ASTR/PHYS 3070: Foundations Astronomy

Week 4 Tuesday

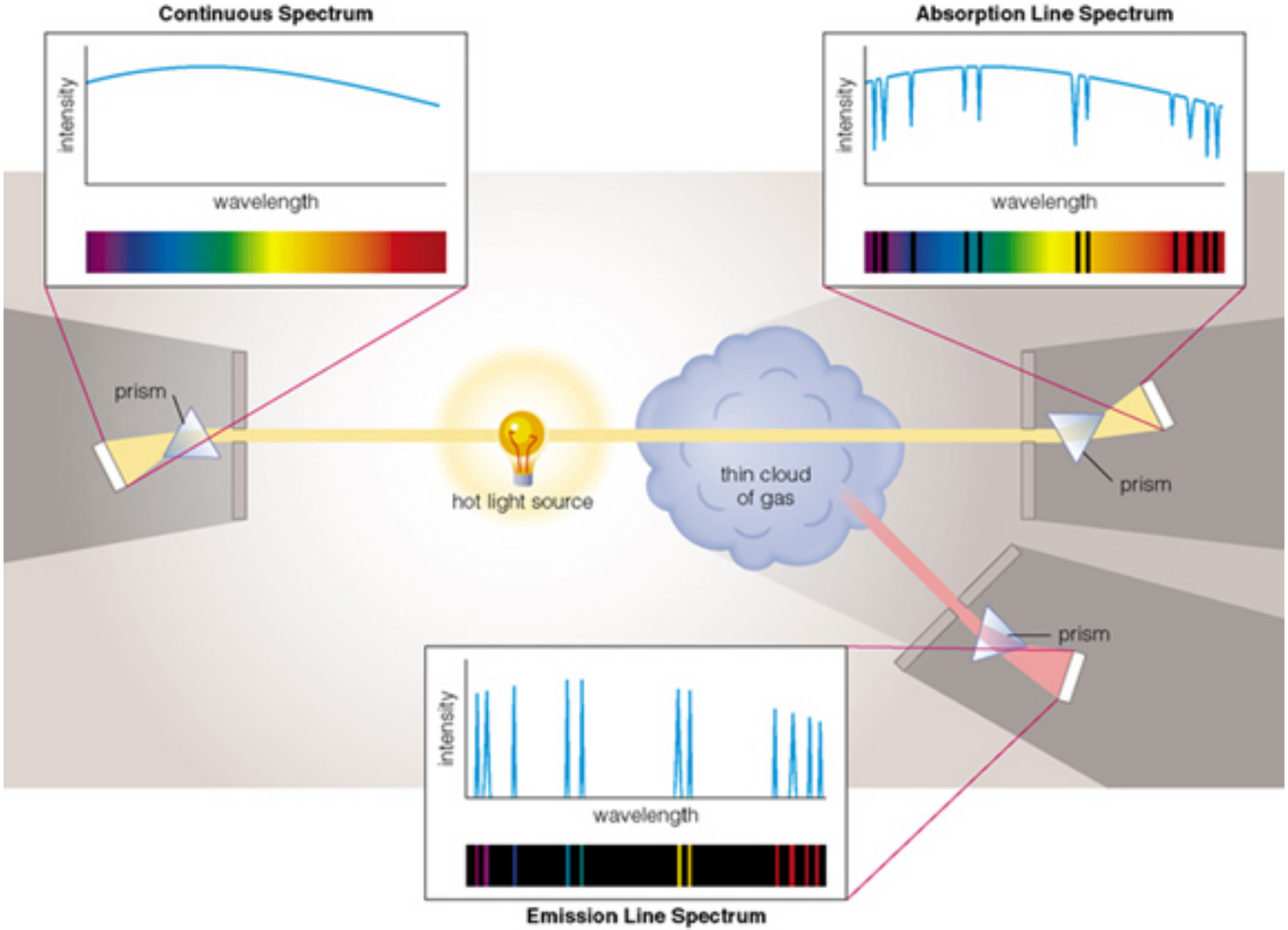
Today's Agenda

- Kirchoff's laws & Lines shift
- Lines broaden
- Radiative Transfer
- Equilibrium / blackbody spectrum
  - (as much as we get to)

Announcements / Reminders

- Read Chapter 5, 6.1, 6.4-7
- HW 3 due September 17th at 11:59pm via Canvas upload

- HEAP talk at 4pm in INSCC auditorium
  - Former U student (now at NASA Ames) talks about haze in planetary atmospheres

