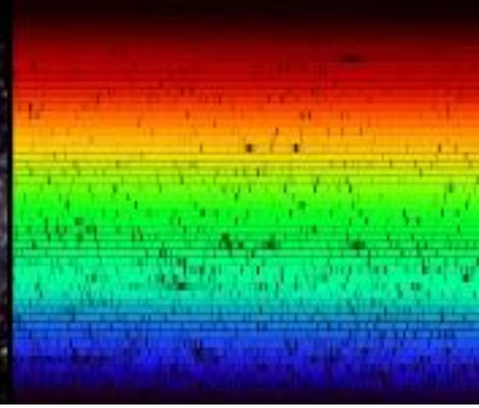


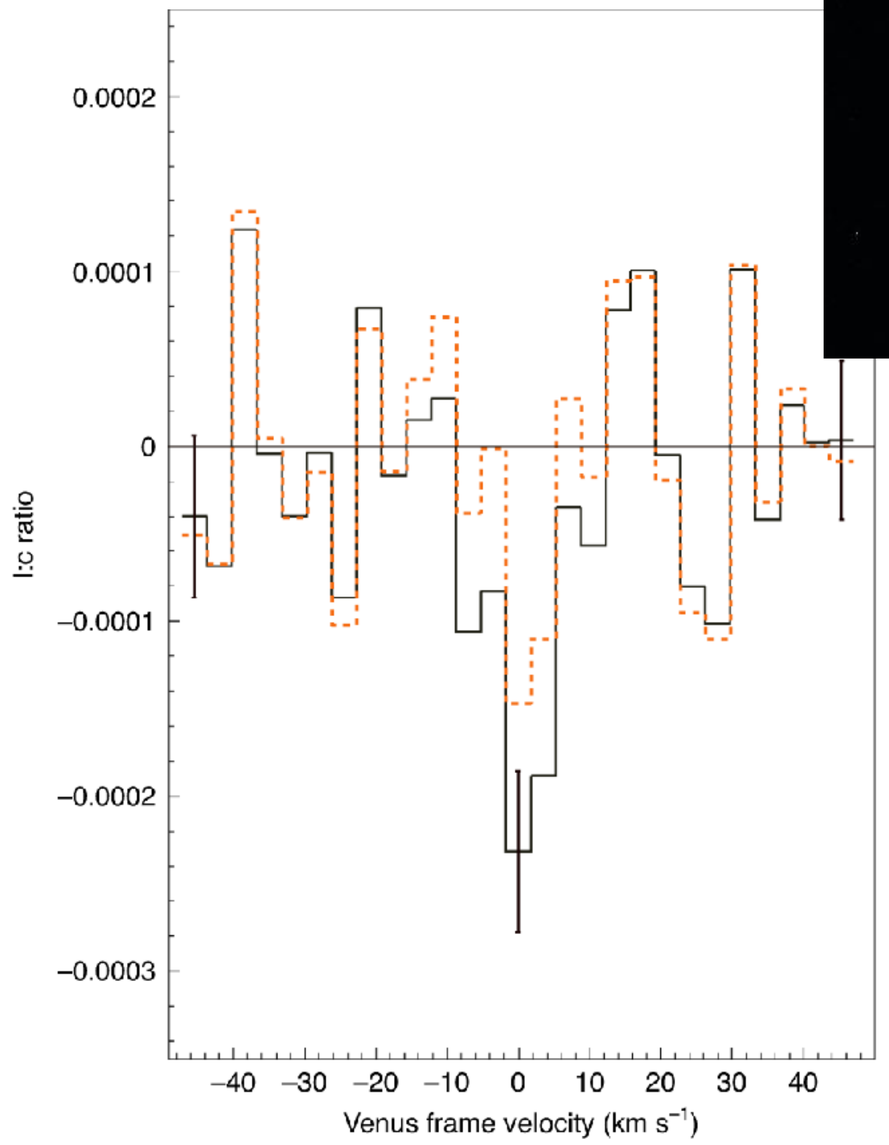
Week 4: Light / Solar System

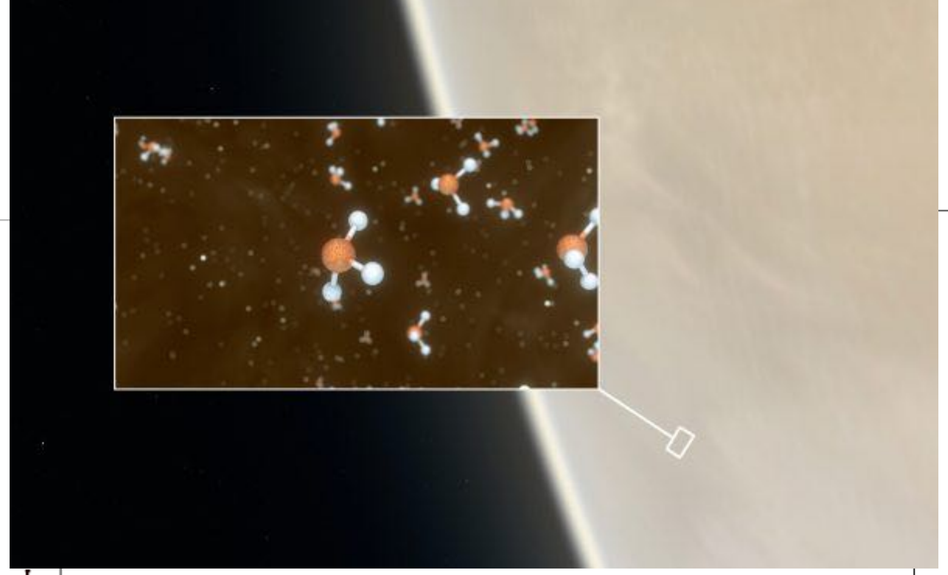
HW 2 past due (any submission before now is OK)

HW 3 due on Thursday @ 10:45am

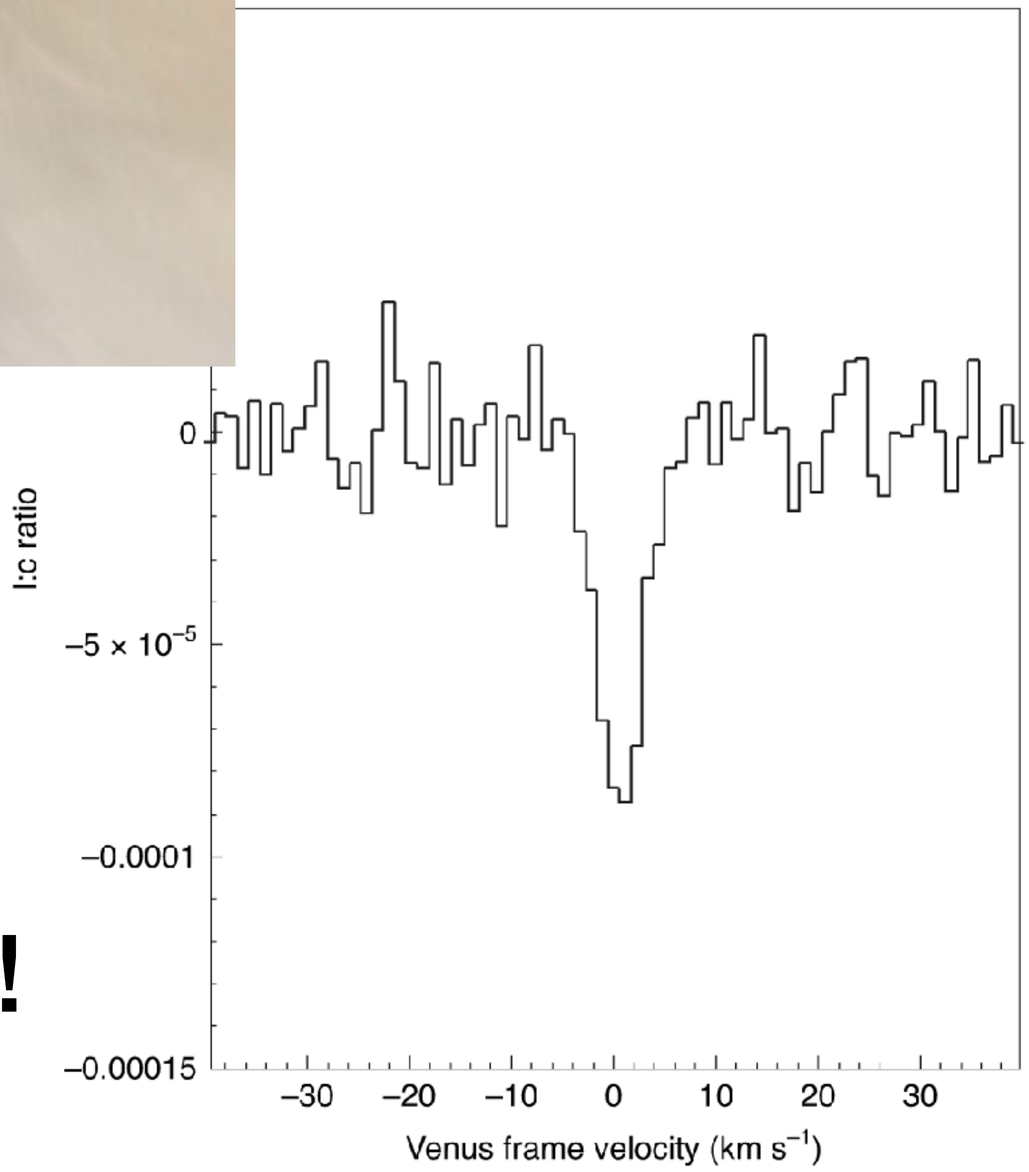
Read Ch. 5 (except 5.5),
and 7.1, 8.1-2, 11.1-2 for Thursday

