Today

- Electromagnetic Radiation
  - Light & beyond
- Thermal Radiation
- Wien & Stefan-Boltzmann Laws

Electromagnetic Radiation

aka Light

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

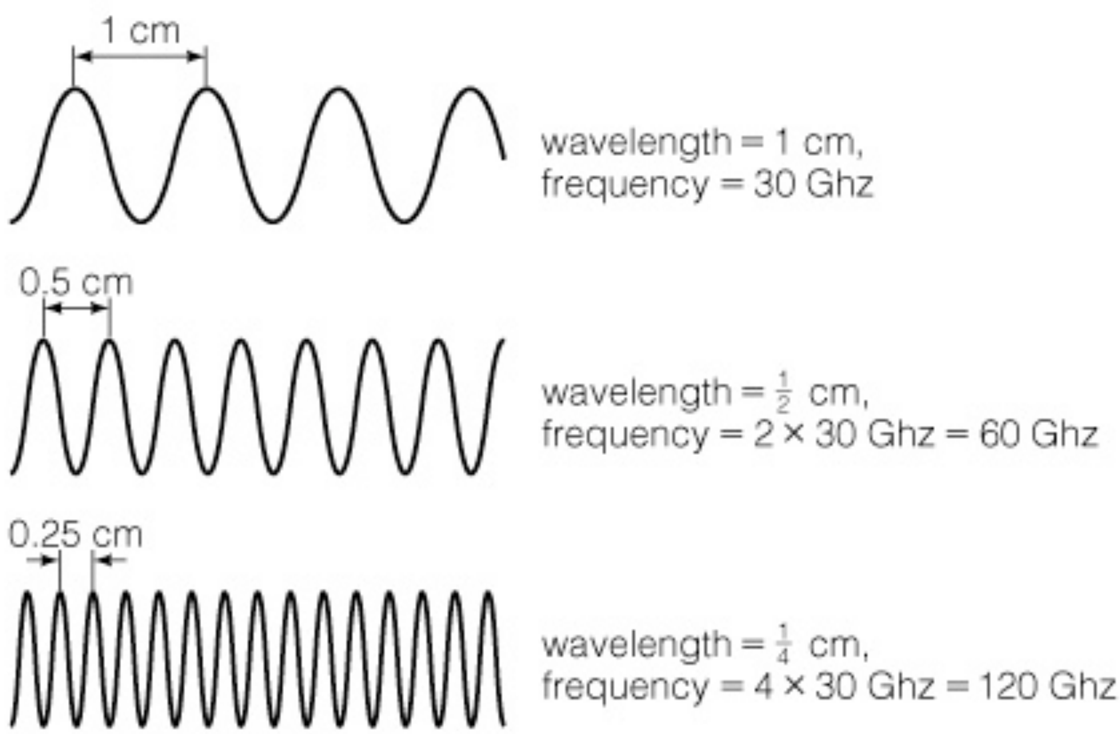
Sometimes it behaves like ripples on a pond (waves).
Sometimes it behaves like billiard balls (particles).

