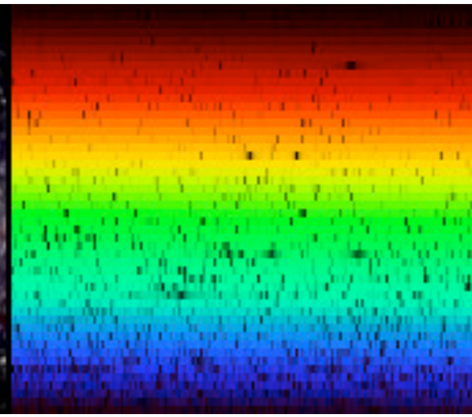
# ASTR/PHYS 3070: Foundations Astronomy



# Week 3 Tuesday

## Today's Agenda

- Kepler's Laws & Gravity
- Basic Orbital Dynamics
- Problems in groups!
- Let there be light

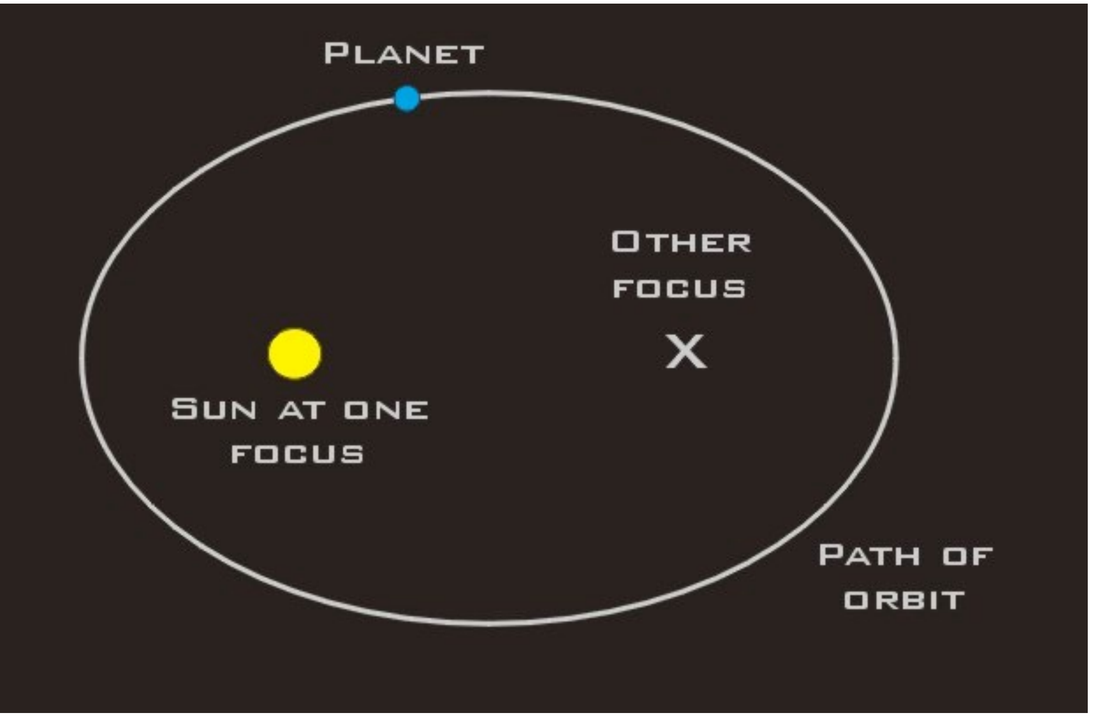
## Announcements / Reminders

- Read Chapter 5
- HW 2 due September 10th at 11:59pm via Canvas upload

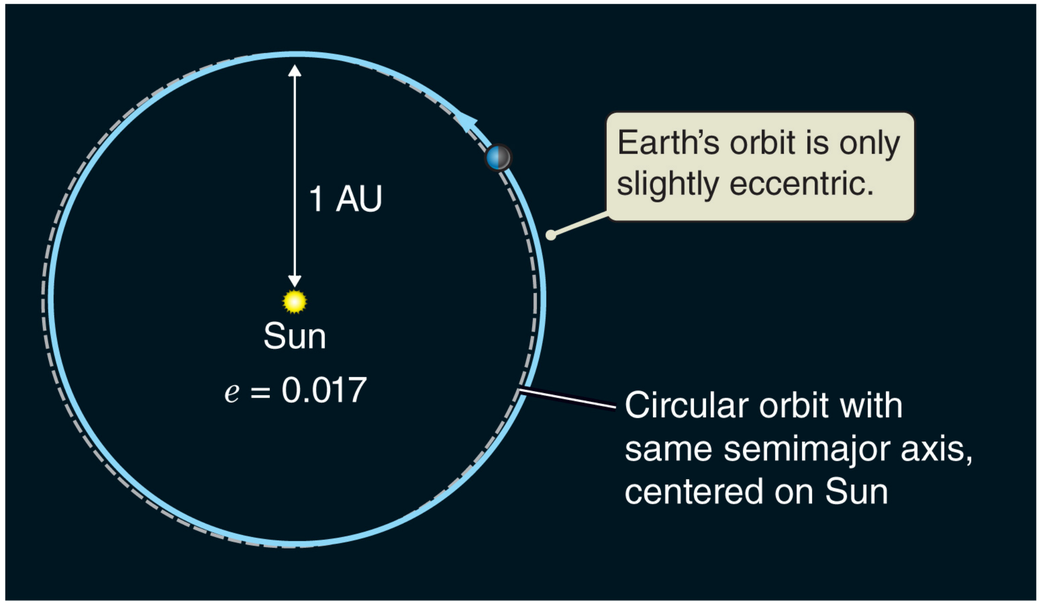
- HW 1 returned soon

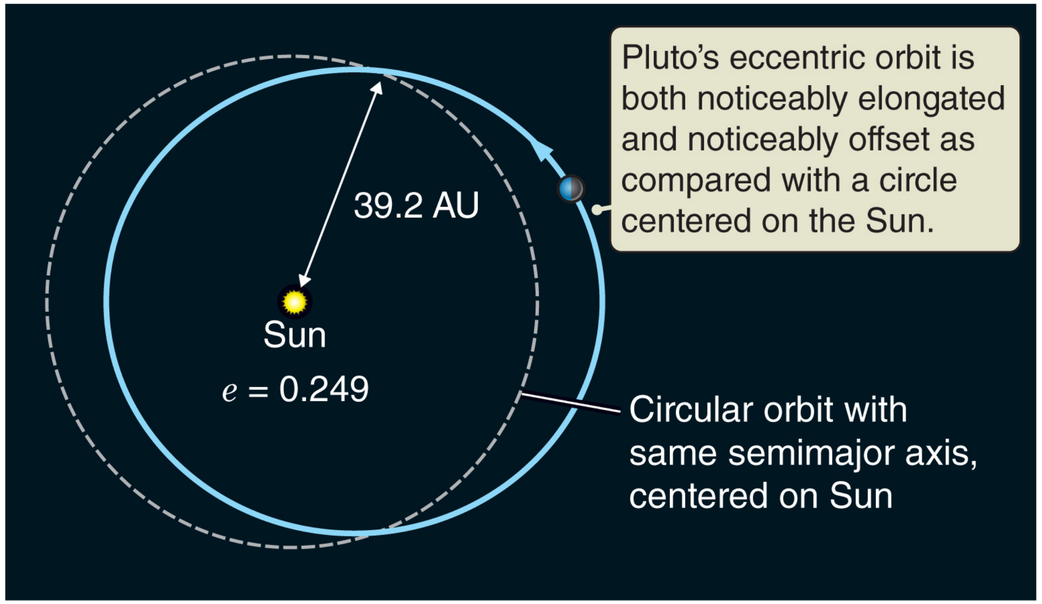
# Kepler's 3 Laws!

**1) Planets move around the Sun on elliptical paths, with the Sun at one focus of the ellipse**

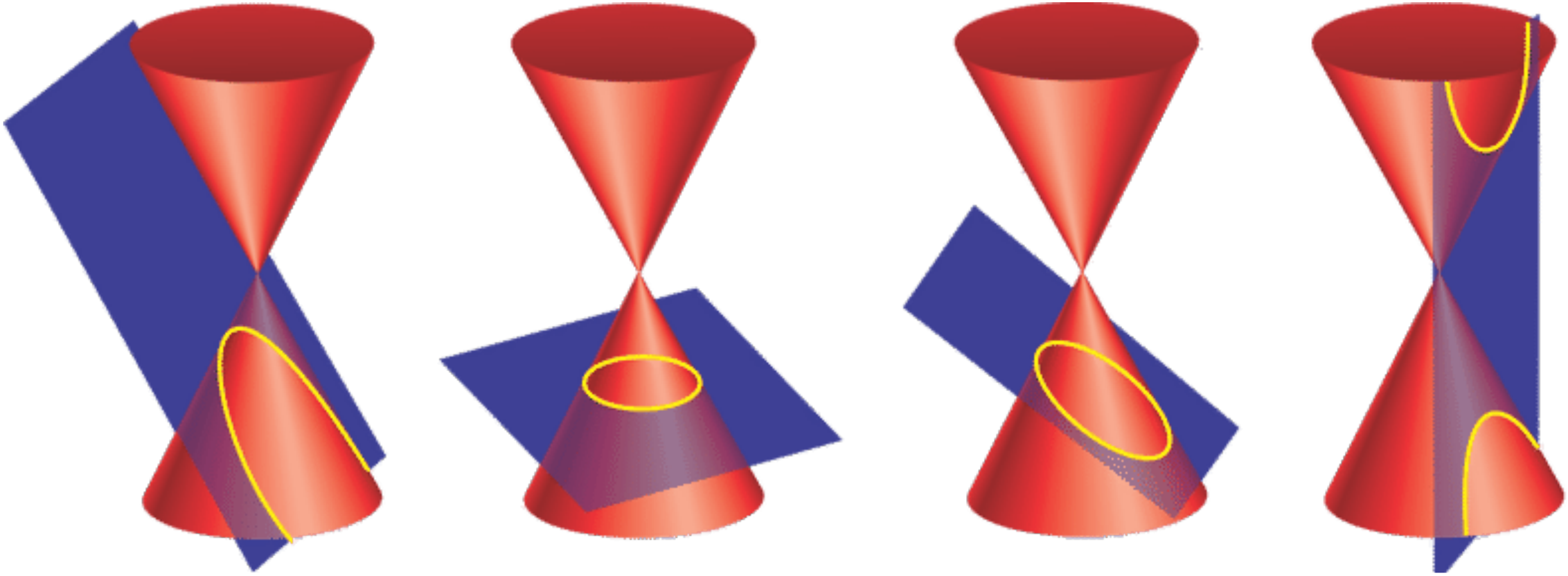



Major Axis



# Orbits are Conic Sections



Parabola
$e = 1$
$E_{tot} = 0$

Circle
$e = 0$
$E_{tot} < 0$ (minimum for a given $L$)

