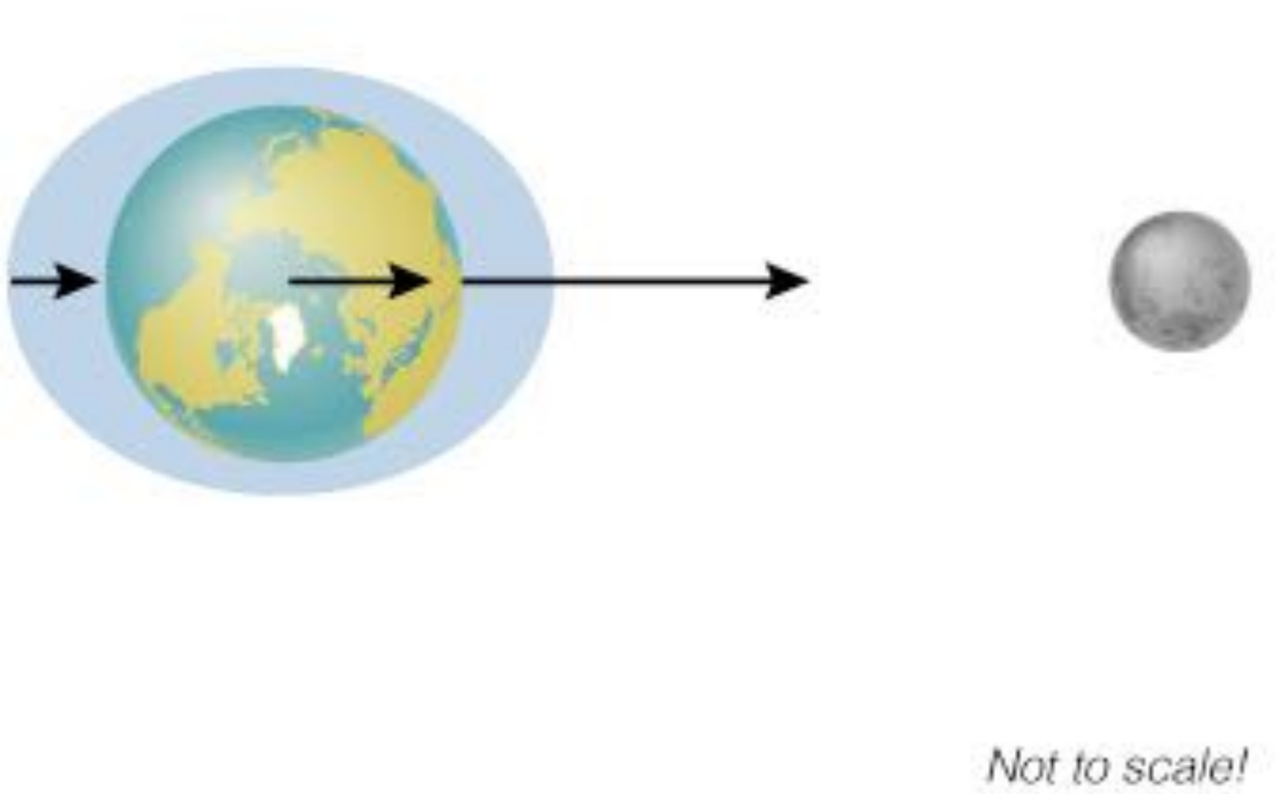
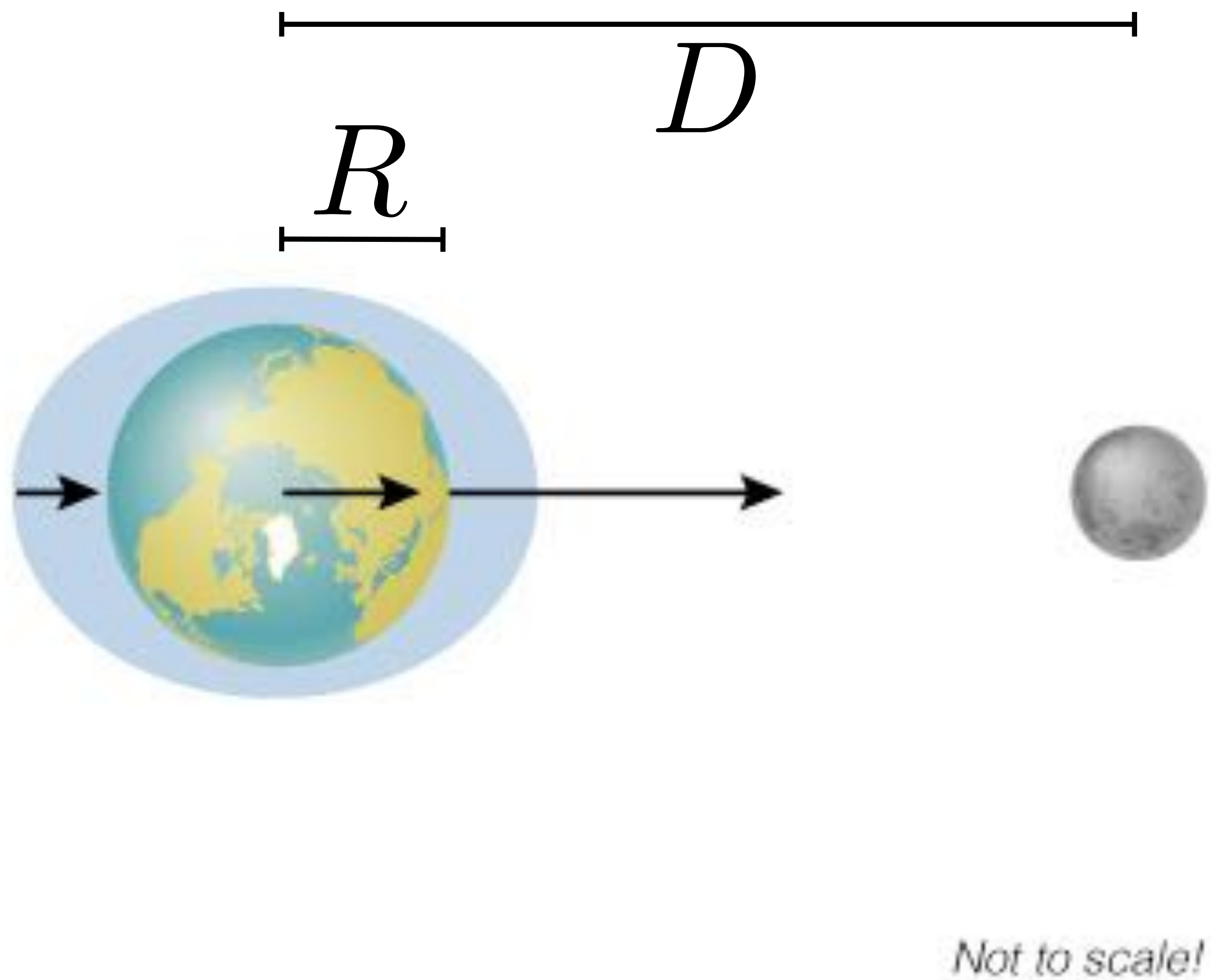
Tides



Tides are the result of differential gravity

- The Moon’s gravity pulls harder on near side of Earth than on far side (inverse square law).
- The difference in the Moon’s gravitational pull stretches Earth.



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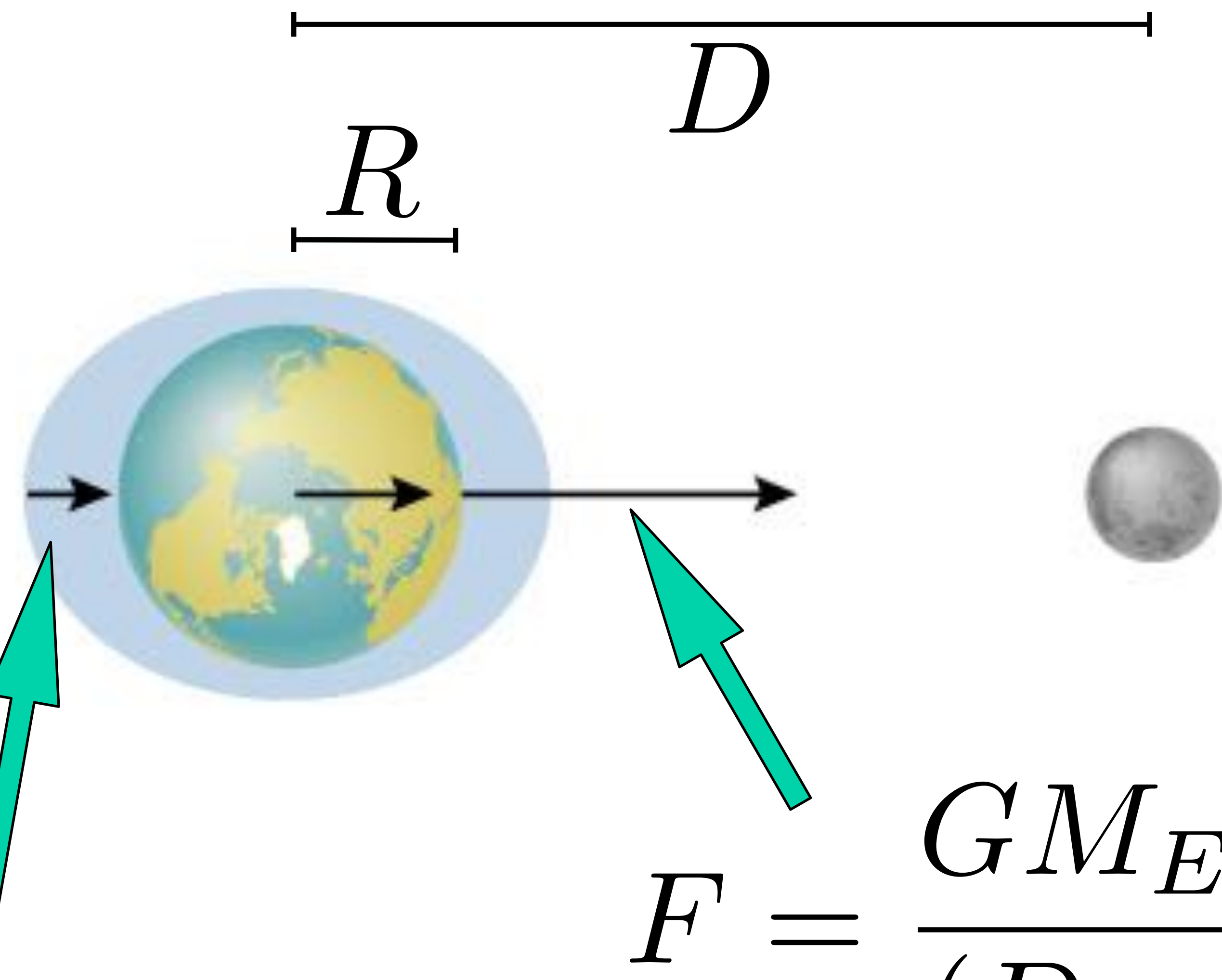


$$F = \frac{G M_E M_m}{(D - R)^2}$$

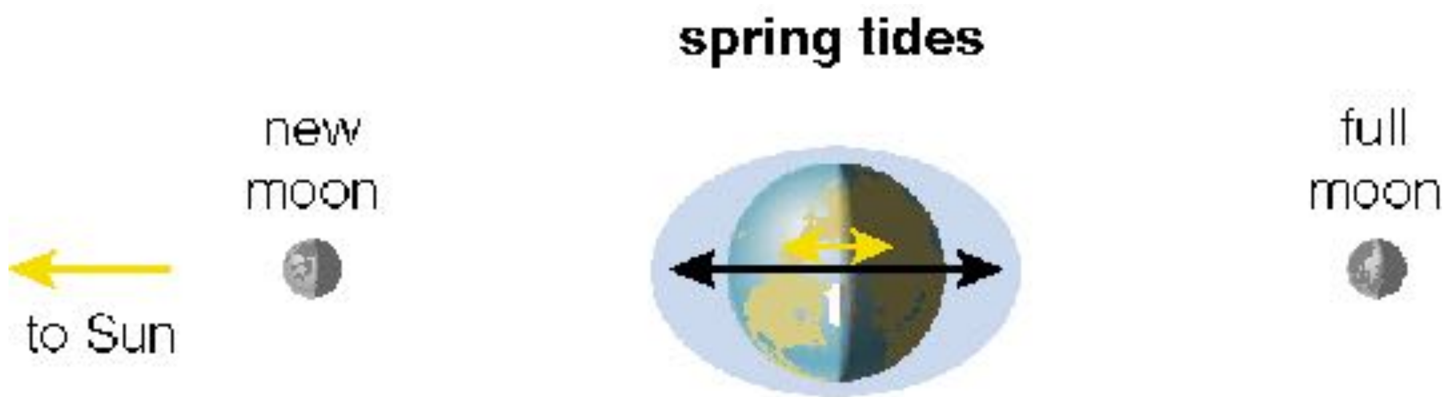
$$F = \frac{G M_E M_m}{(D + R)^2}$$

$D = 384,400$ km

$R = 6,378$ km

So the gravitational attraction towards the moon is about 7% stronger on the near side of the Earth than on the far side.

