Reading: OpenStax, Chapter 3, Sections 3.1-3.3

Brief review of last time: **Og through Newton**

- By watching the skies, humankind eventually uncovered the basic laws that govern the motions of the planets, stars, and galaxies
- Using Newton's laws, we can measure the most fundamental property of things in the Universe - their mass

Today: **Universal Forces & Messengers from the Cosmos**

- Introduction to your second instructor: me!
- Gravity as a Cosmic, Universal force
- Light as a manifestation of another force - Electromagnetism (E-M)

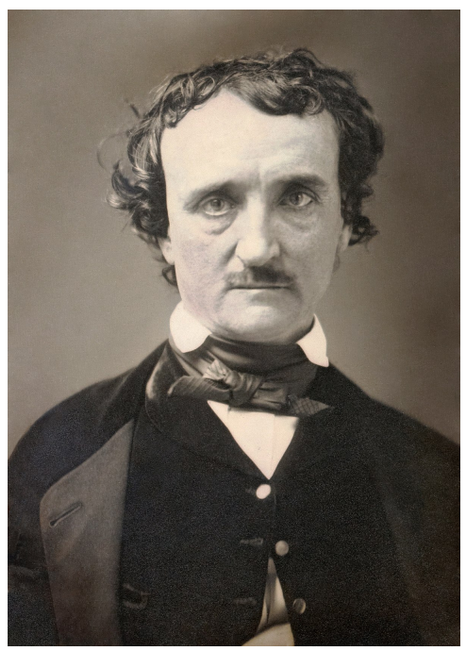
Prof. Jake Simon

- Born in Illinois (about 6 hours away from here!) — I too am a corn-fed, Midwesterner
- Went to University of Illinois
- PhD at UVA
- Postdoctoral work in Boulder, CO
- Back “home” (i.e., to the Midwest) in Fall 2019

University of Virginia
Famous People

- Phil Plait (the “Bad Astronomer”; https://www.discovermagazine.com/blog/bad-astronomy)

- Tina Fey



- Edgar Allan Poe

Four Fundamental Forces

- Gravity
- Electromagnetism
- Strong nuclear force
- Weak nuclear force

Newton's Law of Universal Gravitation

Gravity is

- a **central** force: strength drops with distance^2
- a **universal** force: same form everywhere
- a **cosmic** force: inherent property of matter

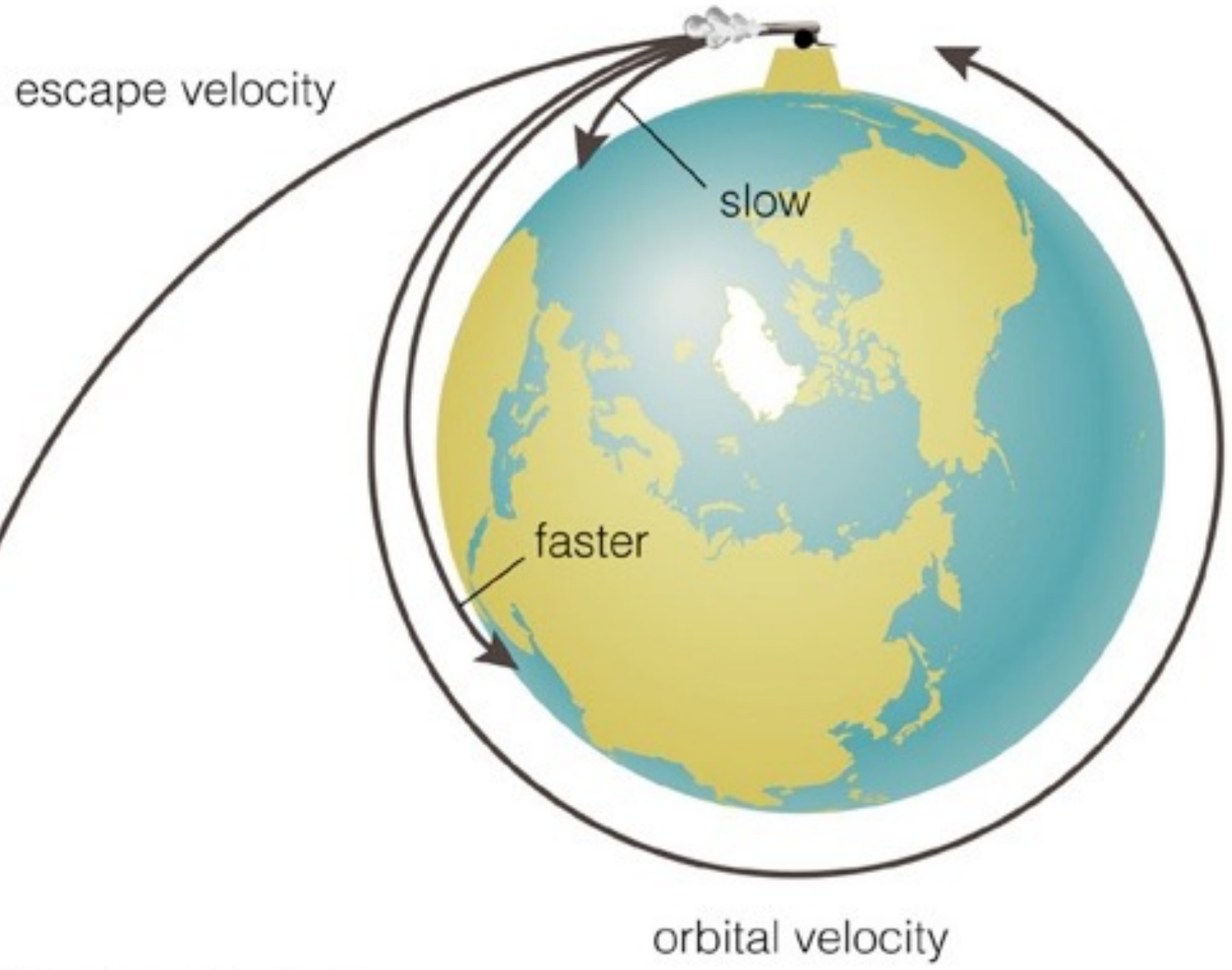
Apple falls -> Earth and apple attract each other

