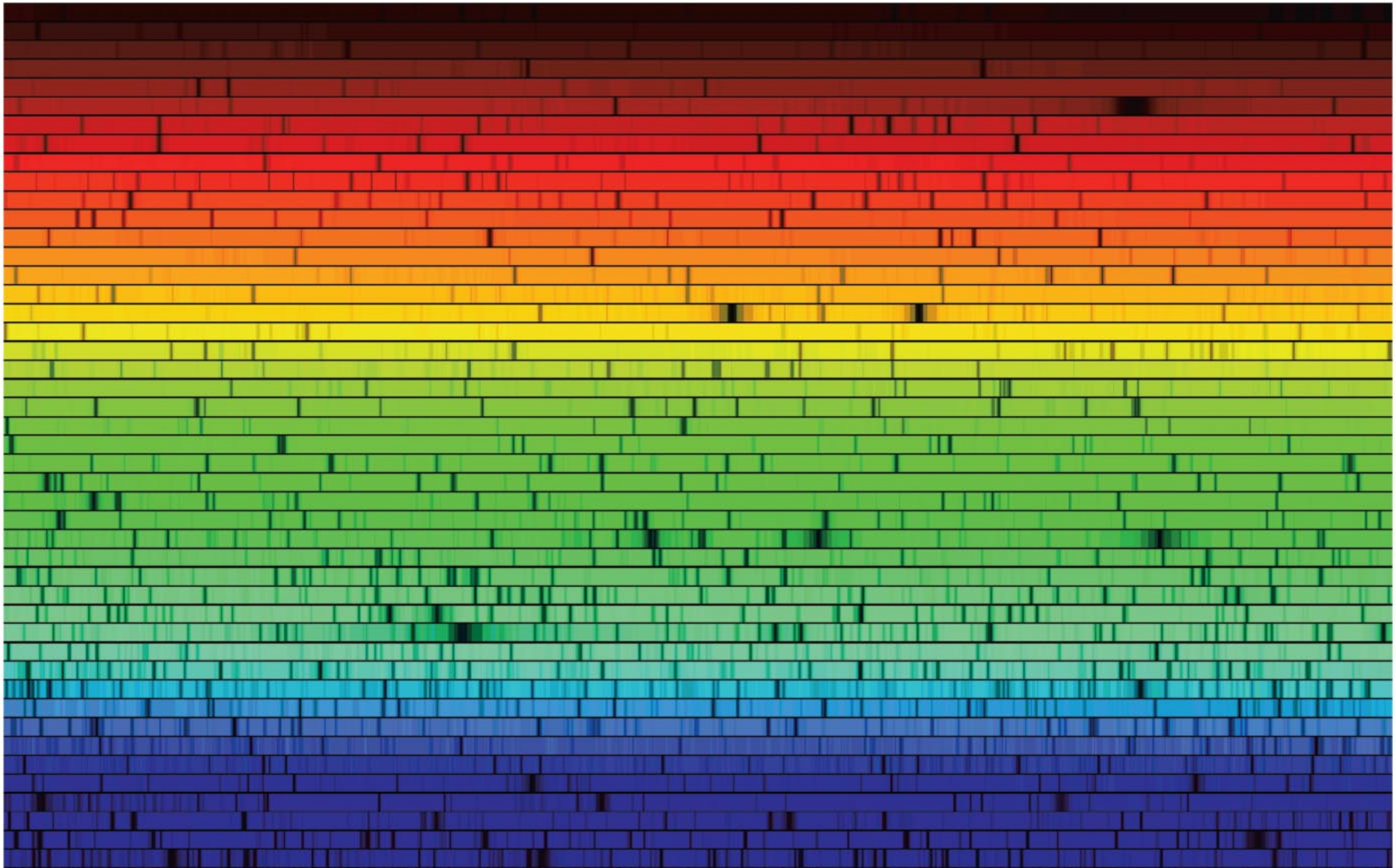
Today

- Light
  - The Electromagnetic Spectrum
- Thermal Radiation
  - Wien's Law
  - Stefan-Boltzmann Law
- Kirchoff's Laws
  - Emission and Absorption
  - Spectra & Composition

Electromagnetic Radiation



Electromagnetic Radiation

aka Light

“Radiation” sounds scary, but there are many benign forms of radiation - including visible light, radio waves, and infrared radiation.

These are all fundamentally the same stuff.

Electromagnetic Radiation

aka Light

- Properties of Light are simultaneously
  - **wave-like** AND
  - **particle-like**

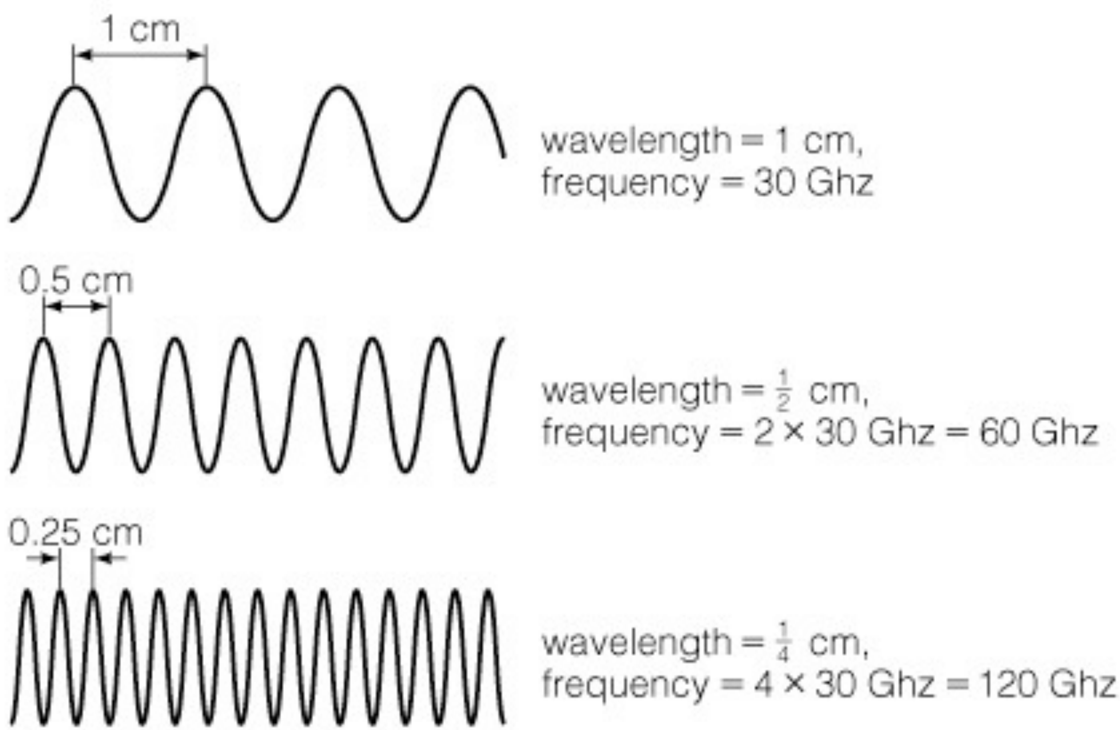
Sometimes it behaves like ripples on a pond (waves).
Sometimes it behaves like billiard balls (particles).

Called the “wave-particle” duality in quantum mechanics.

Particles of Light

- Particles of light are called **photons.**
- Each photon has a wavelength and a frequency.
- The energy of a photon depends on its frequency.