JCMT



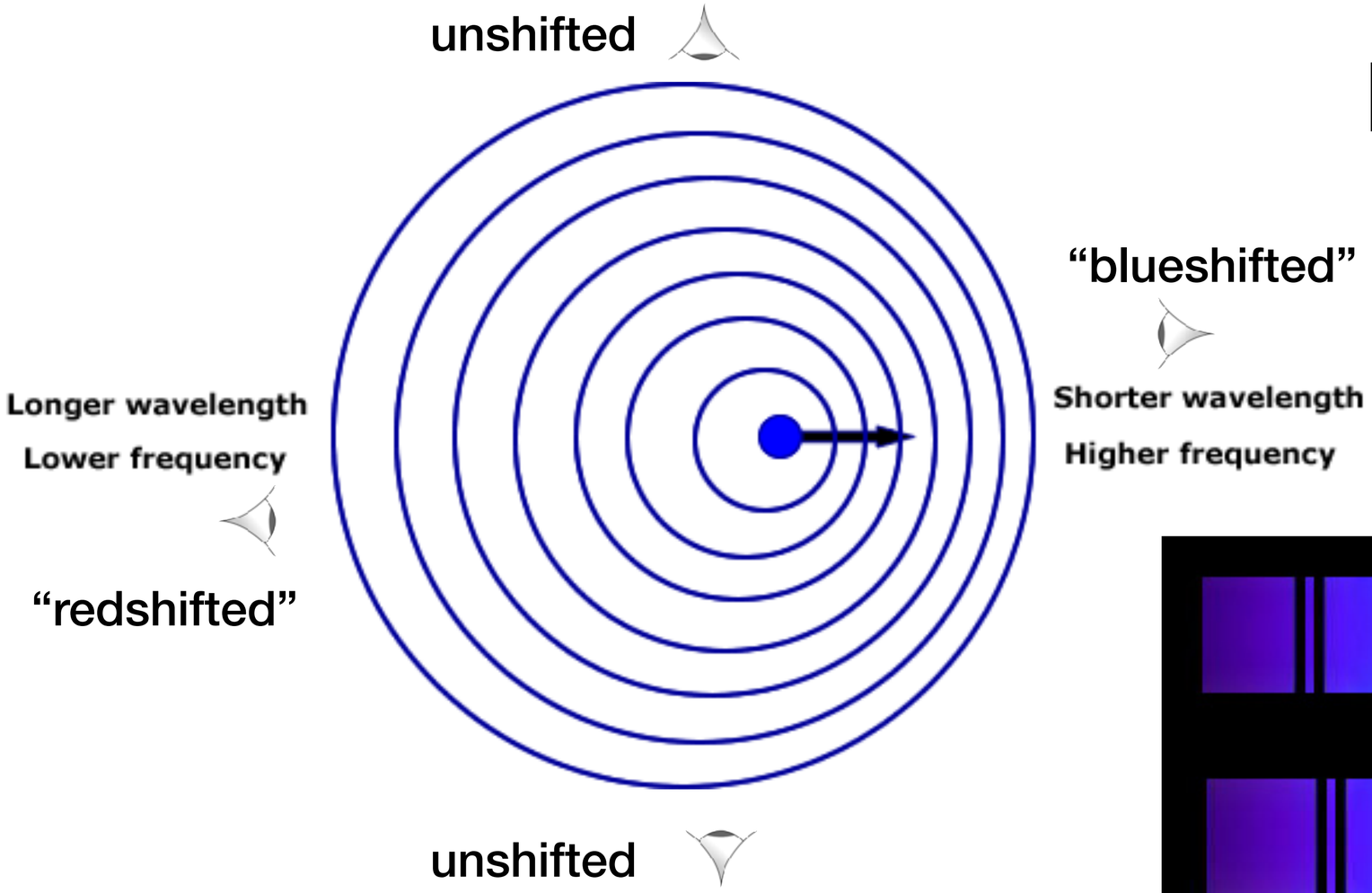


ALMA

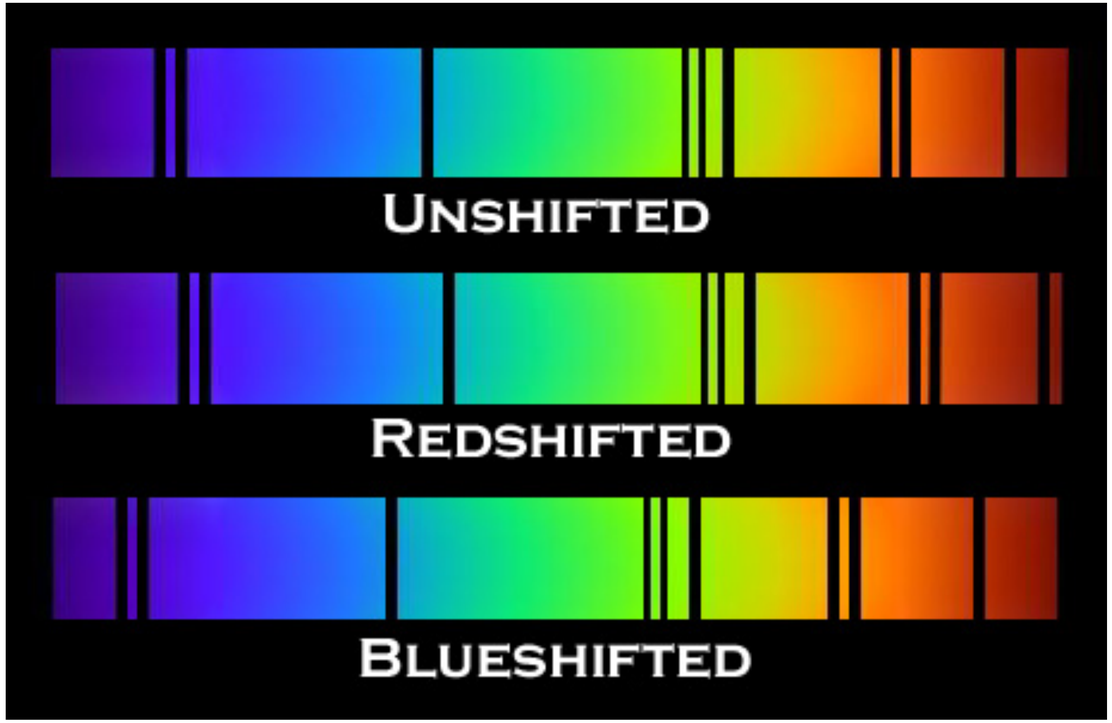


Life on ~~Mars~~ *VENUS*?!?!?!

Doppler Shift



$$z = \frac{\Delta\lambda}{\lambda} = \frac{\Delta\nu}{\nu}$$



Allows us to infer motions
along the “line of sight”

Lines are not delta functions!

i.e., the difference b/t energy levels is NOT exact

Motion-induced Broadening (small Doppler shifts cause lines to appear more broad)

- Thermal Broadening
- Rotational Broadening
- Turbulent Broadening

Other Types of Broadening

- Natural Broadening
- Pressure Broadening
- Zeeman Broadening

Natural Broadening

$$\frac{dN_{\rm phot}}{dt} = n_2 A_{21}$$

$$A_{21} \sim 10^8 \ {\rm s}^{-1} \quad \text{(permitted)}$$

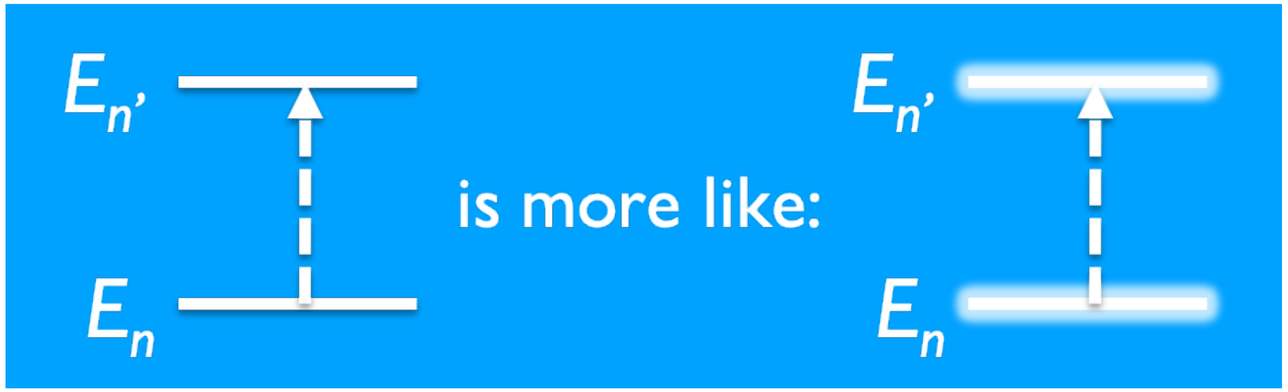
$$\sim 1 \ {\rm s}^{-1} \quad \text{(forbidden)}$$

Heisenberg uncertainty principle

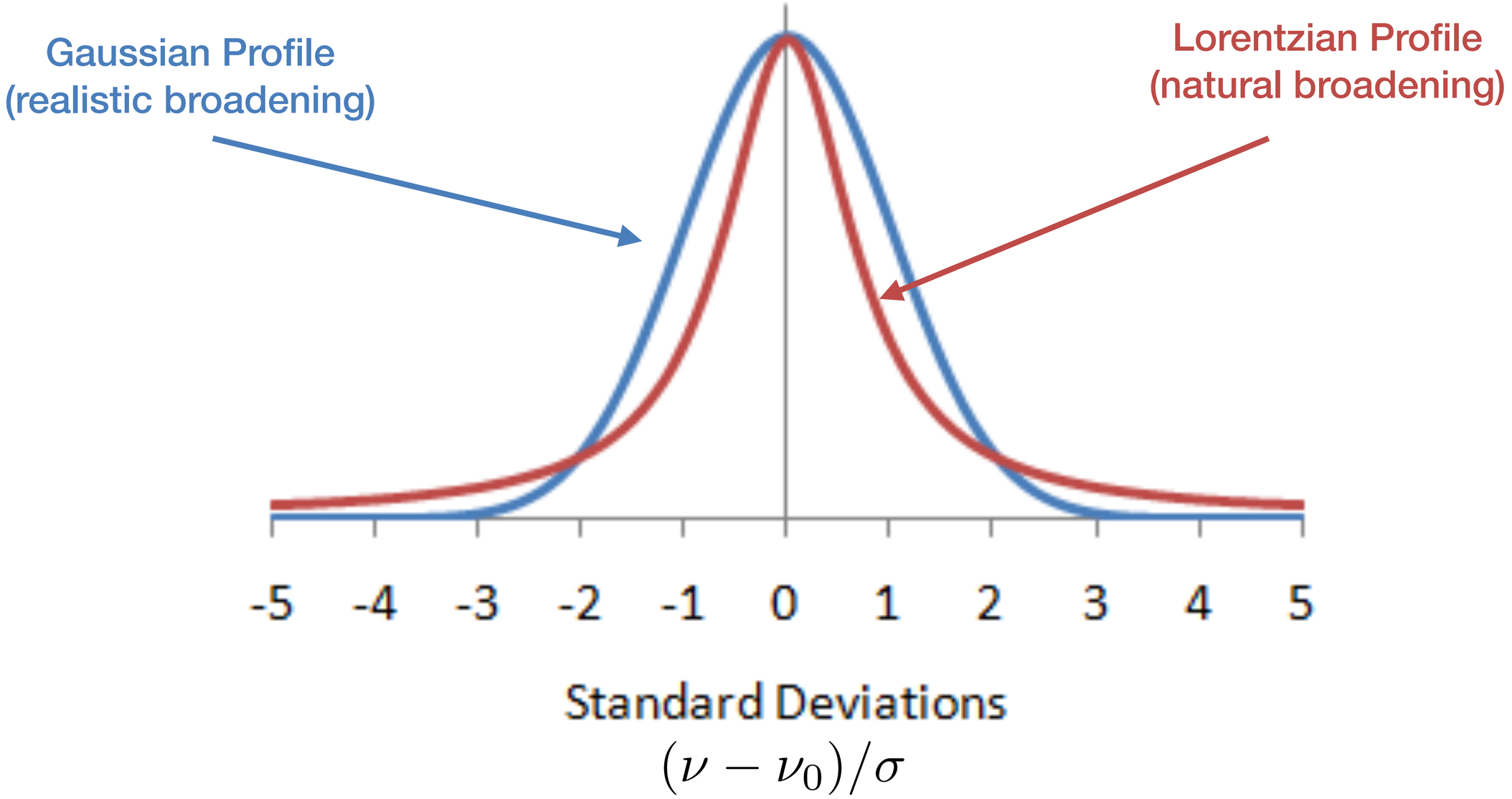
$$\Delta x \cdot \Delta p \gtrsim \hbar$$

$$(\frac{\Delta x}{c})(\Delta p \cdot c) \gtrsim \hbar$$

$$\Delta t \cdot \Delta E \gtrsim \hbar$$



Broadened Line Shapes



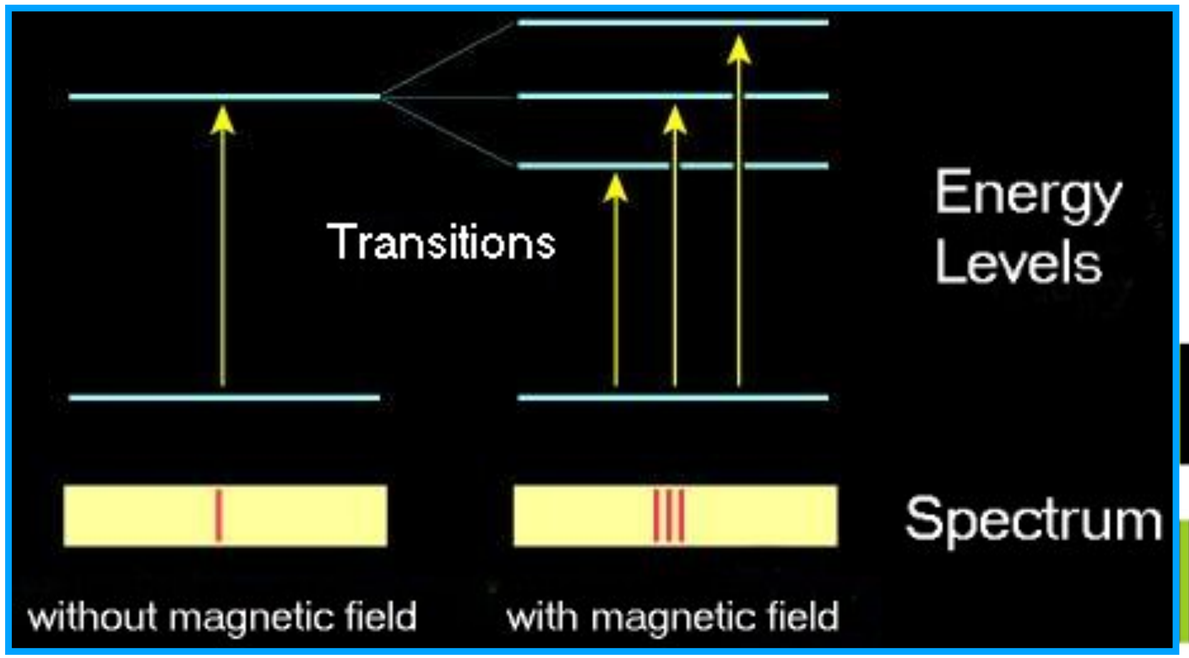
Lines are not delta functions!