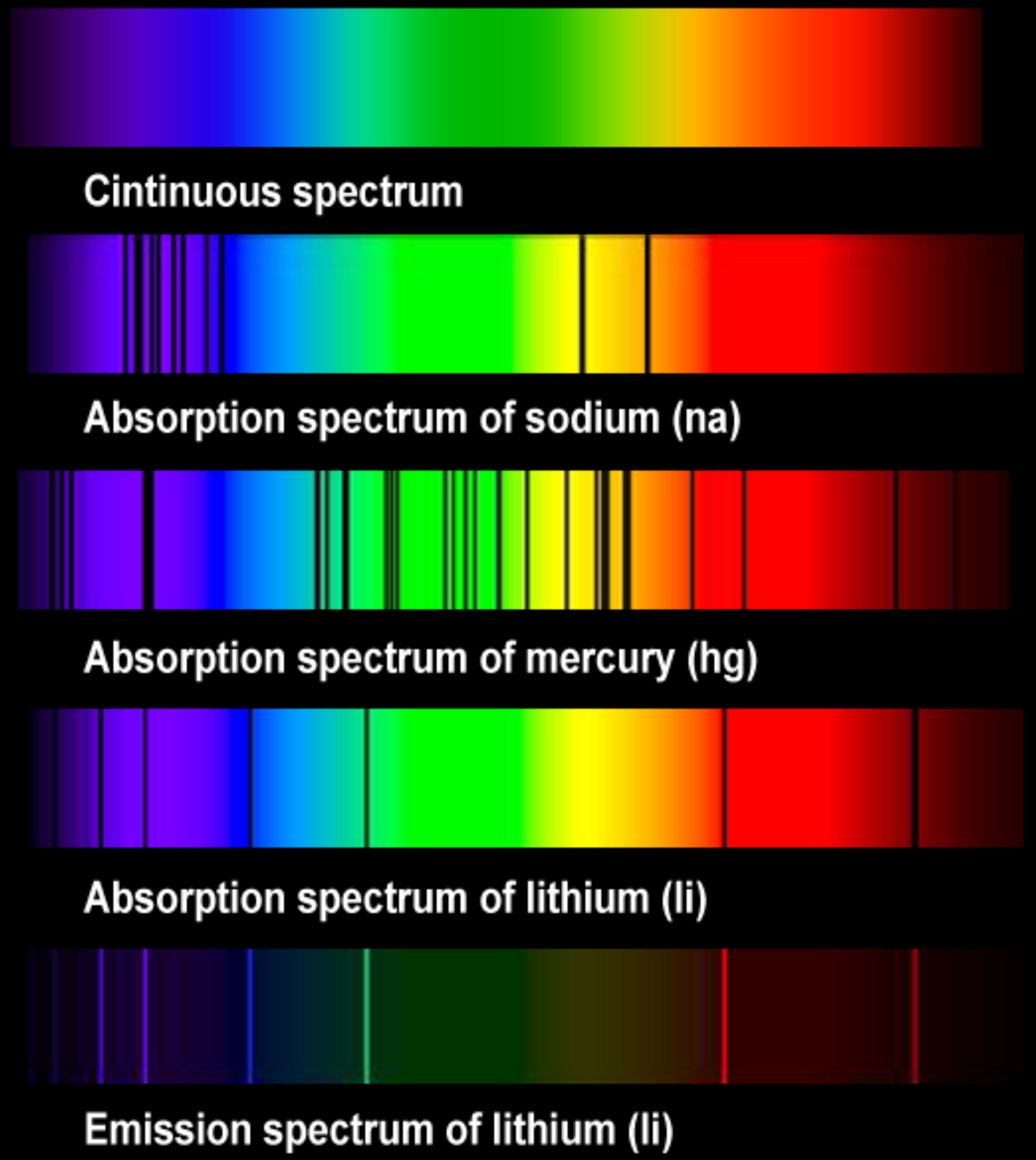

Continuous Spectrum
intensity
wavelength
Absorption Line Spectrum
intensity
wavelength
prism
hot light source
thin cloud of gas
prism
prism
intensity
wavelength
Emission Line Spectrum

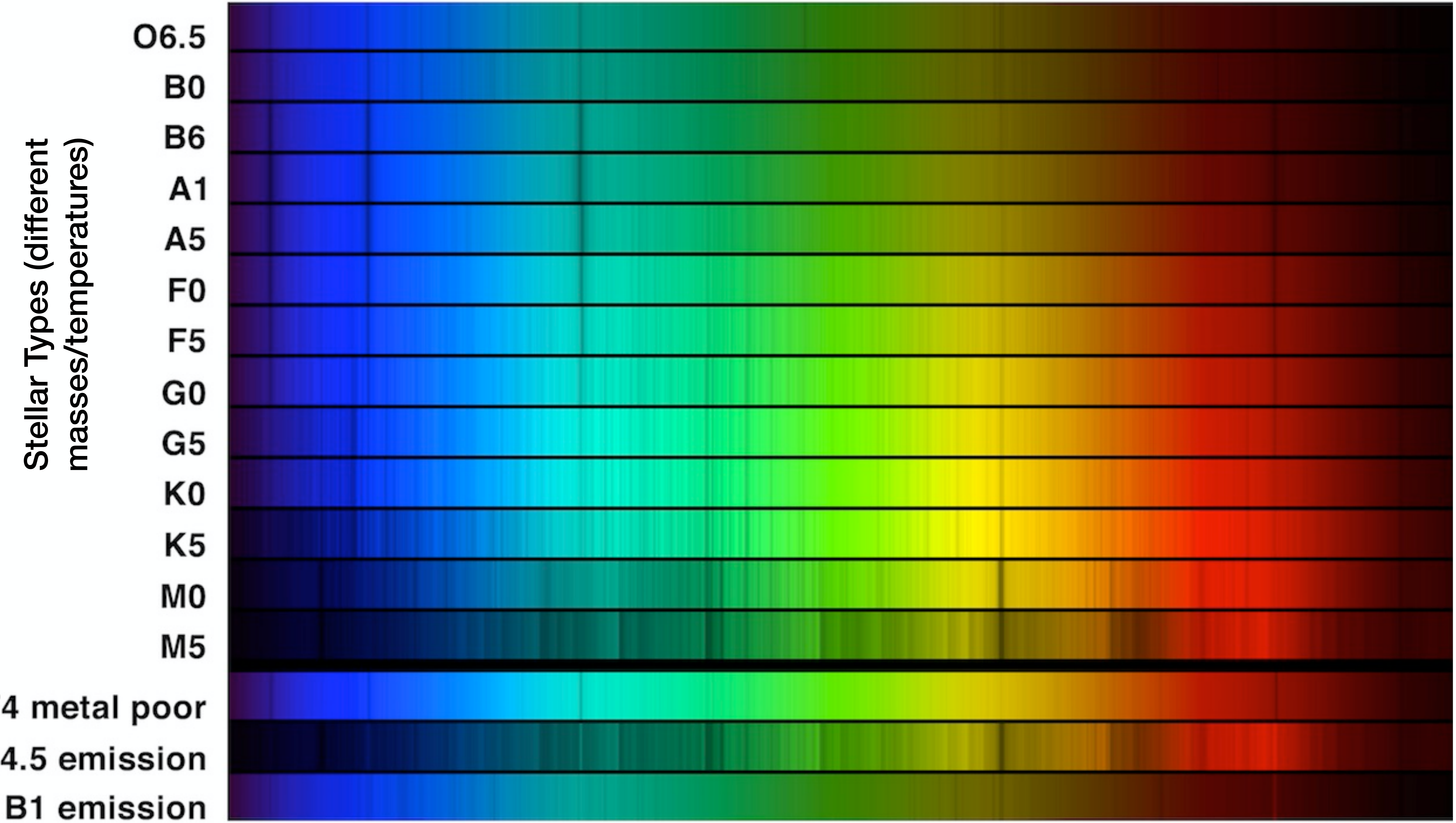
Spectra are like Fingerprints

They encode what and how much of an element is present in a gas (of a cloud, star, etc.), how hot it is, and whether it's being excited by something else

Each element has a unique pattern of lines, which can be seen in absorption or emission

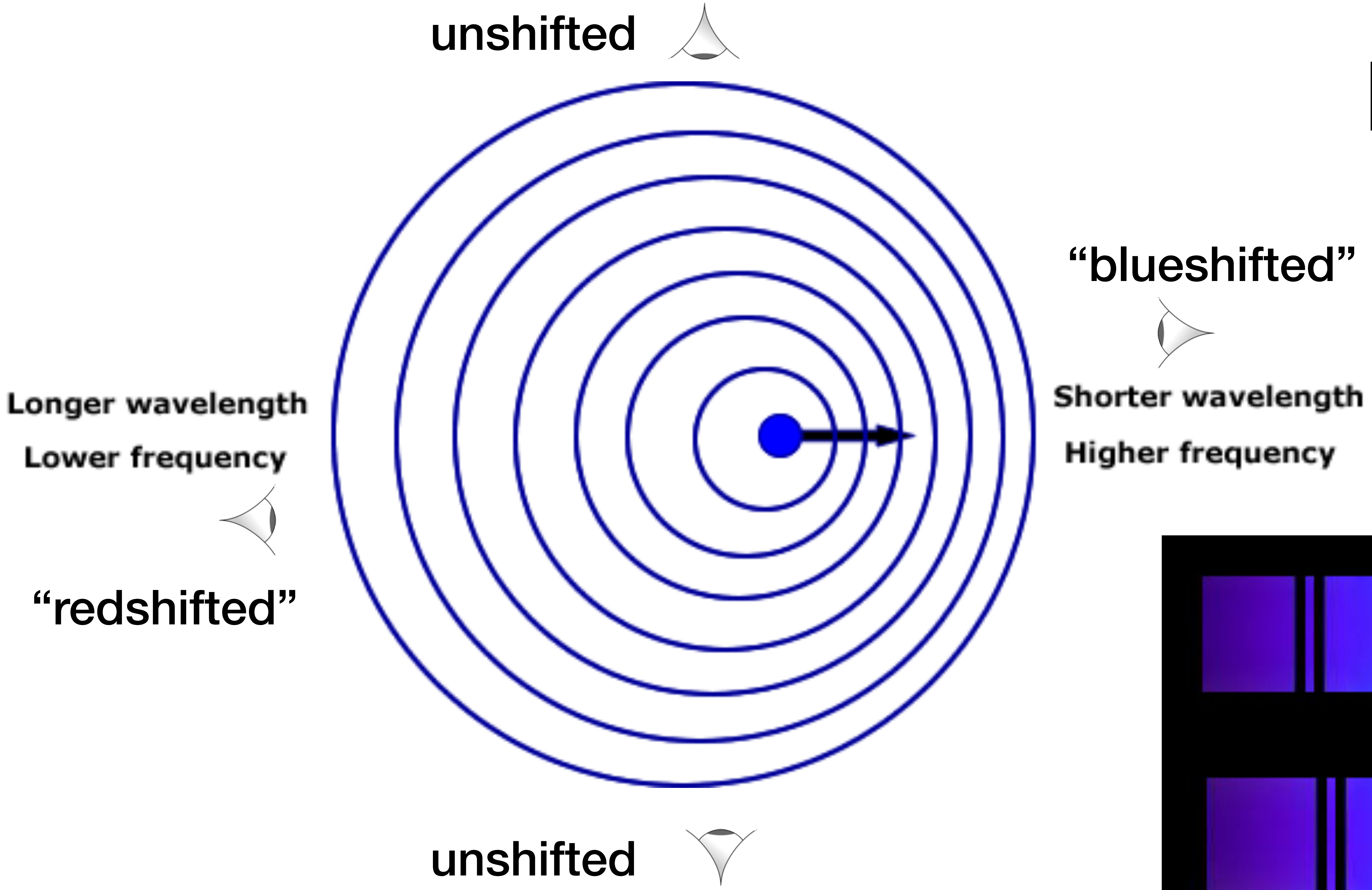
$$\Delta E = E_n - E_{n'} = (13.6\ \mathrm{eV})\ Z^2 \left[\frac{1}{(n')^2} - \frac{1}{n^2}\right]$$