Wavelength and Frequency



Wavelength & Frequency

λ = wavelength (separation between crests)

f = frequency (rate of oscillation)

c = speed of light = 3×10^8 m/s

$$\lambda f = c$$

Wavelength, Frequency, and Energy

photon energy:

$$E = hf = hc/\lambda$$

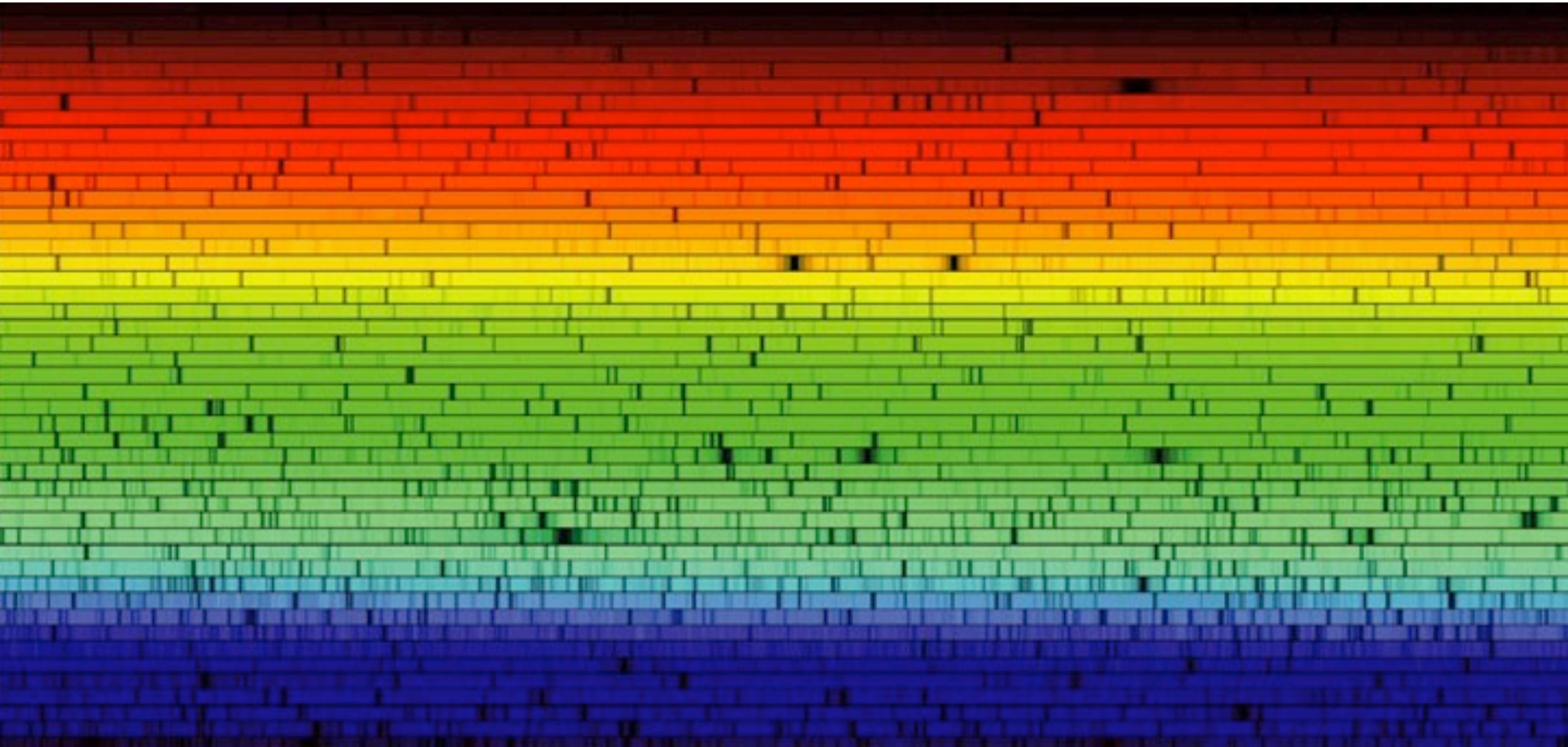
$$h = 6.626 \times 10^{-34} \text{ joule} \times \text{s}$$

(Planck's constant)

The frequency f can be arbitrarily high or low, so the energy carried by an individual photon can be arbitrarily high or low. However, the energy always comes in a finite unit of one photon at a time, not continuously.

Spectrum

- Originally, "the range of colors obtained by passing sunlight through a glass prism"
- Quantitatively, the Intensity of electromagnetic radiation as a function of wavelength