Ellipse
$0 < e < 1$
$E_{tot} < 0$

Hyperbola
$e > 1$
$E_{tot} > 0$

# Kepler's 3rd Law

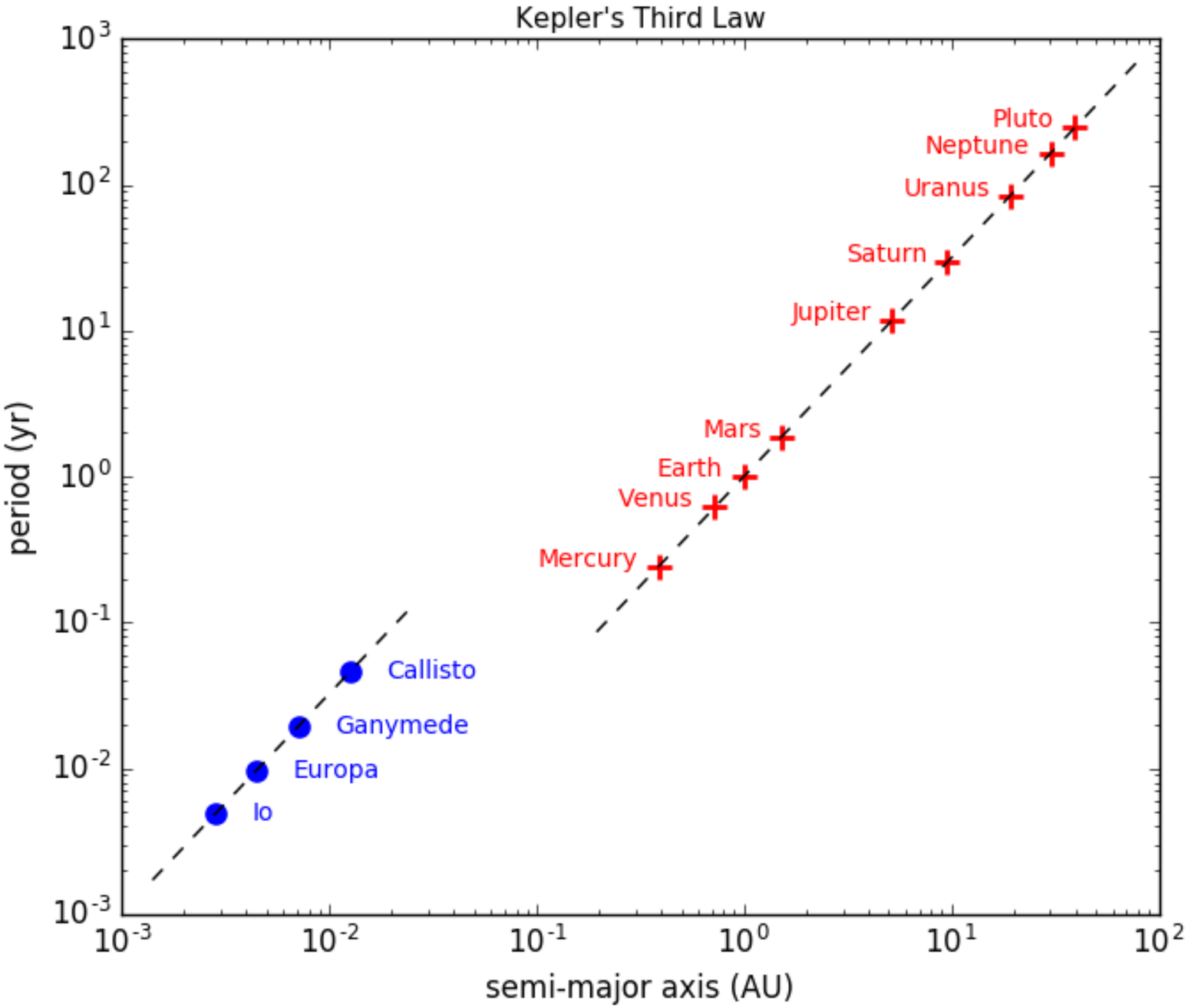
Log-log plot
Relations to some power (called power laws) appear as straight lines