2 Tides a day

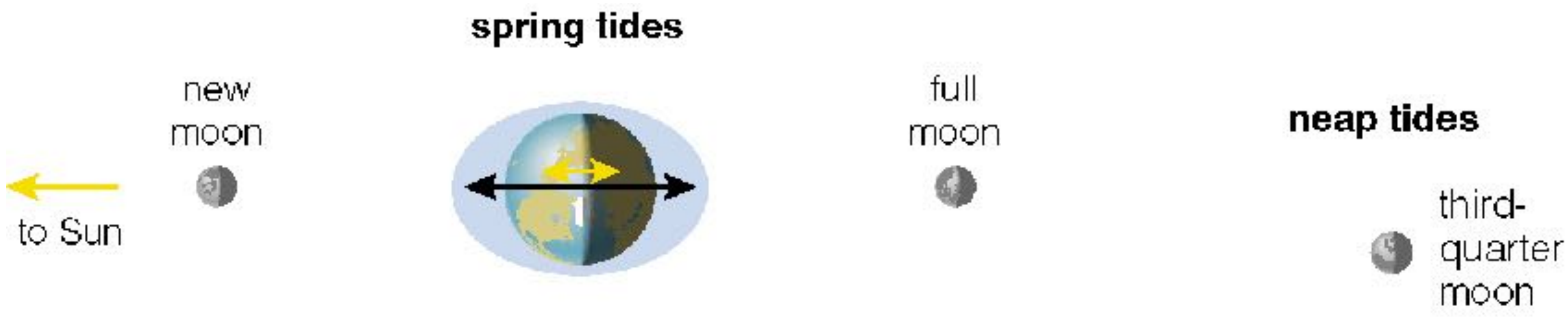


The combined force of the sun and moon causes the ideal gravitational surface to be slightly non-spherical.

Consequently, Earth’s oceans to fill a slightly oblate spheroid.

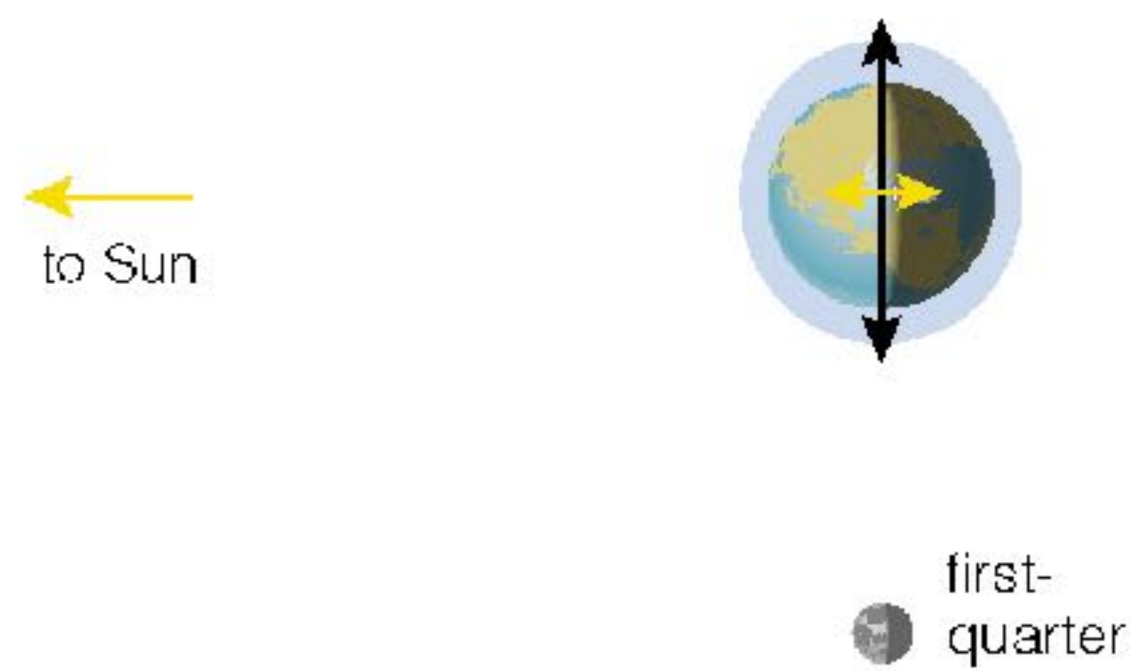
The Earth spins under this spheroid, so we have two pairs of low & high tides a day.

Tides and Phases

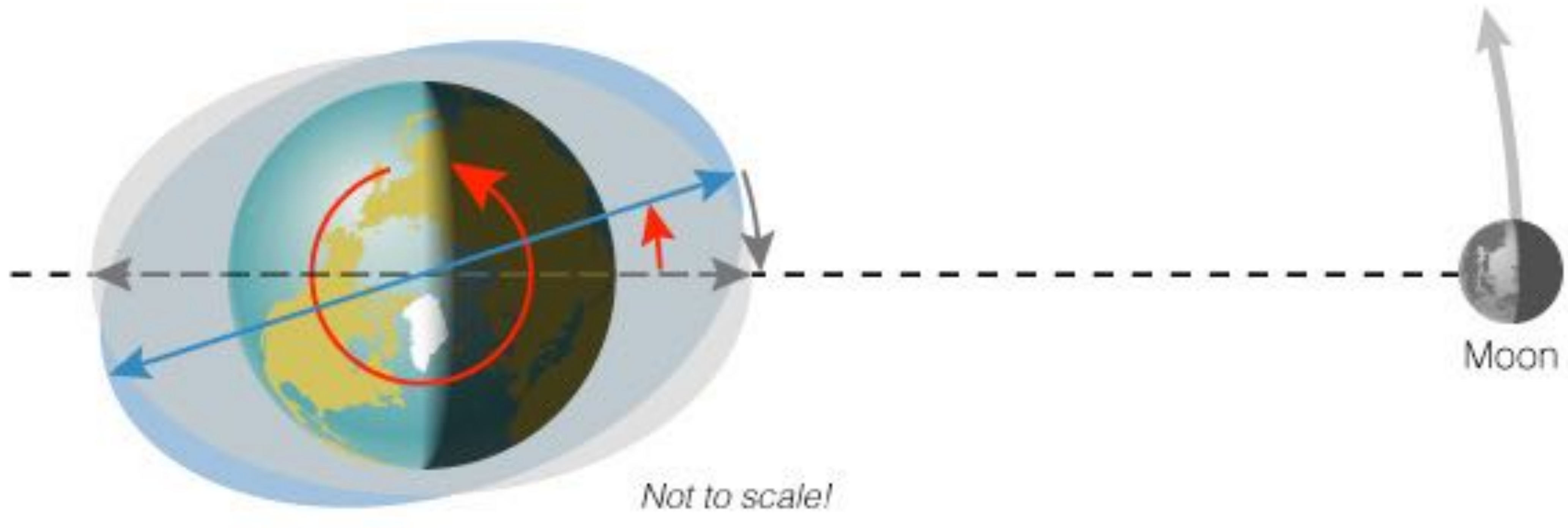


Size of tides depends on the phase of the Moon.

Spring tides are stronger than neap tides because the sun and moon team up at new & full moon.

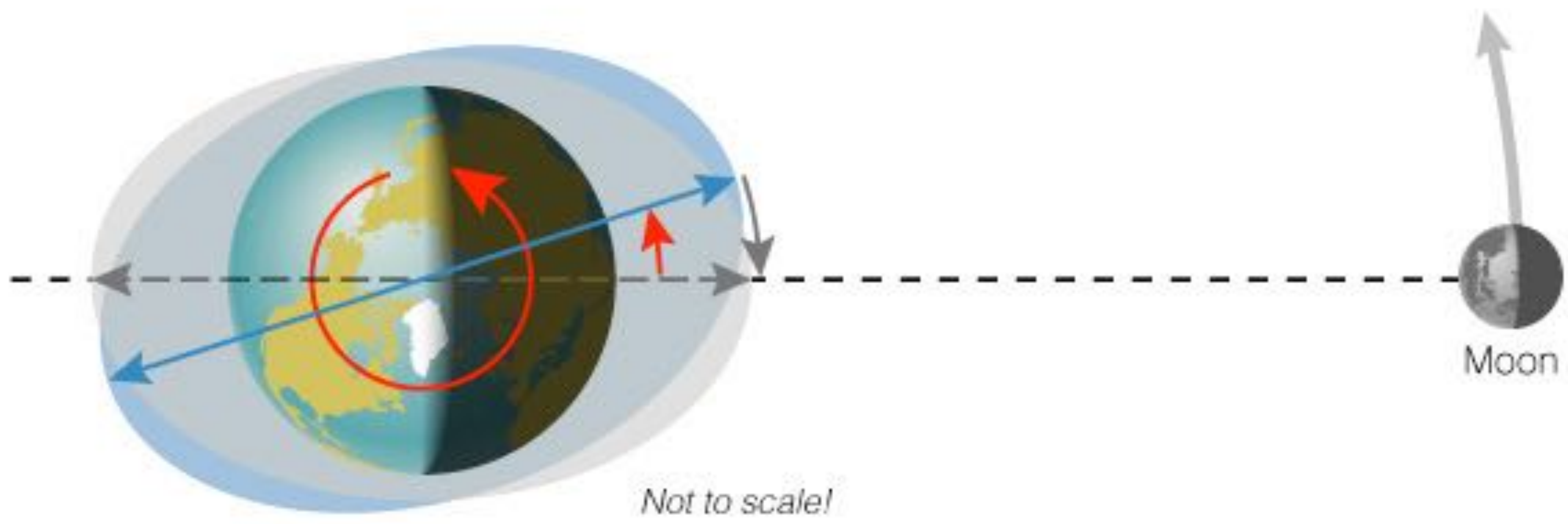


Tidal Friction



- The spin of the Earth drags the tidal bulge of the ocean ahead of the ideal oblate spheroid, which is aligned with the moon.
- The gravity of the moon pulls back on the leading, near side bulge more strongly than it pulls forward the far side bulge.
- The net result is **tidal friction**, which results in a gradual braking of the spin of the Earth.