Stellar Types (different masses/temperatures)
O6.5
B0
B6
A1
A5
F0
F5
G0
G5
K0
K5
M0
M5
F4 metal poor
M4.5 emission
B1 emission

Doppler Shift

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

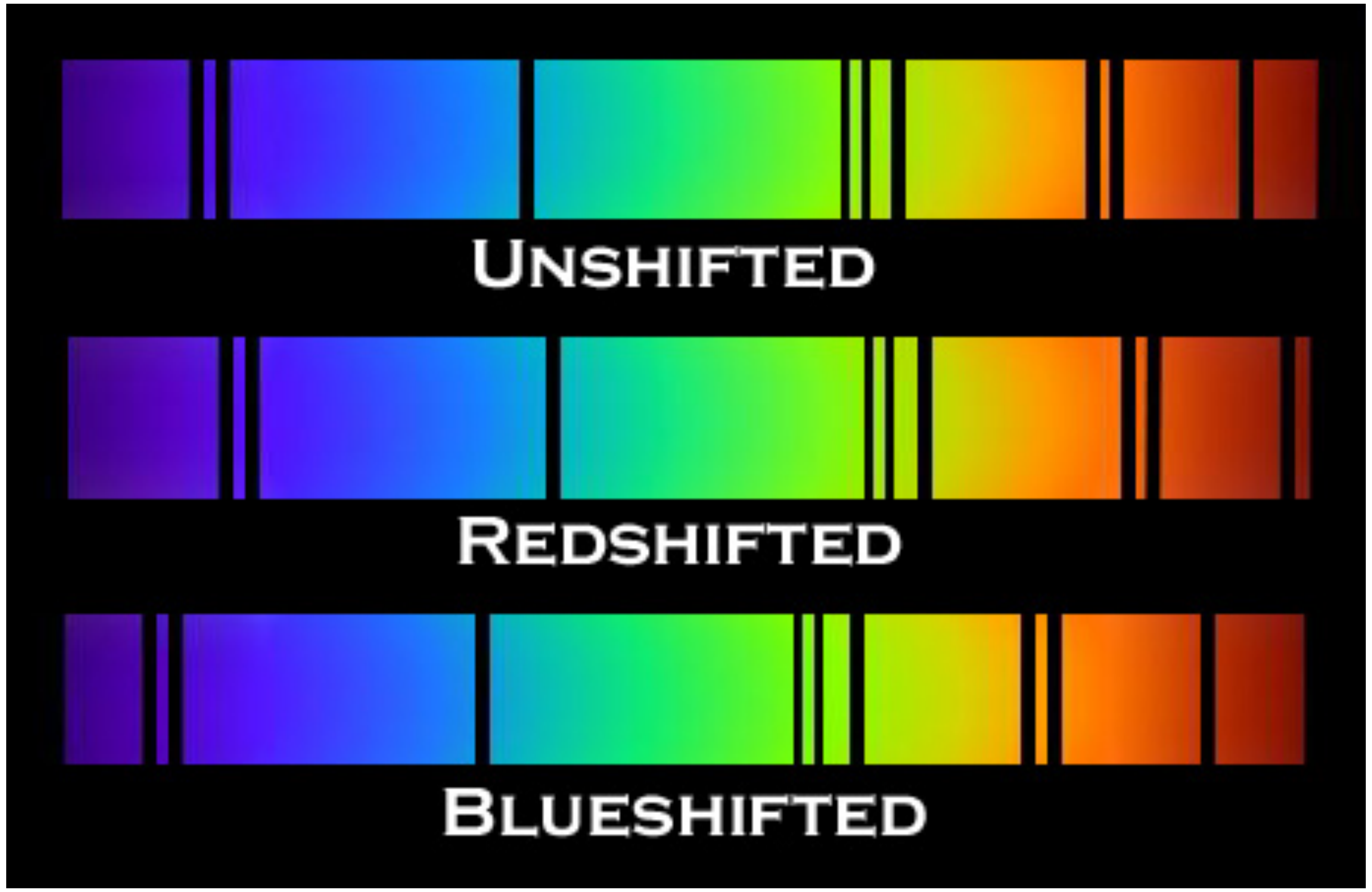


unshifted

“blueshifted”

“redshifted”

unshifted



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

Practice with redshift

- You measure the spectrum of a star and see an absorption line at a wavelength of 530 nm from an element with a laboratory absorption line at 540 nm.
  - What is the star's redshift? Is it moving toward or away from us?
  - How fast is it moving toward/away from us? What's its total velocity?

- What if instead you measured the frequency to be 5.3×10^{14} Hz (with rest frequency 5.4×10^{14} Hz)?