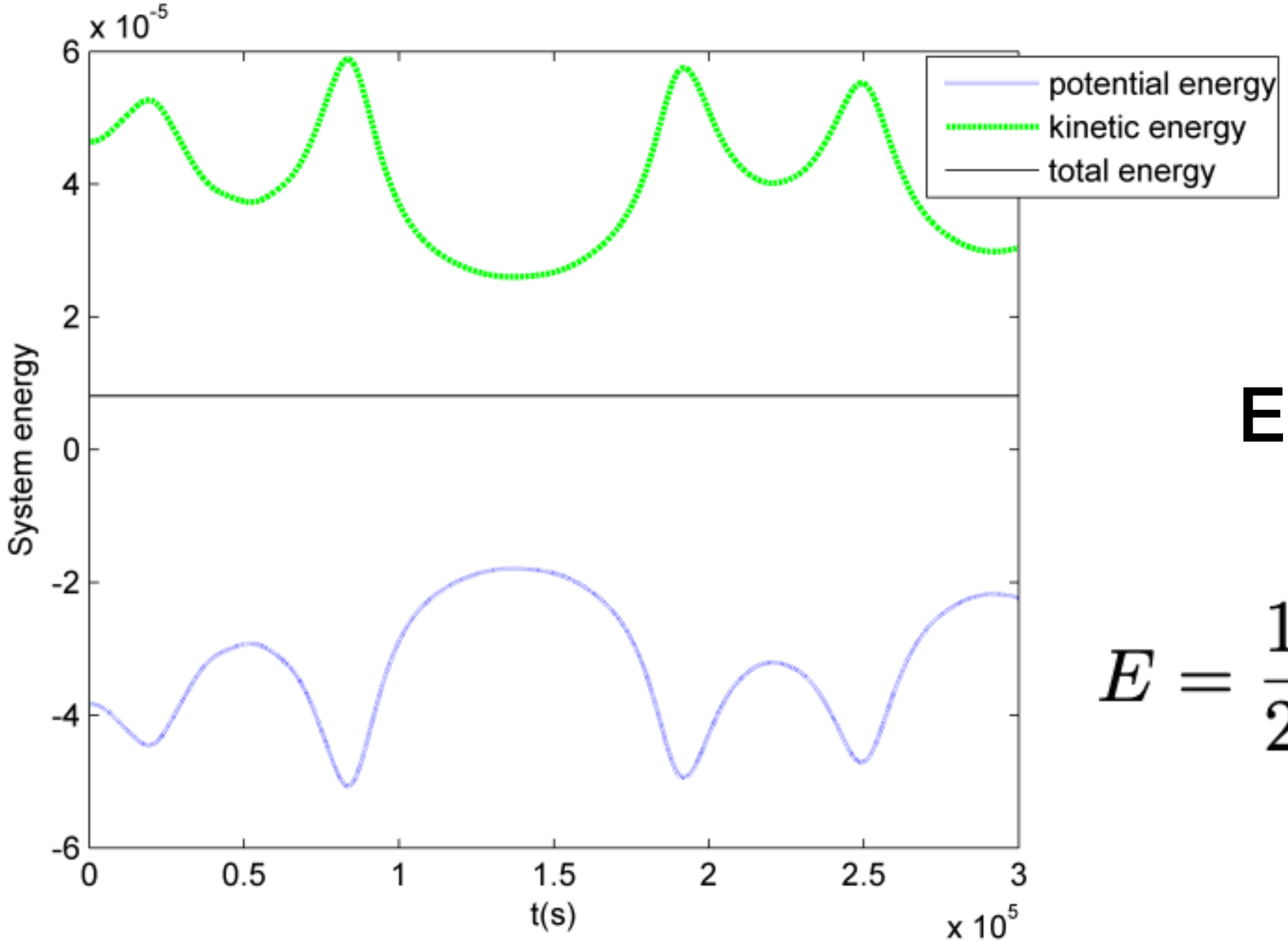
$$y = Ax^p$$

$$\log_{10}(y) = \log_{10}(Ax^p)$$

$$= \log_{10} A + p \log_{10} x$$

$$y' = B + Cx'$$

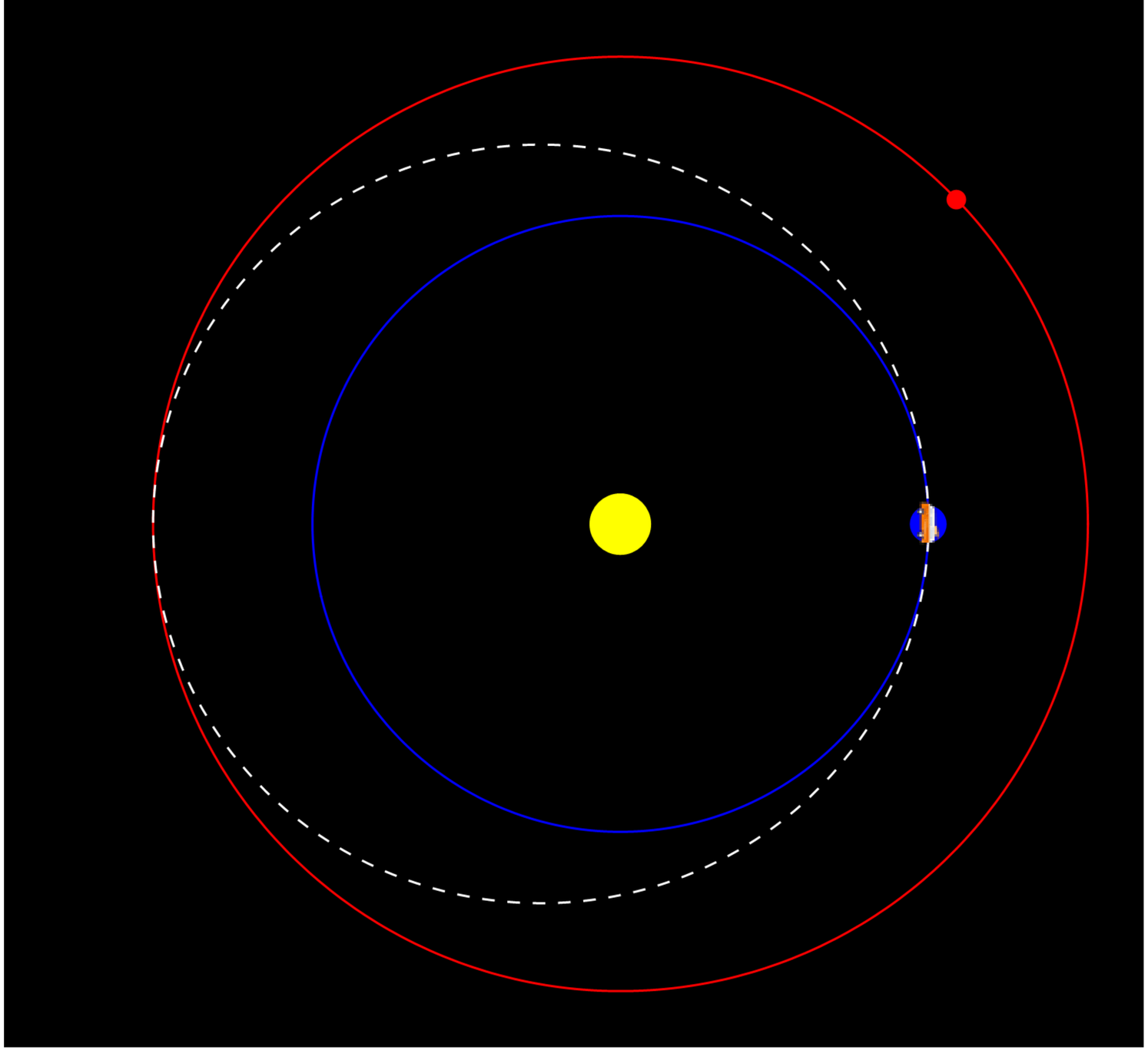





# Orbital Energetics

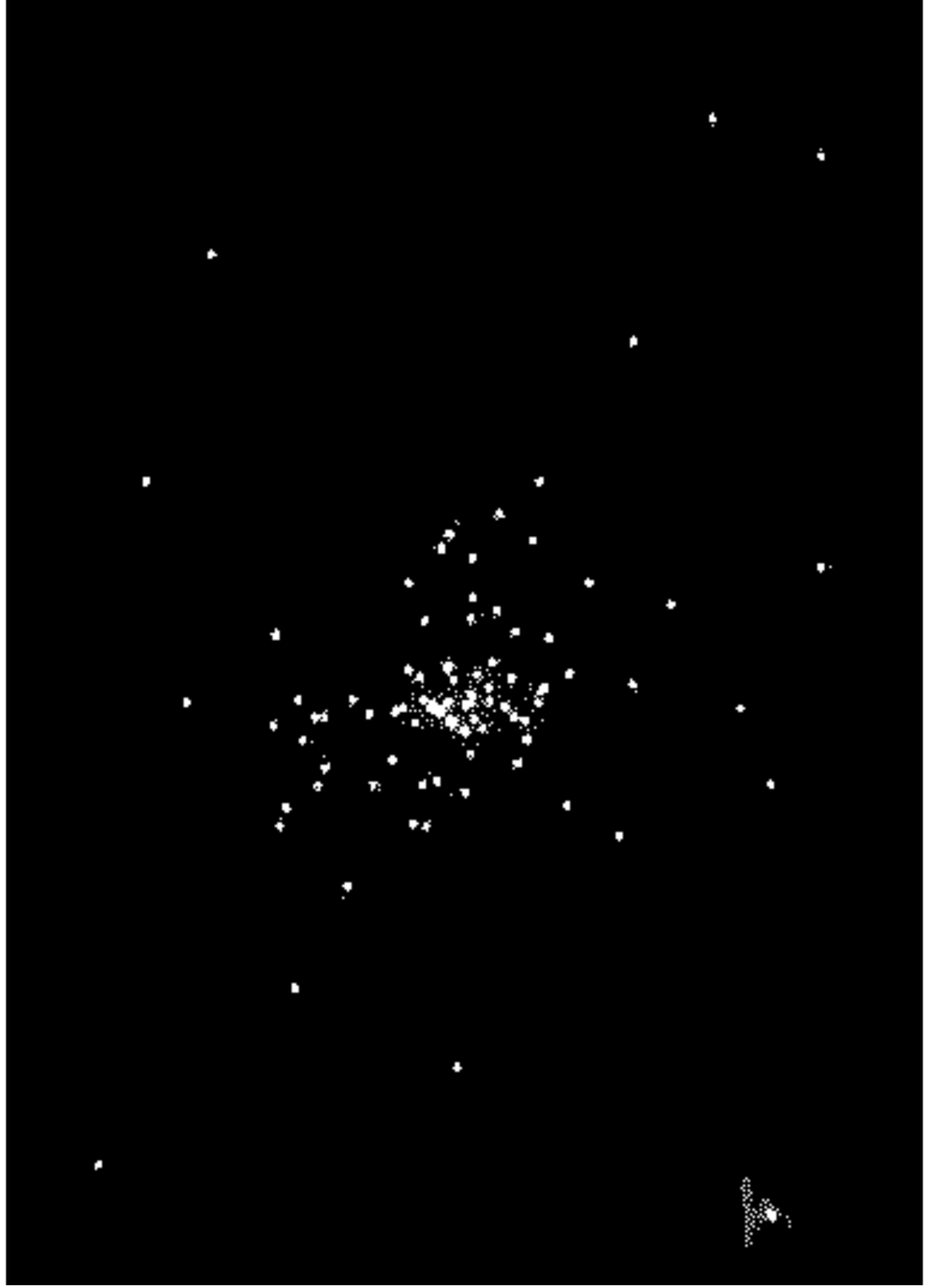
$$E = \frac{1}{2}mv^2 - \frac{GMm}{r}$$

# Hohmann Transfer Orbit



# Virial Theorem

$$2\langle K\rangle = -\langle U\rangle$$

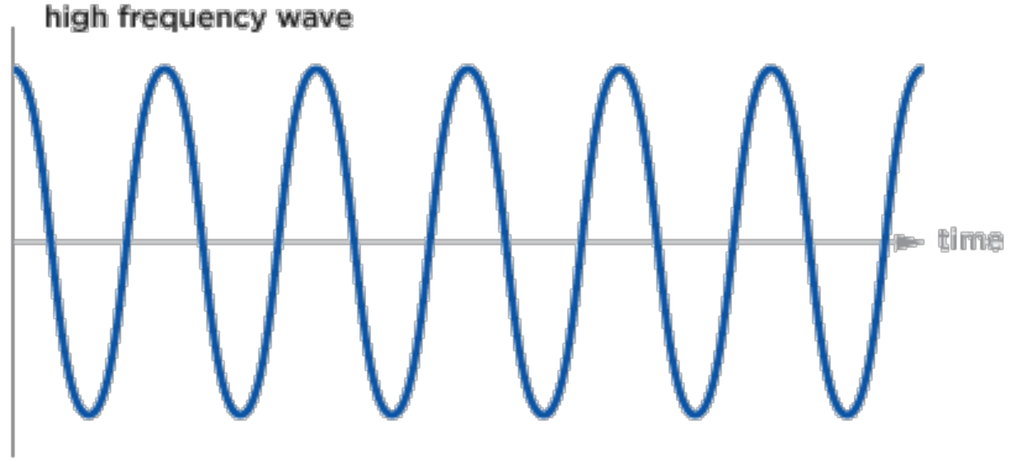


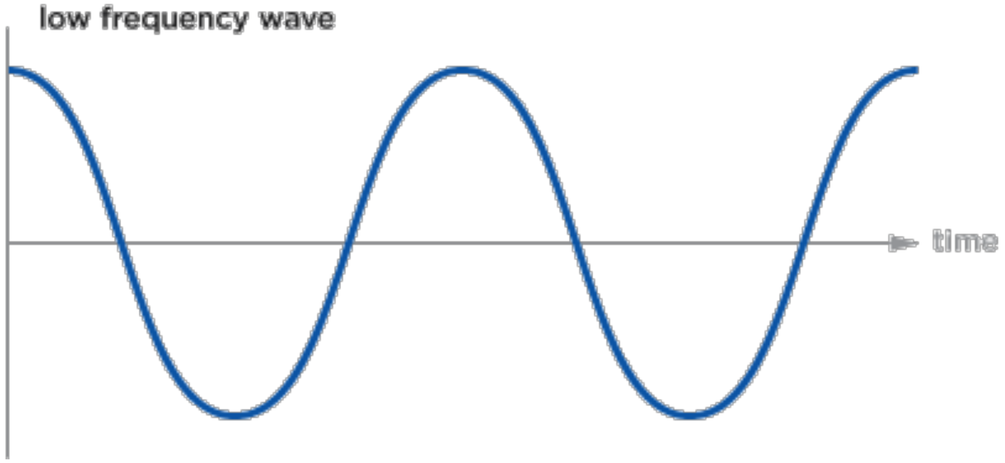
# Chapter 5: Let there be *LIGHT!*

Cover today

- Review of atomic structure, energy exchange processes, and spectroscopy
- Radiative transfer
- Thermodynamic equilibrium
- Blackbody radiation
- Wien's Law

# “Light” is electromagnetic radiation of any wavelength/frequency, not just what eyes see




Classically, can be thought of a wave traveling down an electric field line like an induced transverse wave down a rope.