i.e., the difference b/t energy levels is NOT exact

Dense environments, frequent collisions induce electric fields that modify energy levels

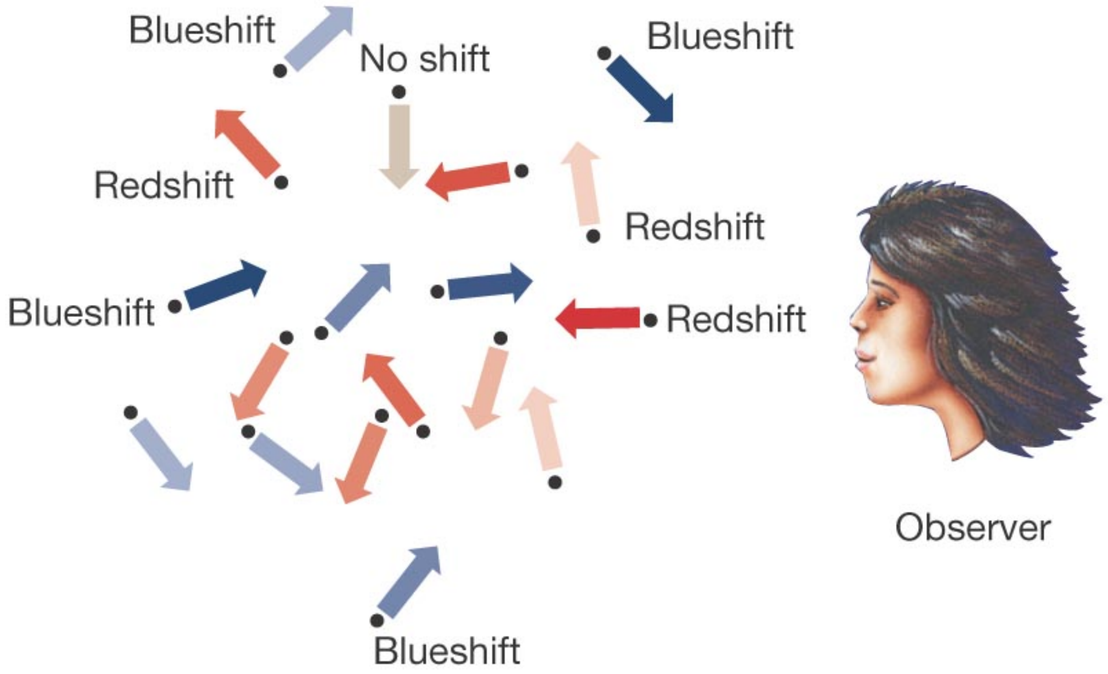
Other Types of Broadening

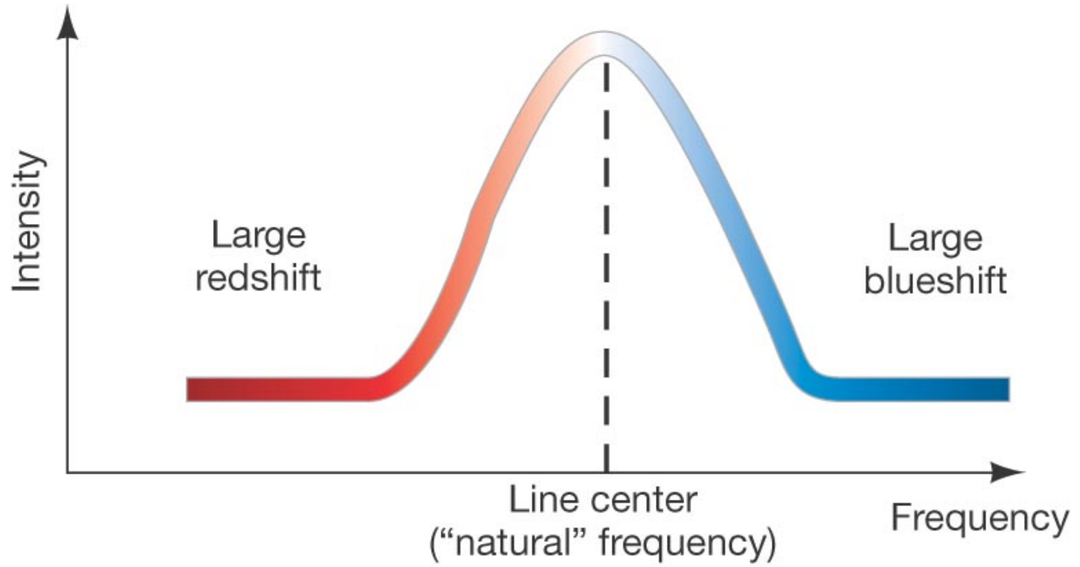
- Natural Broadening
- Pressure Broadening
- Zeeman Broadening



broadened

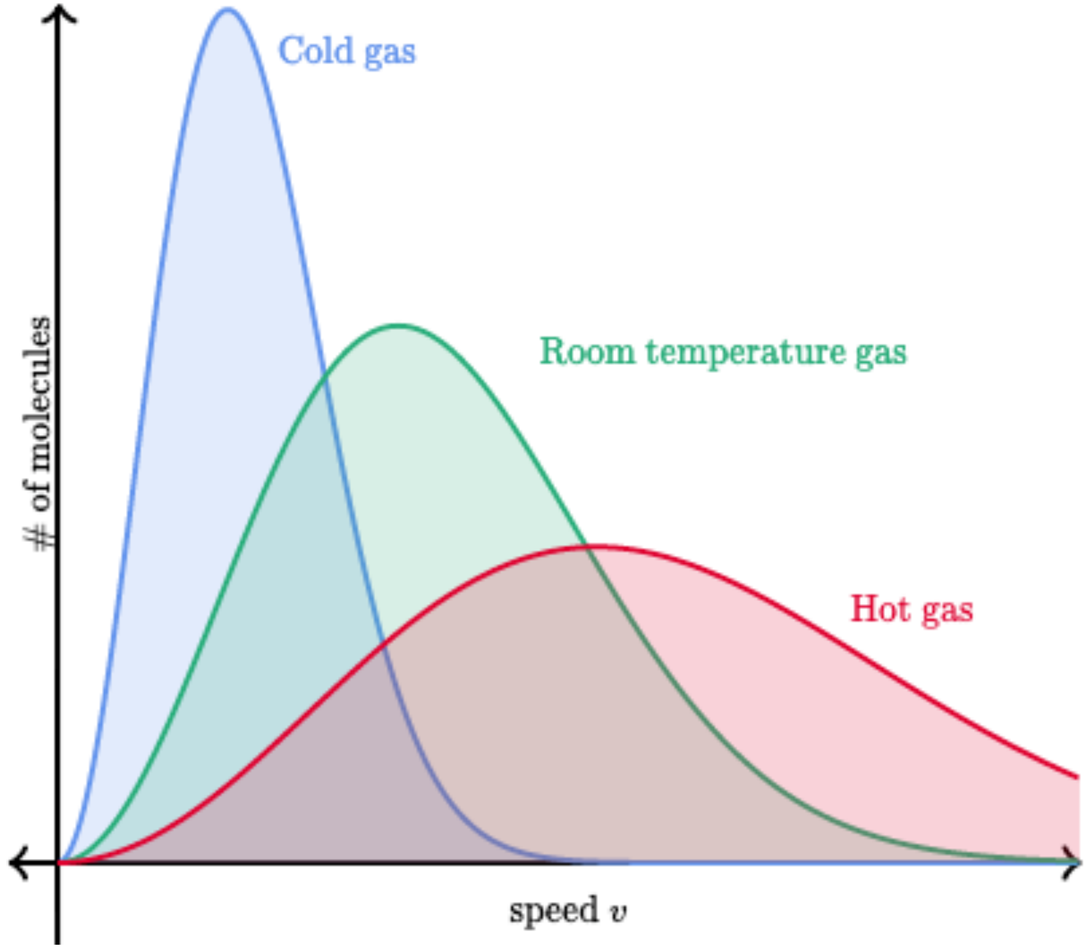
Doppler Broadening





Thermal Broadening

Velocity distribution of particles in thermal equilibrium have a Maxwell-Boltzmann distribution



$$F(v)dv = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 \exp\left(-\frac{mv^2}{2kT}\right) dv$$

$$F(E)dE = F(v)\frac{dv}{dE} = \frac{2}{\sqrt{\pi}kT}\left(\frac{E}{kT}\right)^{1/2} \exp\left(-\frac{E}{kT}\right)$$

$$\langle x \rangle = \int x f(x) dx$$

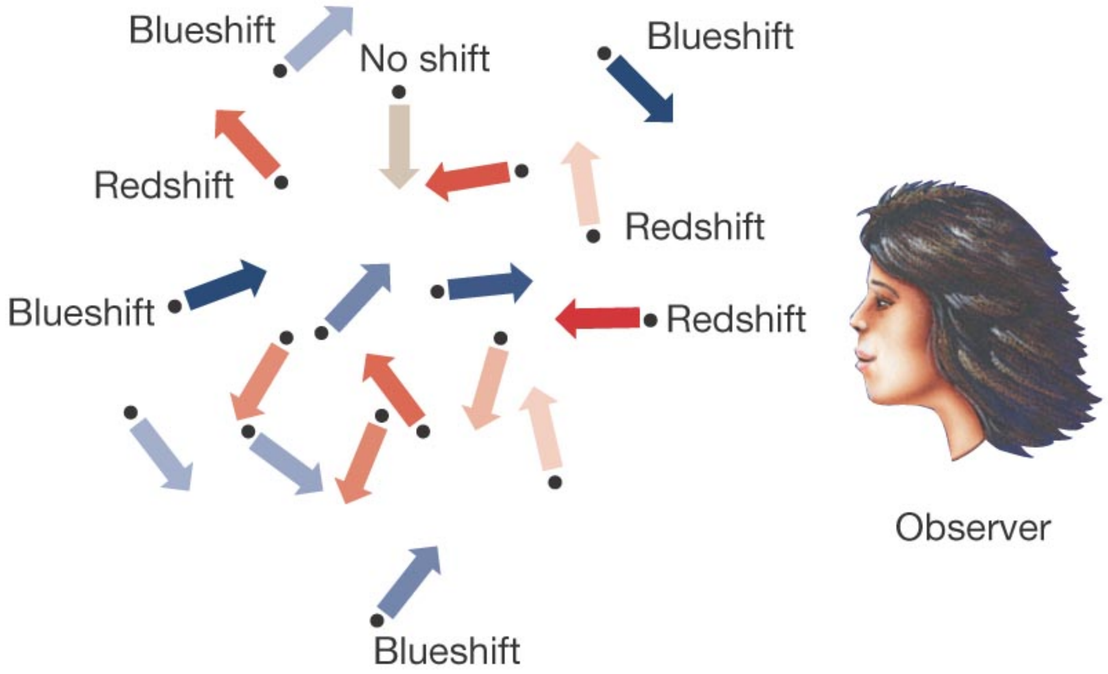
$$\langle v \rangle = \sqrt{\frac{8kT}{\pi m}}$$