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

$$\lambda f = c$$

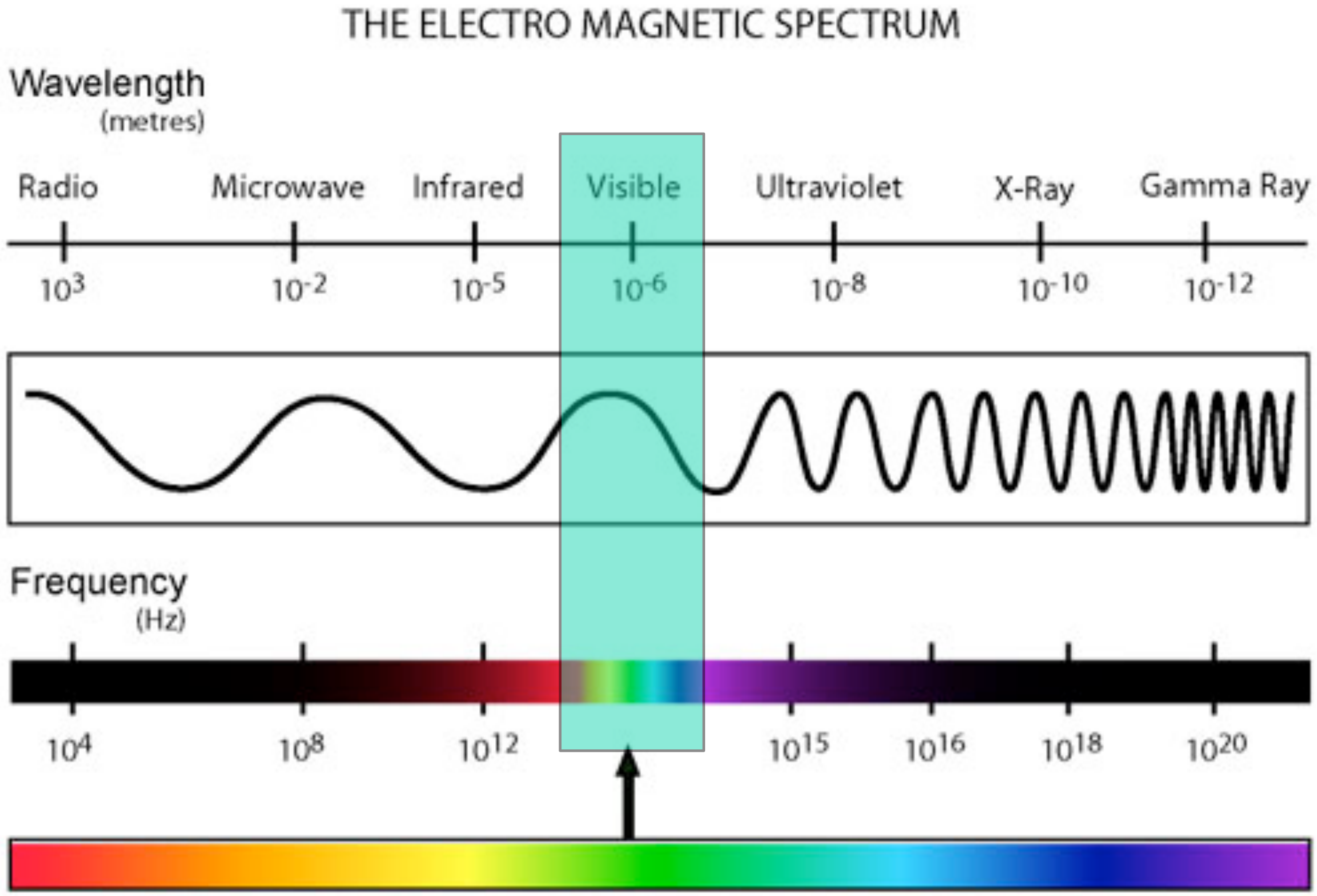
Wavelength, Frequency, and Energy

photon energy:

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

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

(Planck's constant)



E , f increasing

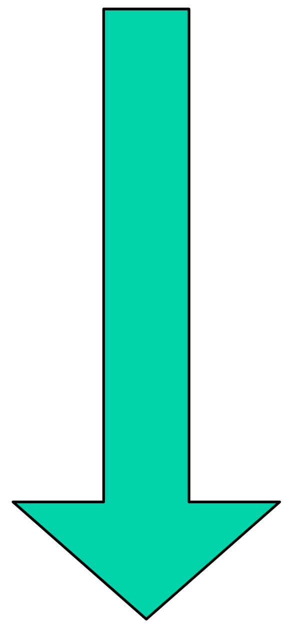
λ decreasing

N1-05

Same stuff, different Energy:

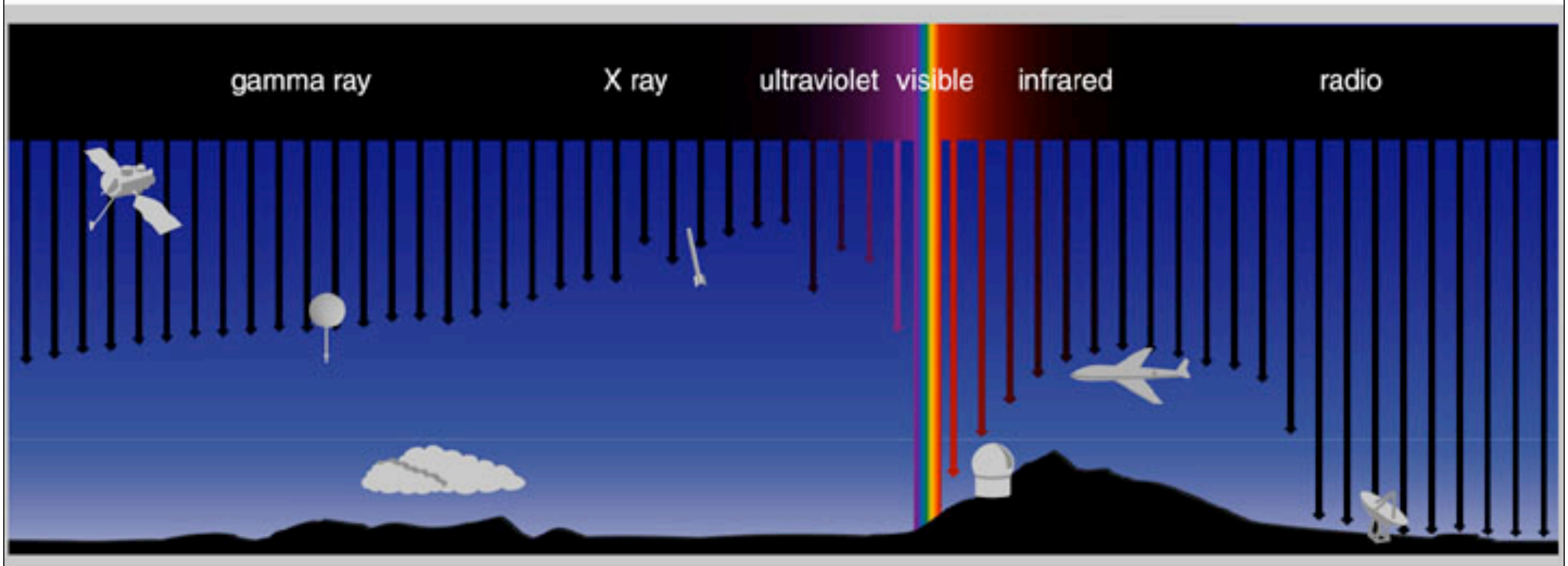
- Radio
- microwave
- infrared
- visible light
- ultraviolet
- X-ray
- gamma ray

Energy per photon increasing



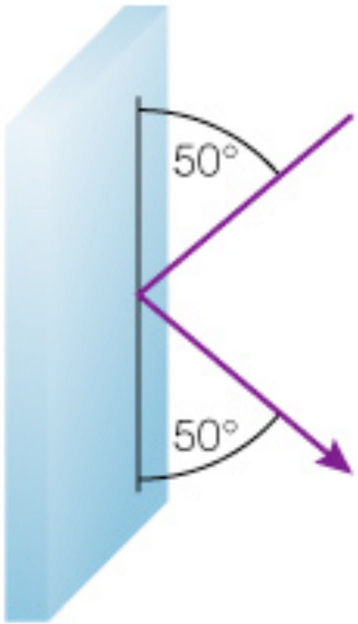
How do light and matter interact?

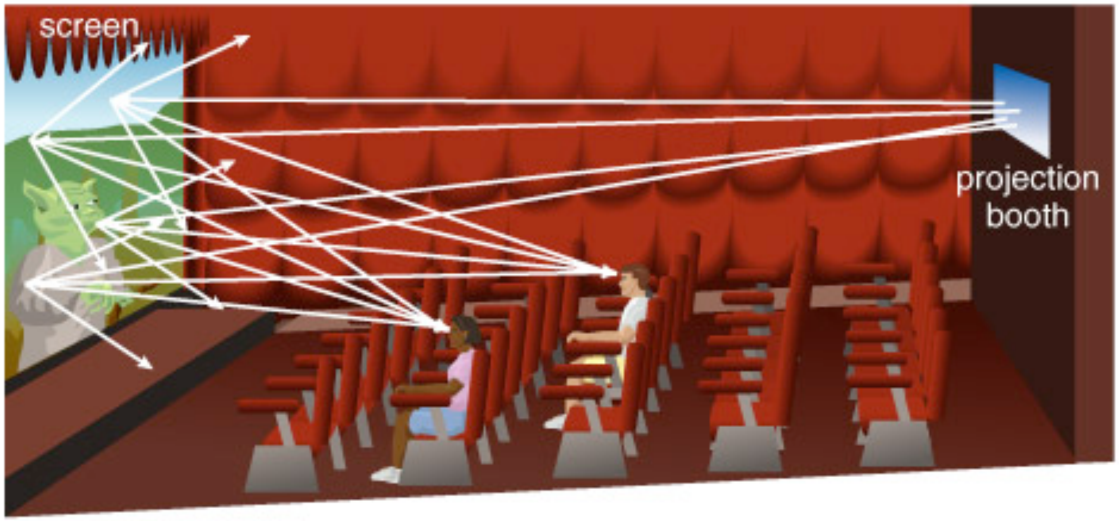
- Emission
- Absorption
- Transmission:
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection or scattering