Moon and Earth attract each other, too

Everything that has mass has a gravitational pull.
Even you, and me!

Gravitational Force

Orbits



https://phet.colorado.edu/sims/html/gravity-and-orbits/latest/gravity-and-orbits_en.html

Newton's Derivation of Kepler #3

- Gravitational force pulling planets toward sun

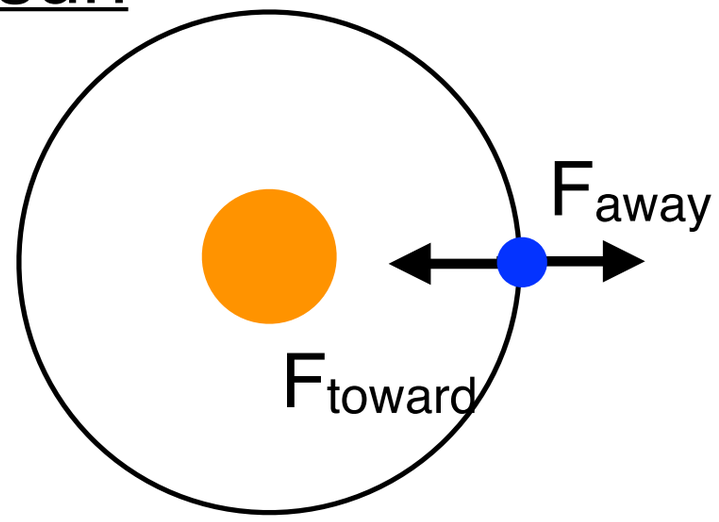
$$F_{\text{toward}} = \frac{GMm}{a^2}$$

(Newton's law of Universal Gravitation)

- centrifugal "force" pulling planets away from sun

$$F_{\text{away}} = \frac{mv^2}{a} \quad \text{or, since} \quad v = \frac{2\pi a}{P}$$

$$F_{\text{away}} = \frac{m4\pi^2 a}{P^2}$$



- If forces equal, then distance between doesn't change!

$$\frac{GMm}{a^2} = \frac{m4\pi^2 a}{P^2} \quad \text{... or ...} \quad P^2 = a^3 \times \left(\frac{4\pi^2}{GM}\right)$$

a constant

this is Kepler's Third Law - **with benefits**!

Newton's Derivation of Kepler #3

$$P^2 = a^3 \times \left(\frac{4\pi^2}{GM} \right)$$

this is Kepler's Third Law - **with benefits**!