Long wavelength

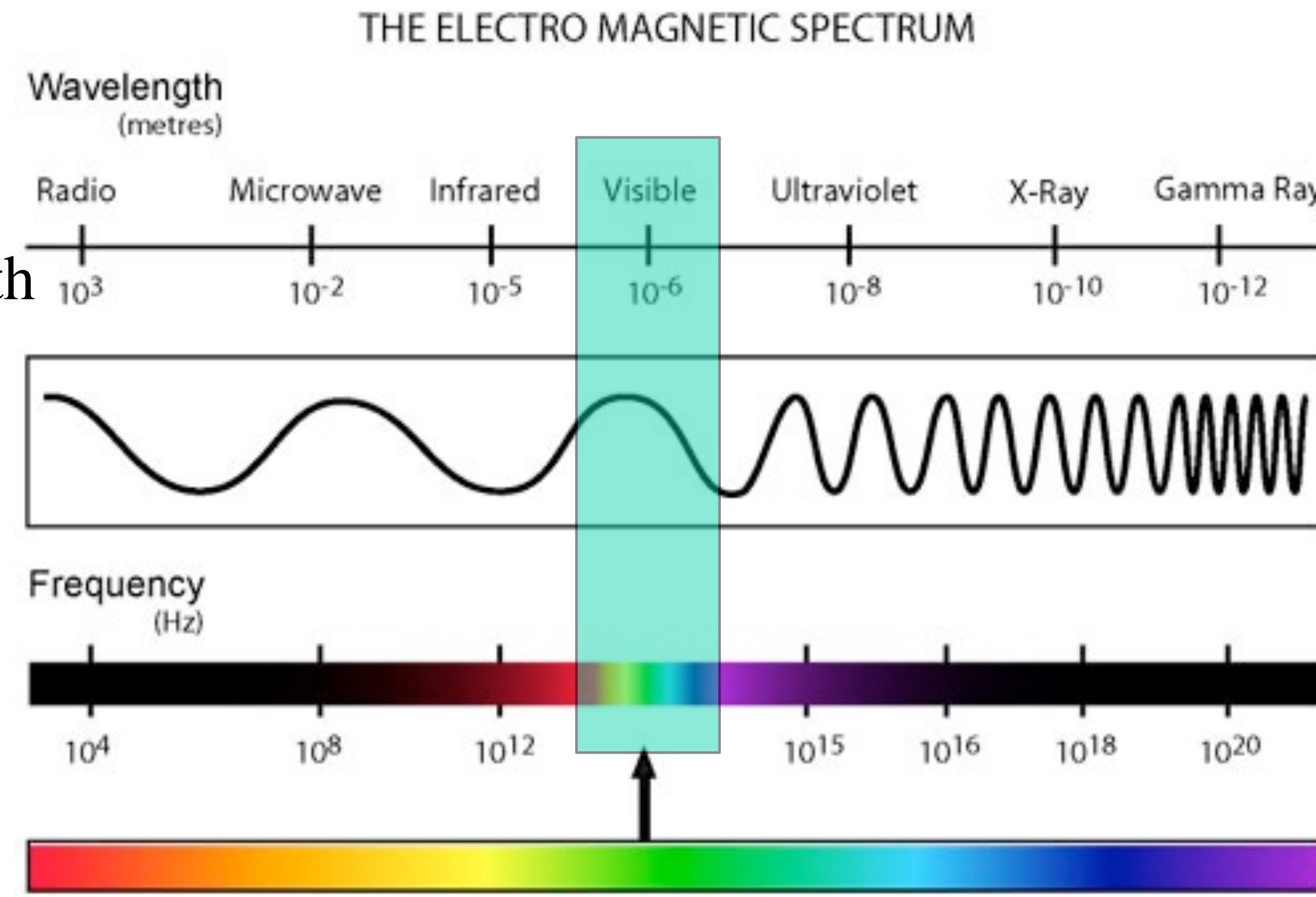
Short wavelength

Low energy

High energy

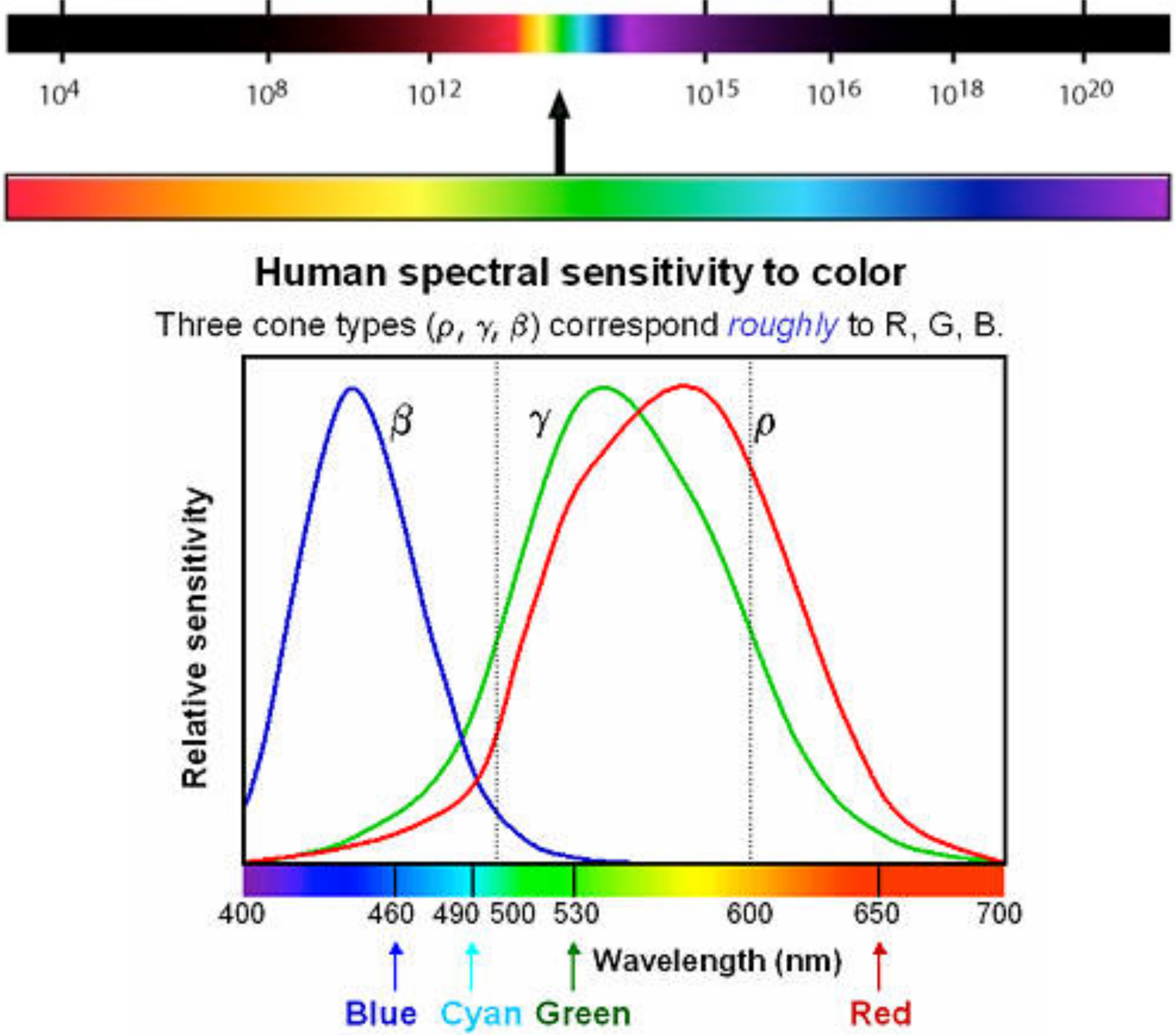
Low frequency

High frequency



$E\ ,f\ \ increasing$

$\lambda\ decreasing$



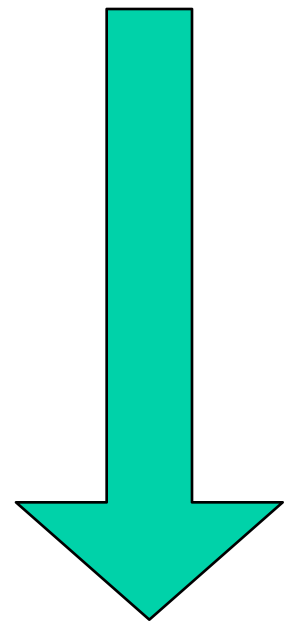
Our eyes are only sensitive to a factor of two range in wavelength, from 380nm (violet) to 700nm (deep red).

Same stuff, different Energy:

Electromagnetic Radiation

- Radio
- microwave
- infrared
- visible light
- ultraviolet
- X-ray
- gamma ray

Energy per photon increasing



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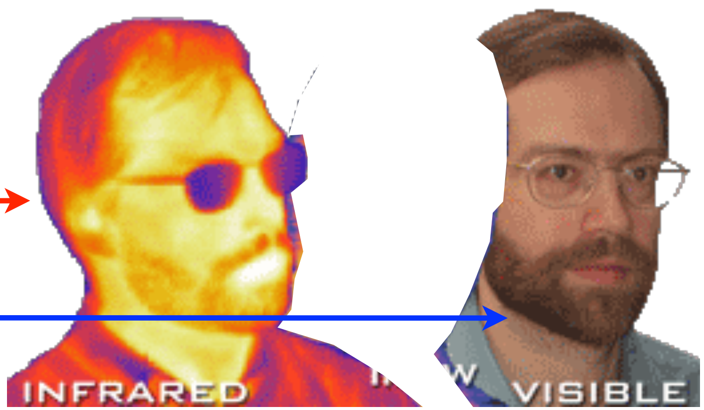

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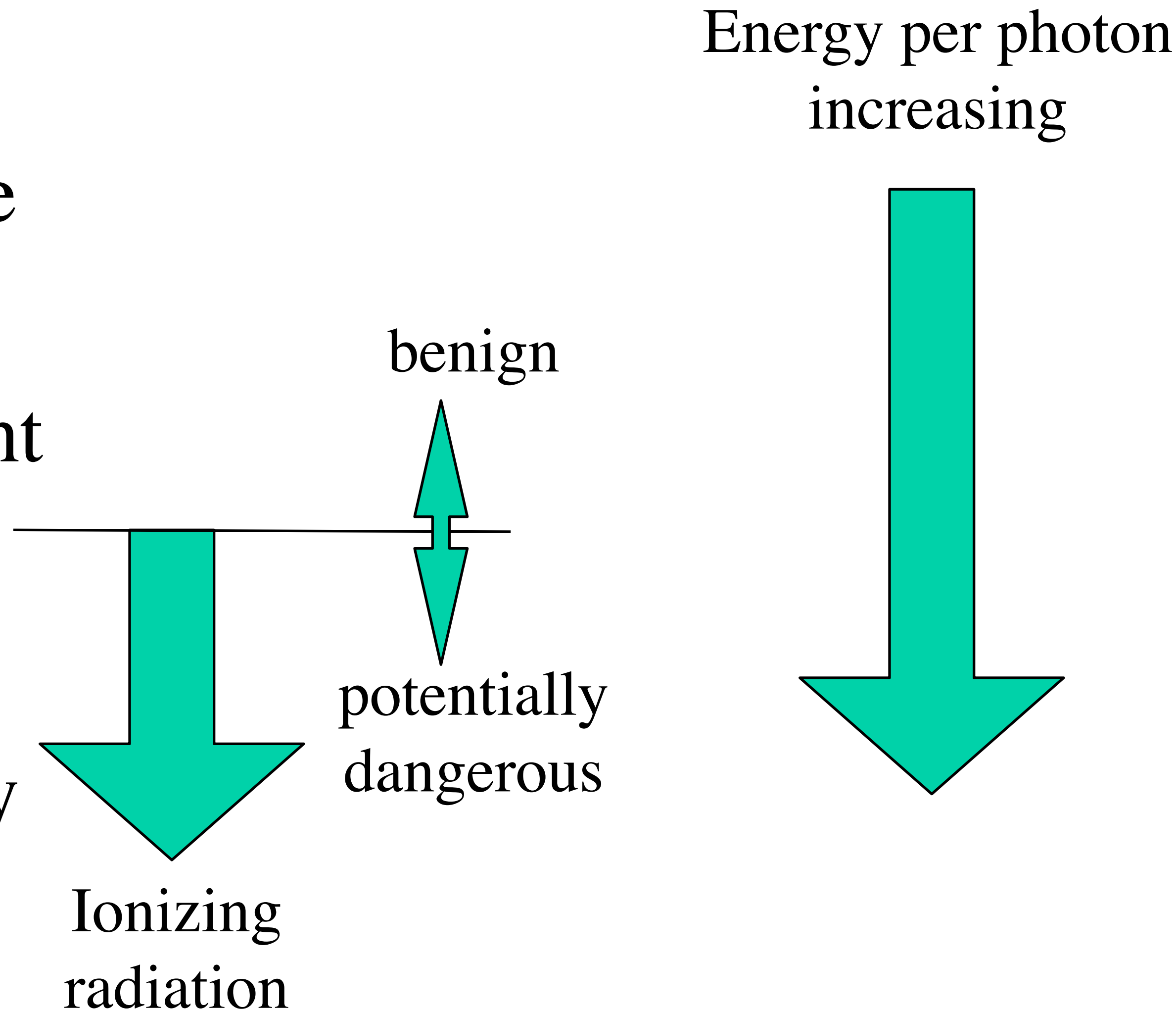