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

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

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

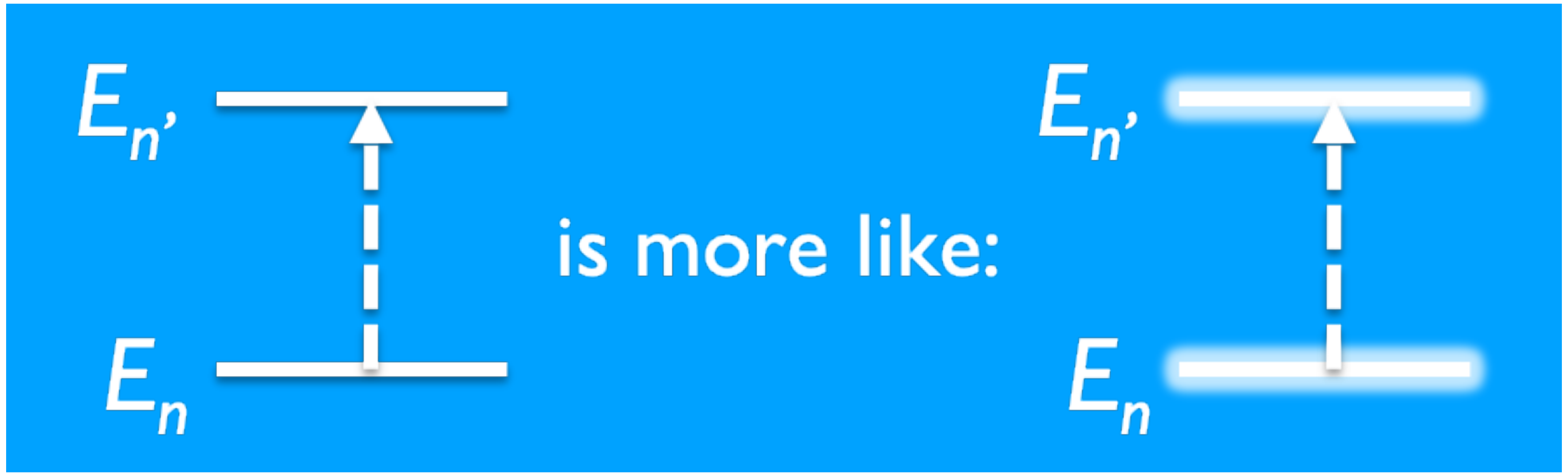
$$\sim 1 \ {\rm s}^{-1}$$ (forbidden)

Heisenberg uncertainty principle

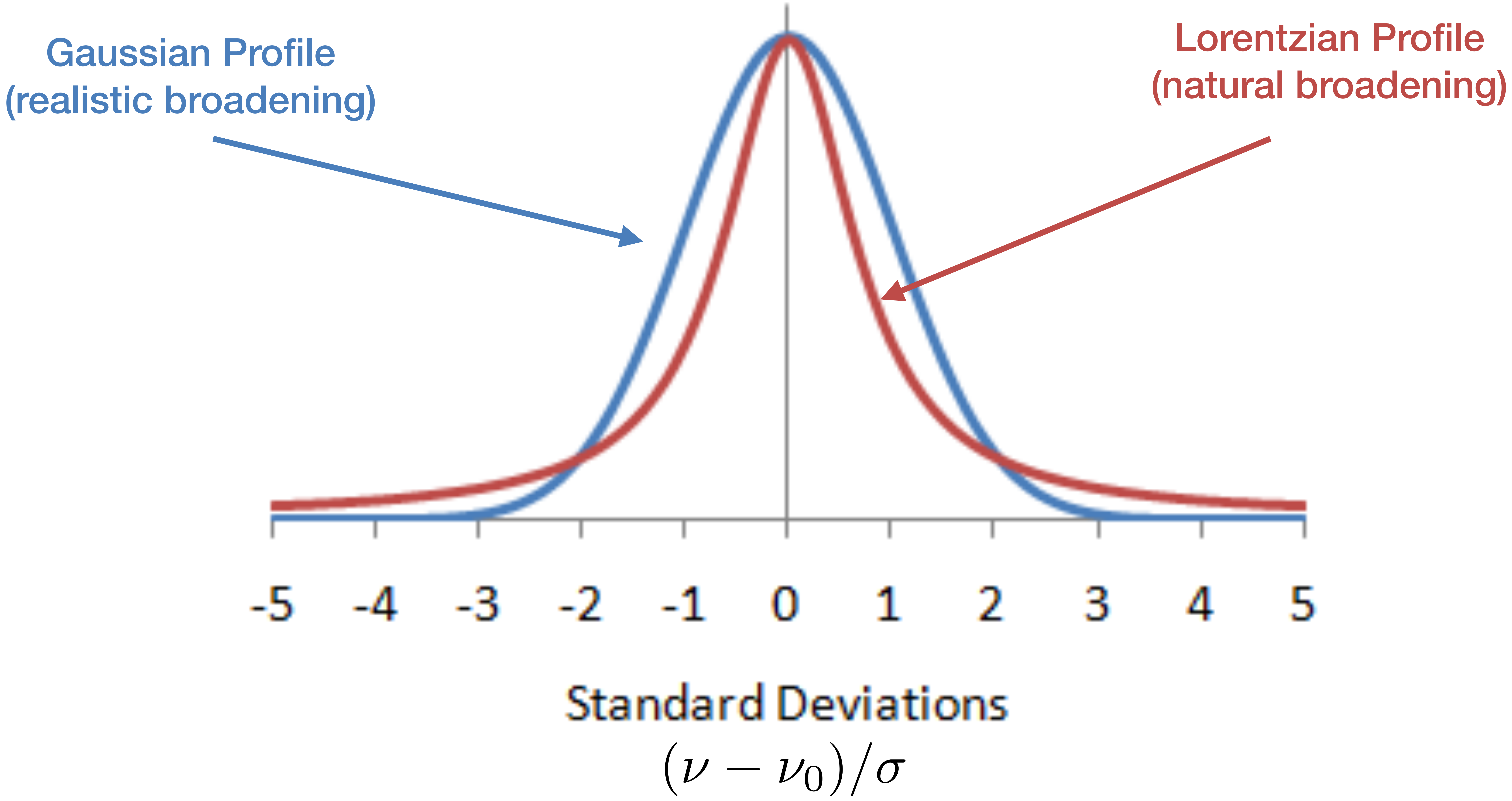
$$\Delta x \cdot \Delta p \gtrsim \hbar$$