For P in years and a in AU, $\left(\frac{4\pi^2}{GM} \right) = 1$

$$P^2 = a^3$$

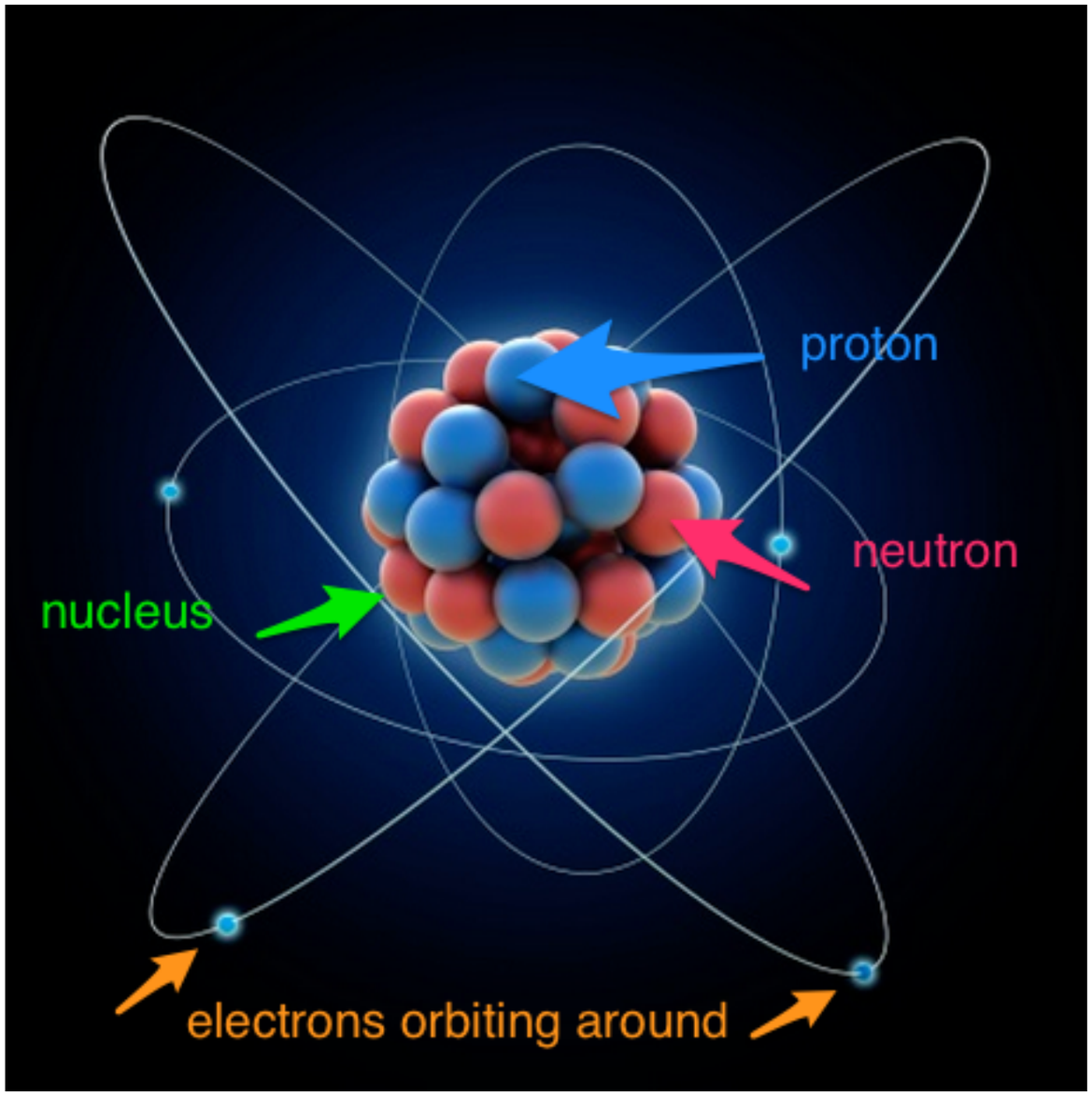
Newton's Legacy

- **Force of Gravity pulls planets towards Sun**
  - without gravity, planets would fly away in straight lines

- Newton's laws of motion and theory of gravity explain -simply- the orbits of the planets

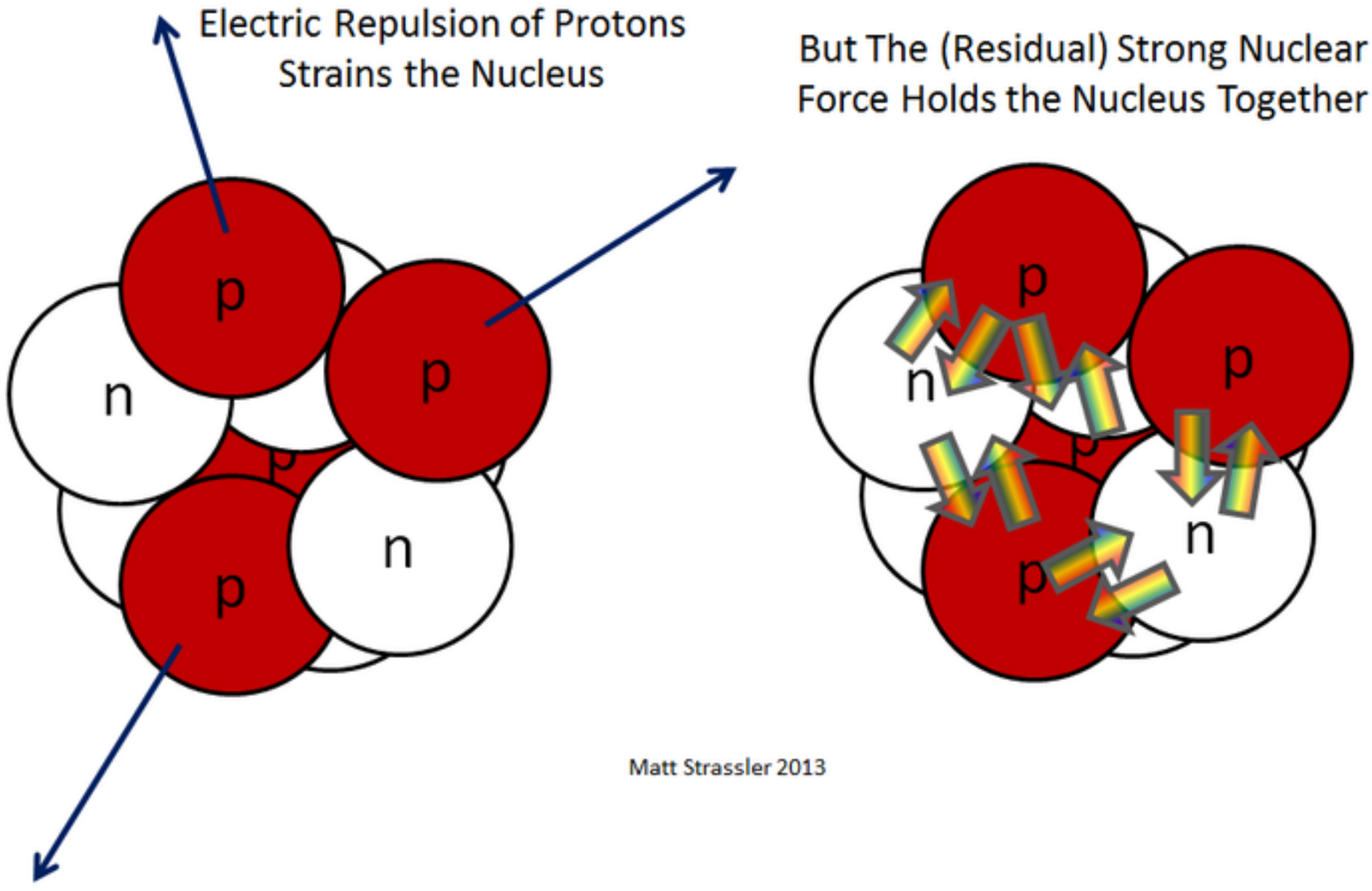
Understanding motions of the planets was the principal discovery of astronomy from prehistory through 1700.