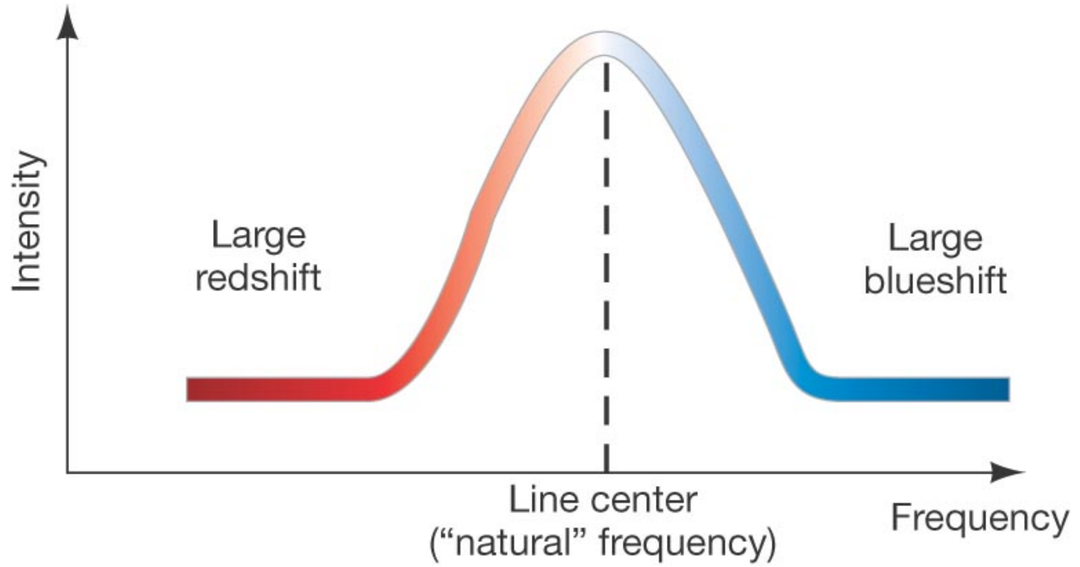
Avg. particle speed

$$\langle E \rangle = \frac{3}{2}kT$$

Avg. particle kinetic energy

Doppler Broadening





line-of-sight "velocity dispersion" (width of a Gaussian distribution)

Thermal Broadening

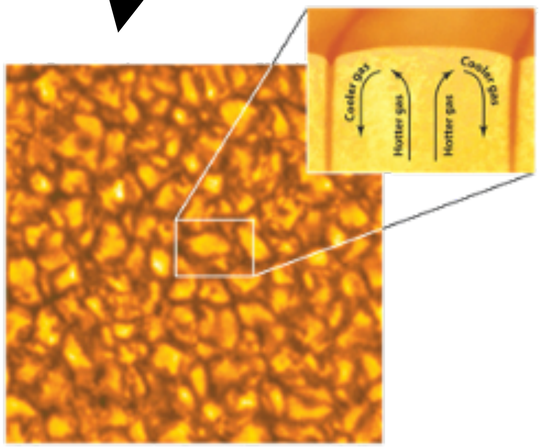
$$\sigma_{\rm los} = \left(\frac{kT}{\mu m_p}\right)^{1/2} \approx 100\ {\rm m\ s^{-1}} \left(\frac{T}{1\ K}\right)^{1/2} \mu^{-1/2} \longrightarrow \frac{\Delta\lambda}{\lambda} \approx \frac{\sigma_{\rm los}}{c}$$

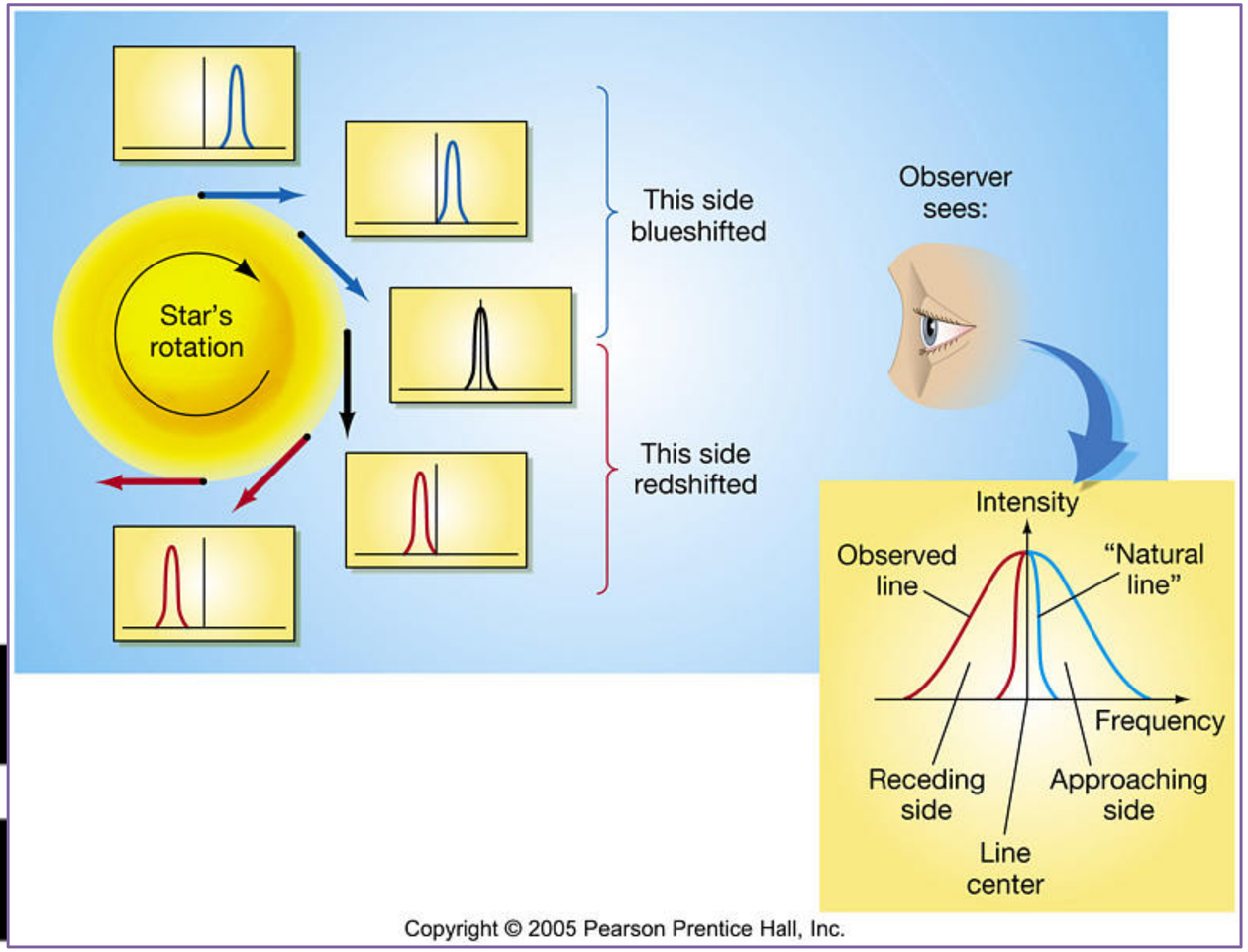
Lines are not delta functions!

i.e., the difference b/t energy levels is NOT exact

Motion-induced Broadening (small Doppler shifts cause lines to appear more broad)

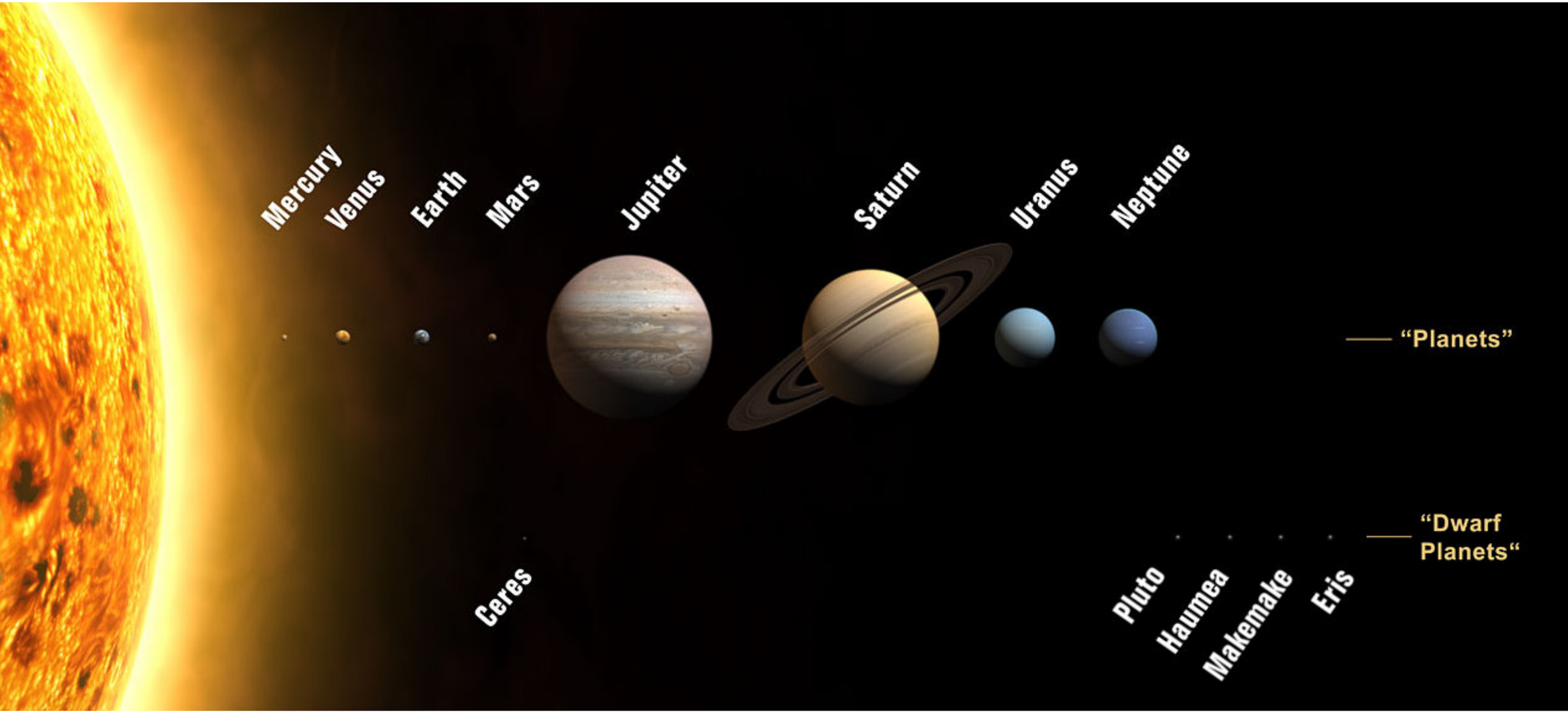
- Thermal Broadening
- Rotational Broadening
- Turbulent Broadening