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

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



Broadened Line Shapes



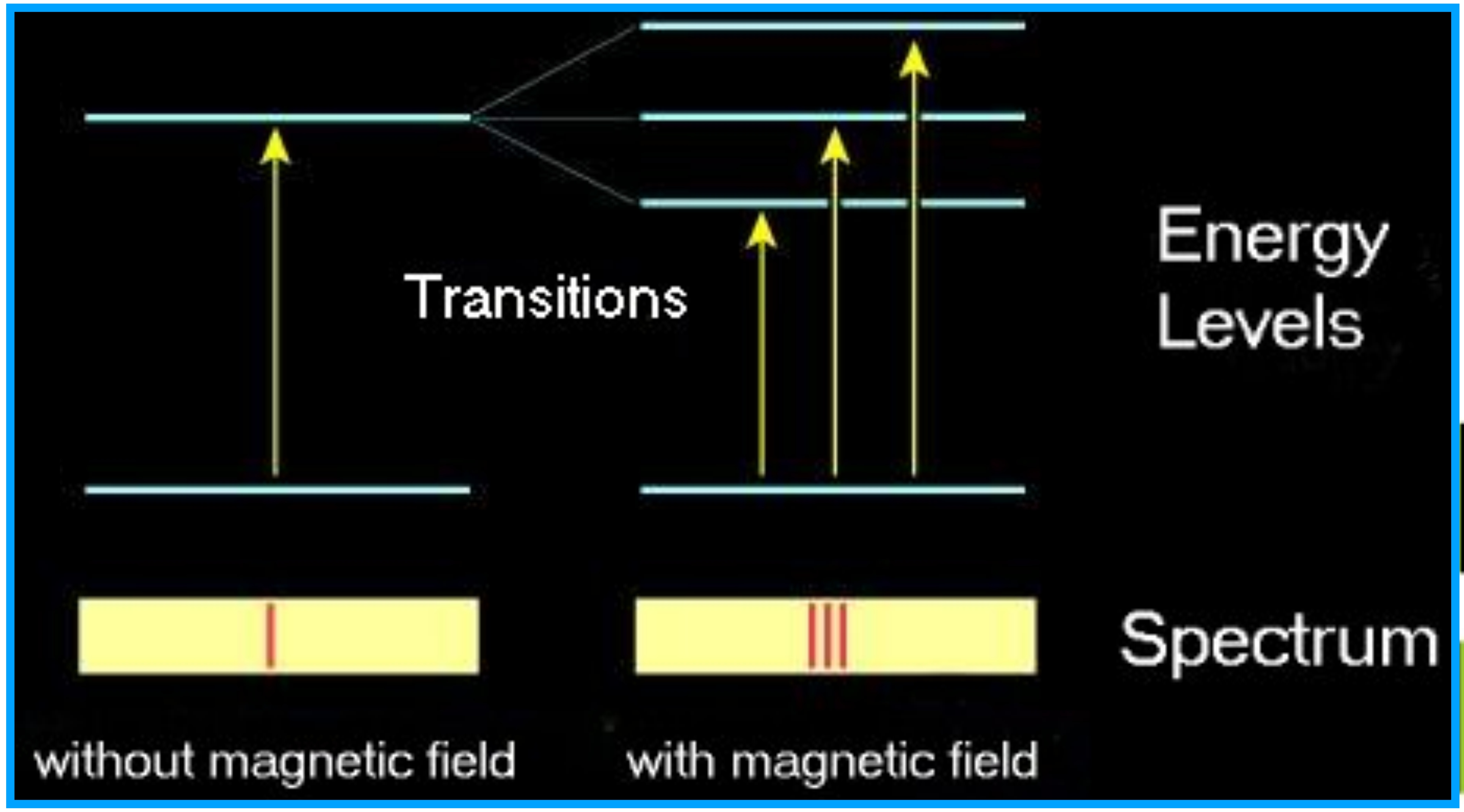
Lines are not delta functions!