Protons, neutrons, electrons



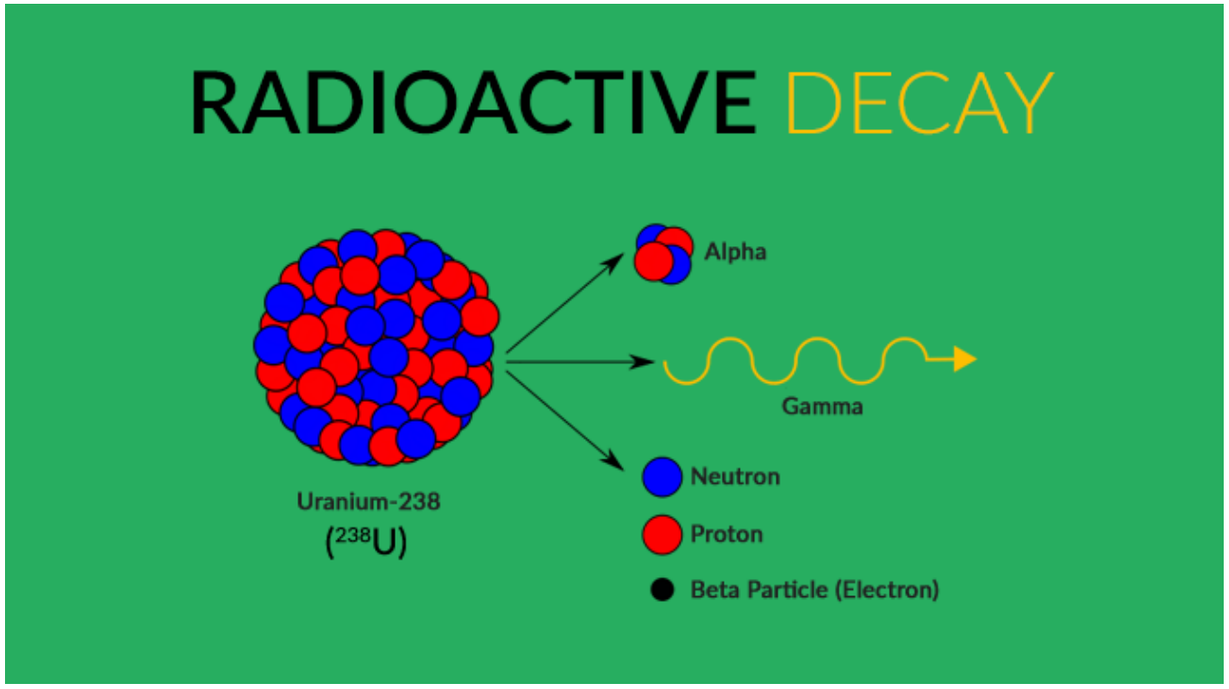
Electromagnetism

Strong Nuclear Force



Matt Strassler 2013

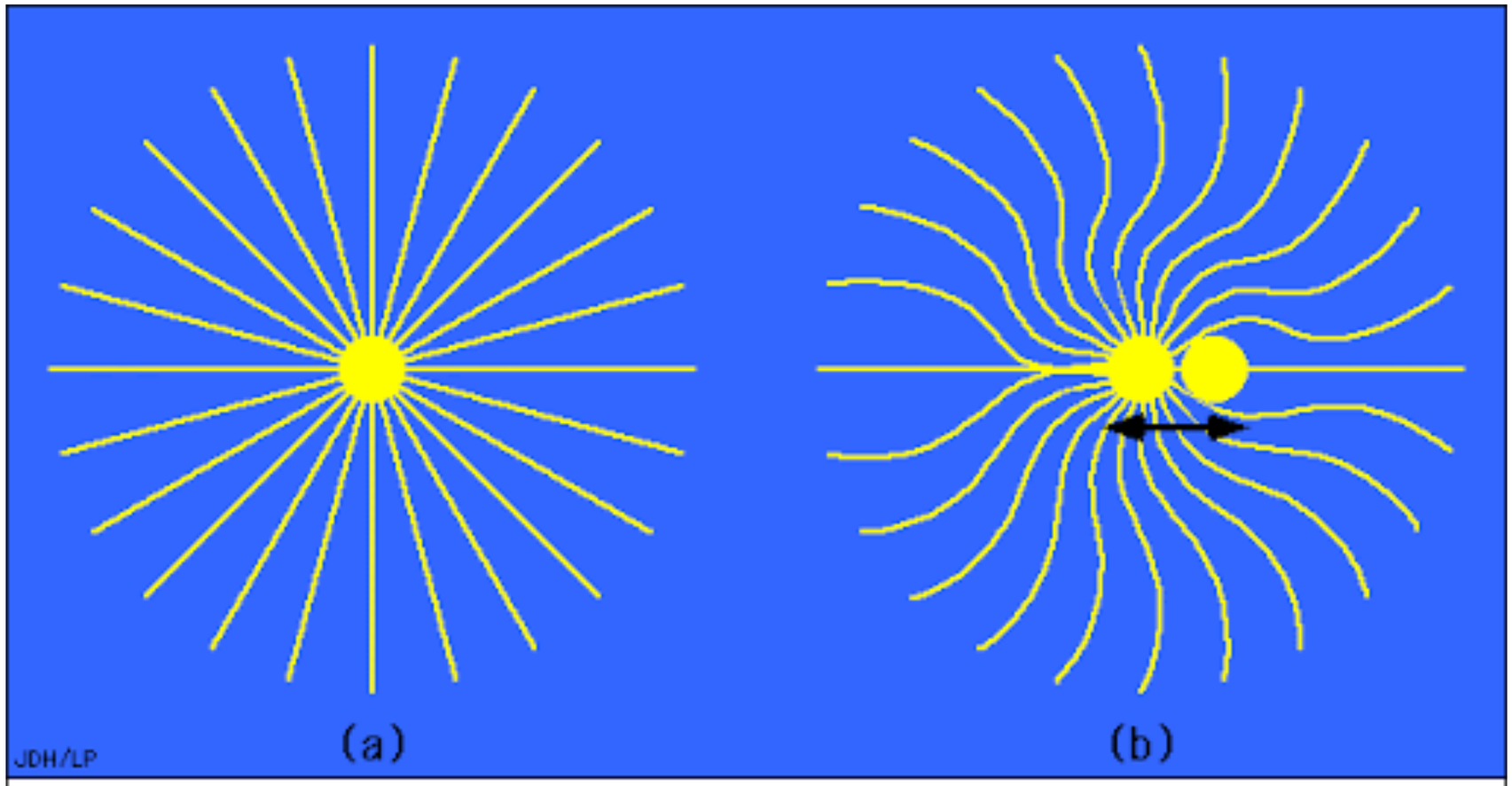
Weak Nuclear Force



Electromagnetism

https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

Electromagnetic Waves

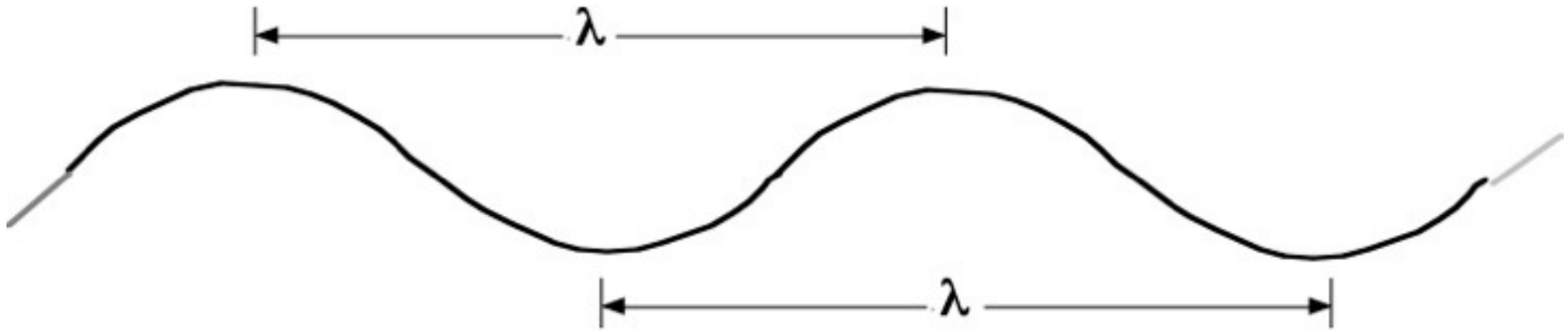


Electric field lines around an electron (a) become wavy as the electron vibrates back and forth (b). The moving electron also generates a magnetic field that forms waves that reinforce the electrical waves and vice versa.

Electromagnetic Waves

Electromagnetic waves are light!

Wave Properties of Light



- "**Wavelength**" (λ)
  - distance between successive crests (or troughs)
- "**Frequency**" (***f***)
  - number of waves passing a point in 1 second
- "**speed of wave**" (***v*** or ***c***)
  - = wavelength x frequency

$$\boldsymbol{v} = \lambda \times f$$

$$V_{\text{sound}} = 340 \text{ meters / second}$$

$$\boldsymbol{V_{\text{light}} = c = 3 \times 10^{8} \text{ meters/ second}}$$

Newton (again!)

showed that white light is composed of many colors . . .