In QM, quanta of the wave are called photons, which have energy and momenta determined by wavelength/frequency.

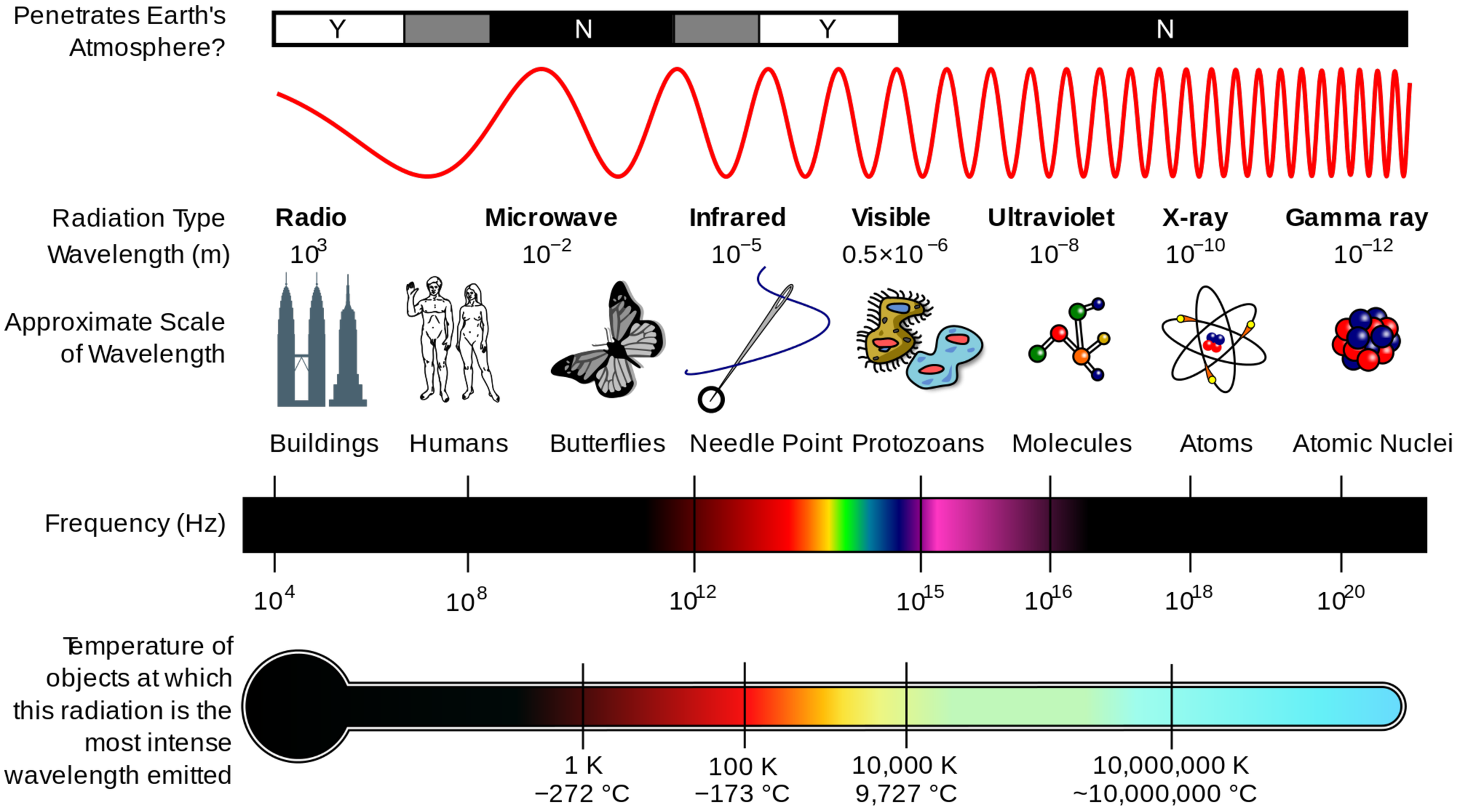
$$E = h\nu = \frac{hc}{\lambda}$$

$$h = 6.626 \times 10^{-34}\ \mathrm{J\ s} = 4.135 \times 10^{-15}\ \mathrm{eV\ s}$$

$$c = 2.998 \times 10^{8}\ \mathrm{m\ s^{-1}}$$

$$\hbar = \frac{h}{2\pi}$$

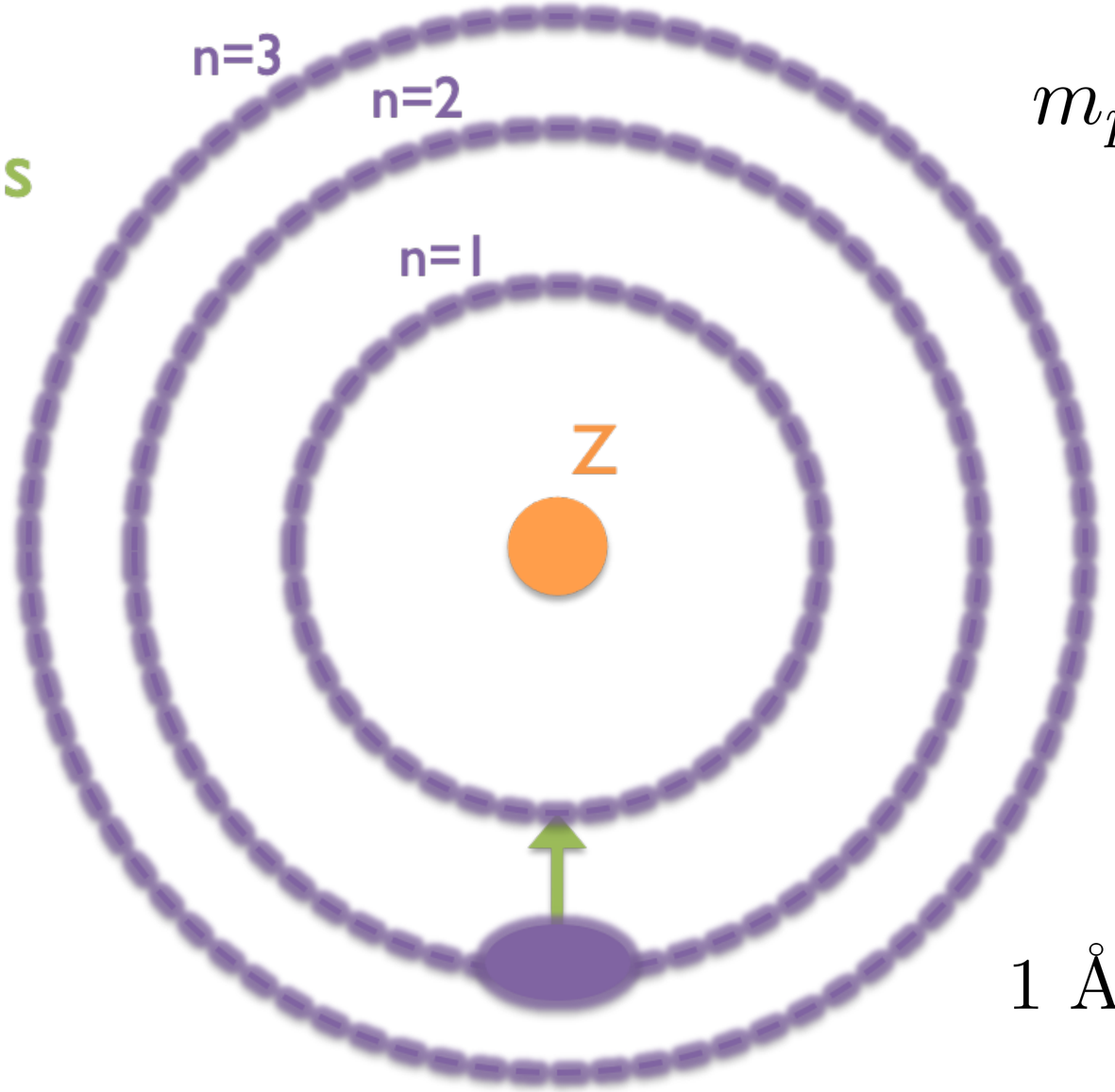
$$1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$$


Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma ray
Wavelength (m)
$10^{3}$
$10^{-2}$
$10^{-5}$
$0.5\times10^{-6}$
$10^{-8}$
$10^{-10}$
$10^{-12}$
Approximate Scale of Wavelength
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
$10^{4}$
$10^{8}$
$10^{12}$
$10^{15}$
$10^{16}$
$10^{18}$
$10^{20}$
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