How do light and matter interact?

- Emission
- Absorption
- Transmission:
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection or scattering
  - we see by scattered light

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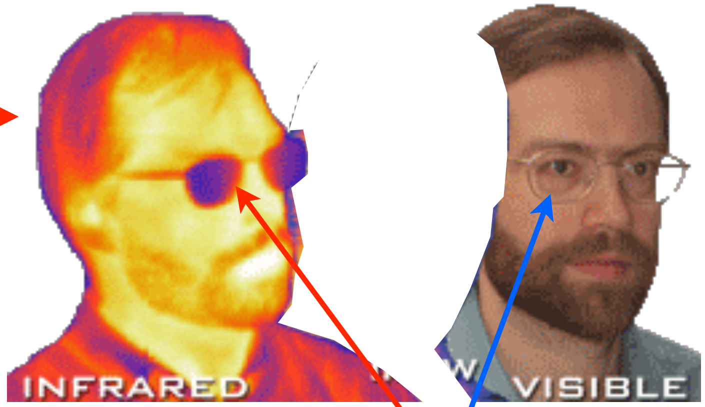
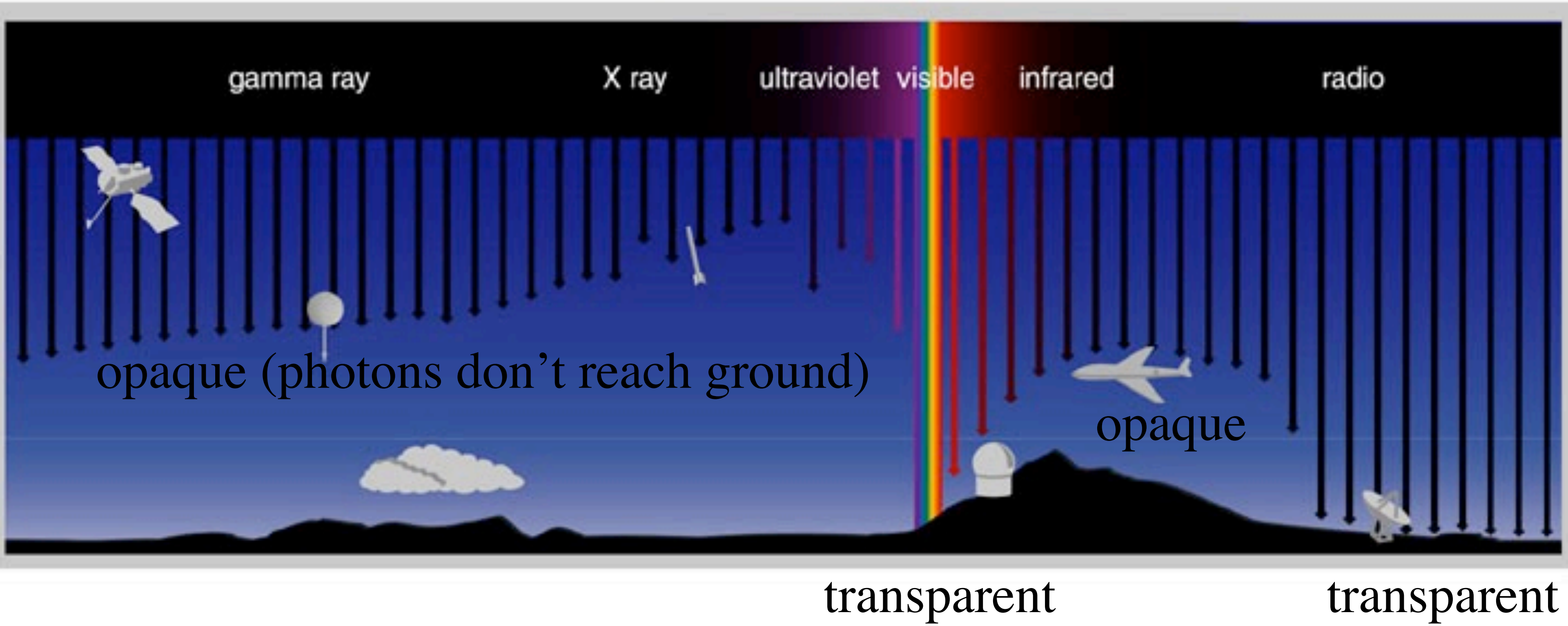
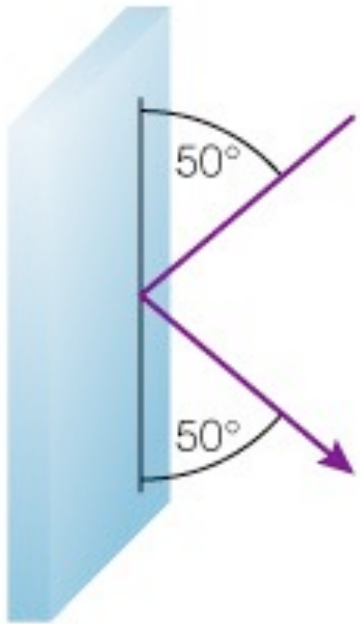


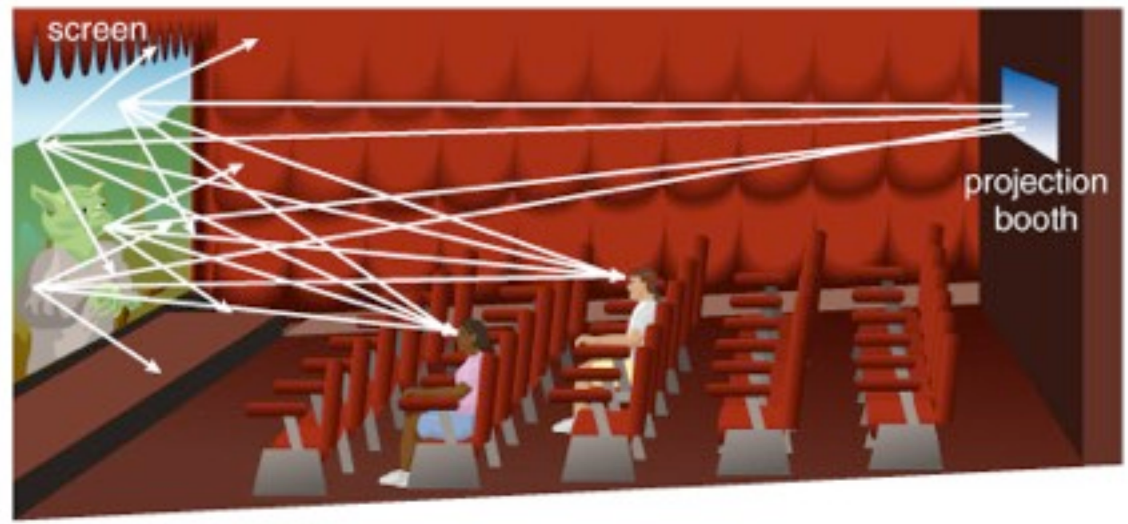
transmission & absorption



Earth's atmosphere is opaque to electromagnetic radiation at most wavelengths. It is transparent only to visible light and radio waves.