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

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

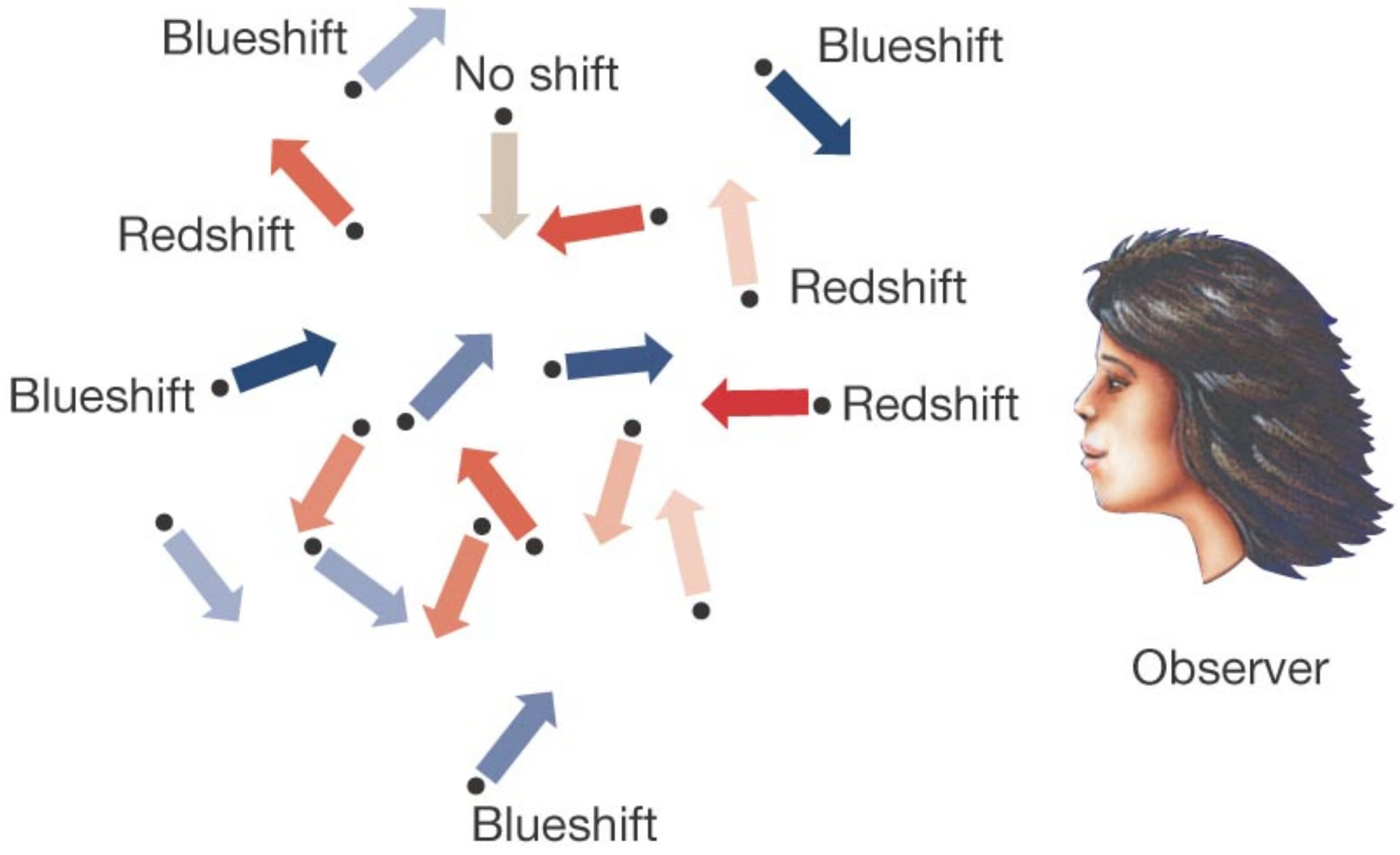
Other Types of Broadening

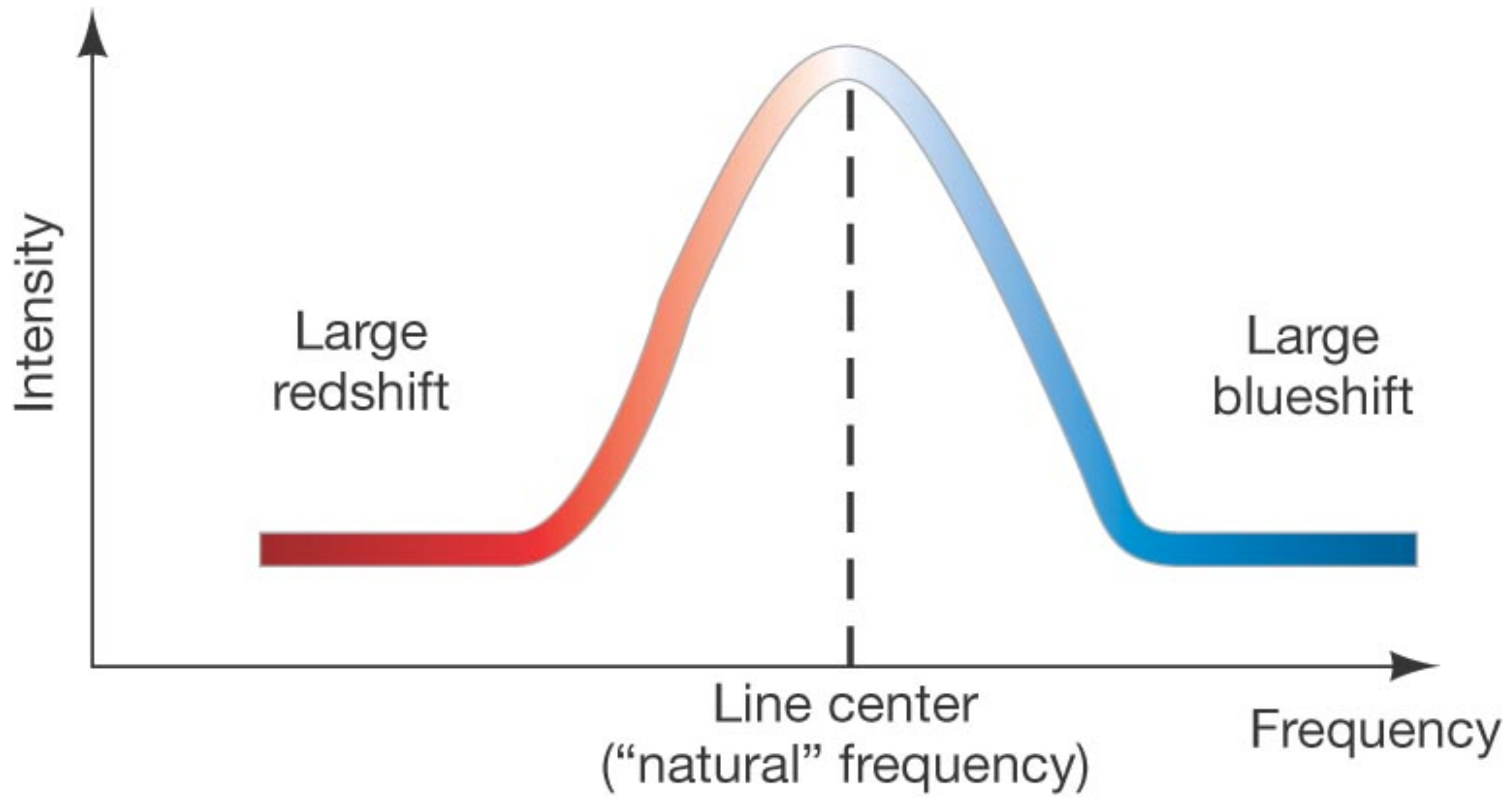
- Natural Broadening
- Pressure Broadening
- Zeeman Broadening



