{12} J_{\rm line} = n_2(A_{21} + B_{21} J_{\rm line})$

Flux density and luminosity

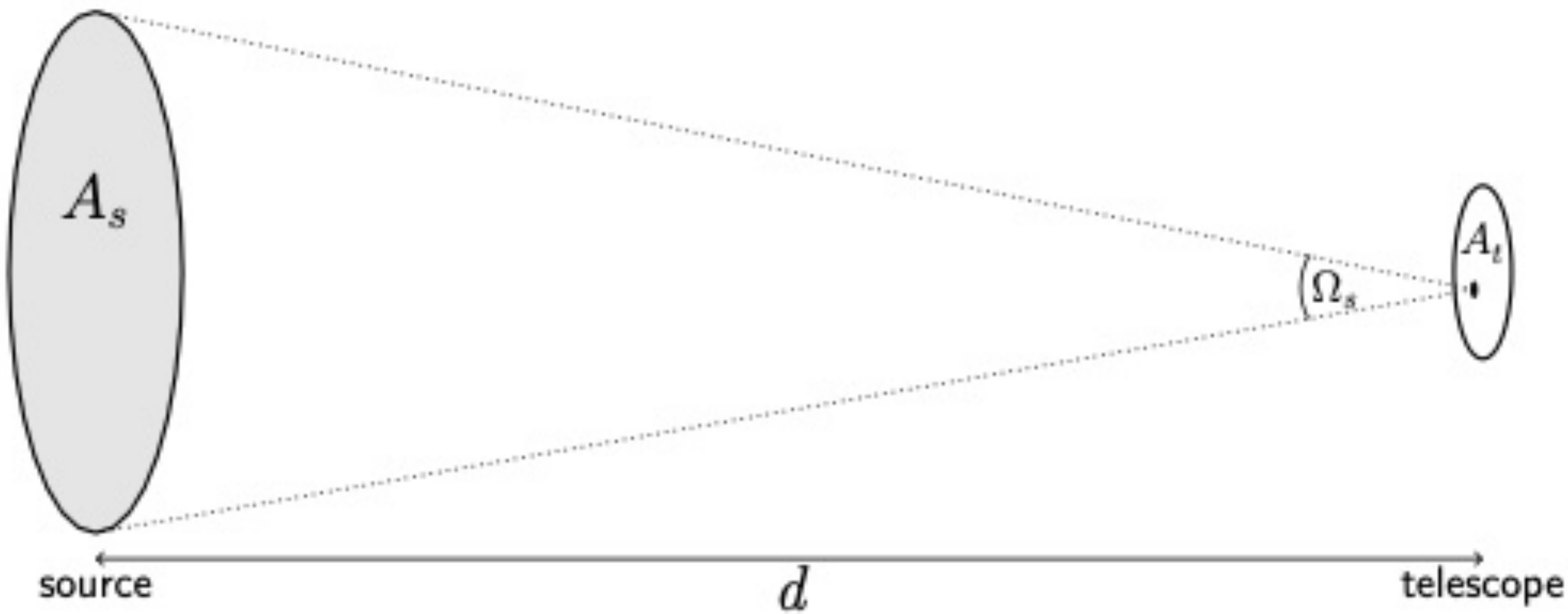


Figure 3.4 The path of light rays from source emission to detection from the perspective of a point in the collecting area of the telescope.

The specific intensity measured by a telescope is the same as that emitted by the source *(think of it as a surface brightness)*.