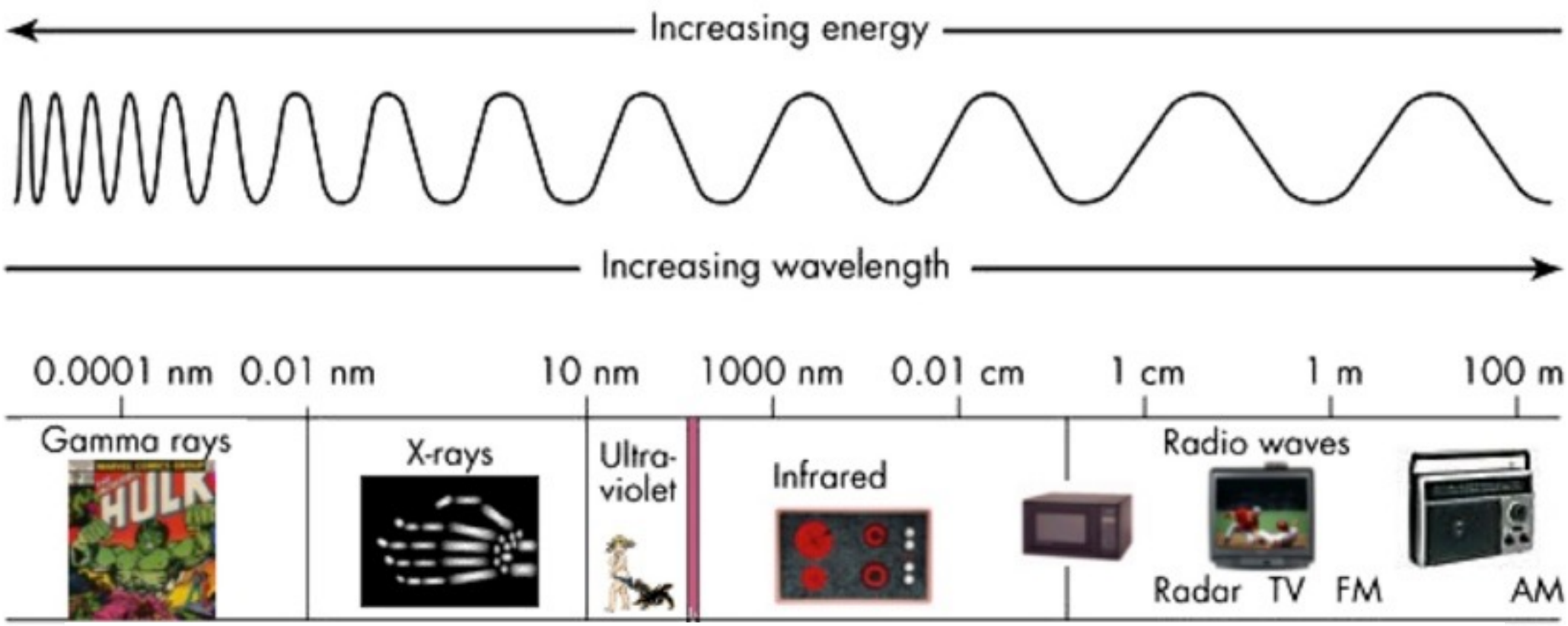
the **RAINBOW**

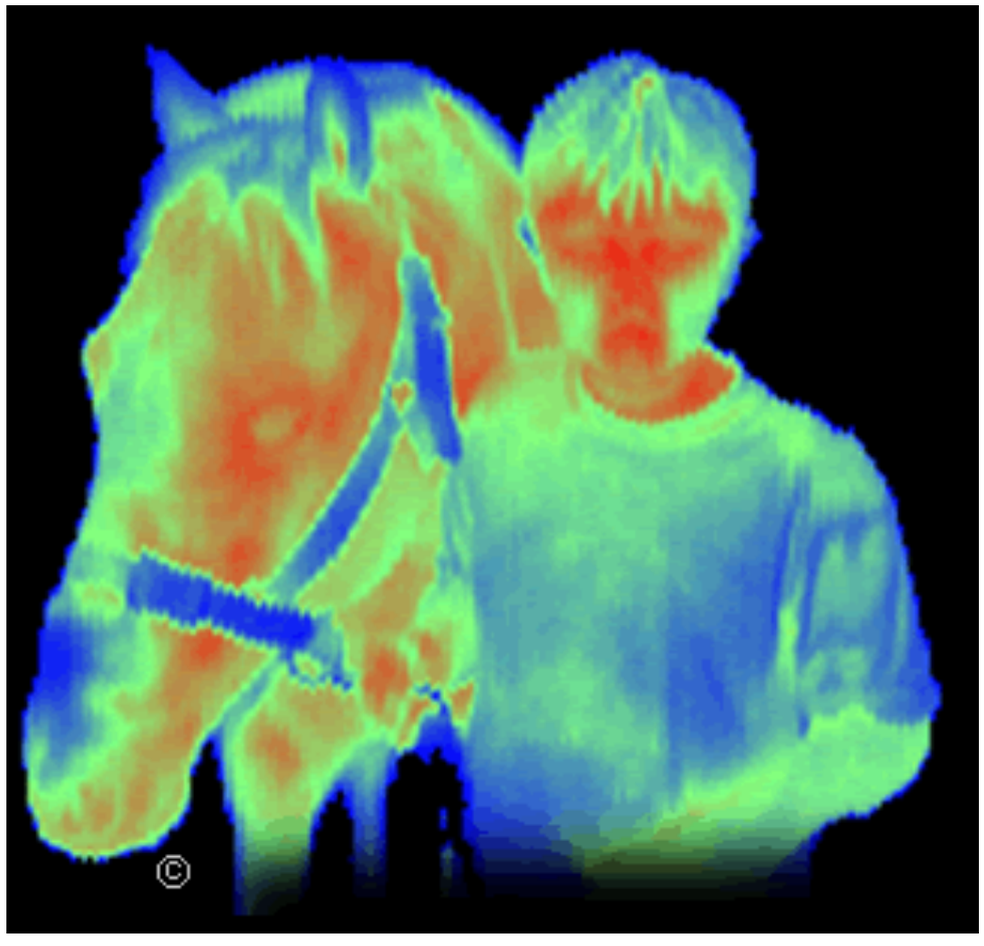
- Sound: different wavelength <–> different pitch
- Light: different wavelength <–> different color
- visible light has very short wavelength
  - blue: $\lambda = 4 \times 10^{-7}$ meters
  - red: $\lambda = 7 \times 10^{-7}$ meters
- new unit: the "nanometer" (nm) = 10^{-9} meter