broadened

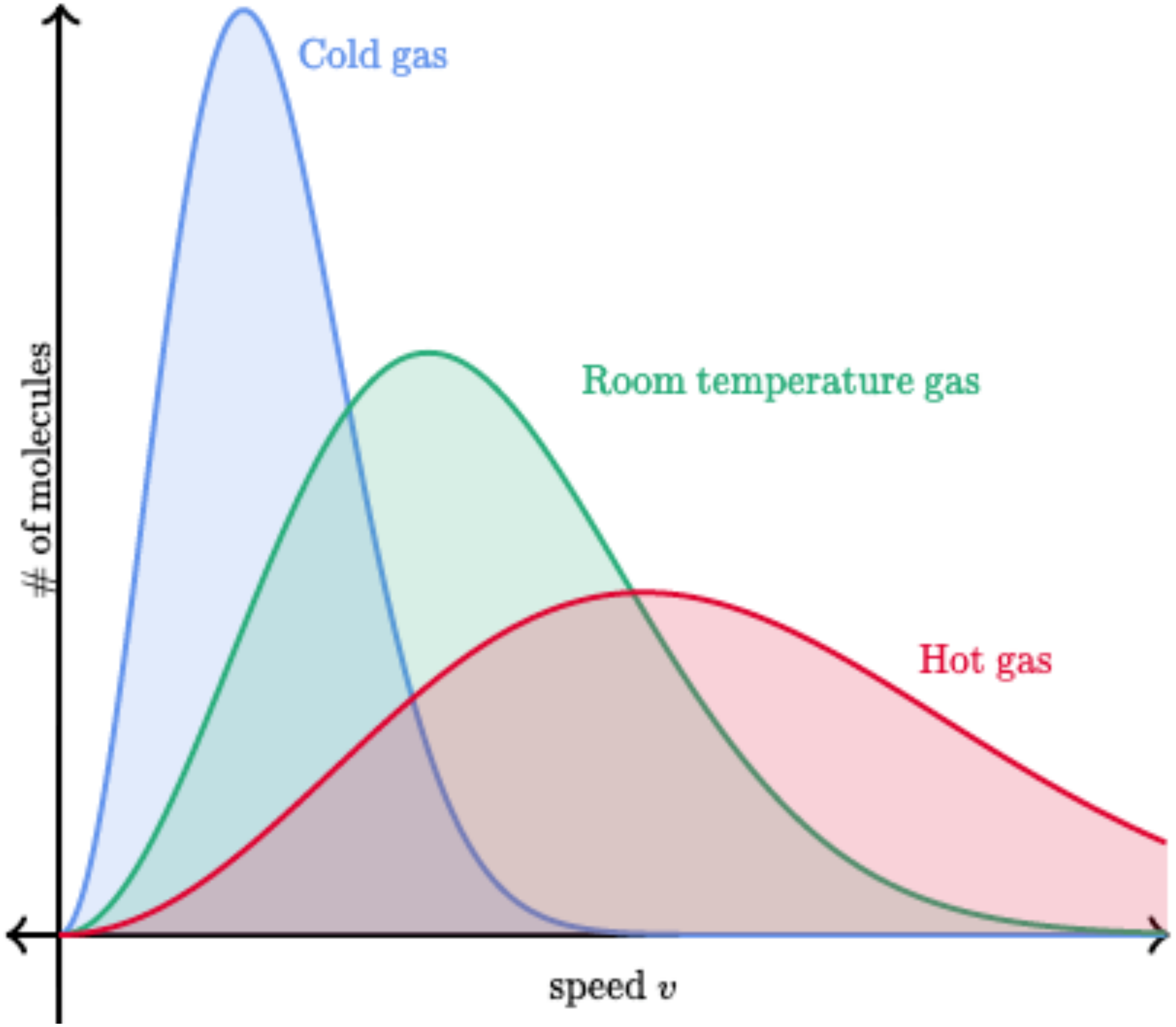
Doppler Broadening





Thermal Broadening

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



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

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

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

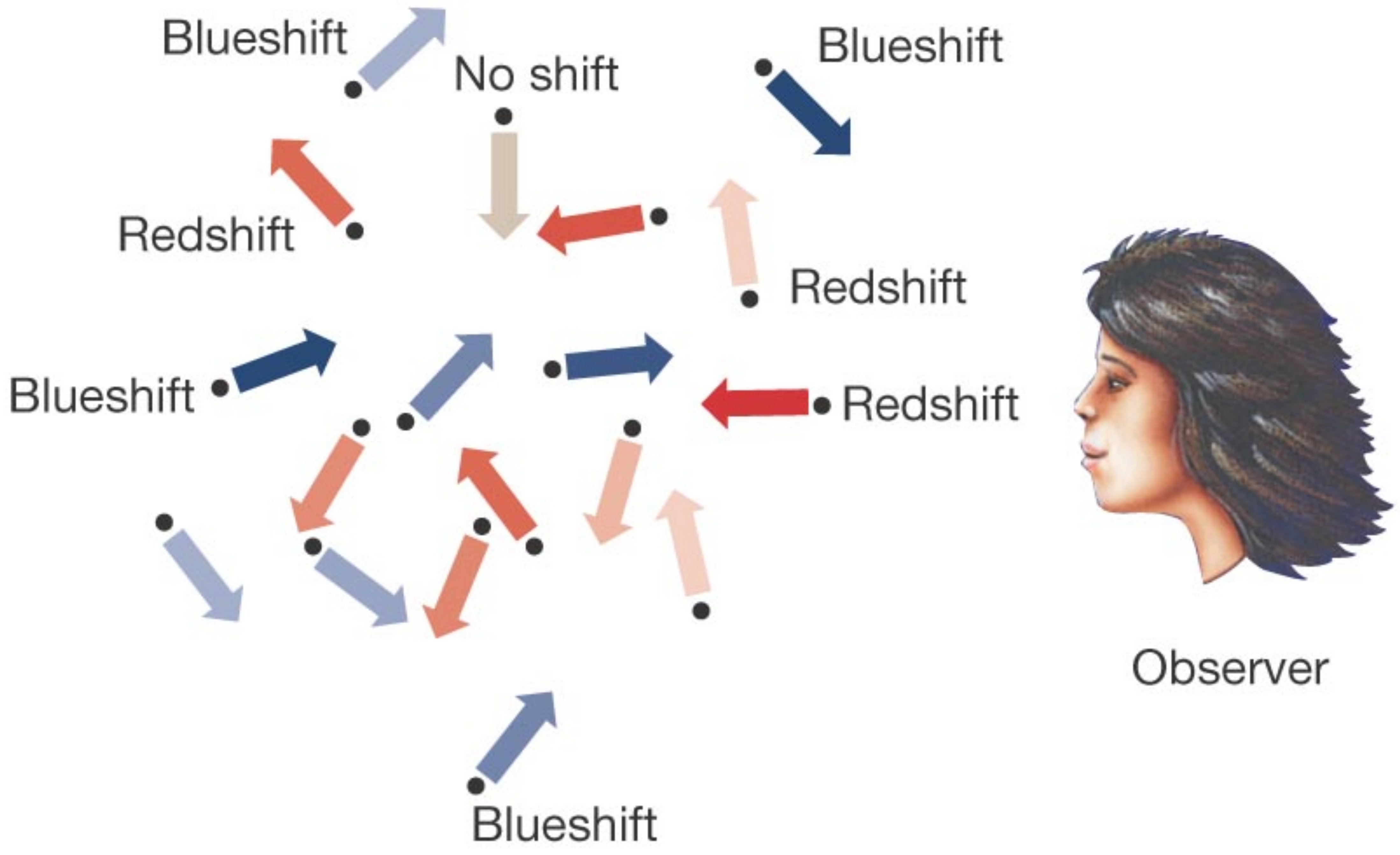
$$\langle v \rangle = \sqrt{\frac{8kT}{\pi m}}$$