Reflection and Scattering

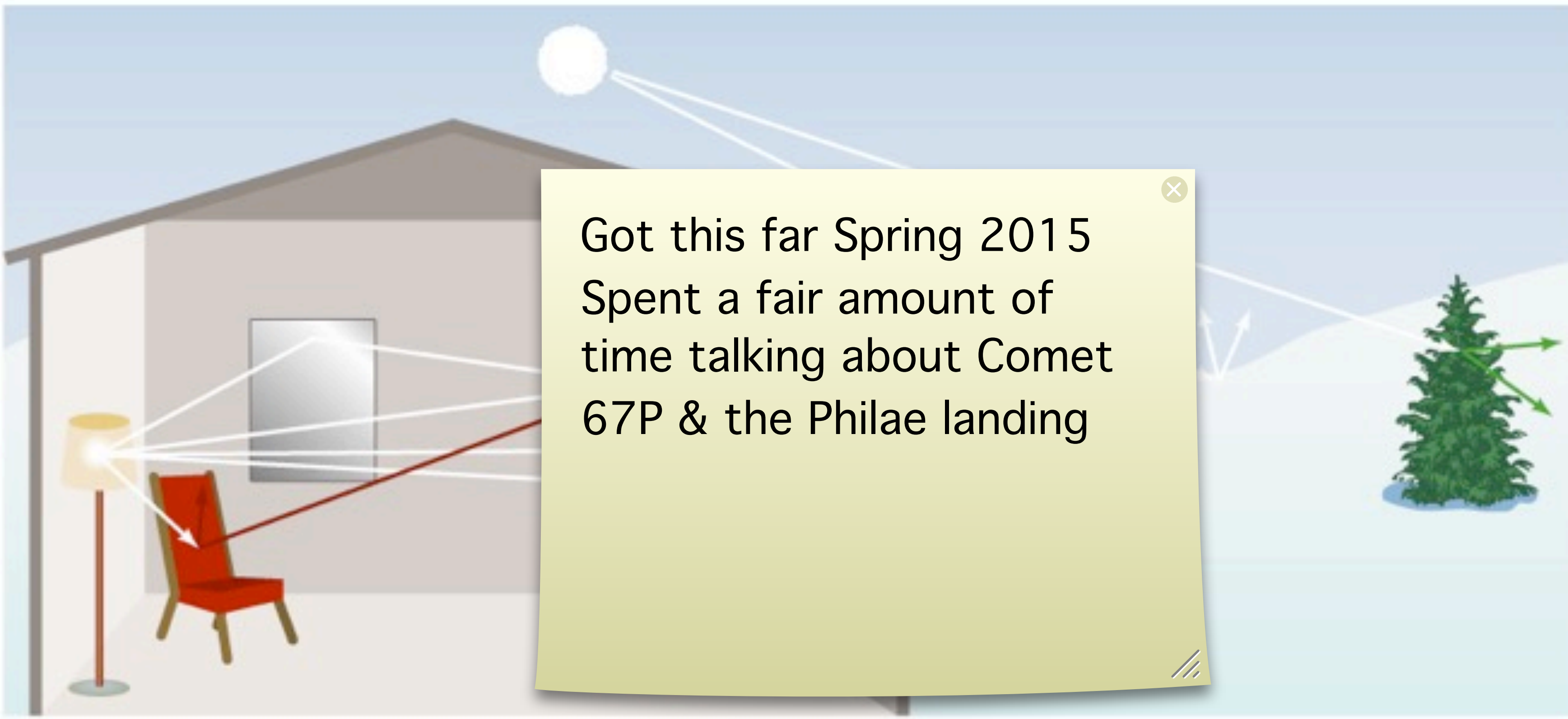




Mirror reflects light in a particular direction.

Movie screen scatters light in all directions.

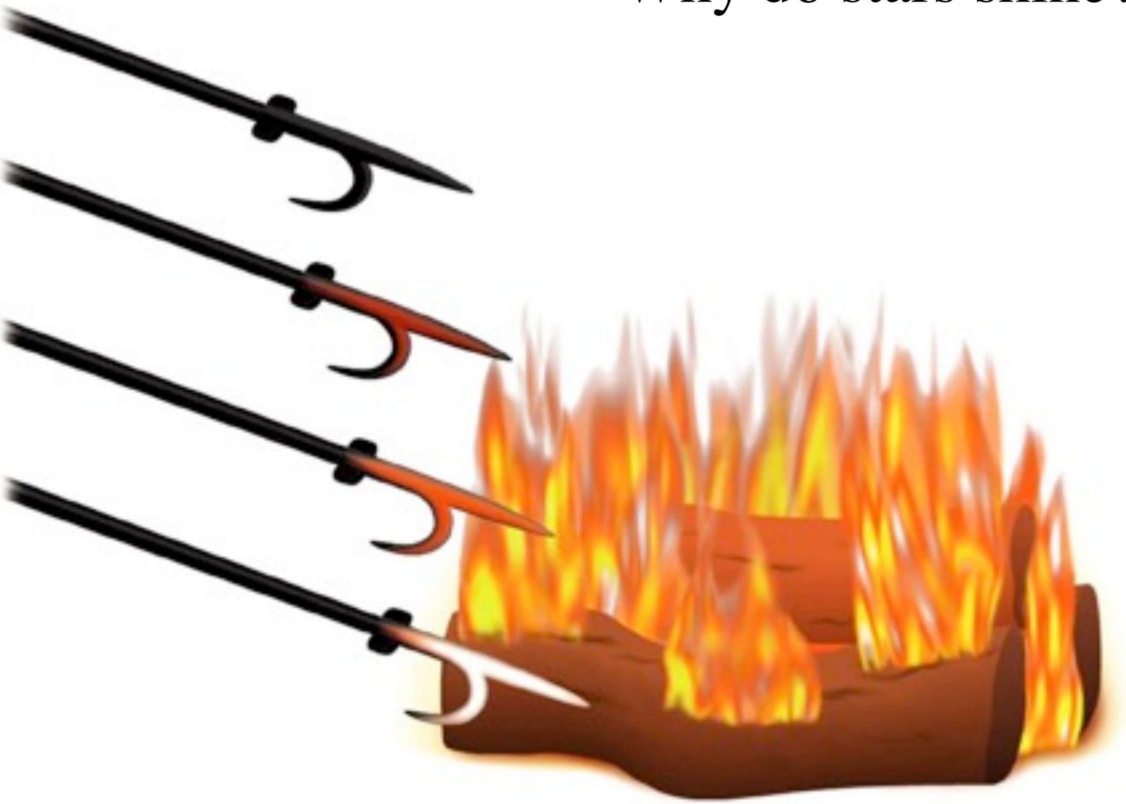
We see by scattered light



Interactions between light and matter determine the appearance of everything around us.

Production of light

Why do stars shine?



They're hot!