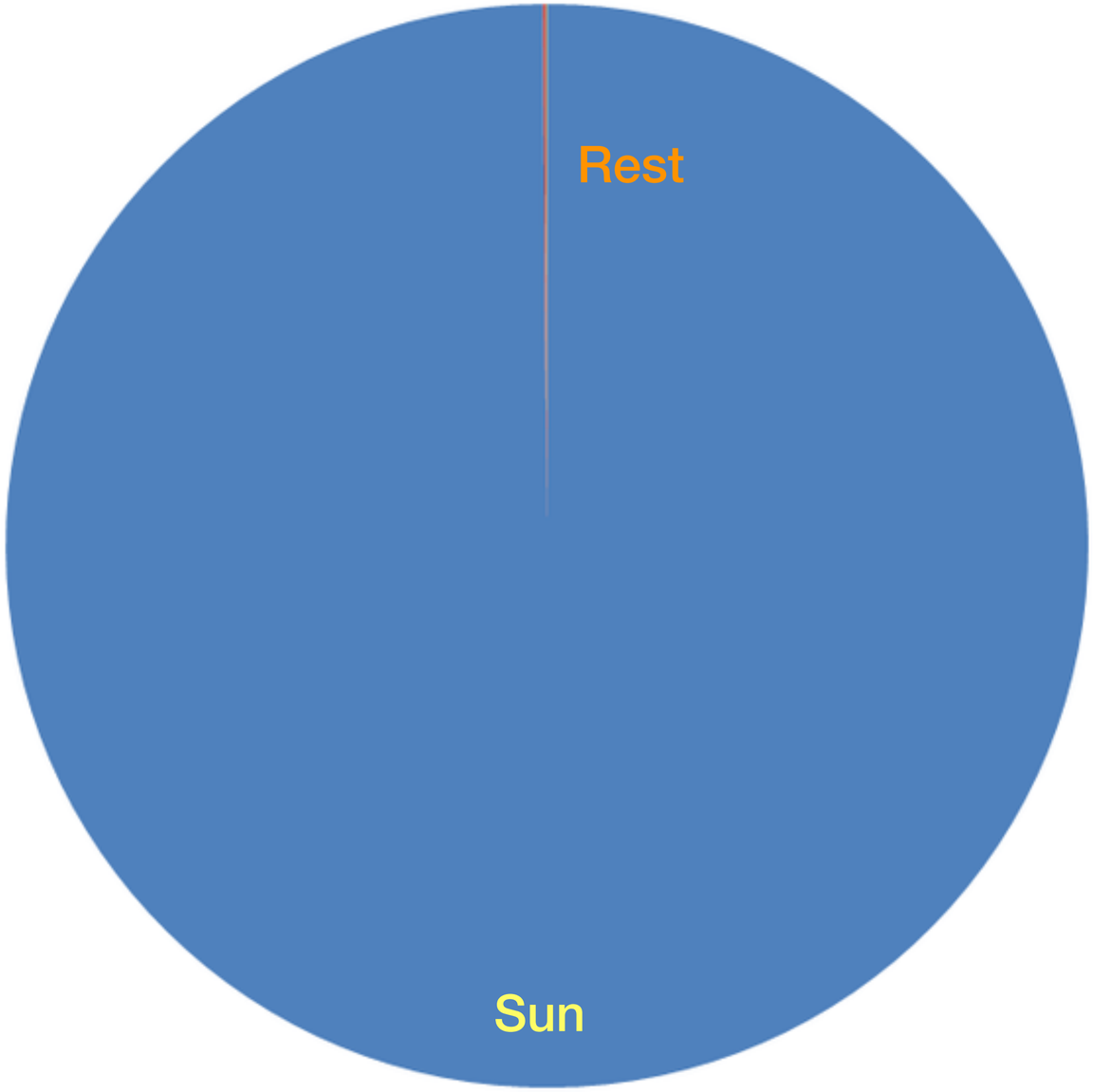


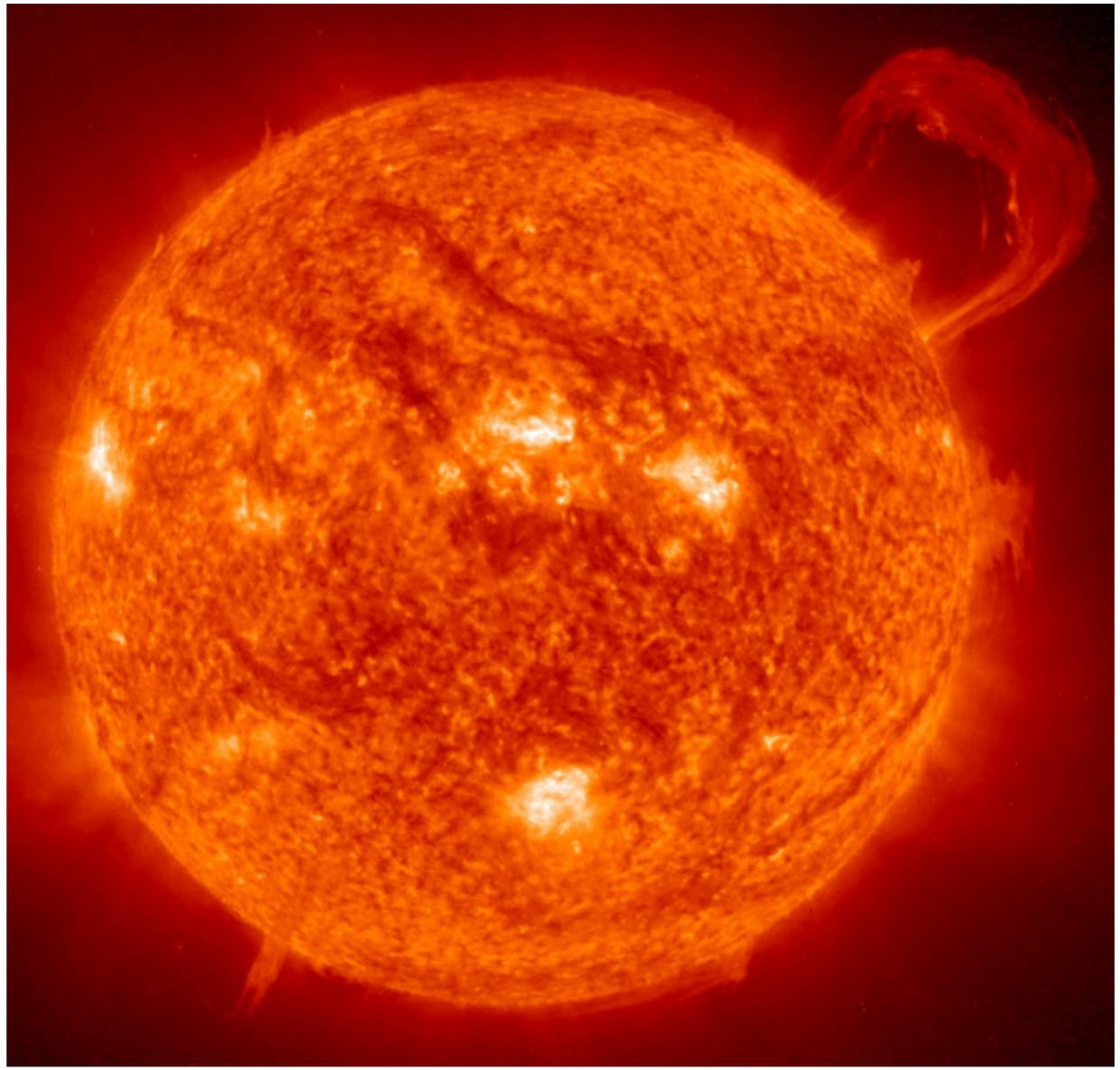
Radiative Transfer / mfp / optical depth / Blackbody Spectra