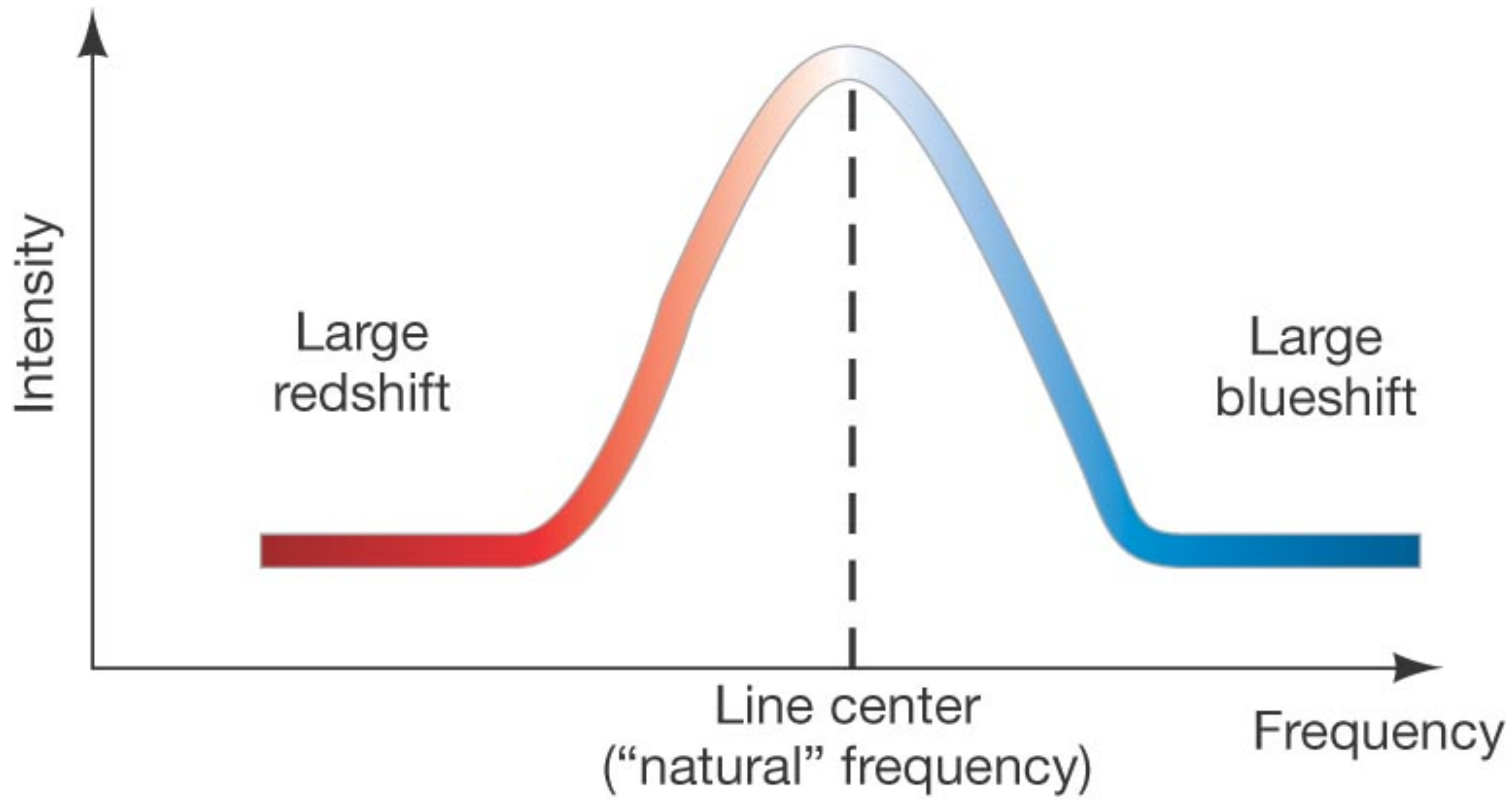
Avg. particle speed

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

Avg. particle kinetic energy

Doppler Broadening





Thermal Broadening

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

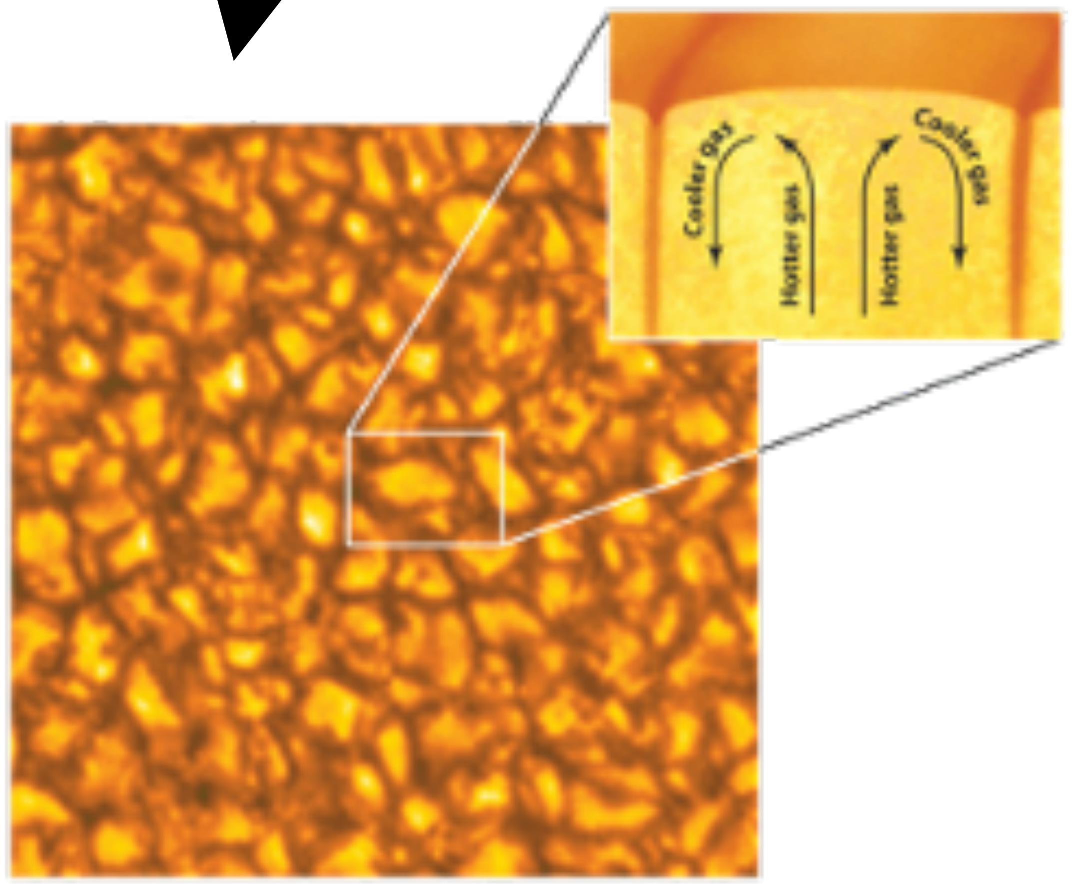
$$\sigma_{\rm los} = \left(\frac{kT}{\mu m_p}\right)^{1/2} \approx 100 \text{ m s}^{-1} \left(\frac{T}{1\ K}\right)^{1/2} \mu^{-1/2} \longrightarrow \frac{\Delta\lambda}{\lambda} \approx \frac{\sigma_{\rm los}}{c}$$

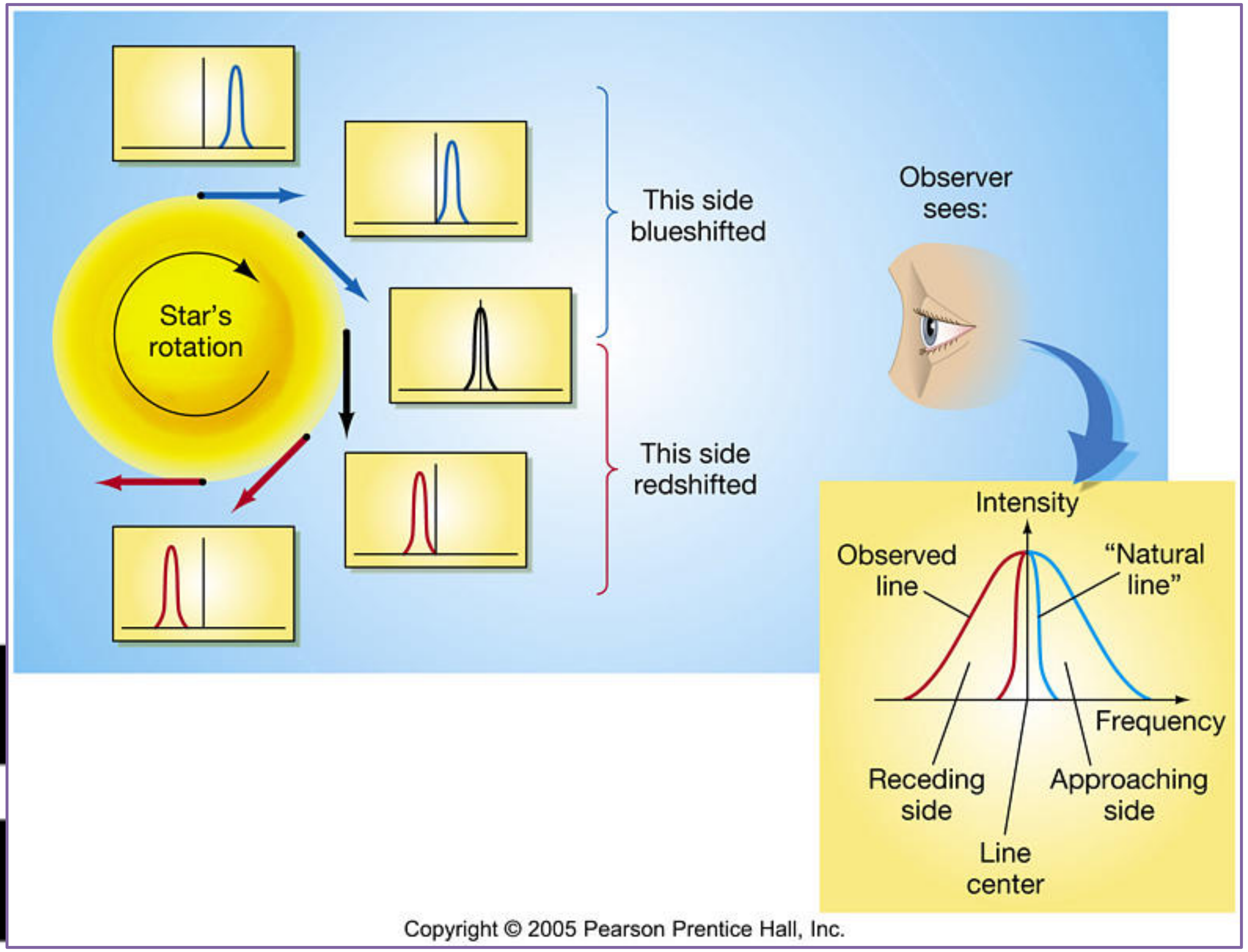
Lines are not delta functions!

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





Copyright © 2005 Pearson Prentice Hall, Inc.

Radiative Transfer / mfp / optical depth / Blackbody Spectra