Tidal Friction



- Tidal friction gradually slows Earth rotation
  - Moon gradually drifts farther from Earth (3.8 centimeters per year)
  - conservation of angular momentum

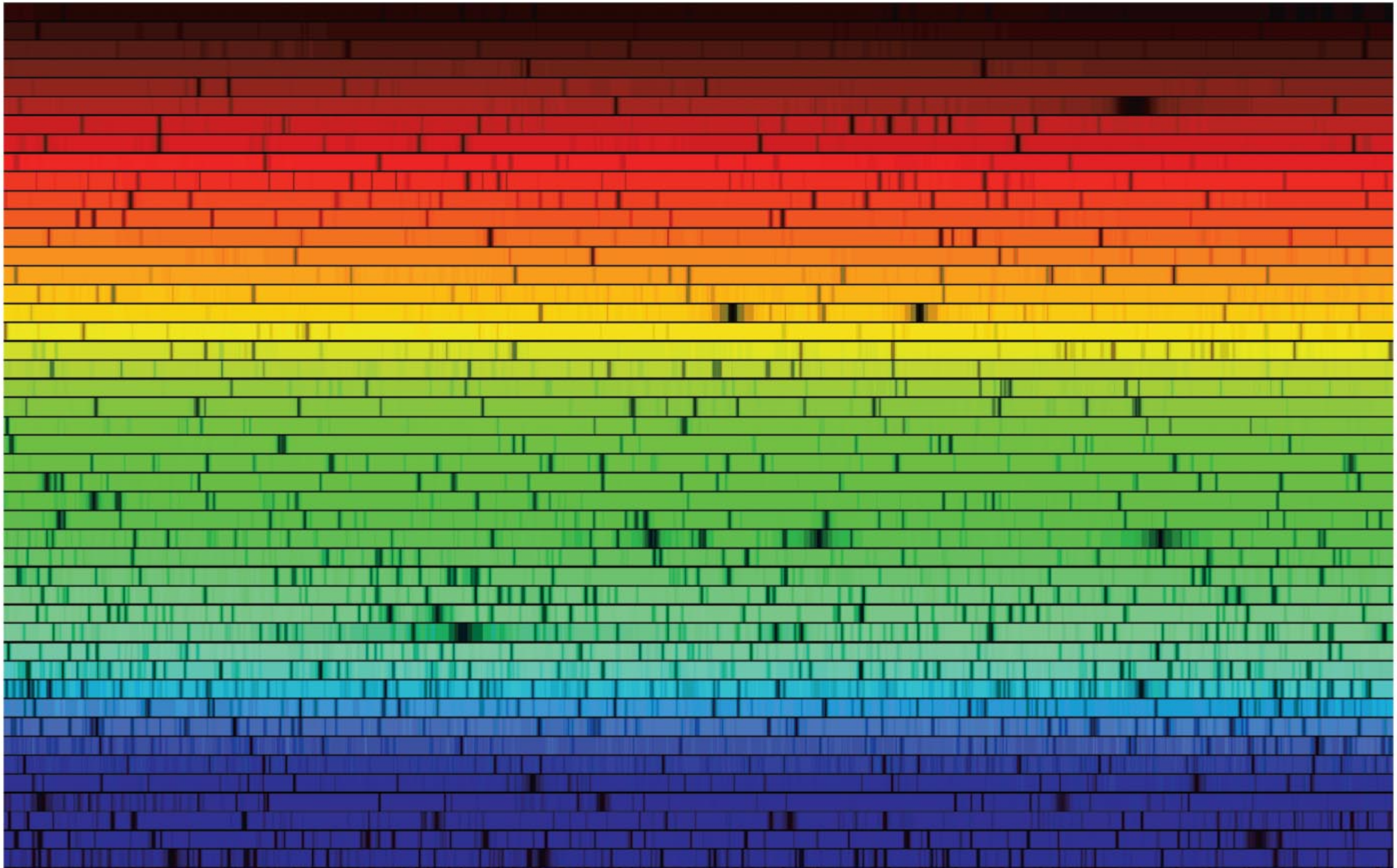
The length of Earth's day increases 2 milliseconds per century

- Moon once spun faster; tidal friction caused it to "lock" in synchronous rotation
  - orbit period:spin period = 1:1

Summary of Tides

- Gravitationally bound objects are spherical
  - e.g., planets, stars
- Tides are caused by the differential gravity of the sun and moon
  - Spring tides are cause when the sun and moon are aligned; neap tides when they are perpendicular.
- Tidal friction gradually changes
  - the orbit of the moon and the spin of the earth

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**

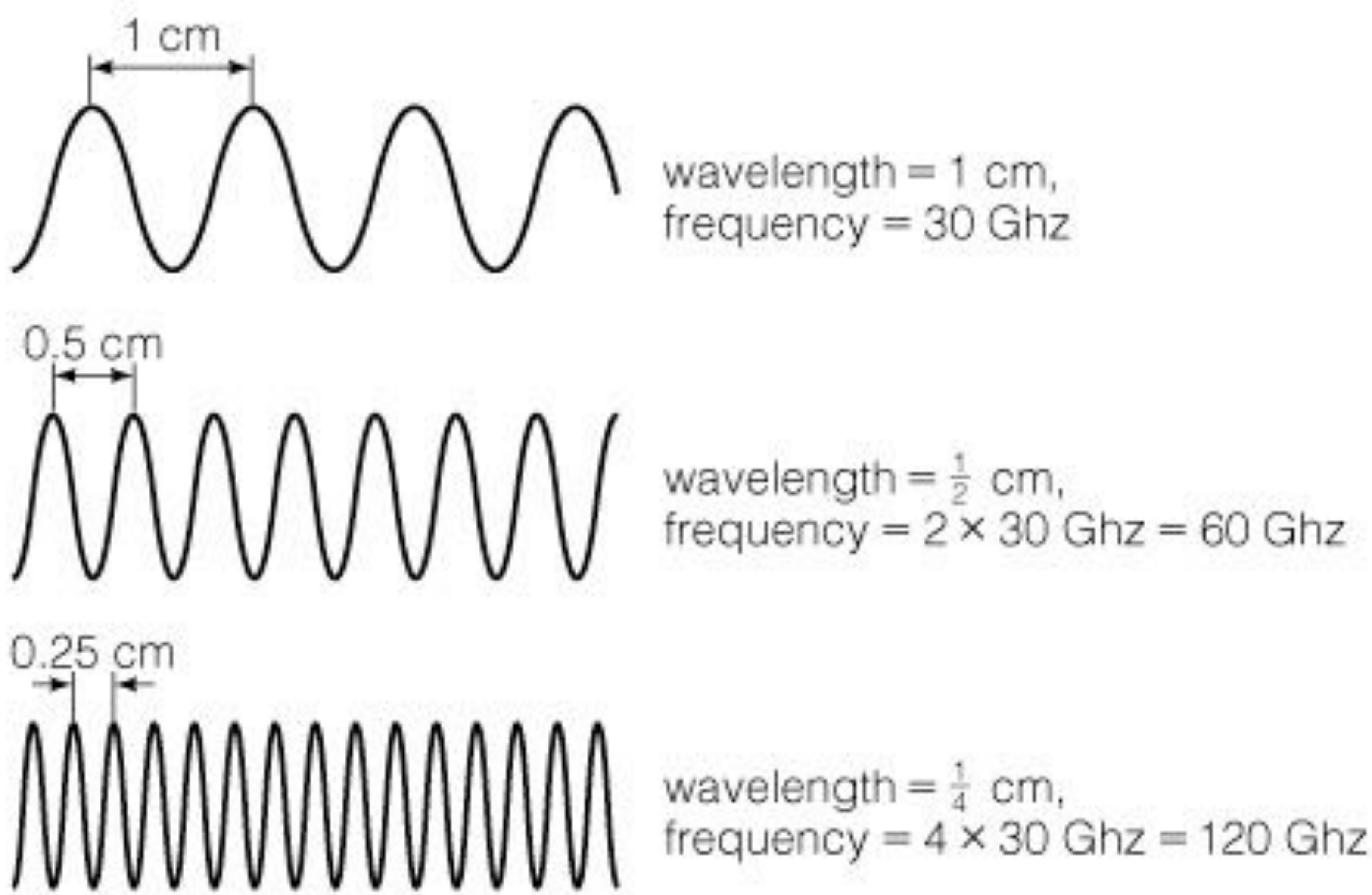
Sometimes it behaves like ripples on a pond (waves).
Sometimes it behaves like billiard balls (particles).

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.