Solar System

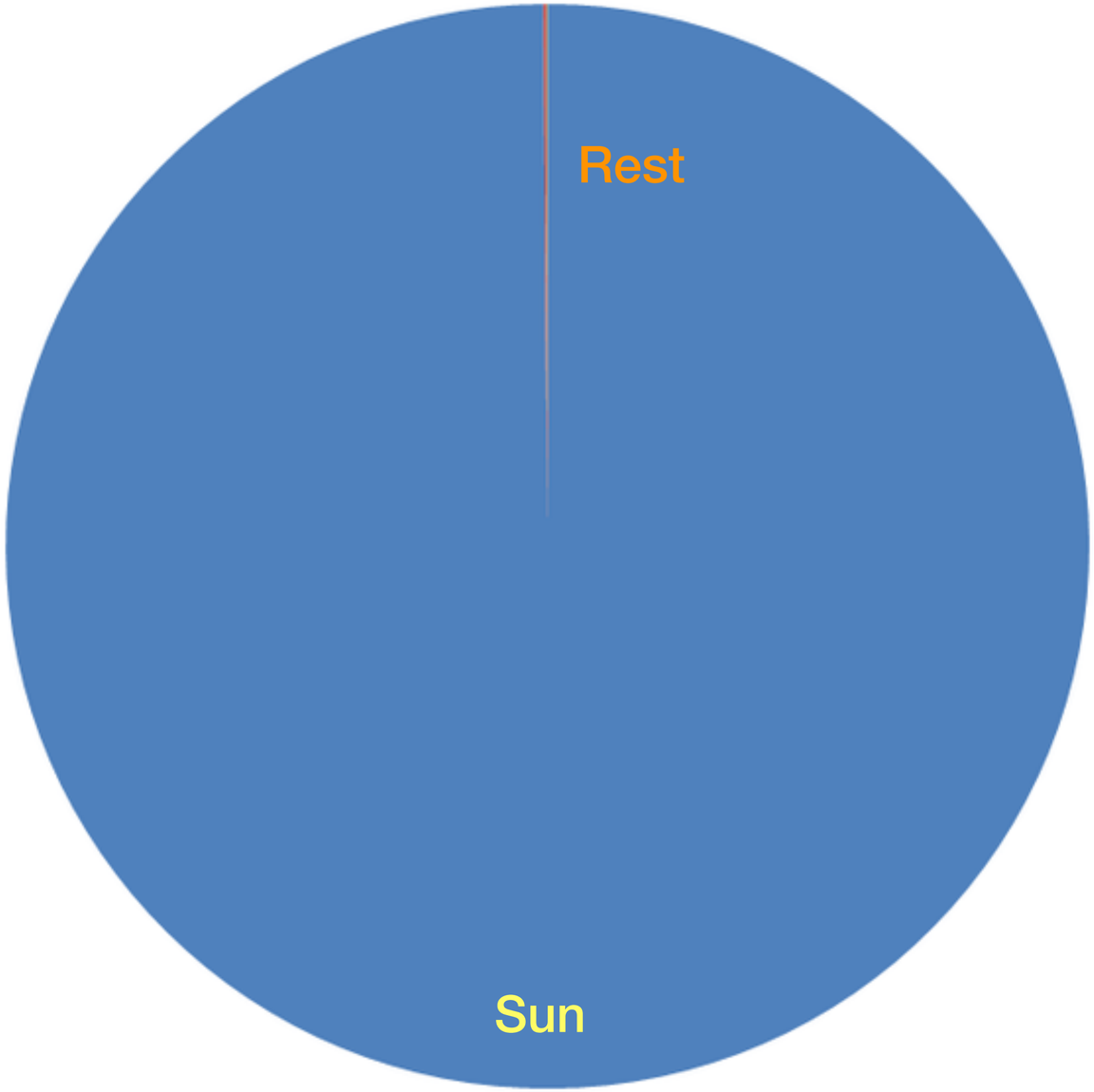


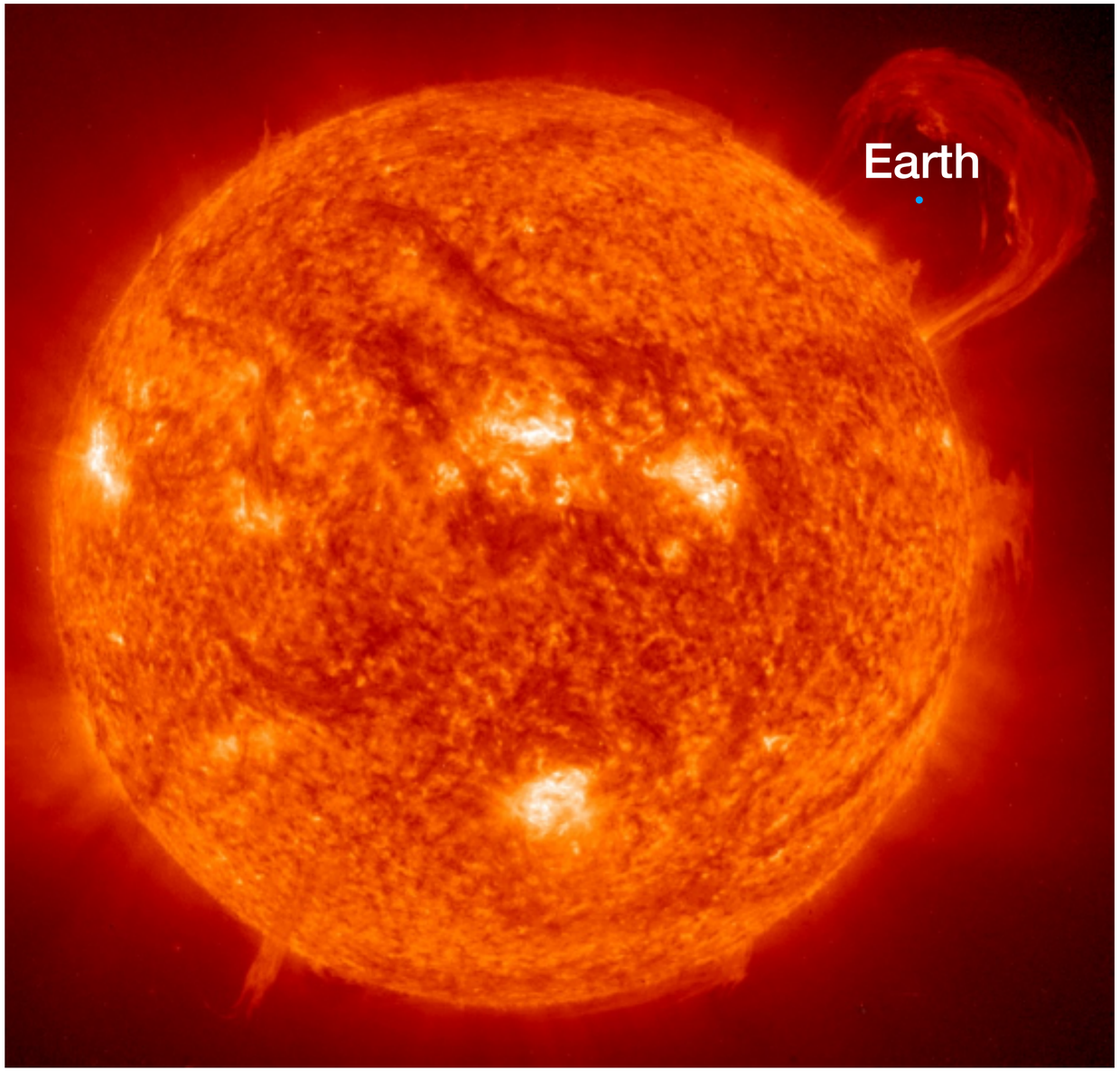
Mass Fractions





Mass Fractions



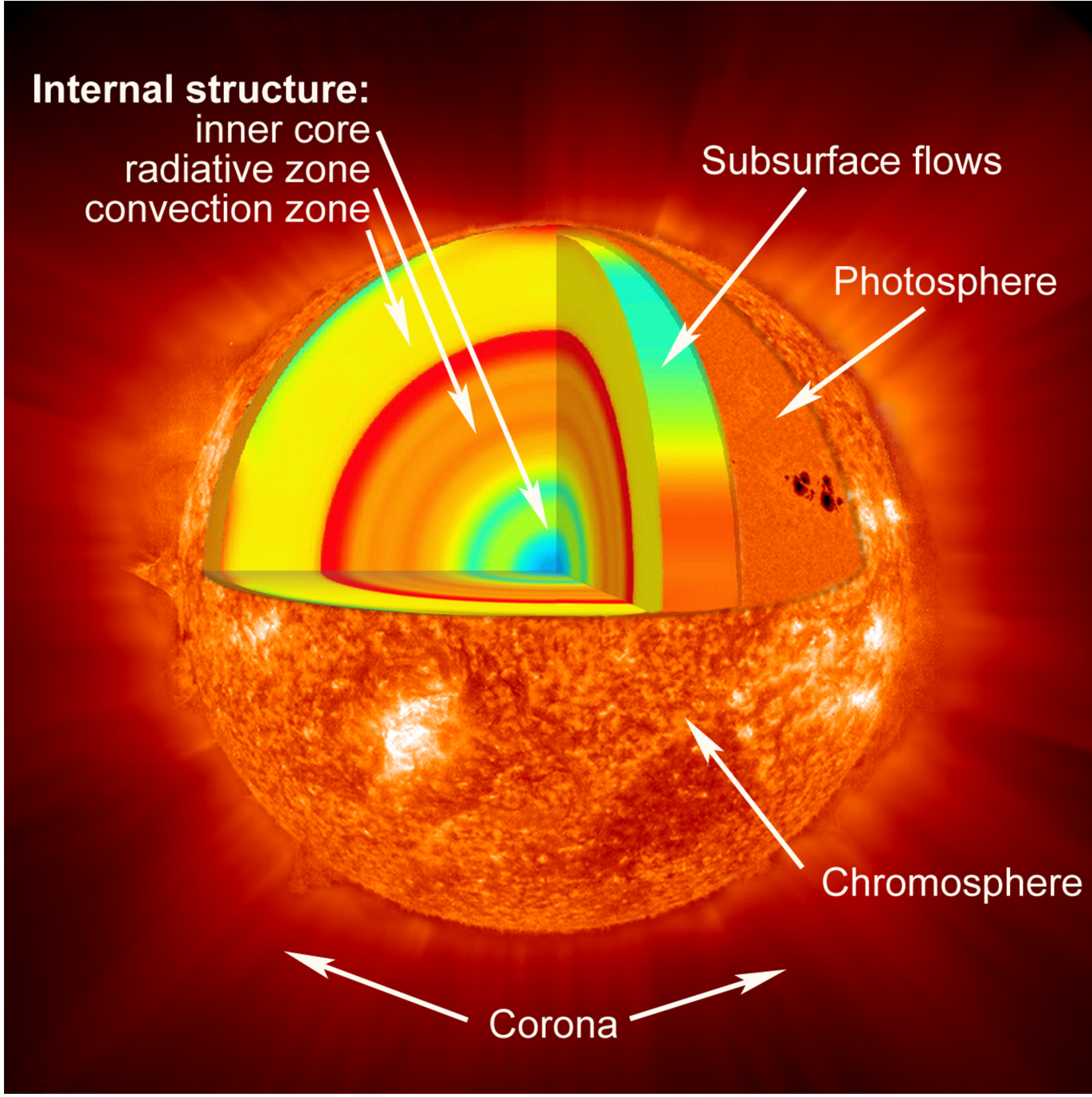


Structure of the Sun

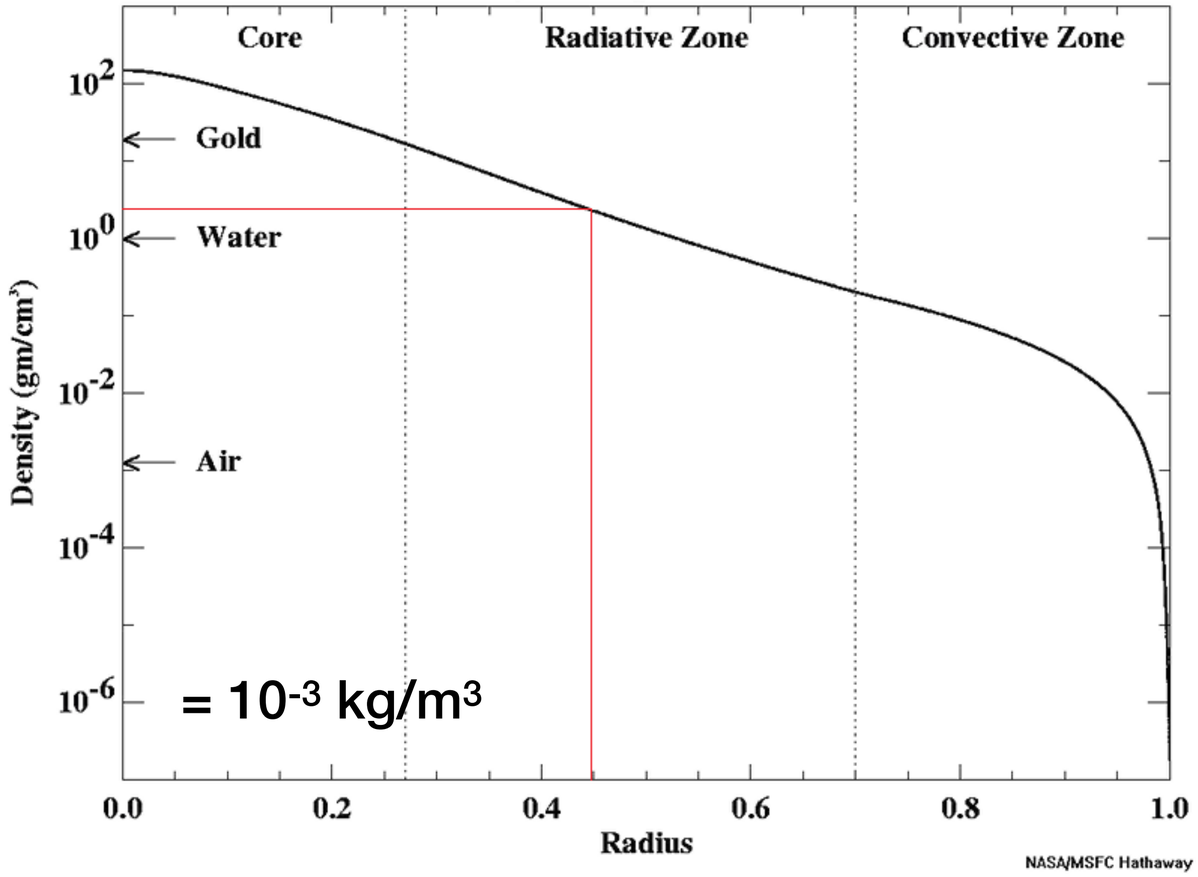
Core:
~15 million K
H —> He fusion produces Sun's photons