Thermal Radiation

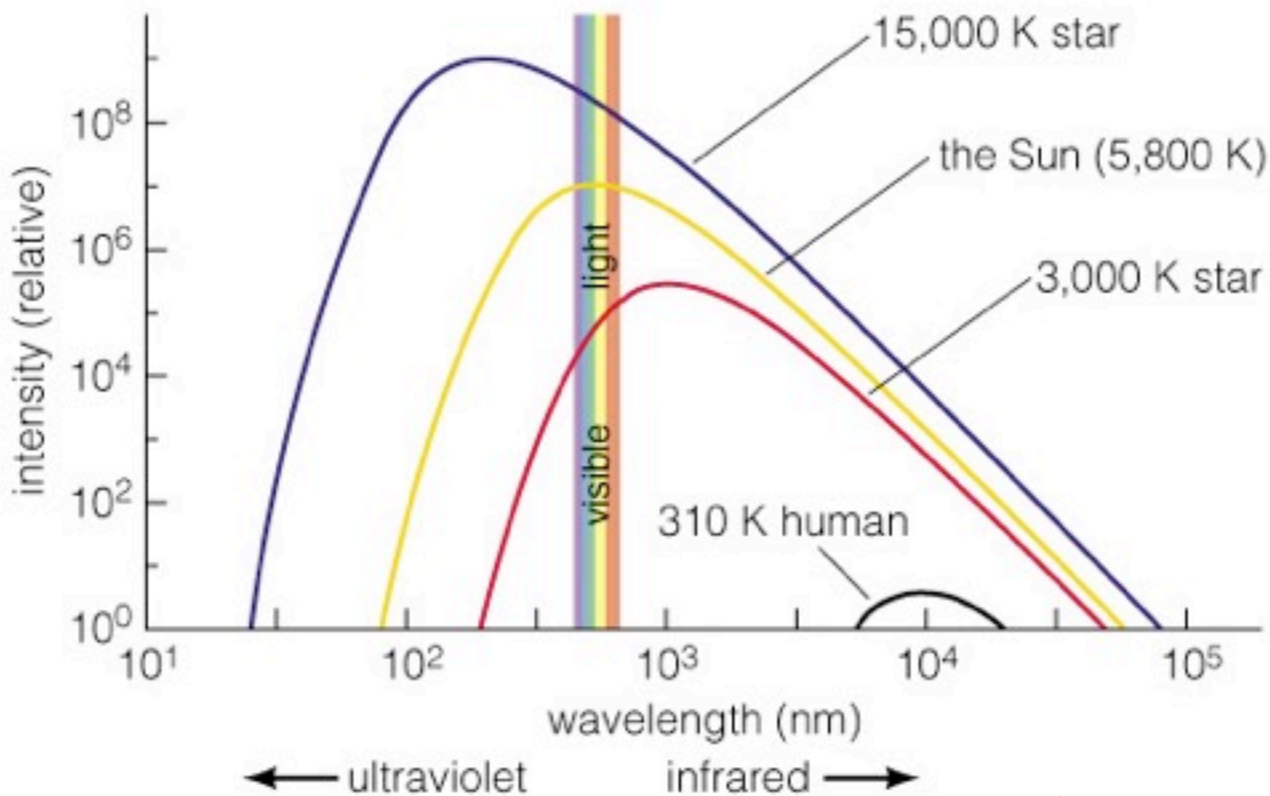
- Nearly all large, dense objects emit thermal radiation, including stars, planets, and you.
- An object's thermal radiation spectrum depends on only one property: its **temperature.**

Properties of Thermal Radiation

1. Hotter objects emit more light at all frequencies per unit area.
2. Hotter objects emit photons with a higher average energy.

Spectrum:

Intensity



Wavelength λ

Wien's Law

- $\lambda_p T = 2.9 \times 10^6$ nm K

- λ_p is the wavelength of maximum emission (in nanometers   nano = 10^{-9})
- T is temperature (in degrees Kelvin)

As **T** increases, wavelength decreases.
So hot object blue; cool objects red.

2 Examples:

- Human body
  - T = 310 K

$$\lambda_p = \frac{2.9 \times 10^6 \text{ nm K}}{310 \text{ K}} = 10,000 \text{ nm}$$

  - We radiate in the infrared

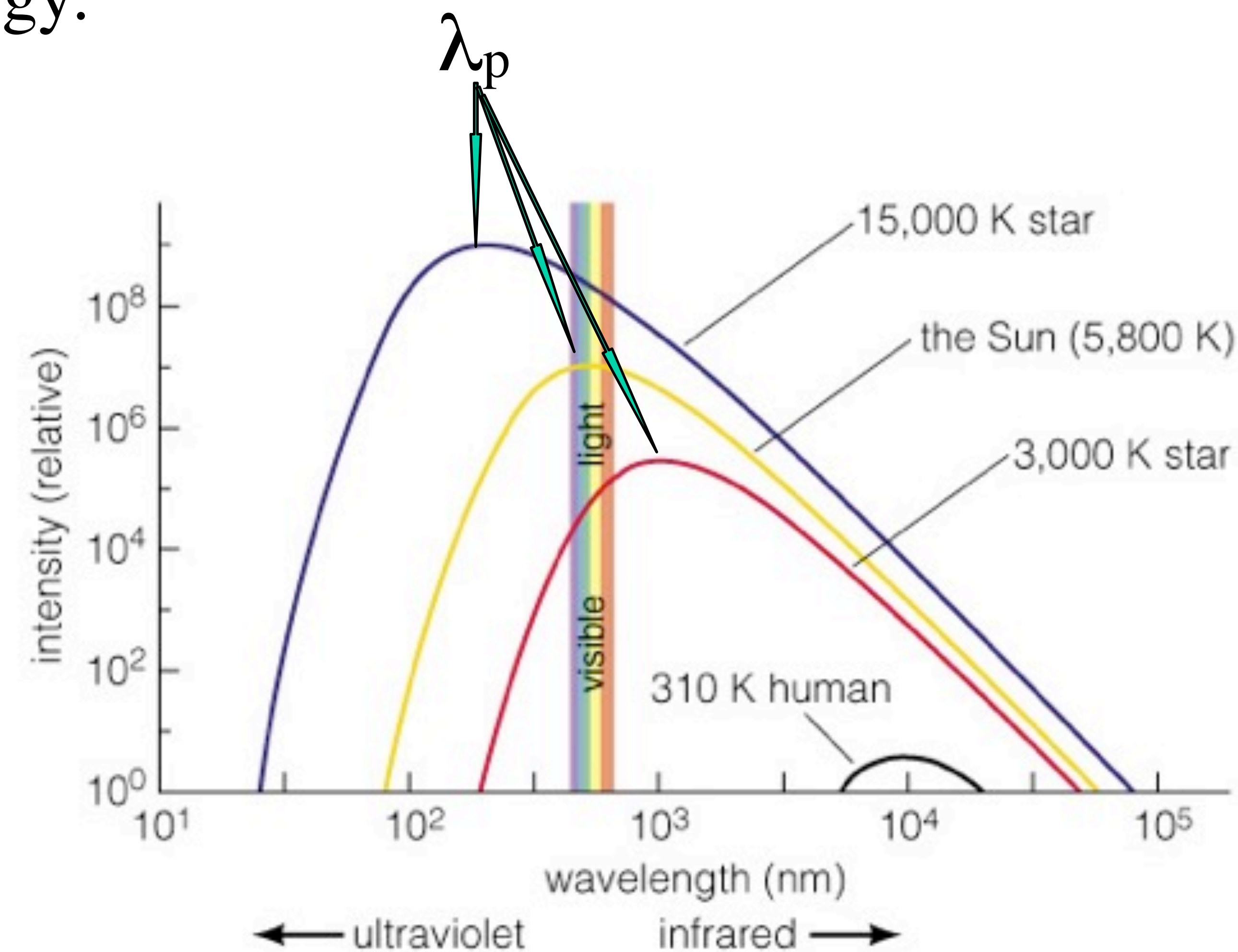
- The Sun
  - T = 5,800 K

$$\lambda_p = \frac{2.9 \times 10^6 \text{ nm K}}{5800 \text{ K}} = 500 \text{ nm}$$

  - The sun radiates visible light

Properties of Thermal Radiation

Hotter objects emit photons with a higher average energy.