Long wavelength

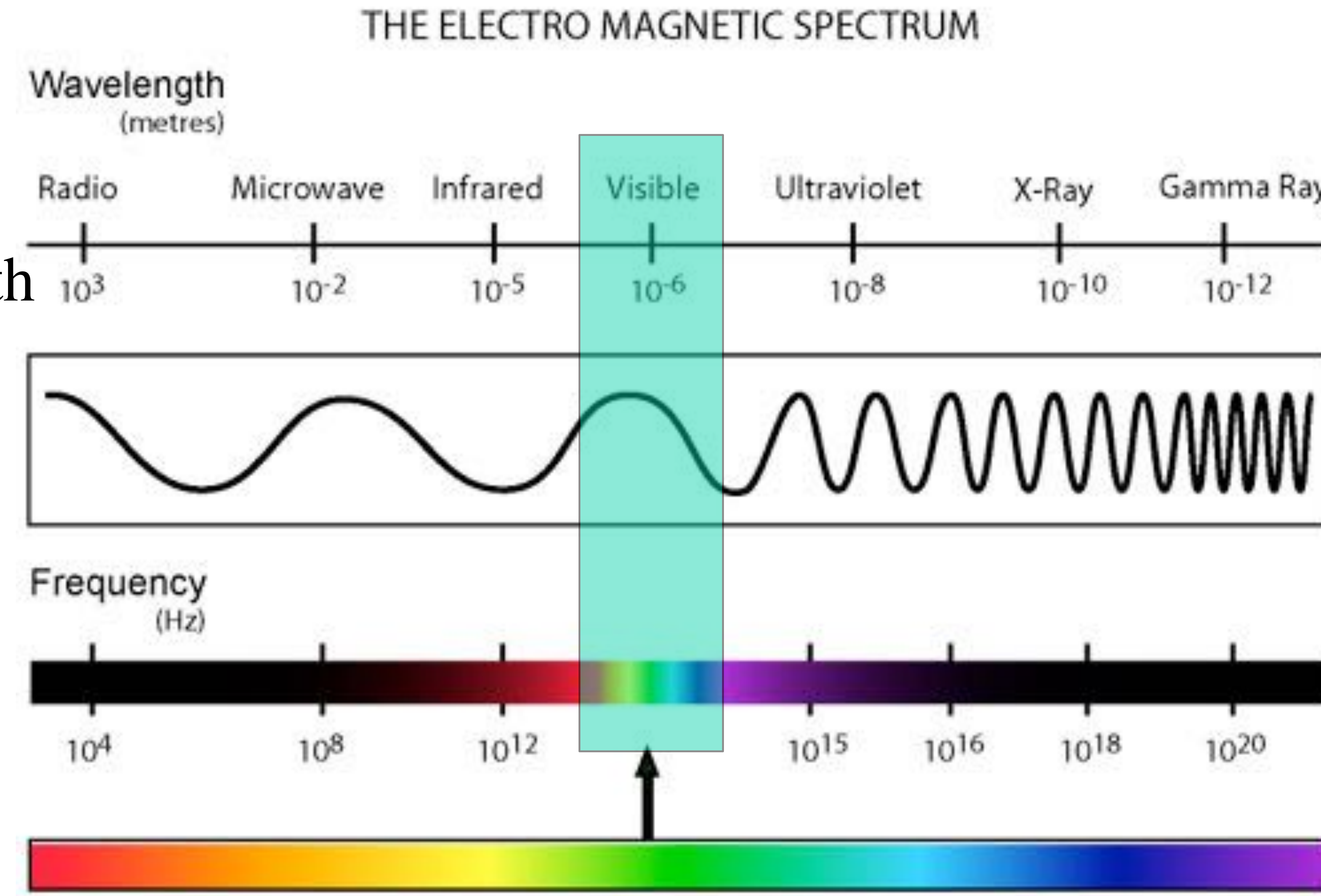
Short wavelength

Low energy

High energy

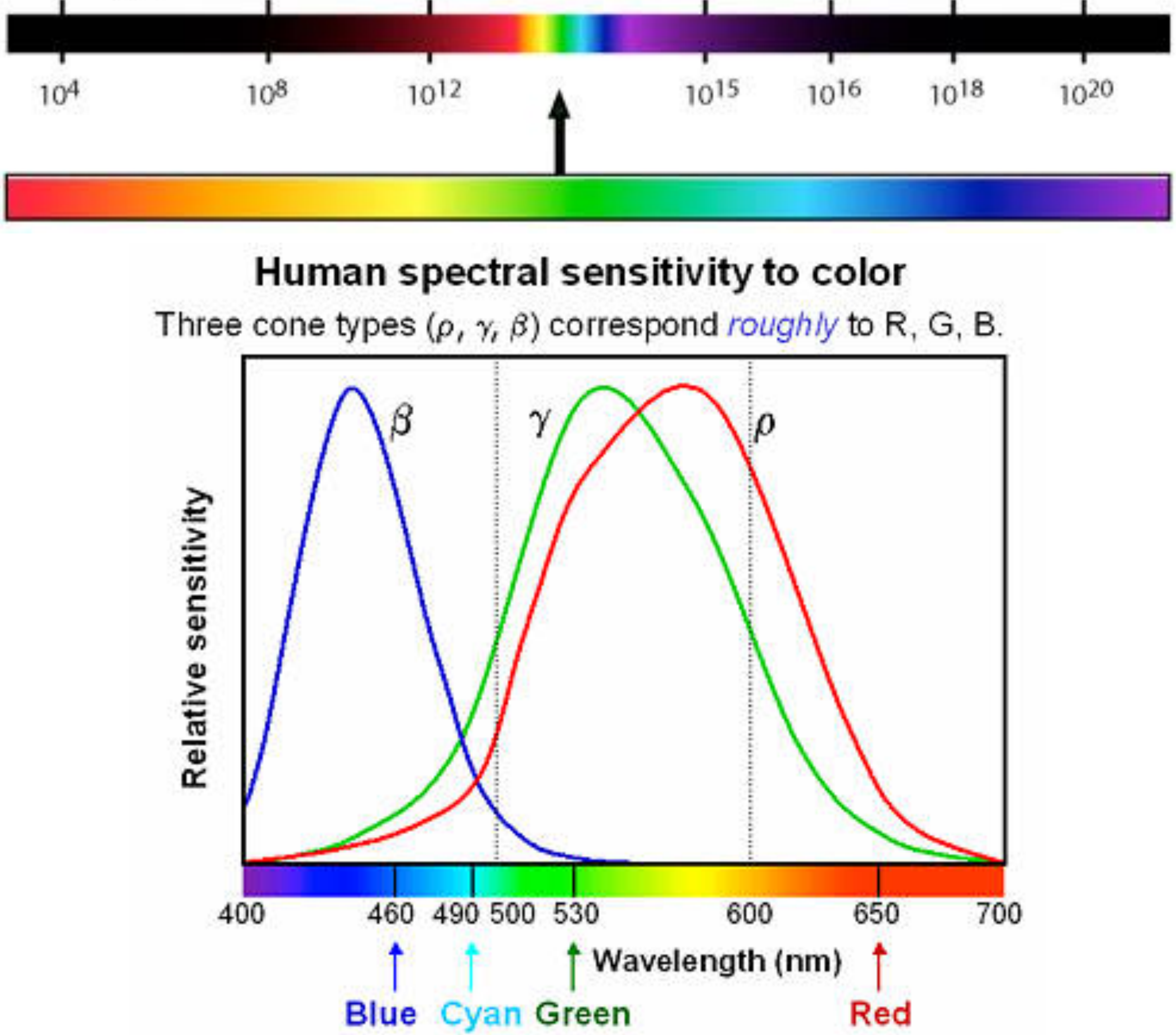
Low frequency

High frequency



$E\ ,f$ *increasing*

λ *decreasing*



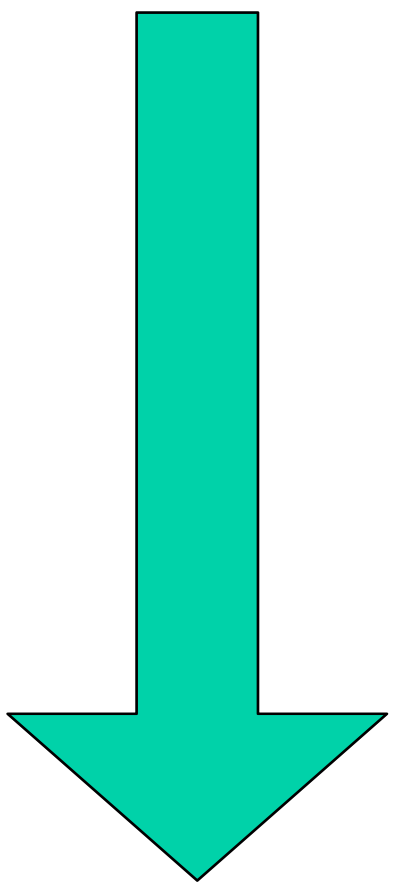
Our eyes are only sensitive to a factor of two range in wavelength, from 380nm (violet) to 700nm (deep red).

Same stuff, different Energy:

<u>Electromagnetic Radiation</u>

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

Energy per photon increasing



Electromagnetic Radiation

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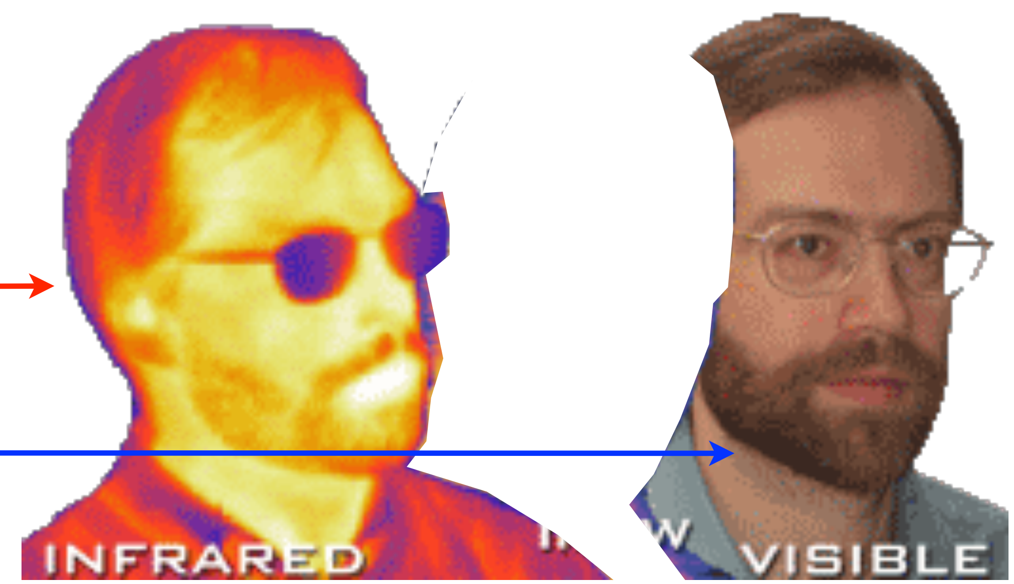

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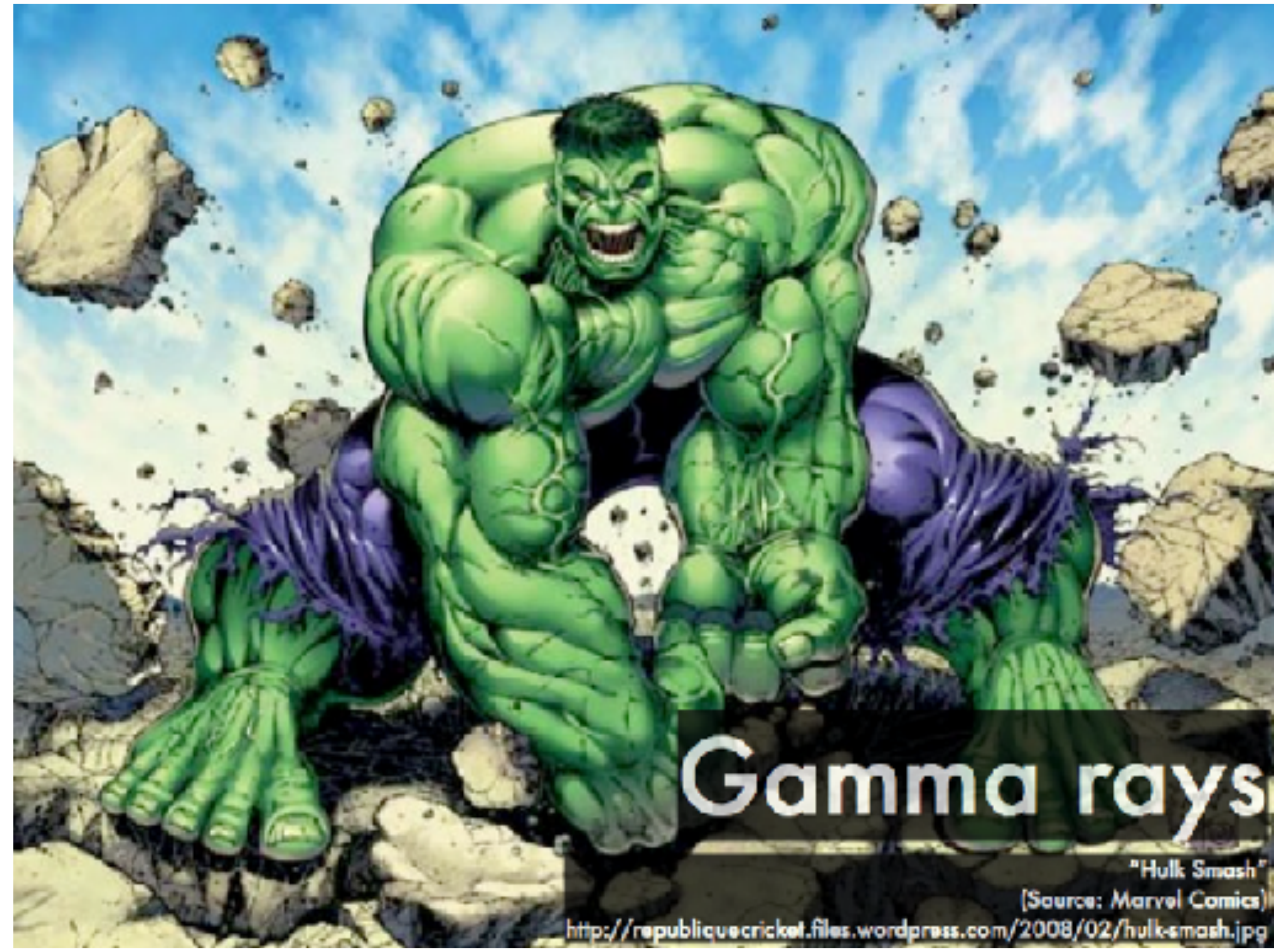