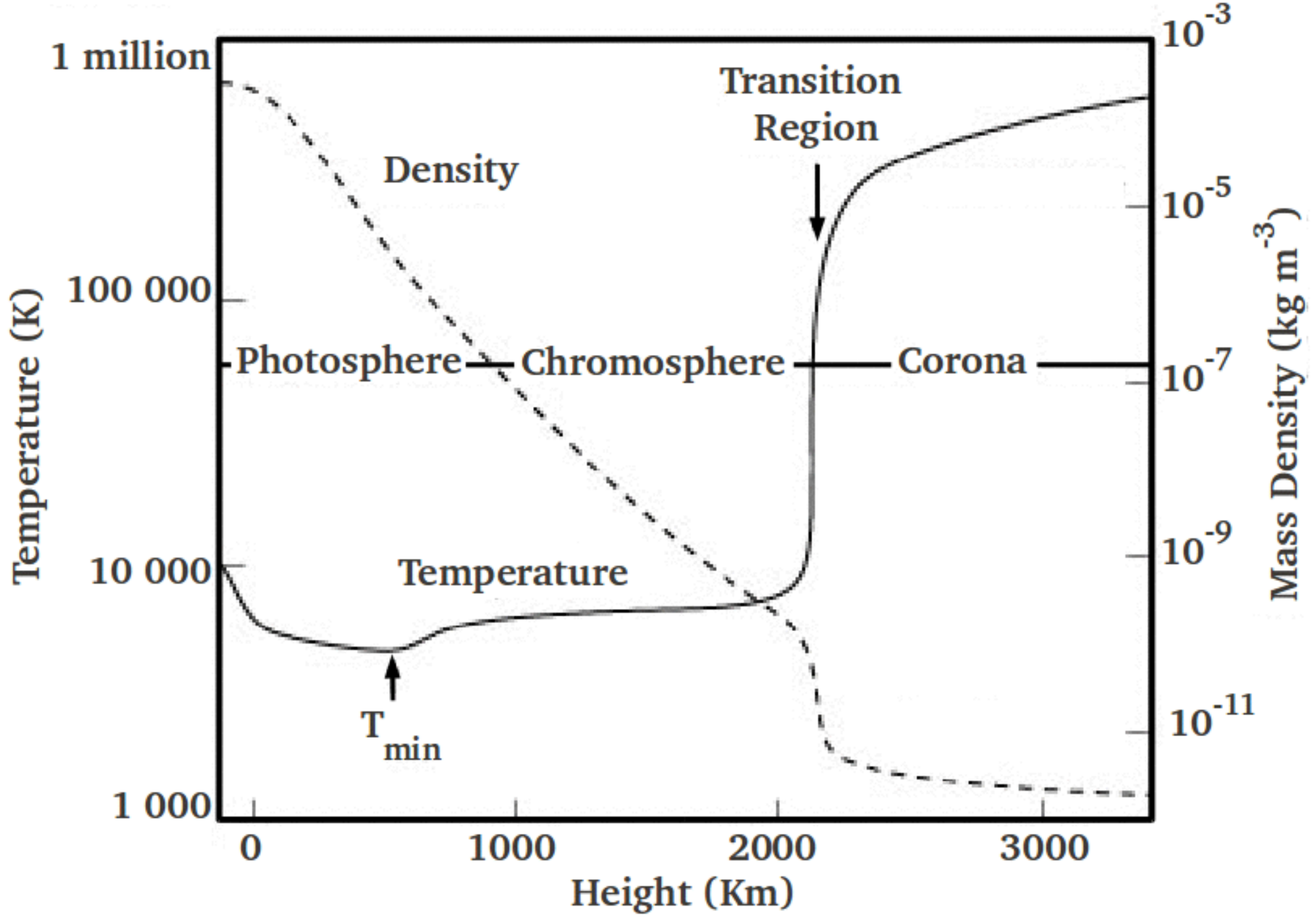
Photons take ~100,000 years to travel through the Sun, then take 8 min to reach the Earth

Temperature decreases outside the core until it falls to 5780 K at the "surface"

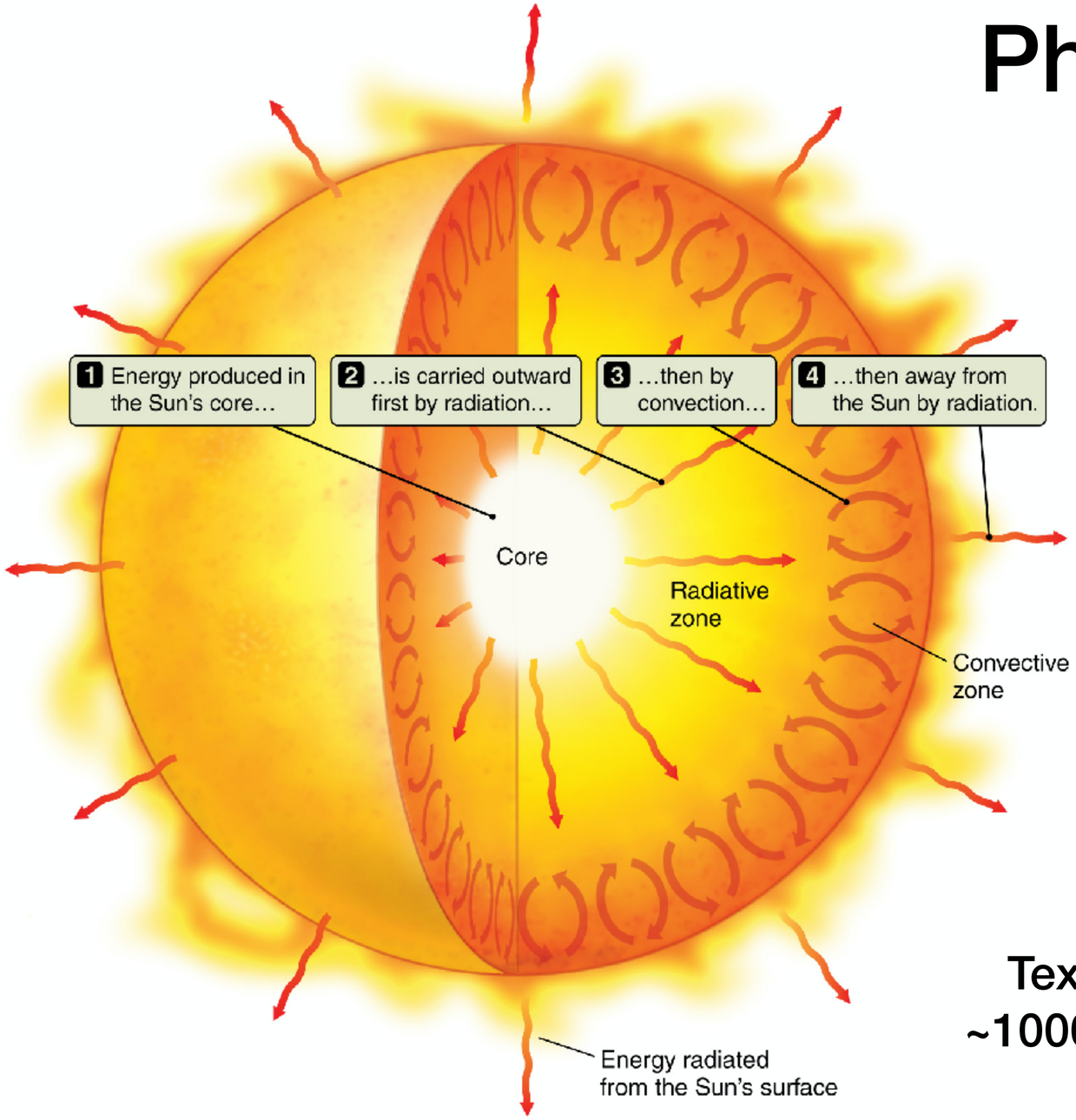


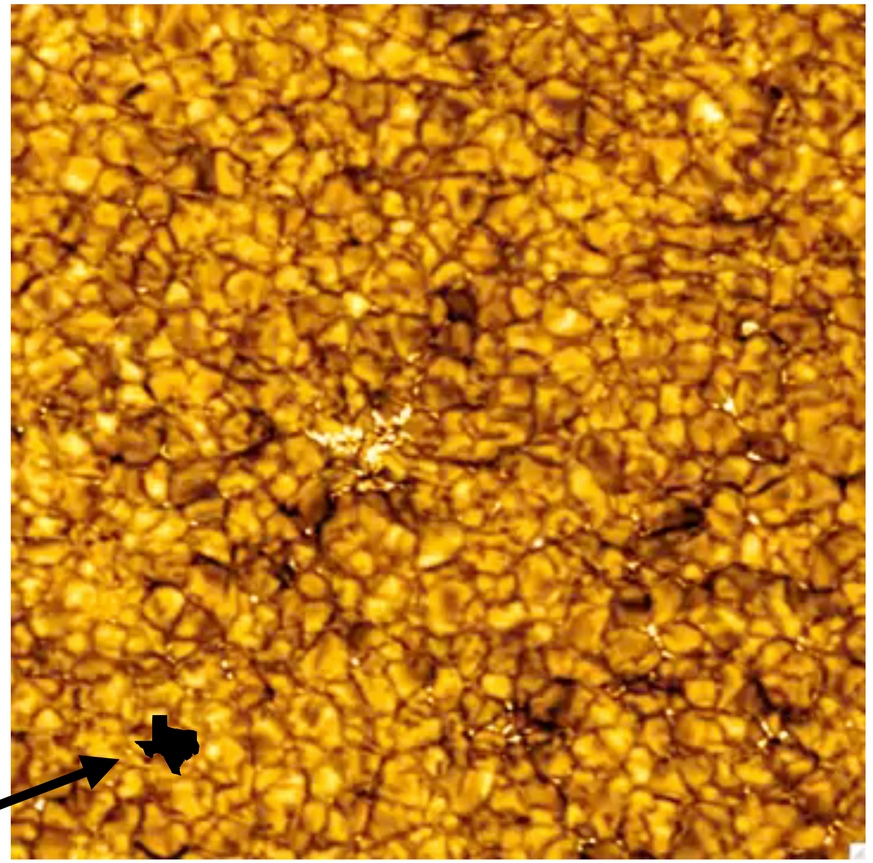
Temperature & Density Profiles of the Sun





Photons ultimately brought by convection cells





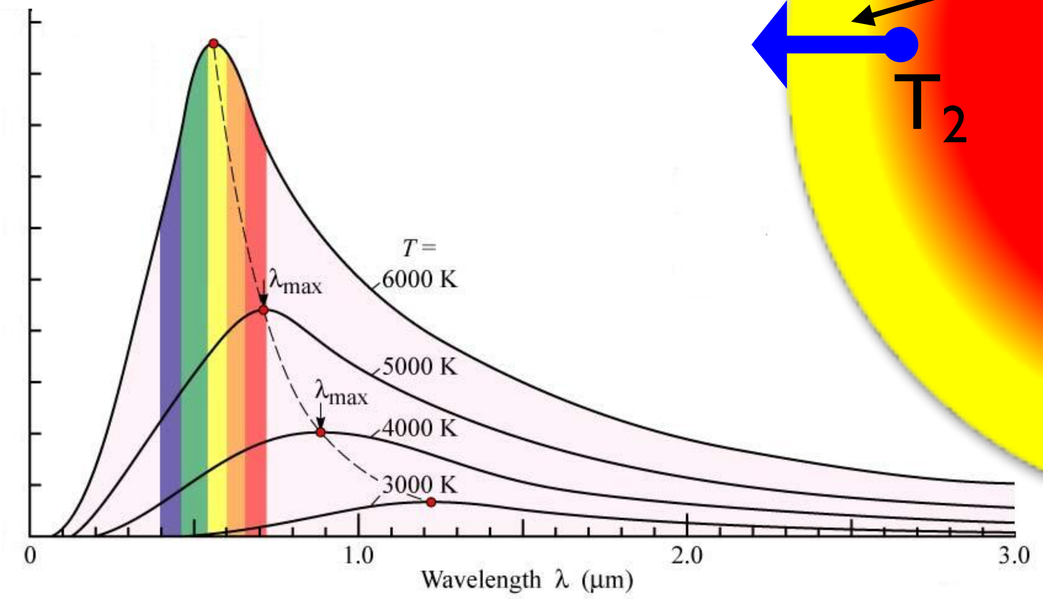
Texas
~1000 km

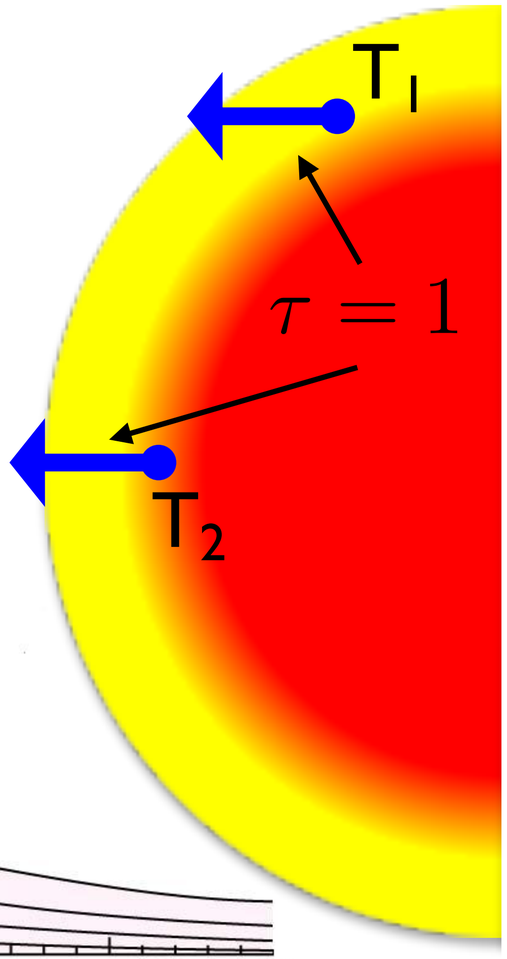
https://www.youtube.com/watch?v=W_Scoj4HqCQ