# Atomic Structure (quantized energy levels)

Z protons

A−Z neutrons




$$m_p = 1.673 \times 10^{-27}\ \mathrm{kg}$$

$$m_e \approx m_p/1836$$

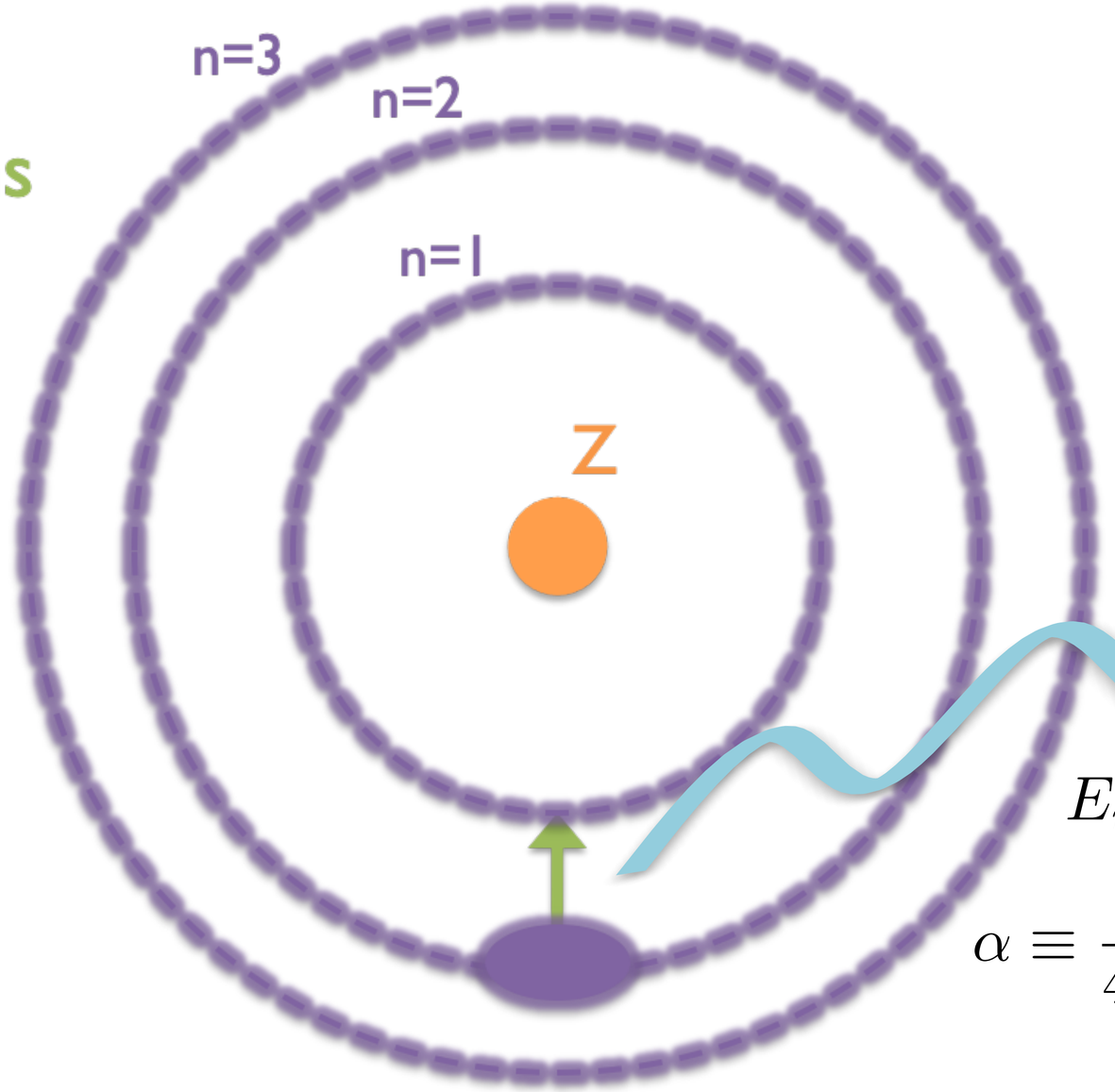
$$m_n \sim m_p$$

$$1\ \text{Å} = 0.1\ \mathrm{nm} = 10^{-10}\ \mathrm{m}$$

# Atomic Structure (quantized energy levels)

Z protons

A−Z neutrons




Photon emitted with wavelength/ frequency equal to difference in energy between allowed orbits (energy levels)

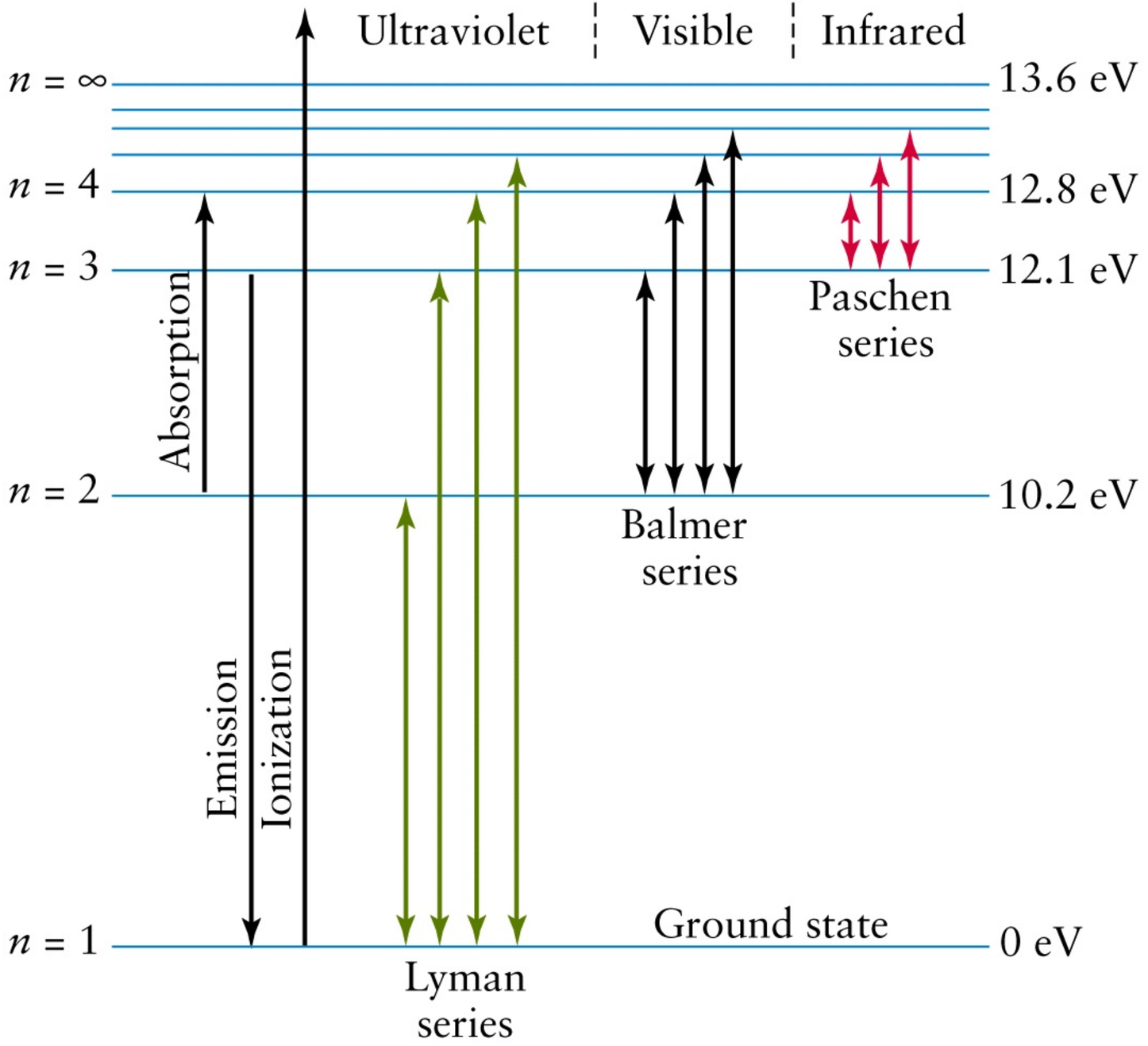
$$E_n = -\frac{m_e c^2}{2}\alpha^2\frac{Z}{n^2}$$

$$\alpha \equiv \frac{1}{4\pi\epsilon_0}\frac{e^2}{\hbar c} \approx 7.30 \times 10^{-3} \approx \frac{1}{137}$$