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

Reflection and Scattering

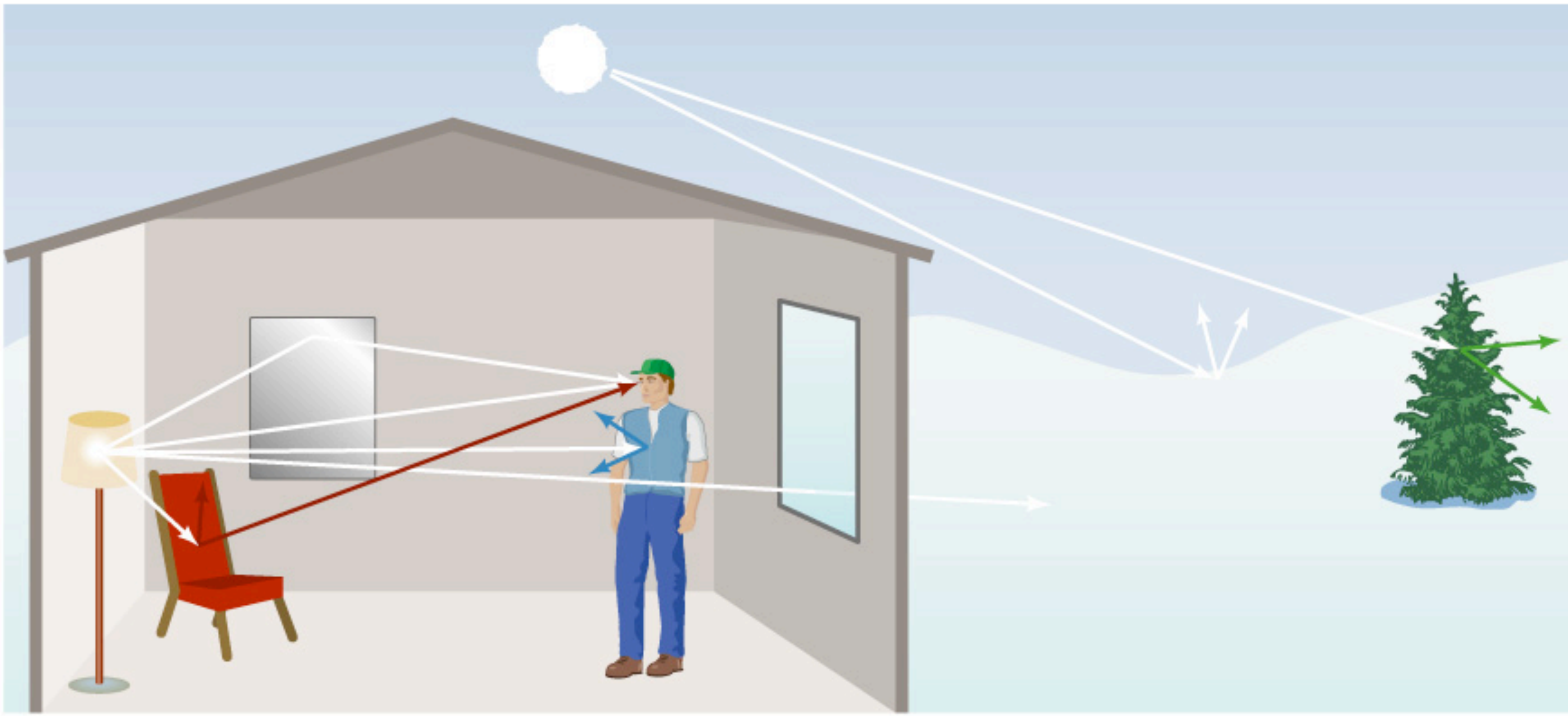




Mirror reflects light in a particular direction.