Stefan-Boltzmann Law

$$L = 4\pi R^2 \sigma T^4$$

surface area of a sphere

- **L** = Luminosity (power radiated)
- **R** = Radius (e.g., of a star)
- **T** = Temperature (of radiating surface, in K)
- **σ** = Stefan-Boltzmann constant
  – just a number to make units work right

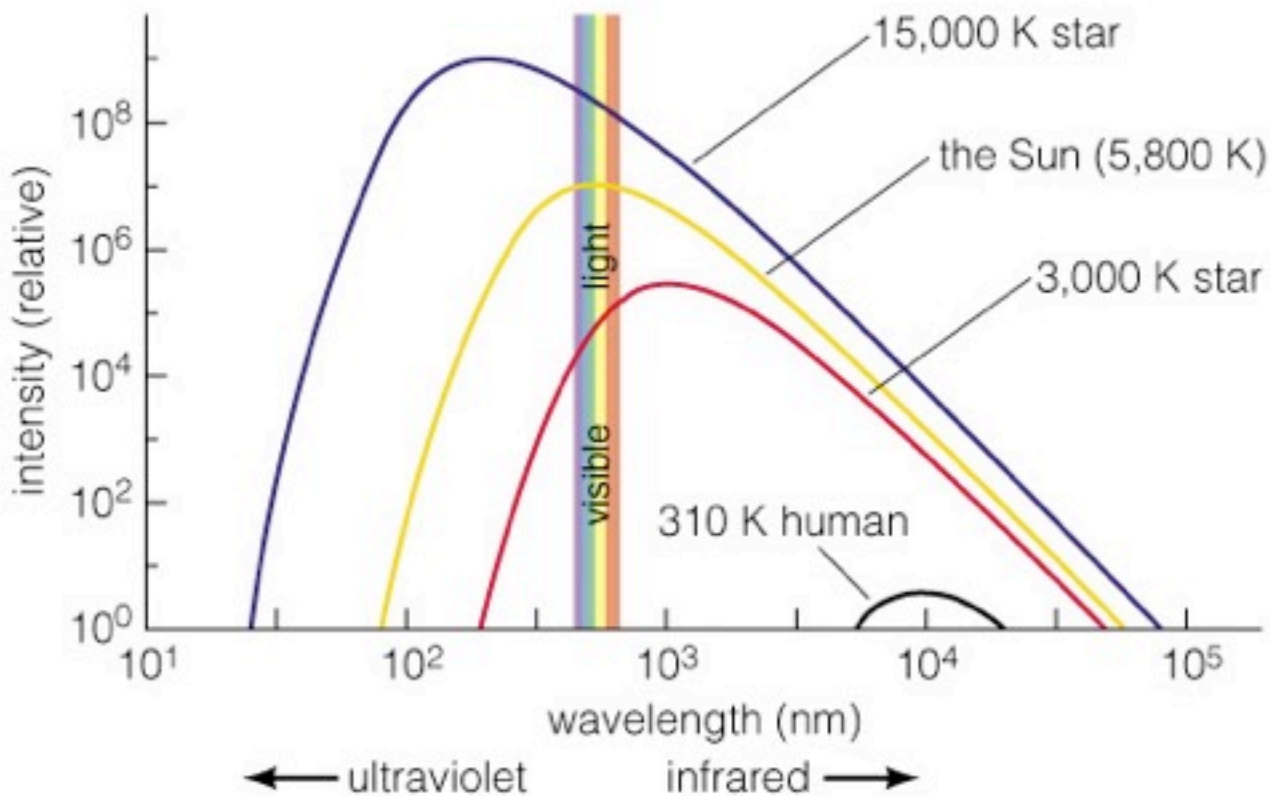
$$L \propto R^2 T^4$$

The absolute brightness of a star depends on its size (**R**) and temperature (**T**).

Properties of Thermal Radiation

Hotter objects emit more light at all frequencies per unit area.

Total luminosity is the area under the curve



Apparent & Absolute brightness

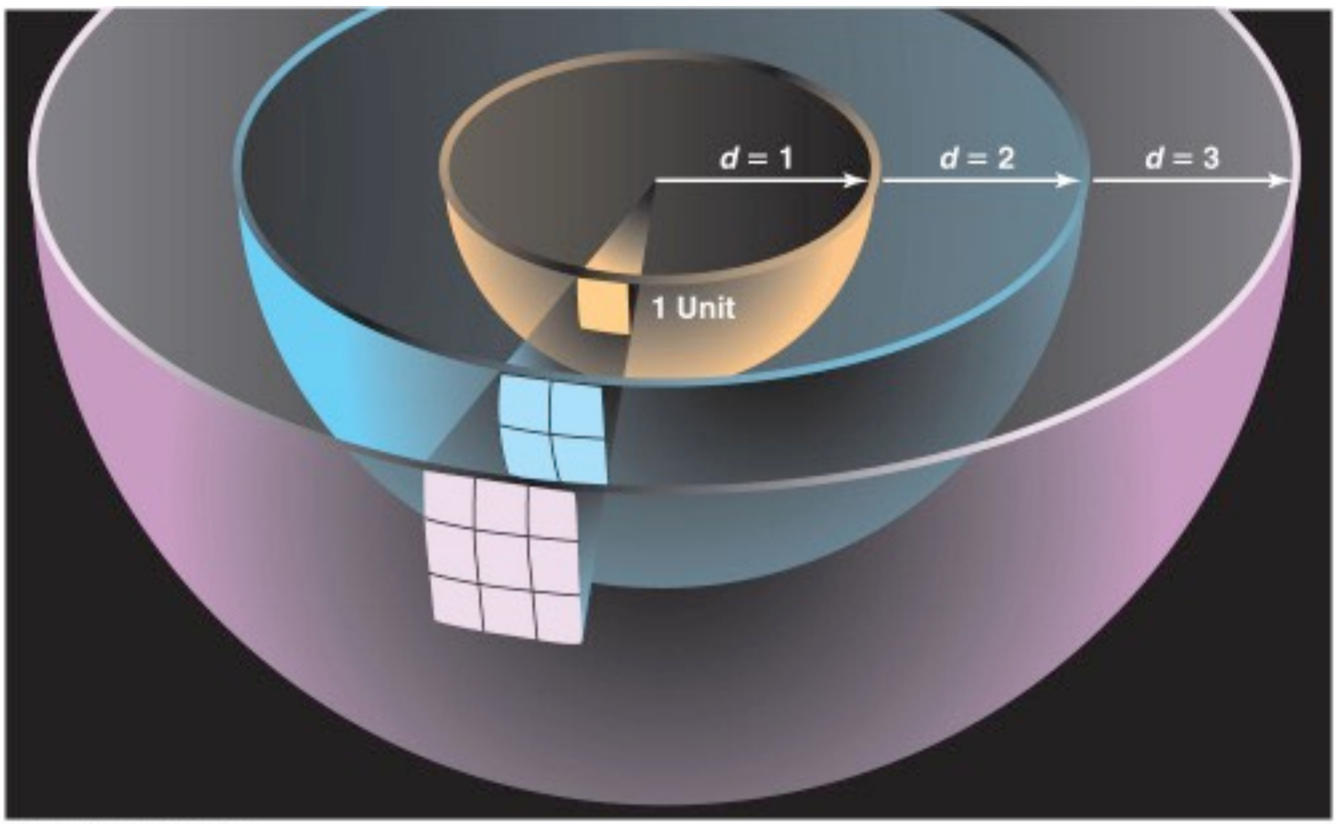
- Apparent brightness
  - What we perceive & measure at the telescope
- Absolute brightness
  - called **Luminosity (L)**
  - Physical power emitted by object
    - Energy radiated per unit time

apparent brightness $b = \frac{L}{4\pi d^2}$

How bright we perceive a star to be
depends on both its intrinsic luminosity and its distance from us.