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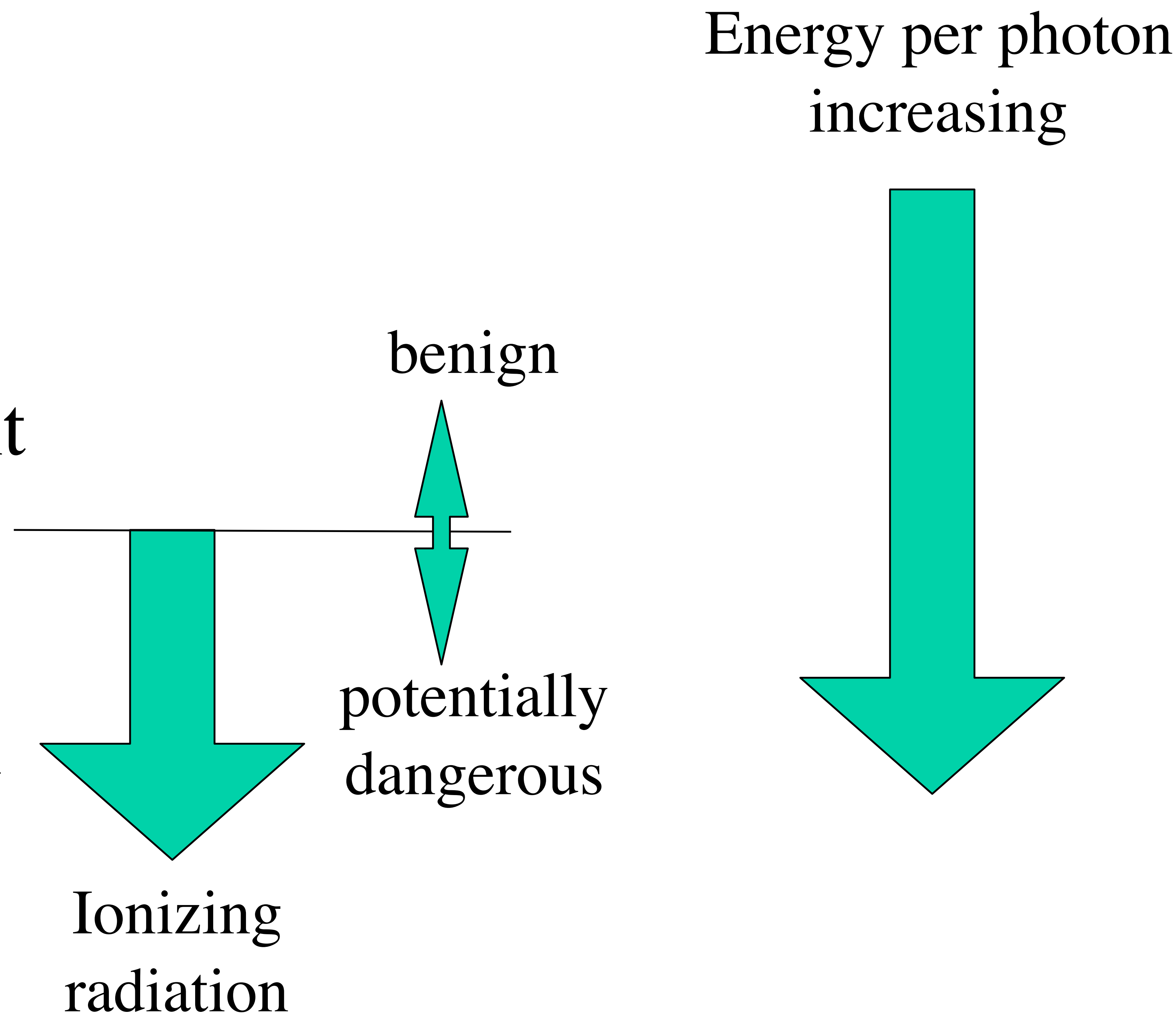

How do light and matter interact?

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

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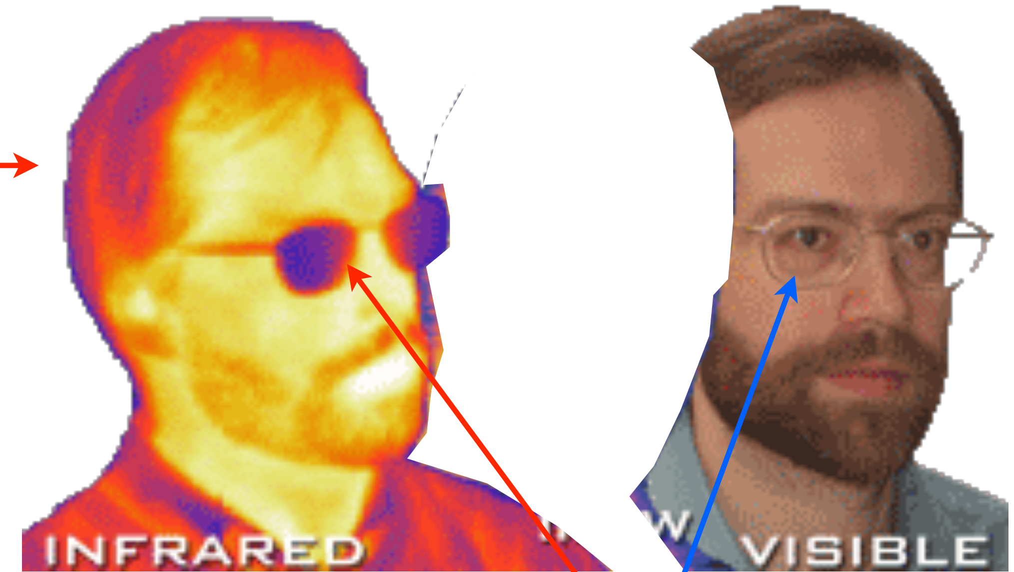
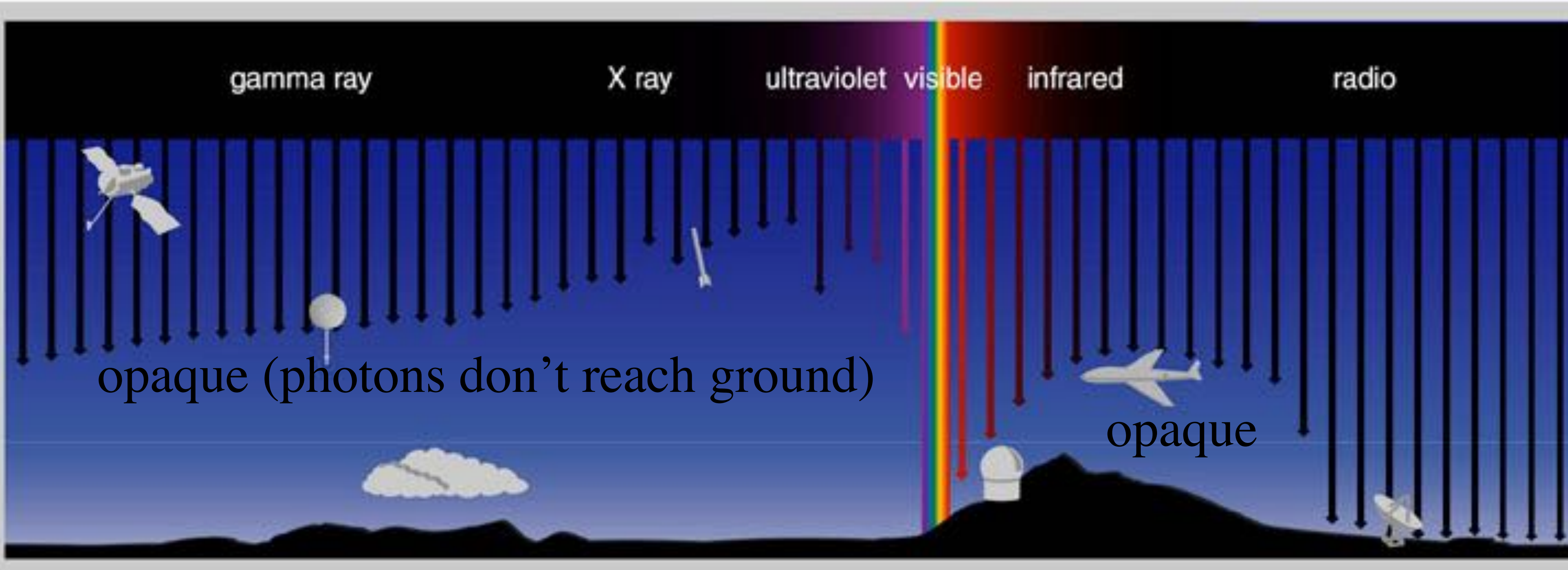