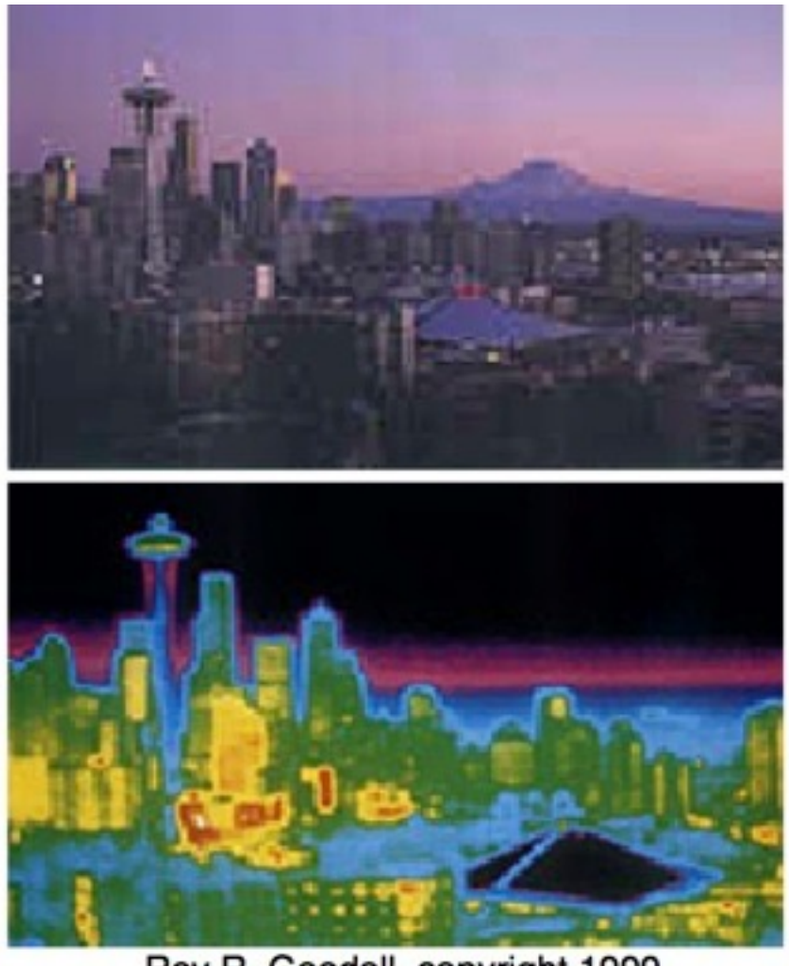
visible light: λ = 400 to 700 nm

The Electromagnetic Spectrum

- visible light ranges from 400 nm to 700 nm
- Usable e-m radiationfrom 0.001nm to >10 km







Roy R. Goodall, copyright 1999

Visible (left) and Infrared (right) view of Seattle.

Light

- (almost) the only way to learn about stars and (almost) everything else in the Universe
- we MUST squeeze out all we can from the feeble light from the stars

What Light Can Tell Us:

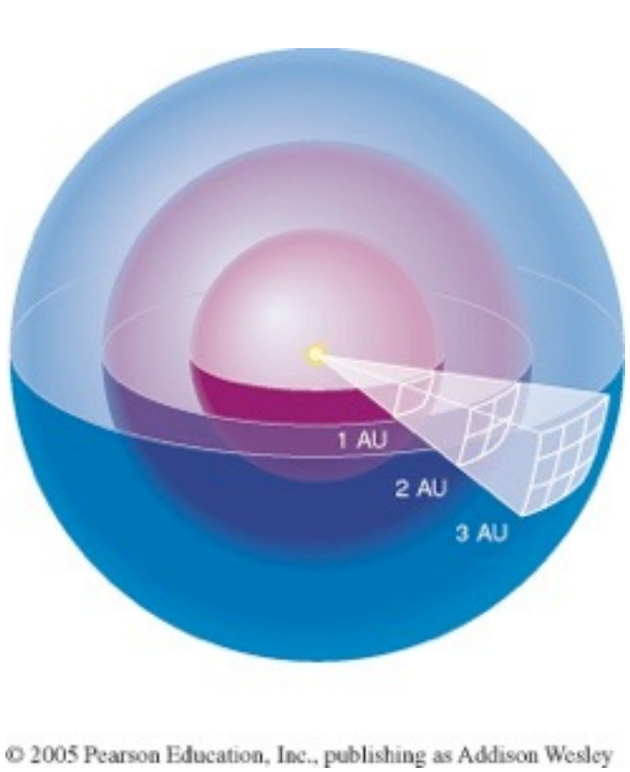
- location in space
- energy output
- temperature
- composition
- motion through space
- etc . . .