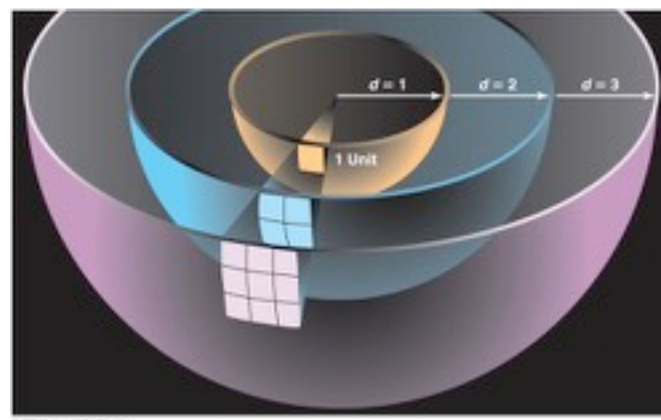
Inverse square law

- The intensity of light diminishes with the inverse square of the distance from the source



Inverse square law

- Just a geometrical effect
  - Light from a point source (e.g., a light bulb or a star) gets spread out in all directions.
  - diminishes by the surface are of the sphere is fills



apparent brightness

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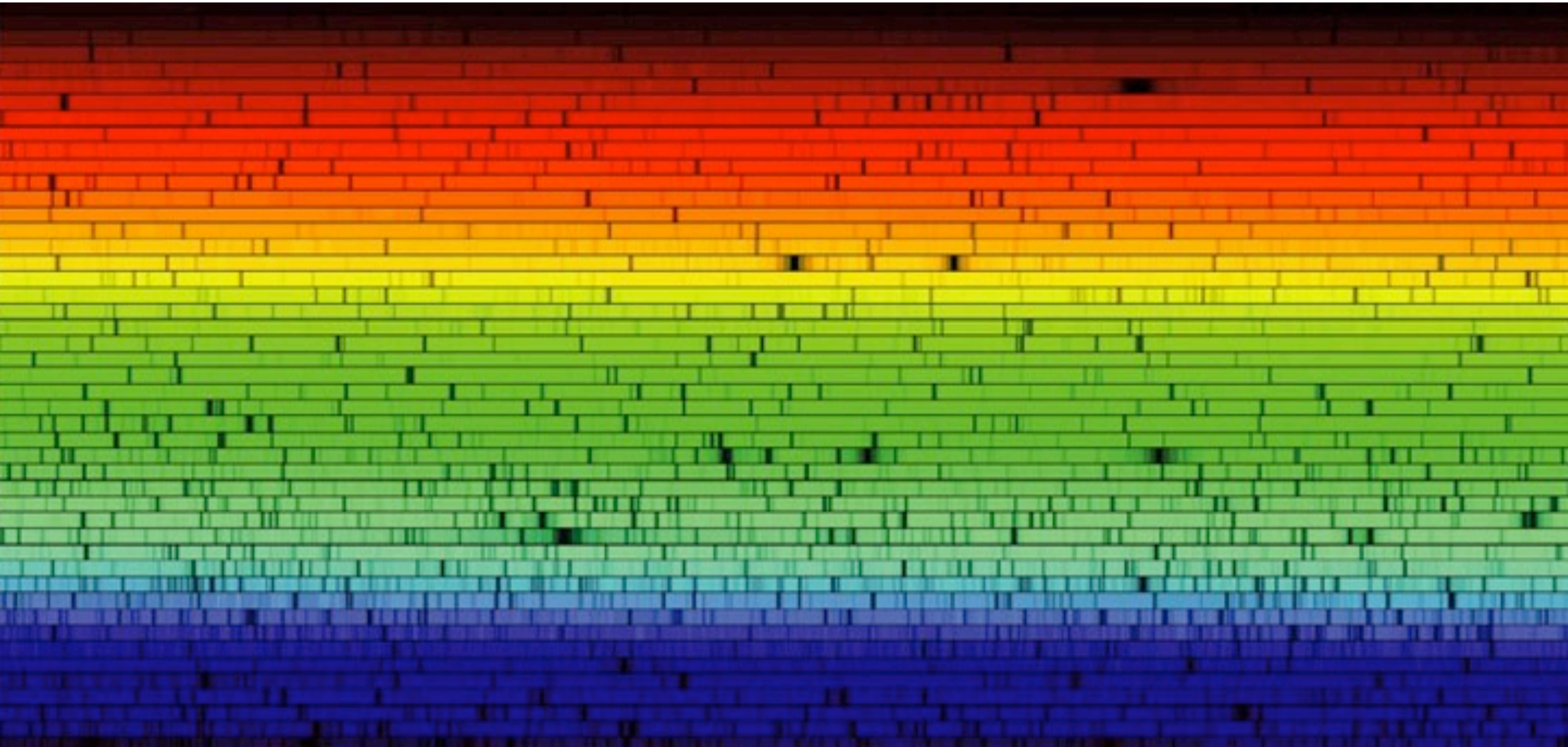
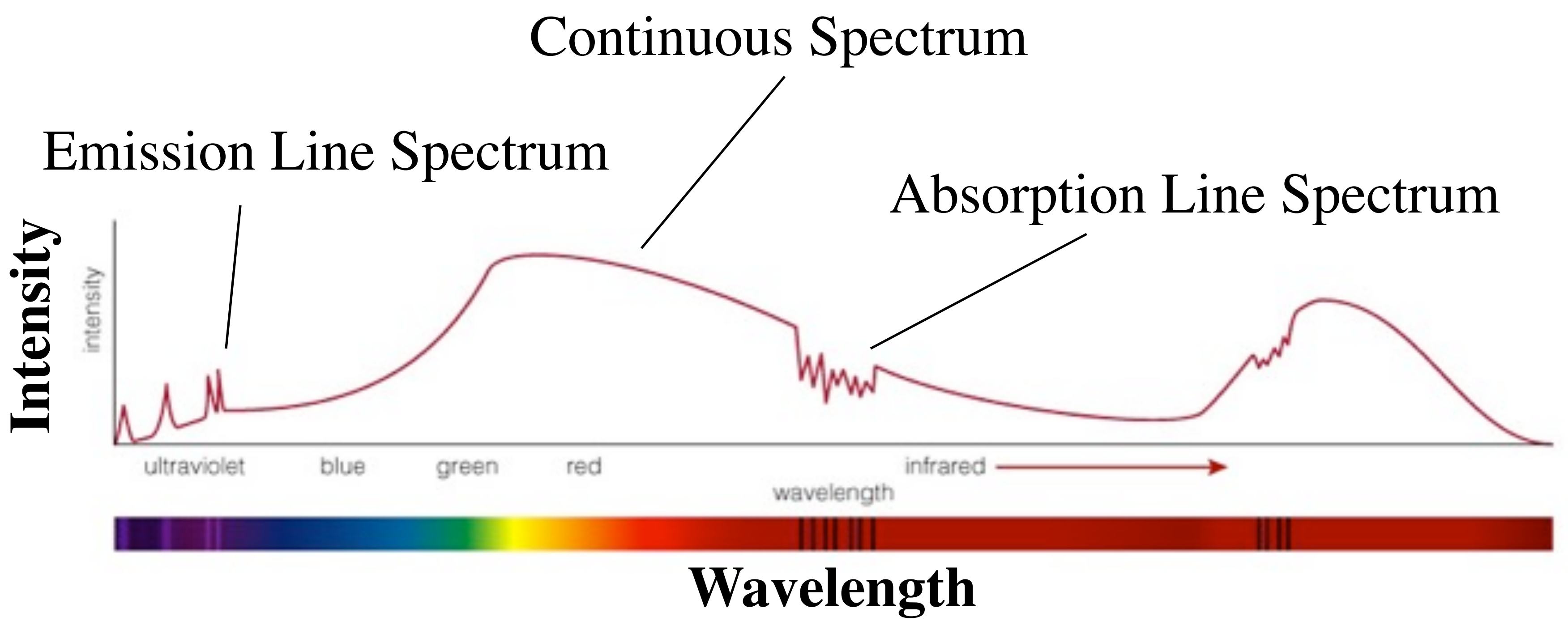


Three basic types of spectra



Spectra of astrophysical objects are usually combinations of these three basic types.

Kirchoff's Laws

- Hot, dense objects emit a
  - **continuous spectrum** e.g., a light bulb
    - light of all colors & wavelengths
    - follows thermal distribution
    - obeys Wien's & Steffan-Boltzmann Laws.
- Hot, diffuse gas emits light only at specific wavelengths.
  - **emission line spectrum** e.g., a neon light
- A cool gas obscuring a continuum source will absorb specific wavelengths
  - **absorption line spectrum** e.g., a star