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

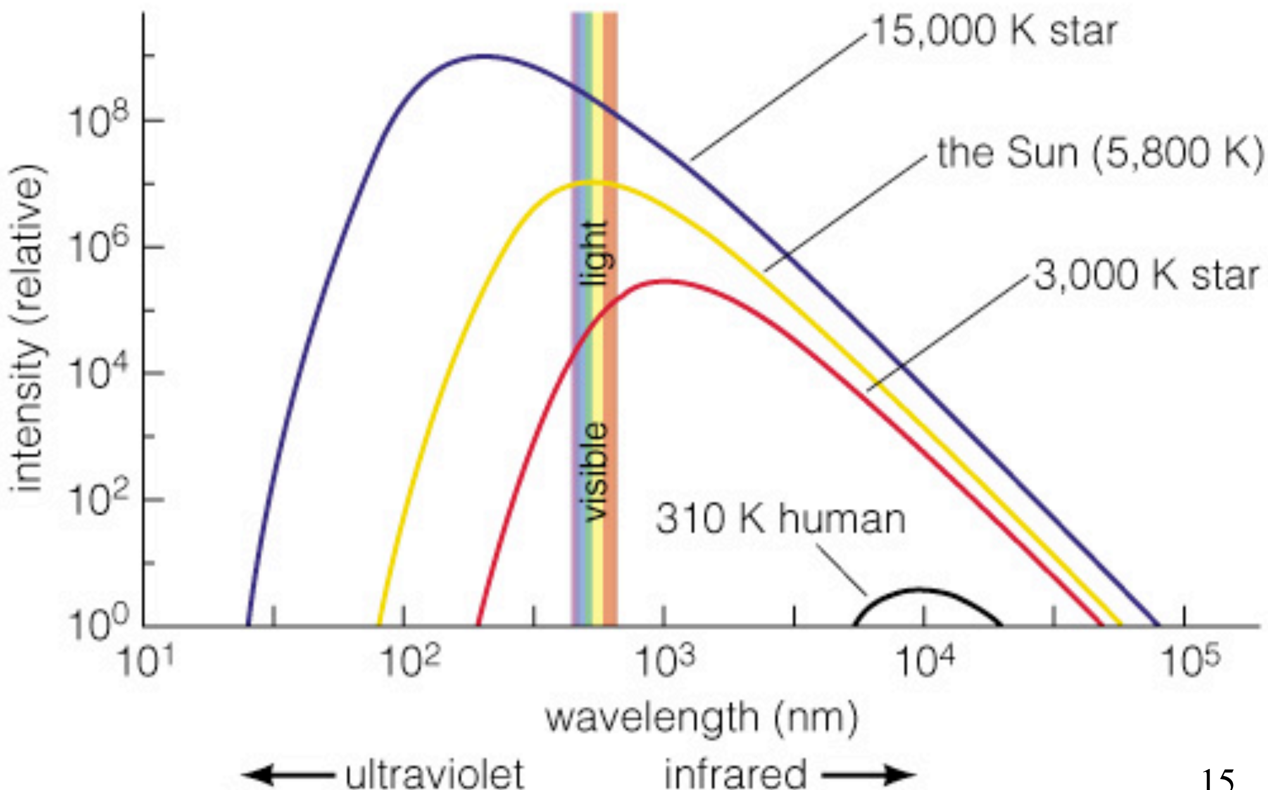
- Nearly all large, dense objects emit thermal radiation, including stars, planets, and you.
- An object's thermal radiation spectrum depends on only one property: its **temperature.**