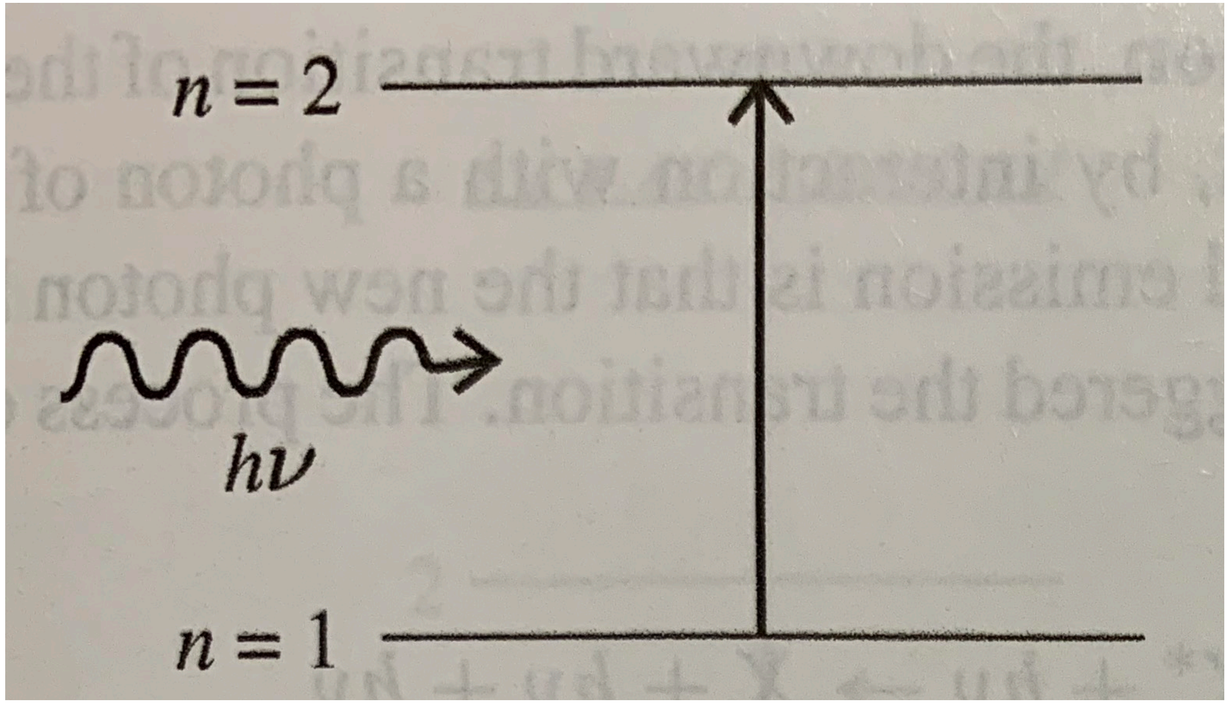
# Energy Levels

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

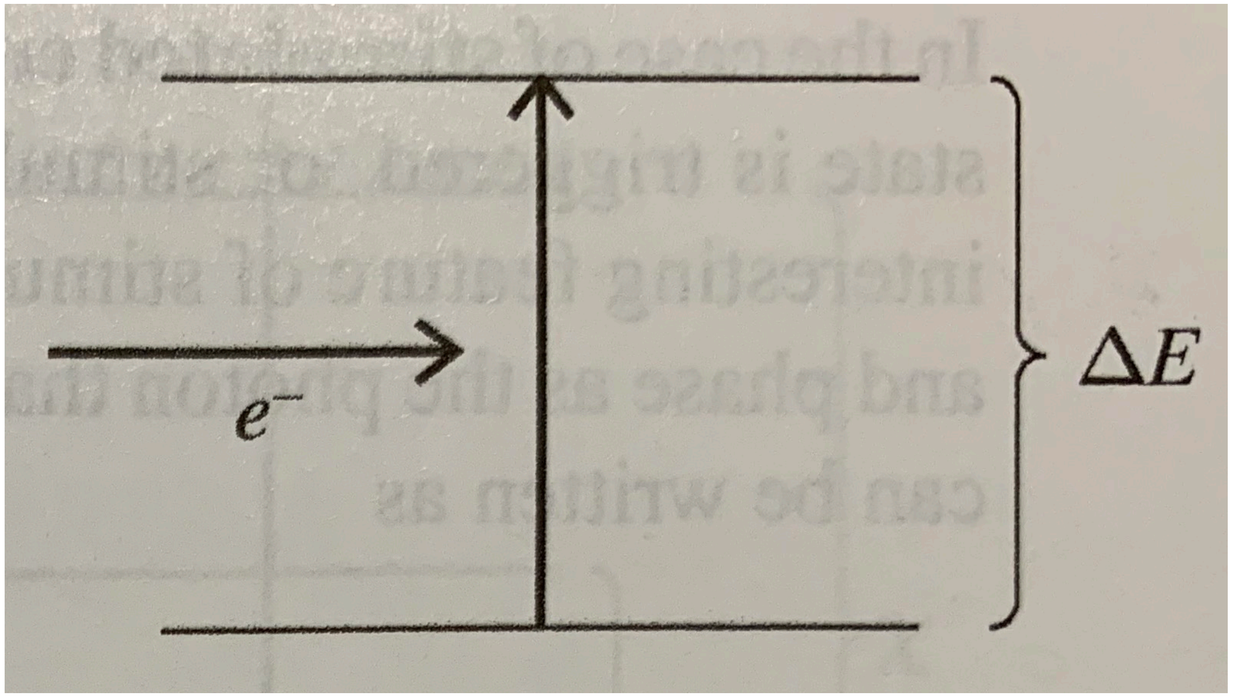
(Energies correspond to neutral hydrogen)