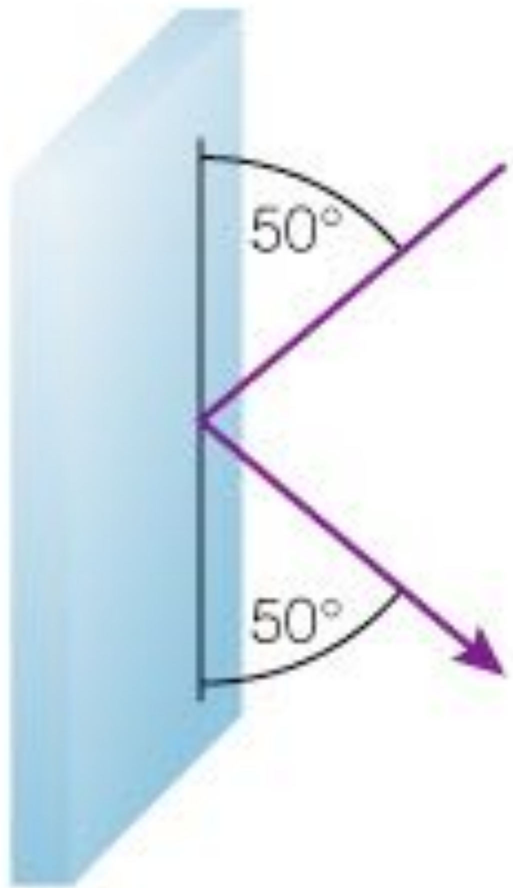
transmission & absorption

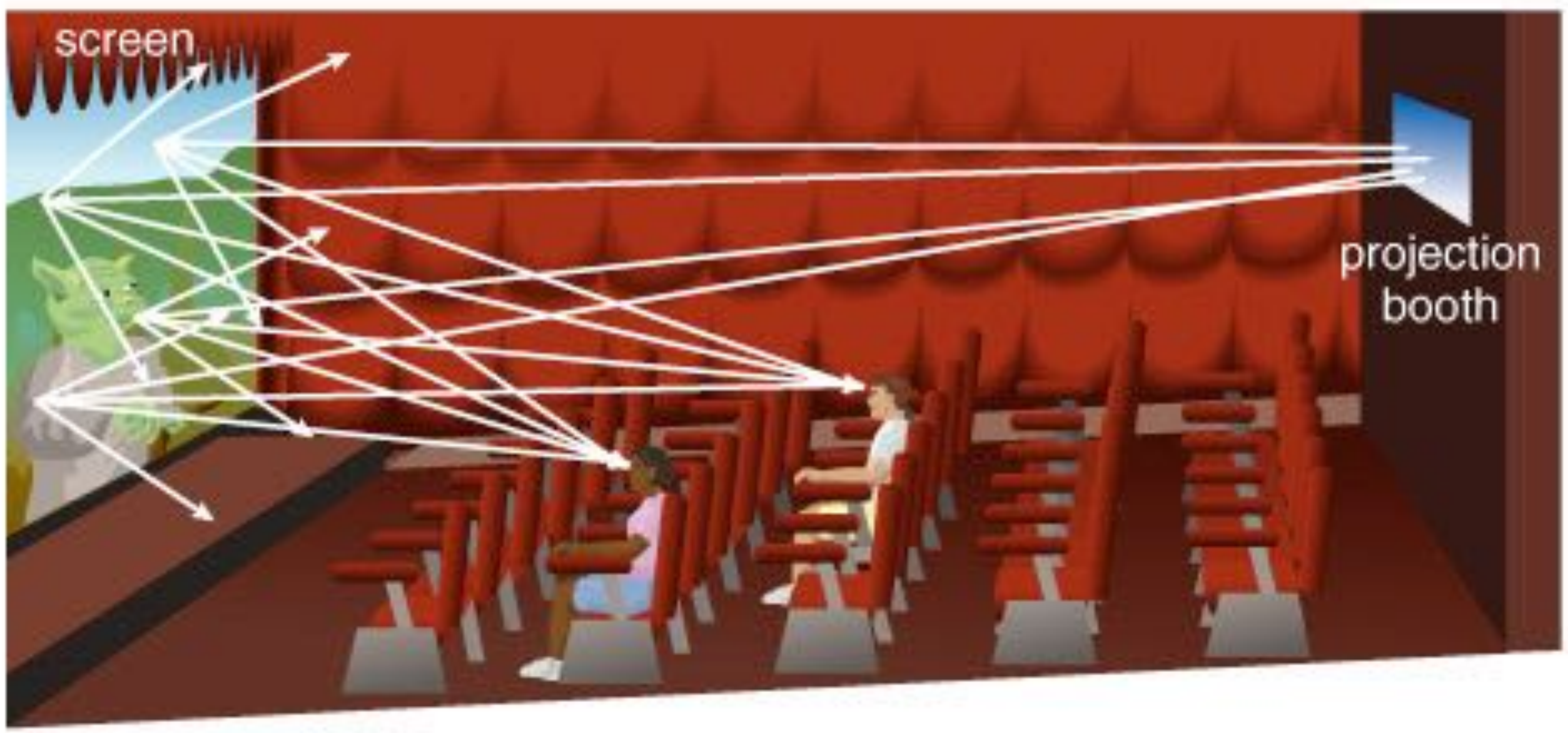


transparent transparent

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

Reflection and Scattering

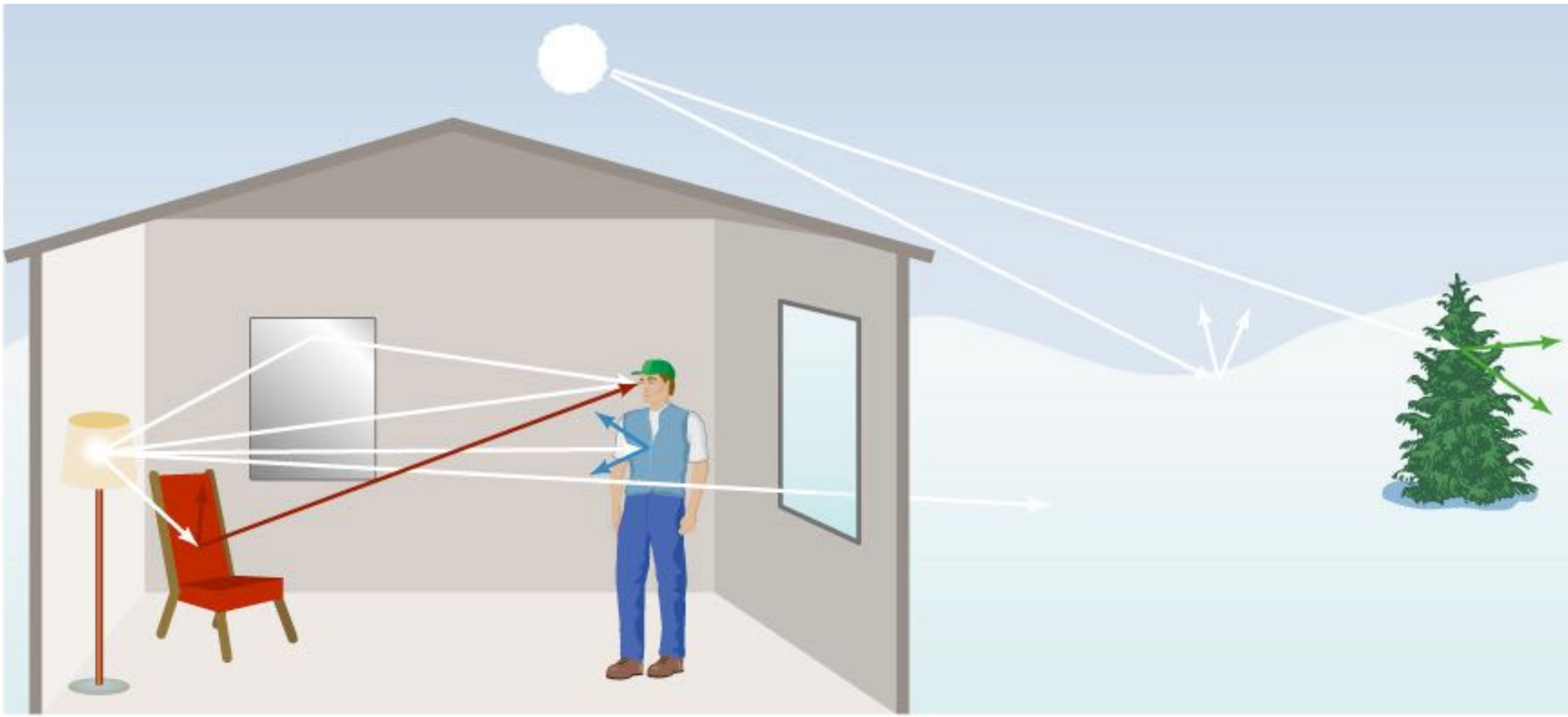




Mirror reflects light in a particular direction.

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.

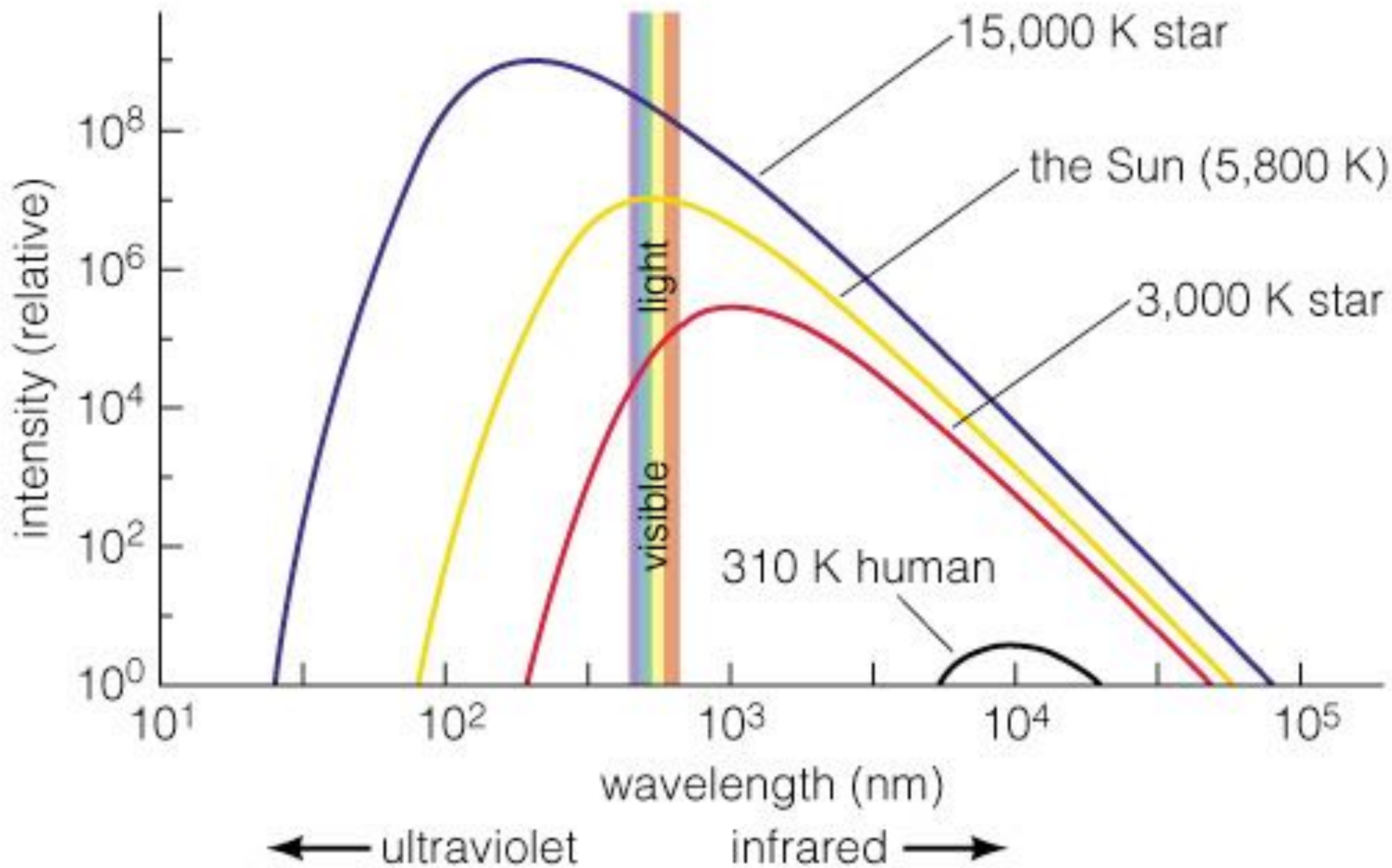
- An object's thermal radiation spectrum depends on only one property: its **temperature.**