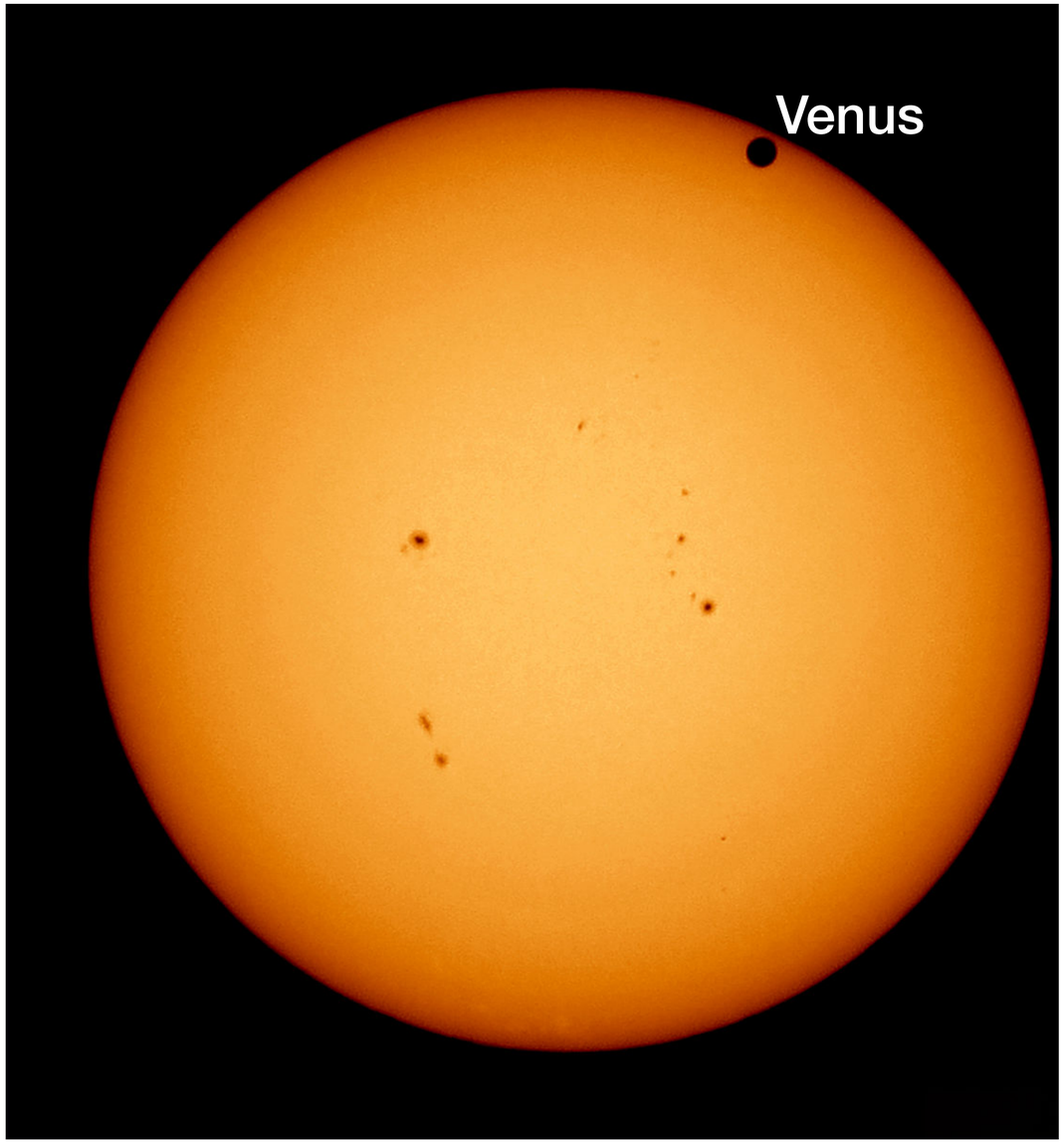
Photosphere: Limb Darkening

$$T_2 > T_1$$

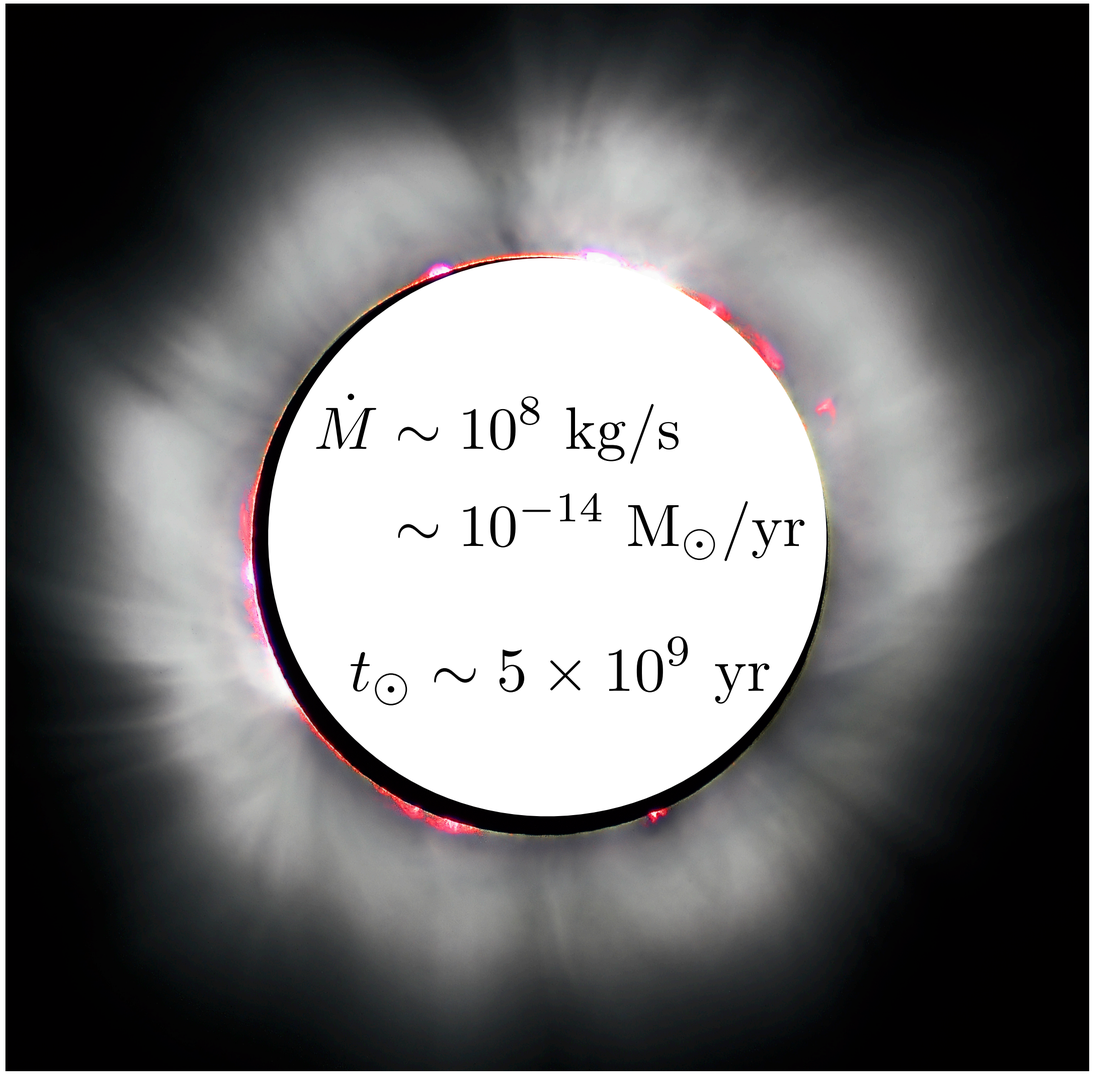
$$I_\lambda(T_2) > I_\lambda(T_1)$$

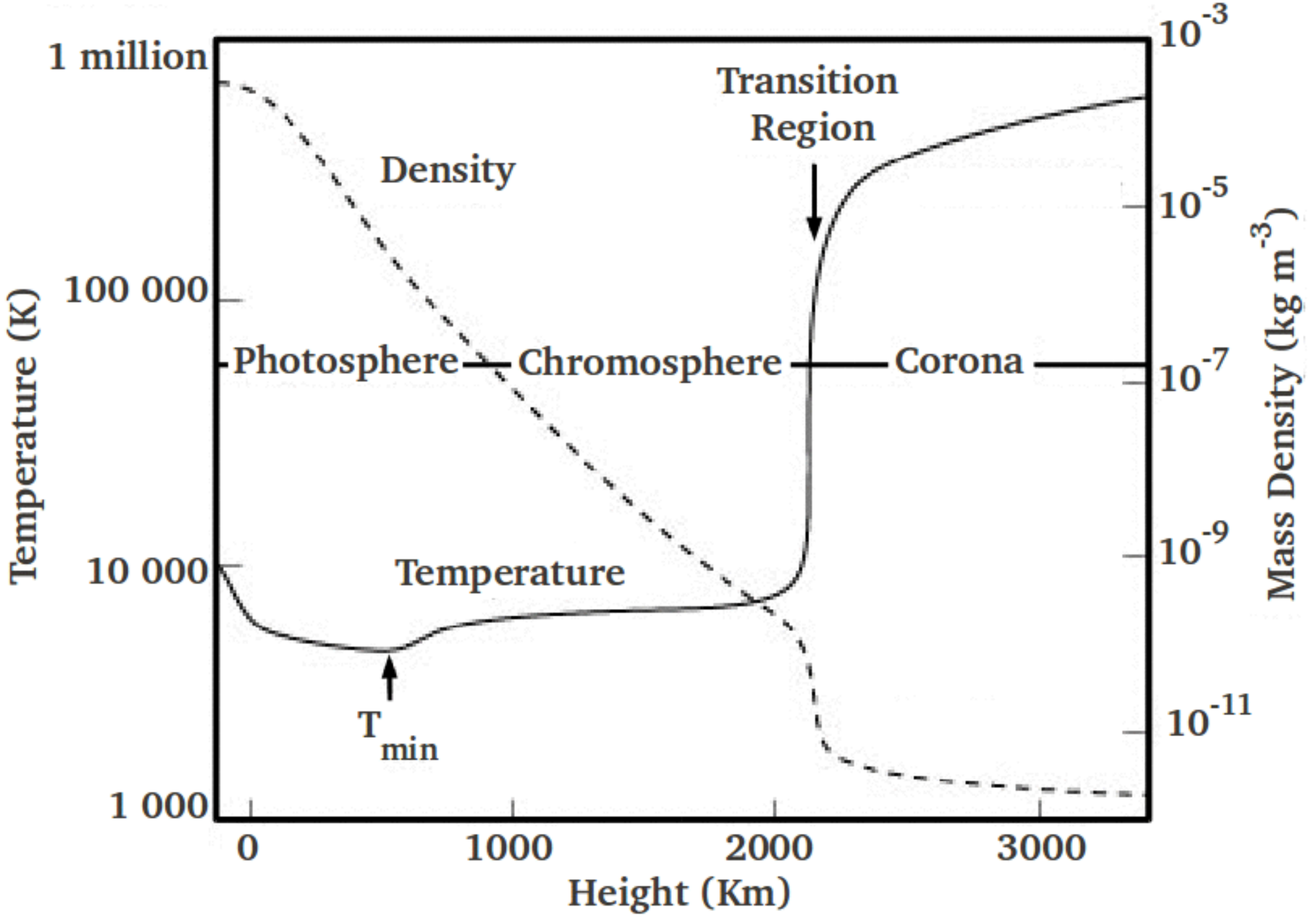






Corona: high T allows particles to reach v_{esc}





Mass Fractions