The Hydrogen Atom

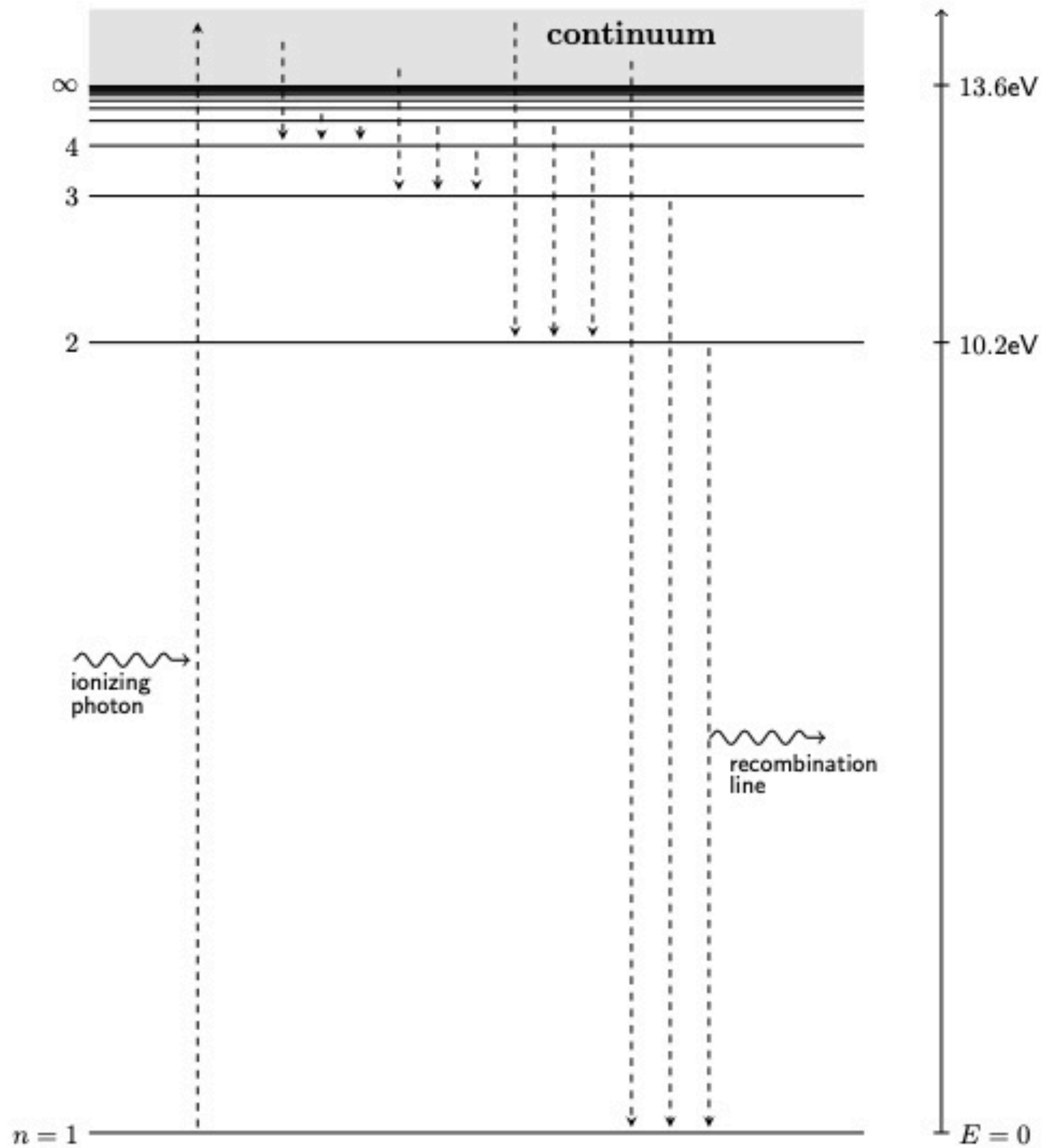


Figure 3.6 The Bohr model for the electronic energy levels in a hydrogen atom. Ultraviolet photons can ionize the atom and recombination produces numerous spectral lines over a wide range of energies.

Ionization potential = 13.6eV
=> λ = 912 Angstroms (UV)
=> v ~ 50 km/s (shocks)

Bohr model, $E_n = E_{\mathrm{IP}}\left(1 - \frac{1}{n^2}\right)$

Huge jump from ground state
to next higher electronic state
$E_2 - E_1 = 10.2$ eV
Lyman α (1216 Angstroms)

Some light reading if you want to learn more about the history behind these results, and biographies of the people who figured it out…