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

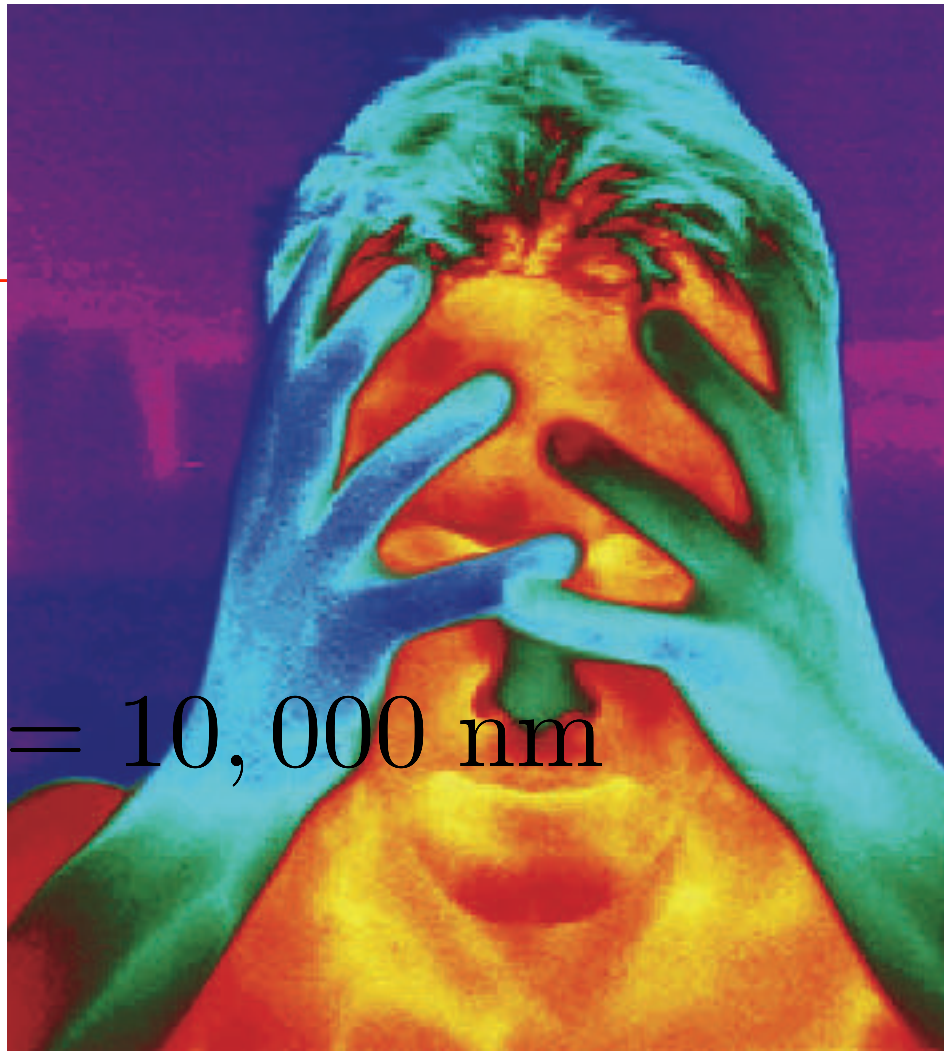
Wien's Law

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

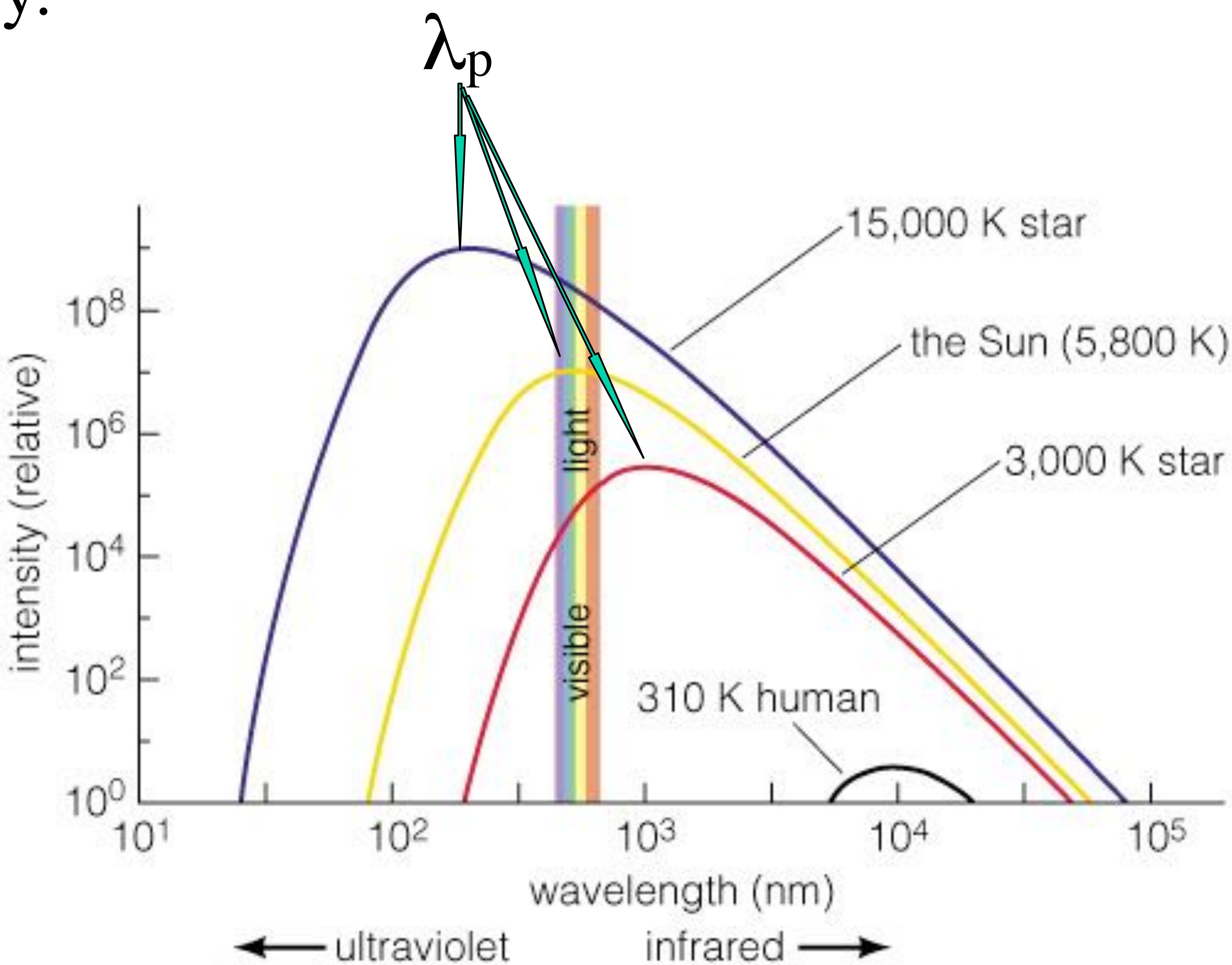
- The Sun
  - T = 5,800 K

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

  - 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

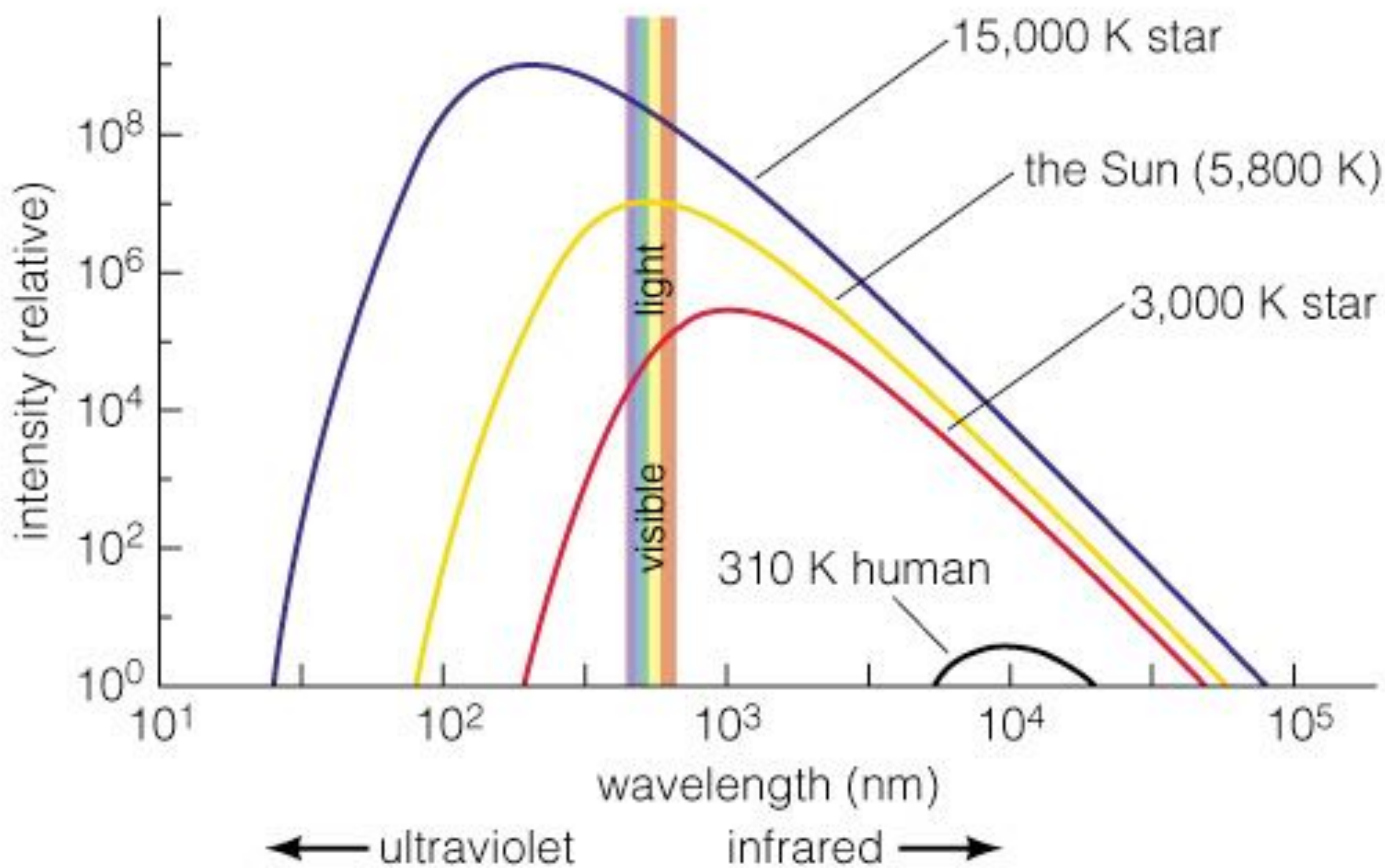
$$L \propto R^2 T^4$$

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

Properties of Thermal Radiation

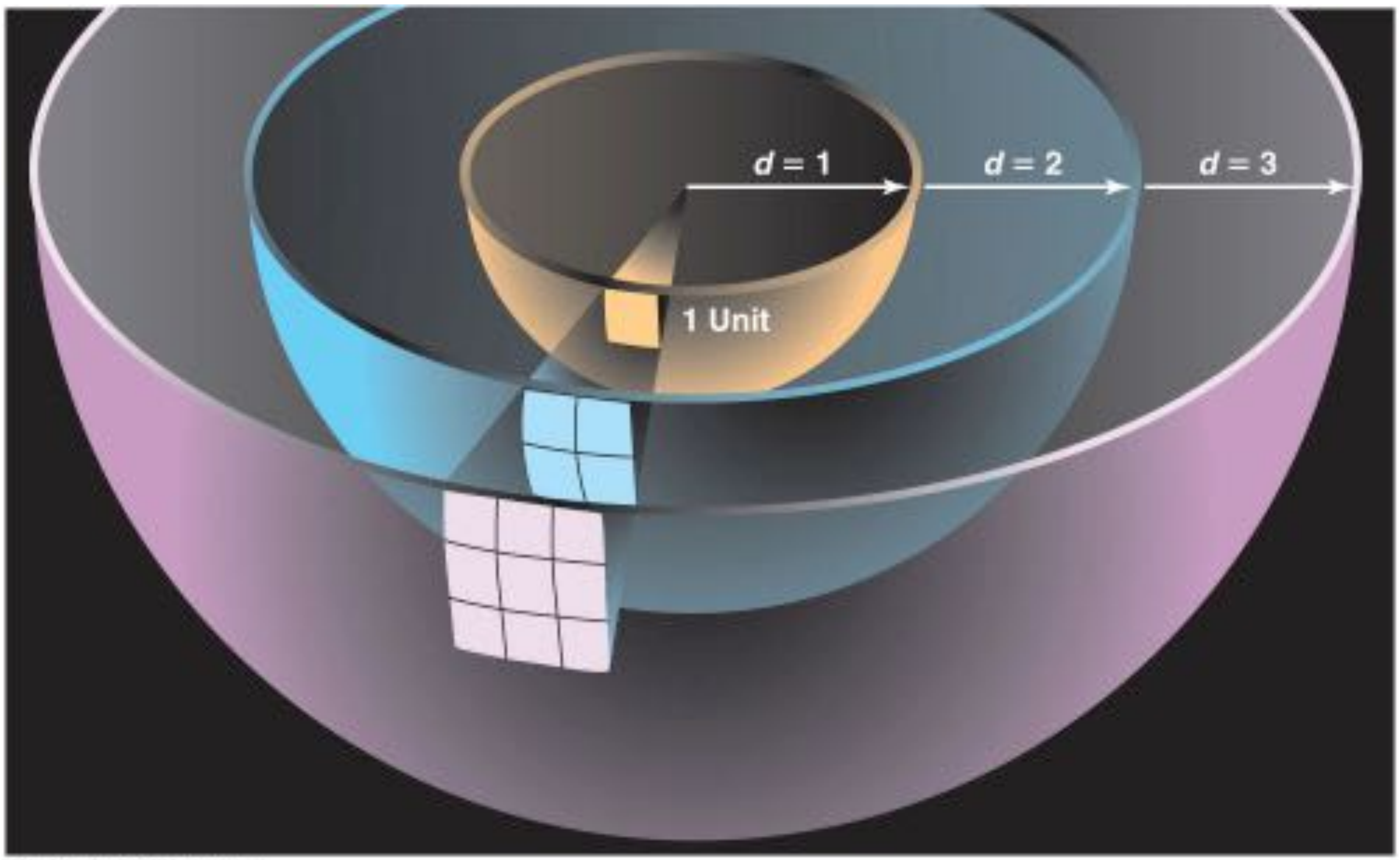
Hotter objects emit more light at all frequencies per unit area.