Measuring Light

- **Luminosity**
  - total rate of energy emission
  - intrinsic to the star

$$L = \frac{\text{energy}}{\text{time}}$$ "ergs per second"

- **Brightness**
  - rate of energy passage through a fixed area:
  - depends on distance



$$B = \frac{\text{ergs/s}}{\#\ \text{ of cm}^2} = \frac{L}{4\pi R^2}$$

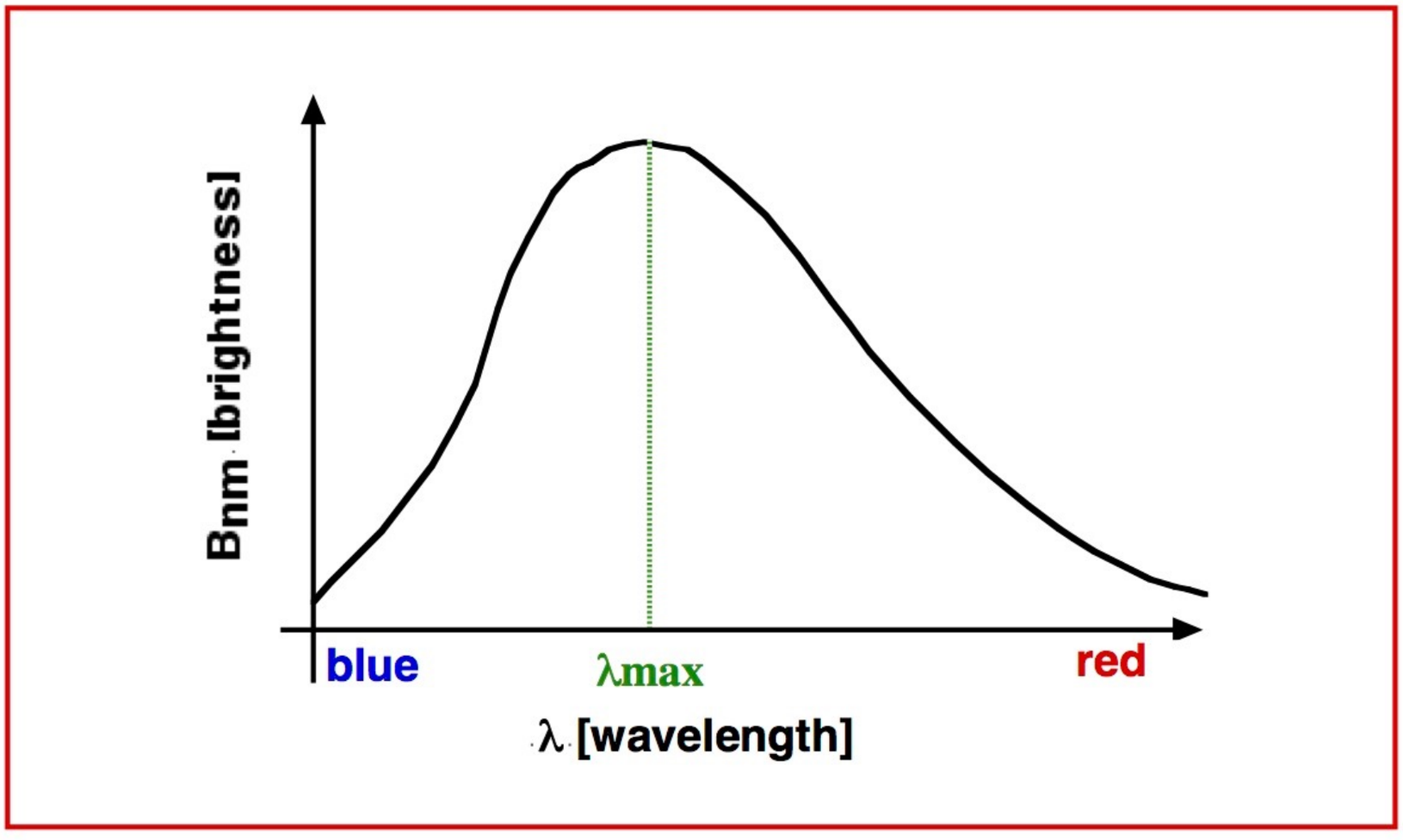
$$B \propto \frac{\text{Luminosity}}{\text{distance}^2}$$

- **INVERSE SQUARE LAW OF LIGHT**

"Continuous" Spectrum

is emitted by hot objects

- a.k.a. "thermal radiation" or "blackbody radiation"



- a black body is a "perfect radiator" ...
  - emits a continuous spectrum
  - spectrum shape determined by temperature only

https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_en.html