# Absorption of Energy

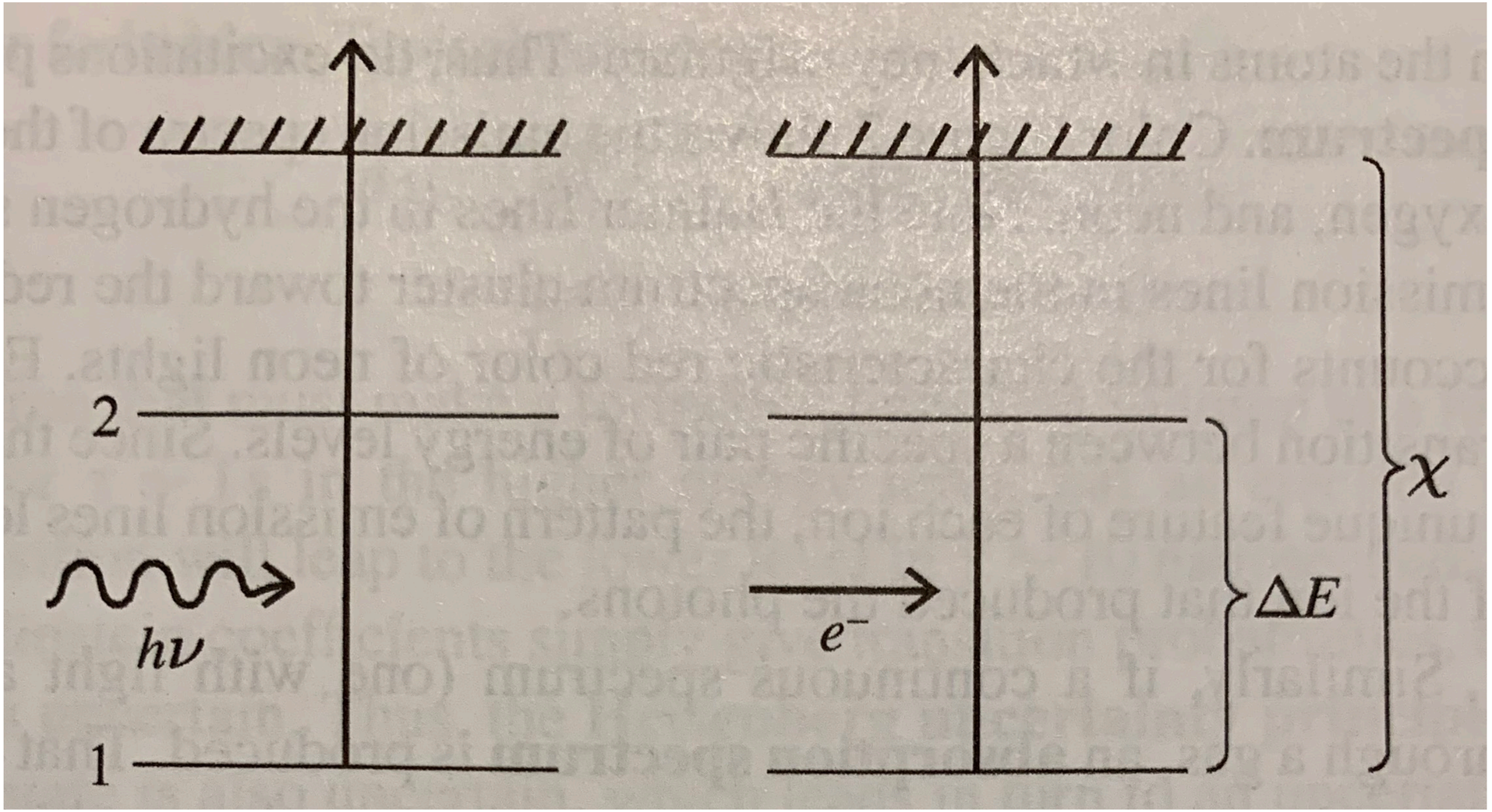



Photoexcitation




Collisional Excitation

# Absorption of Energy

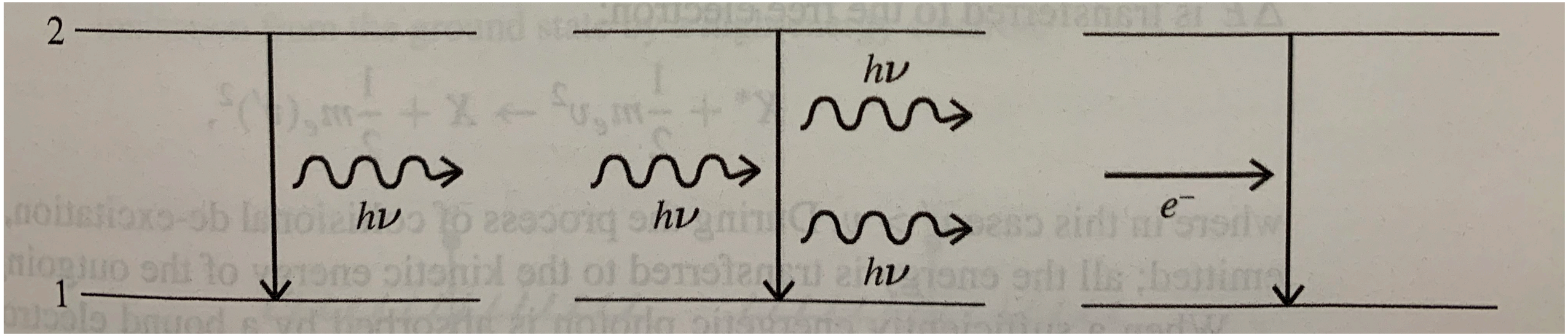



Photoionization

Collisional Ionization

# Emission of Energy

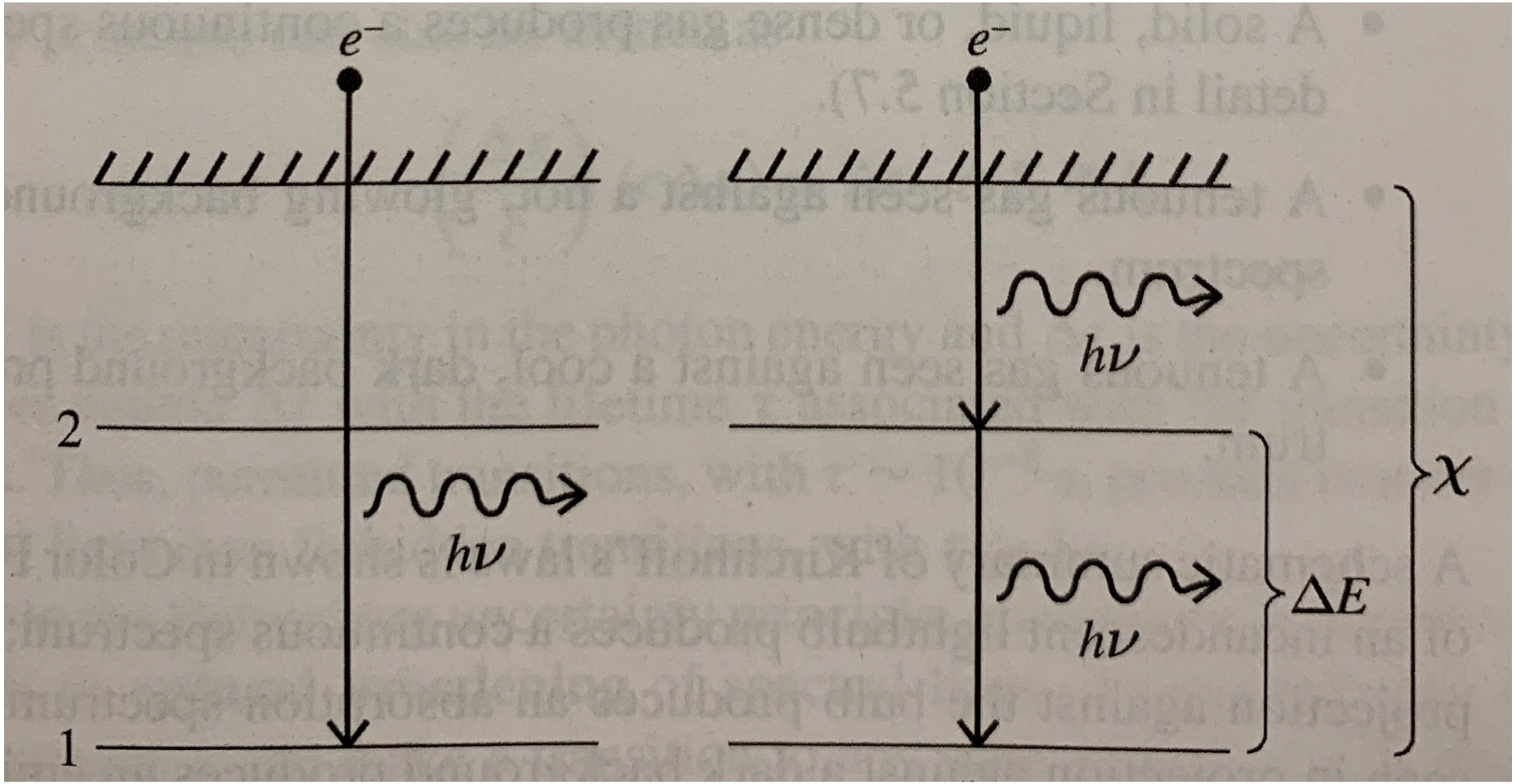
Stimulated Emission




Spontaneous Emission

Collisional De-excitation

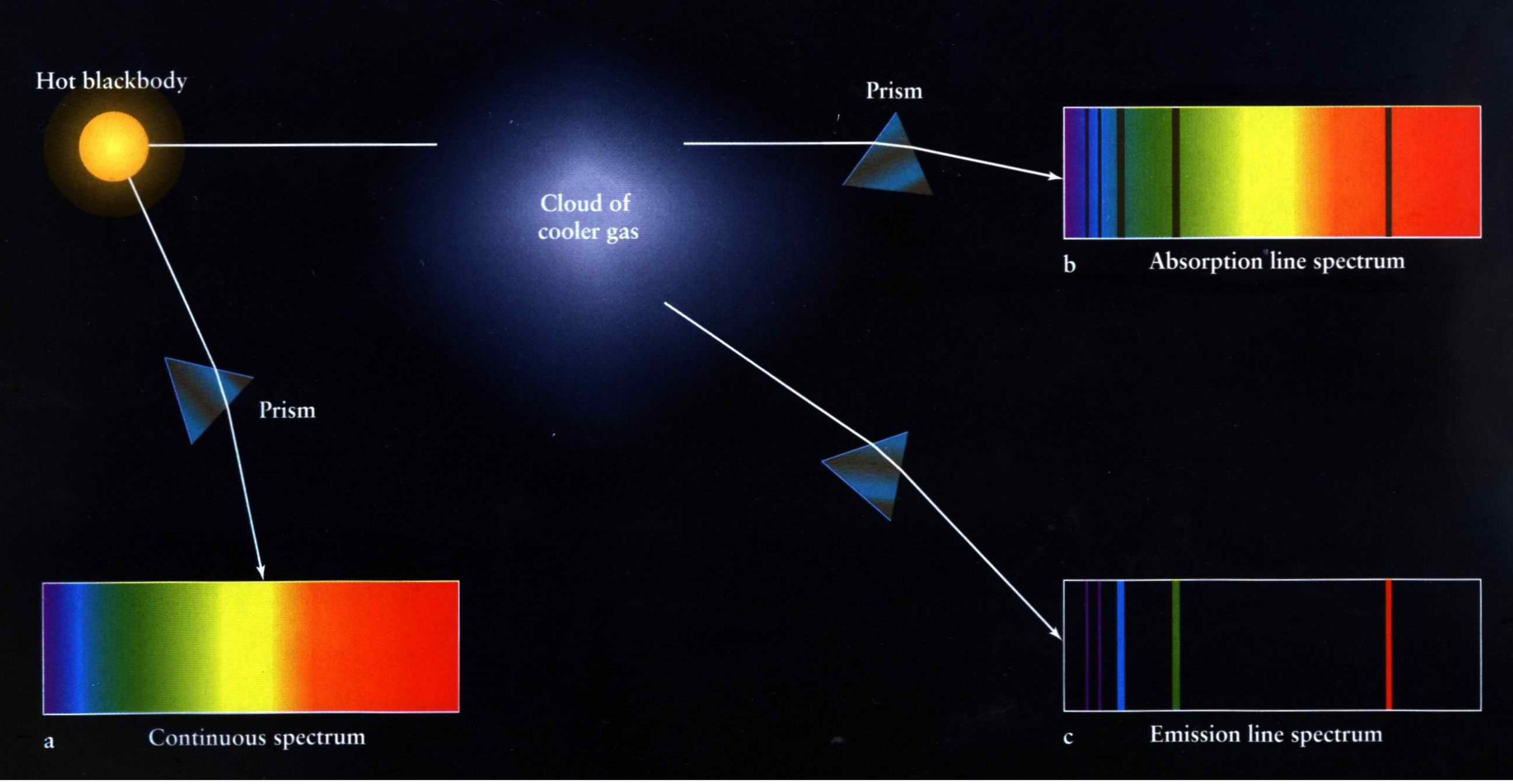
# Emission of Energy

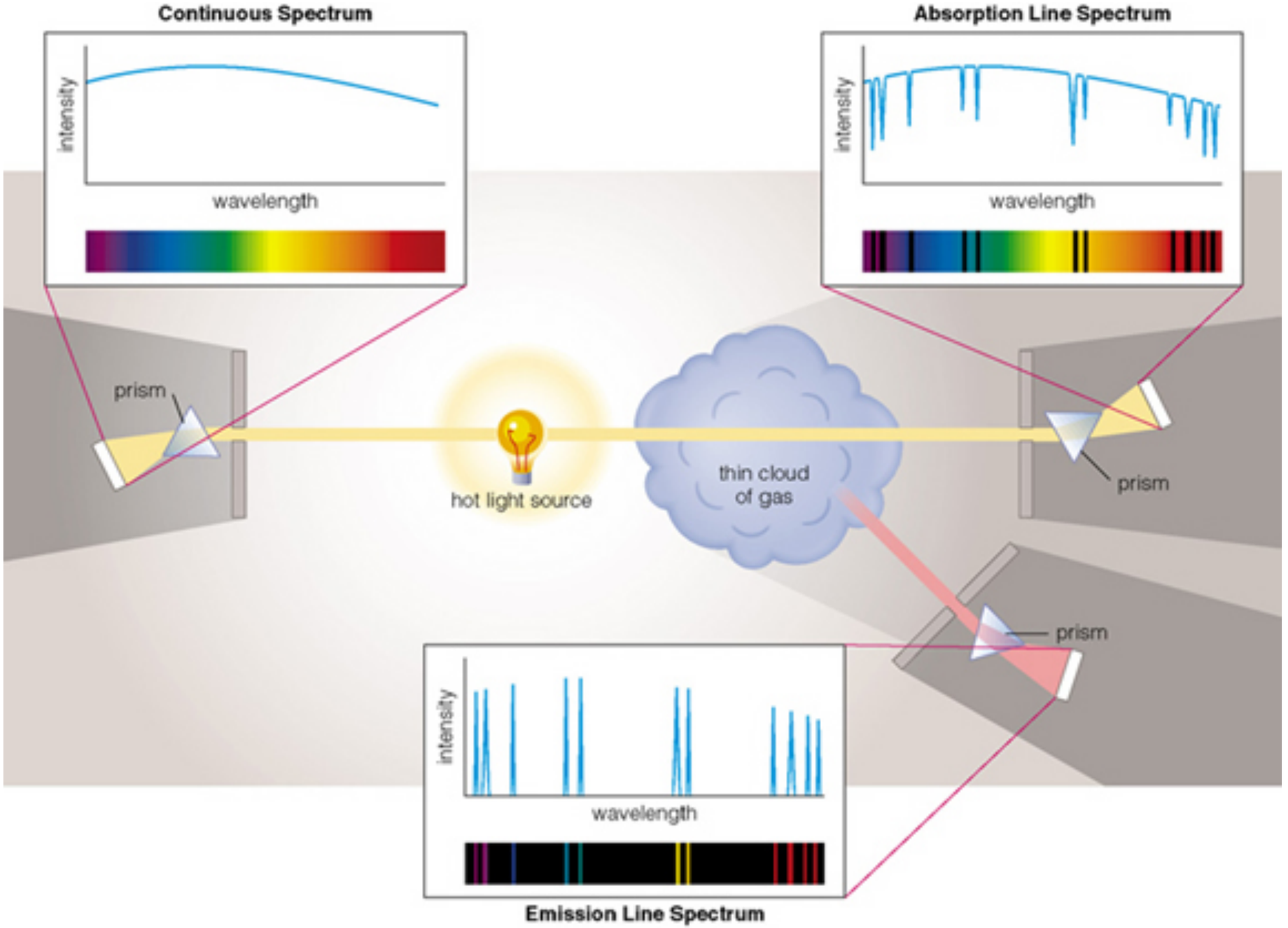



Radiative Recombination

# Kirchoff's Laws

- A solid, liquid, or dense gas produces a continuous spectrum.