Total luminosity is the area under the curve



Inverse square law

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

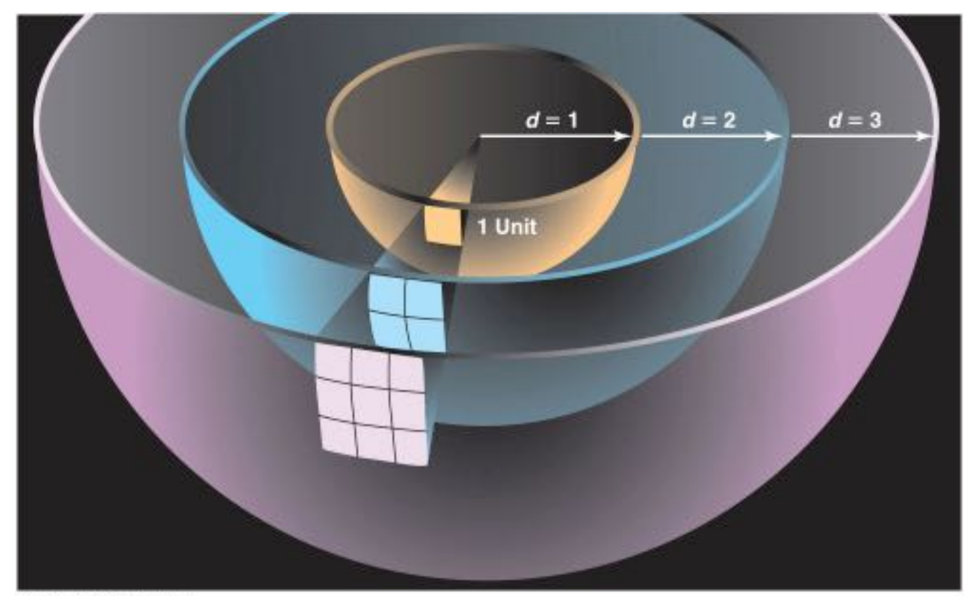


Inverse square law

- 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

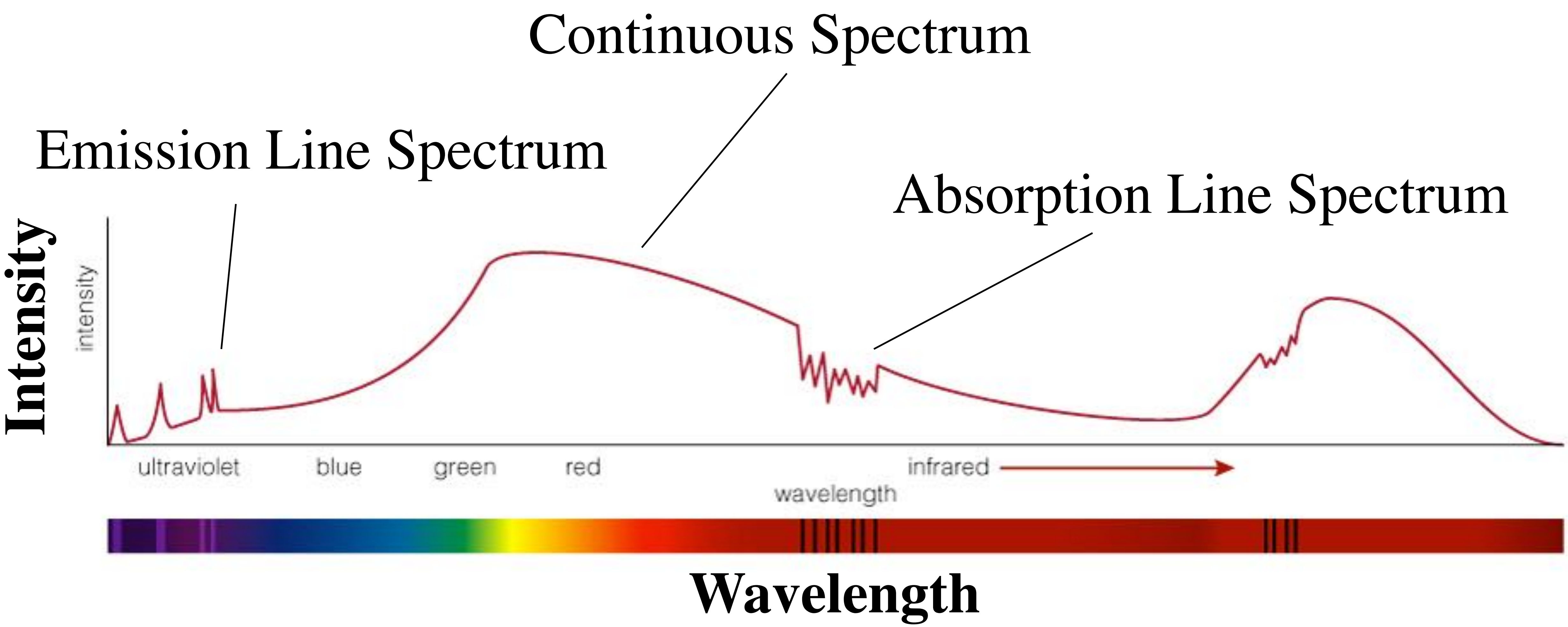
apparent brightness

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



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

Three basic types of spectra

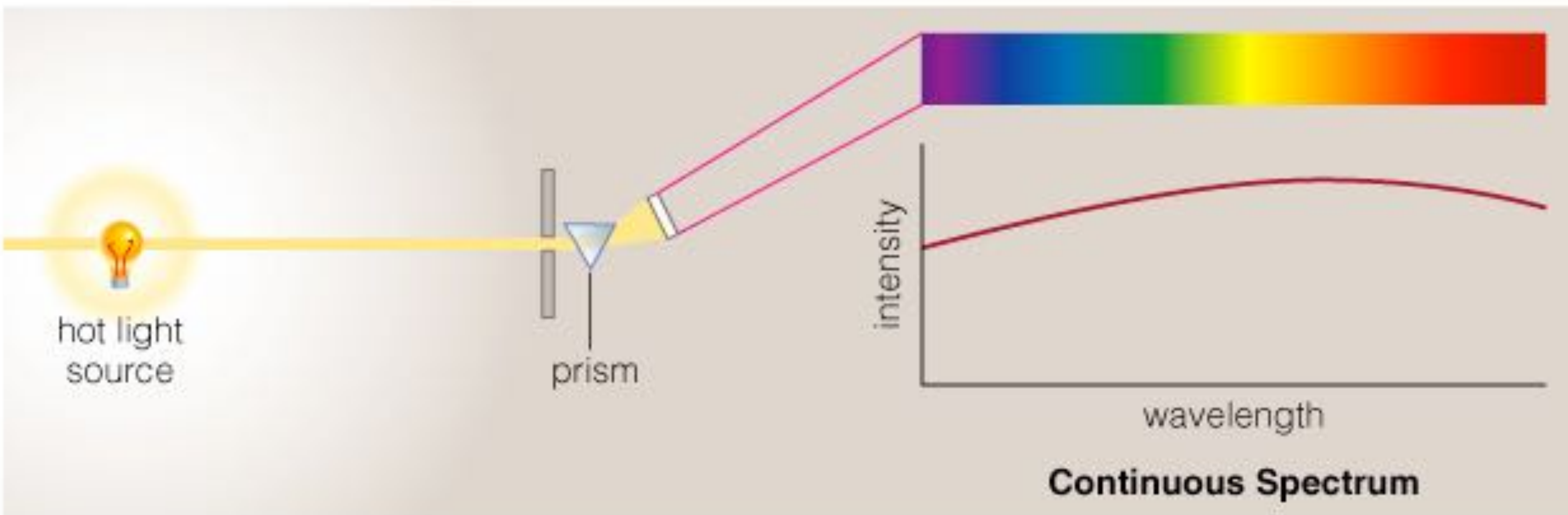


Spectra of astrophysical objects are usually combinations of these three basic types.

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. e.g., a neon light
  - **emission line spectrum**
- A cool gas obscuring a continuum source will absorb specific wavelengths
  - **absorption line spectrum** e.g., a star

Continuous Spectrum



- The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.

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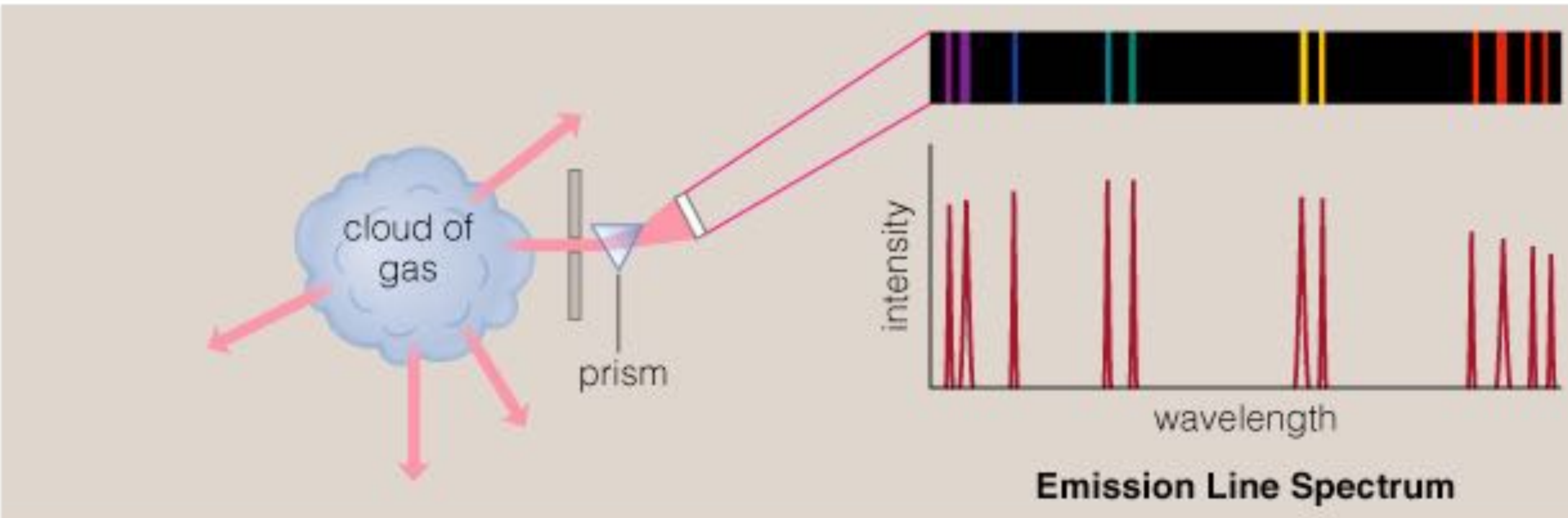
Emission Line Spectrum



- A thin or low-density cloud of gas emits light only at specific wavelengths that depend on its composition and temperature, producing a spectrum with bright emission lines.

Kirchoff's Laws

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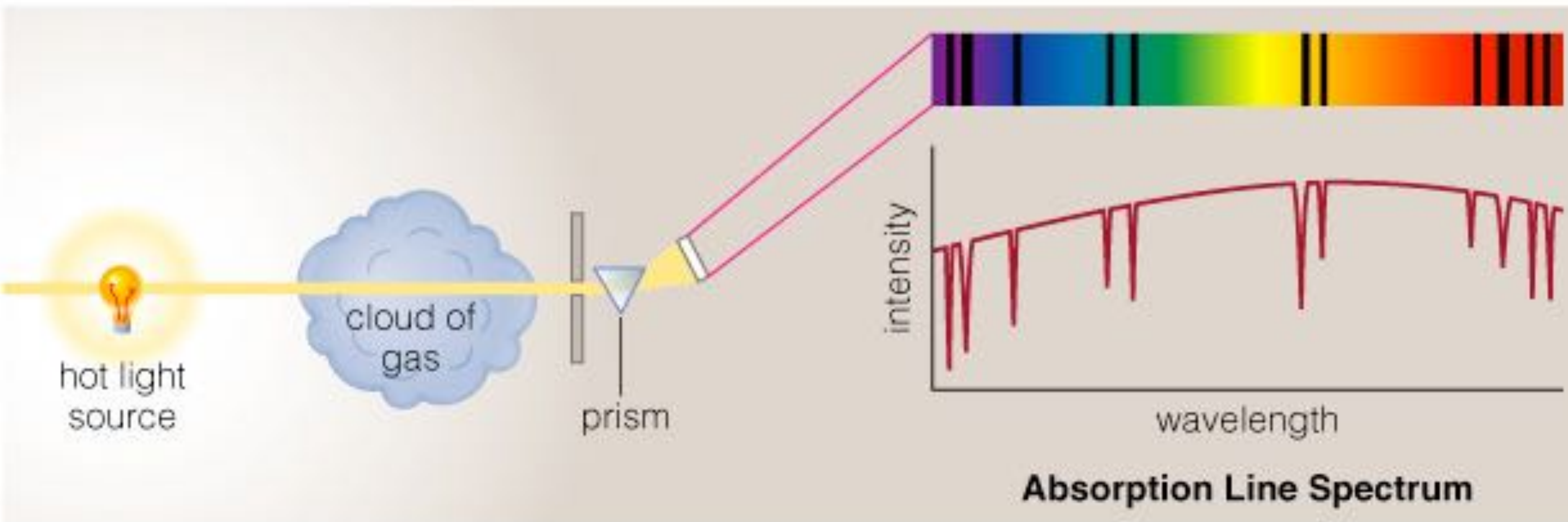
Absorption Line Spectrum



- A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.

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