- A tenuous gas in front of a hot background produces an absorption spectrum.
- A tenuous gas in front of a cool background produces an emission spectrum.


Hot blackbody
Prism
Cloud of cooler gas
Prism
b
Absorption line spectrum
Prism
a
Continuous spectrum
c
Emission line spectrum

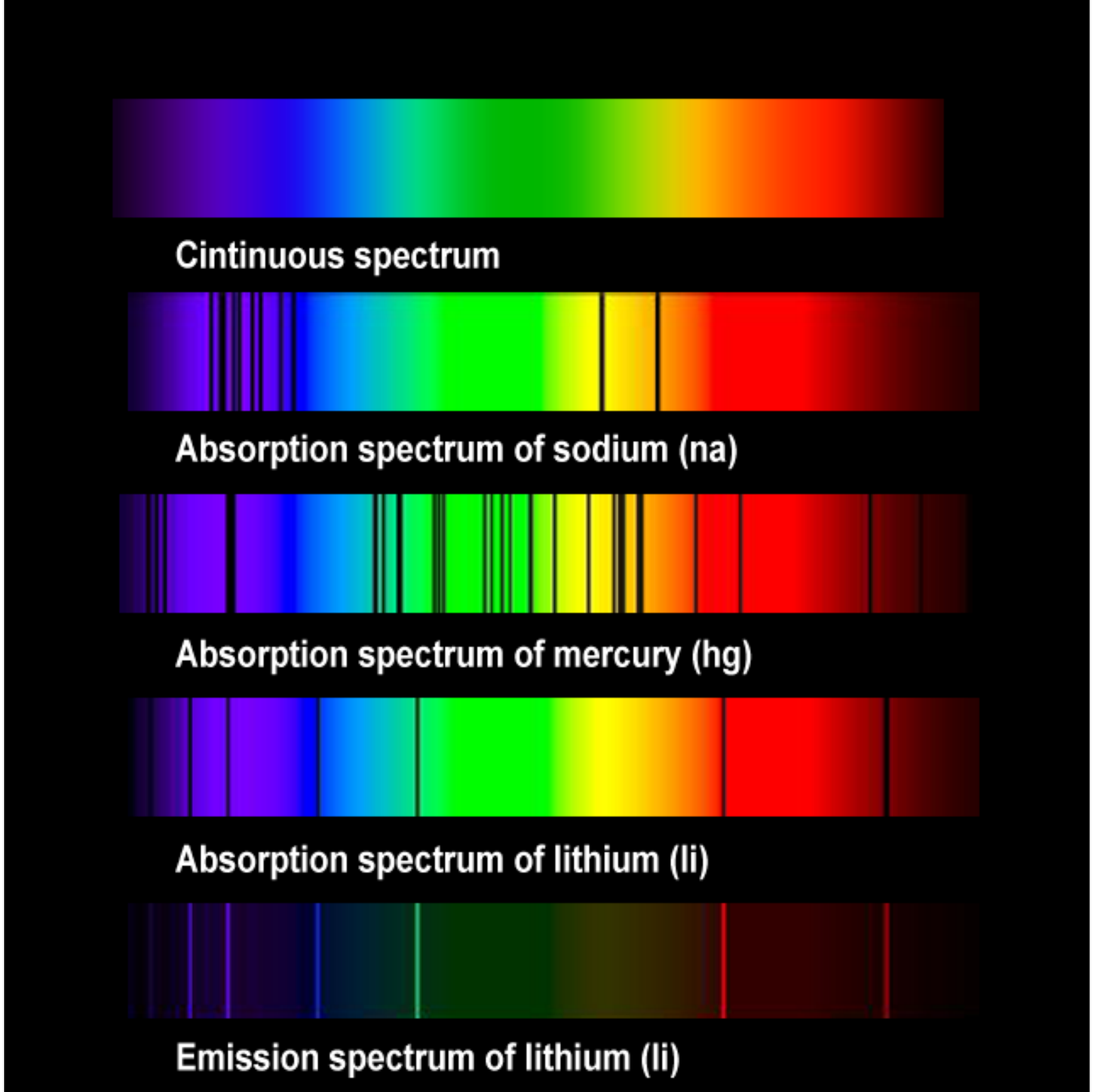

Continuous Spectrum
intensity
wavelength
Absorption Line Spectrum
intensity
wavelength
prism
hot light source
thin cloud
of gas
prism
prism
intensity
wavelength
Emission Line Spectrum

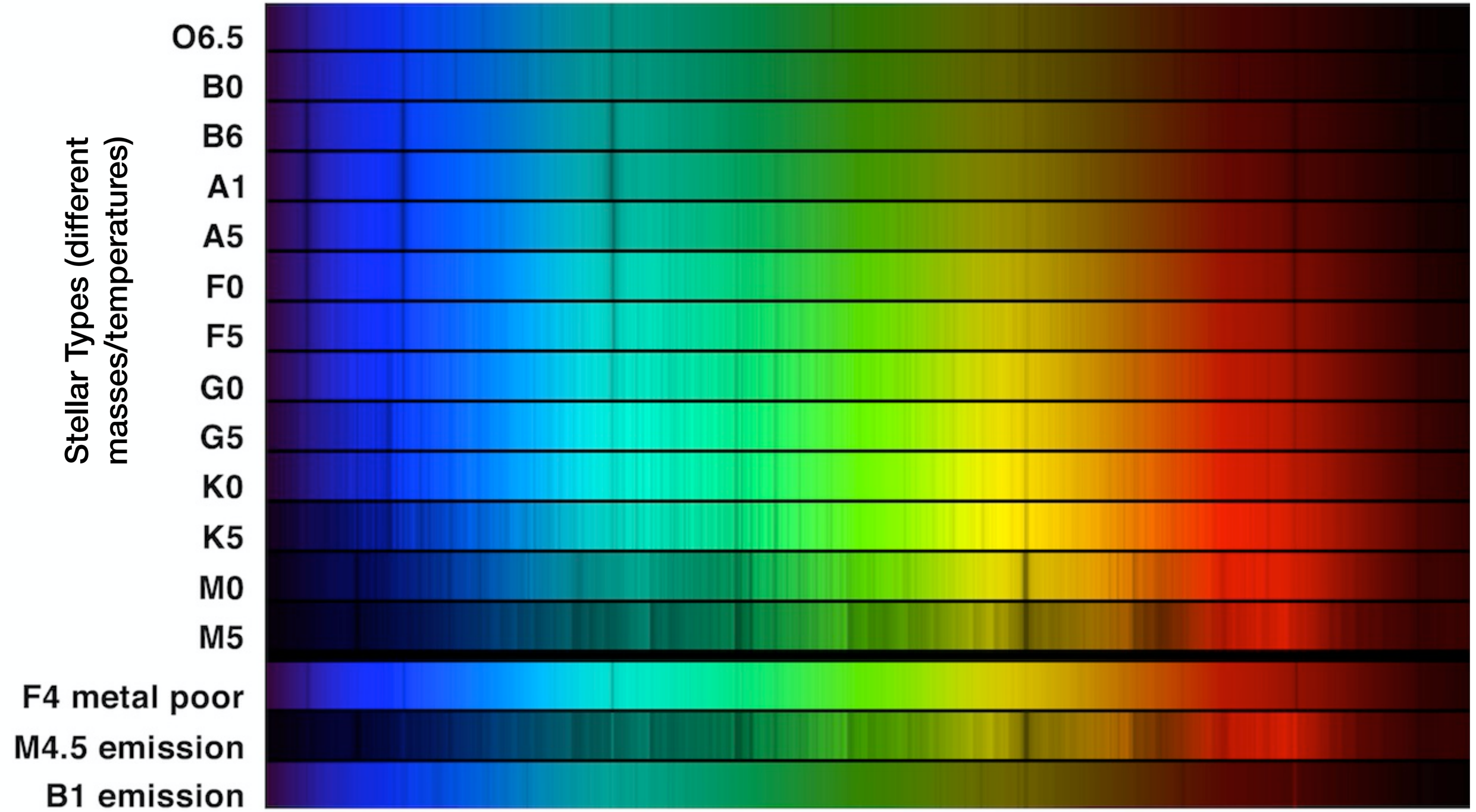
# Spectra are like Fingerprints

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