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

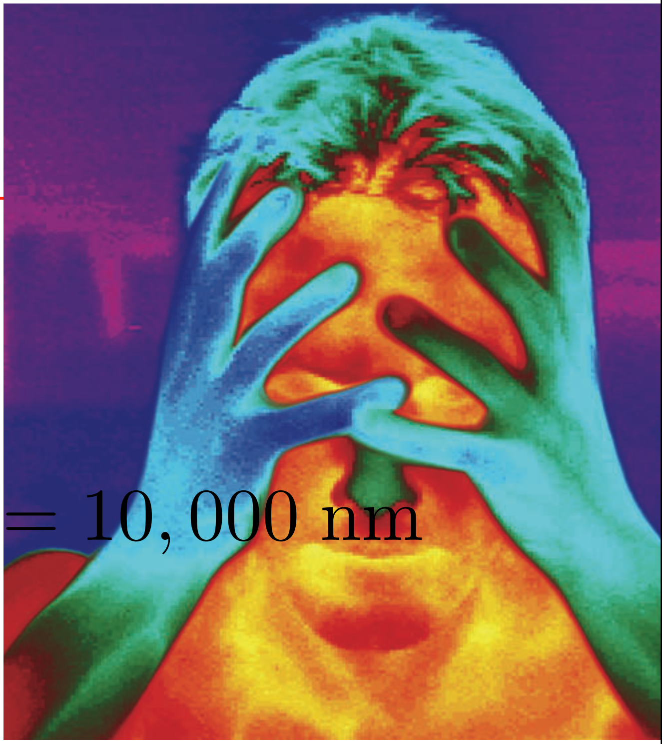
Wien's Law

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

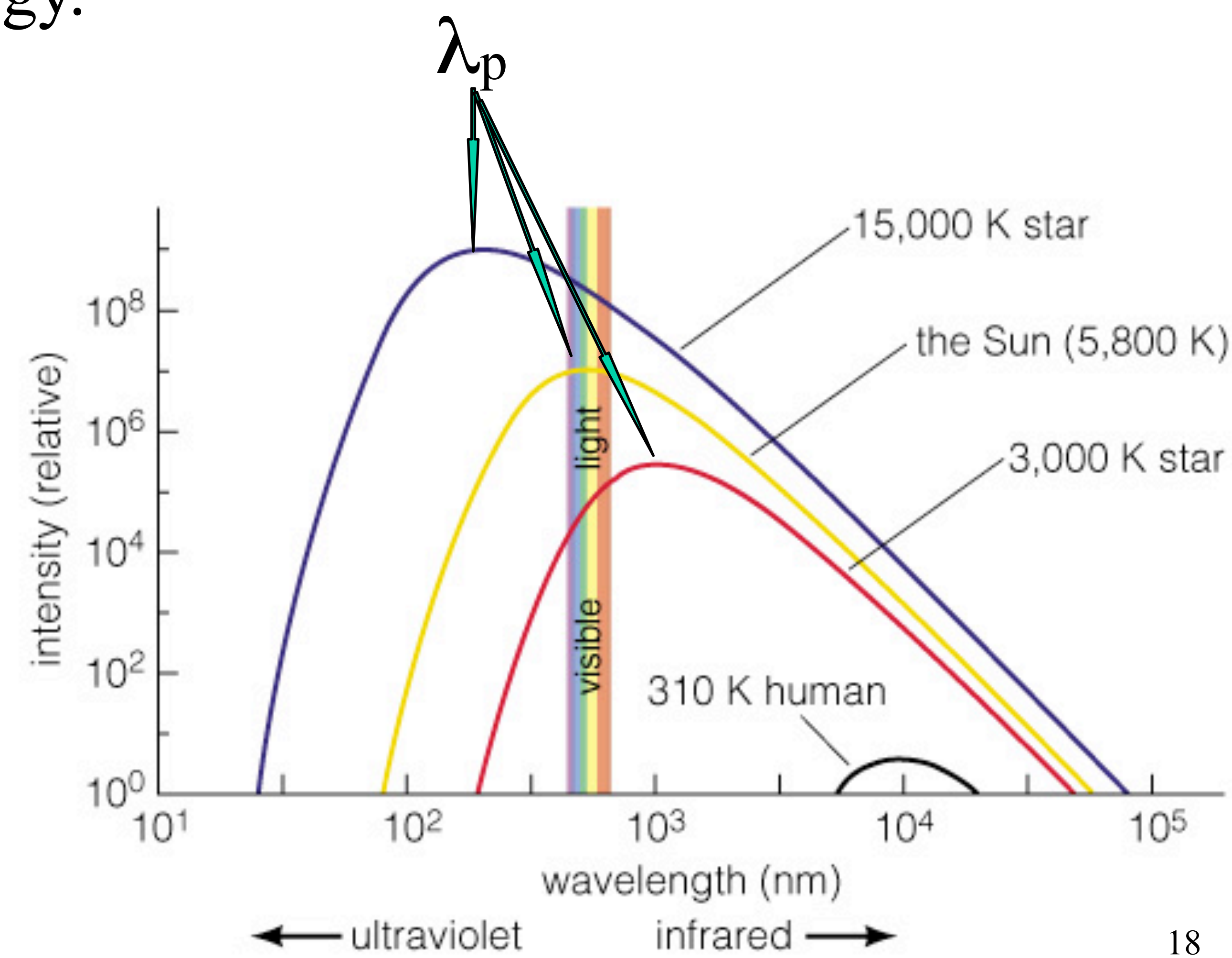
- The Sun
  - T = 5,800 K

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

  - 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 (energy per time 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**).

Using Stefan-Boltzmann Law

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

Suppose you double R while keeping T fixed. What happens to L?

A. L goes down by a factor 4

B. L stays the same

C. L goes up by a factor 4

D. L goes up by a factor 16

E. I don't know

Using Stefan-Boltzmann Law

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Suppose you double T while keeping R fixed. What happens to L?

A. L goes down by a factor 4

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C. L goes up by a factor 4

D. L goes up by a factor 16

E. I don't know

Examples With Stefan-Boltzmann Law

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

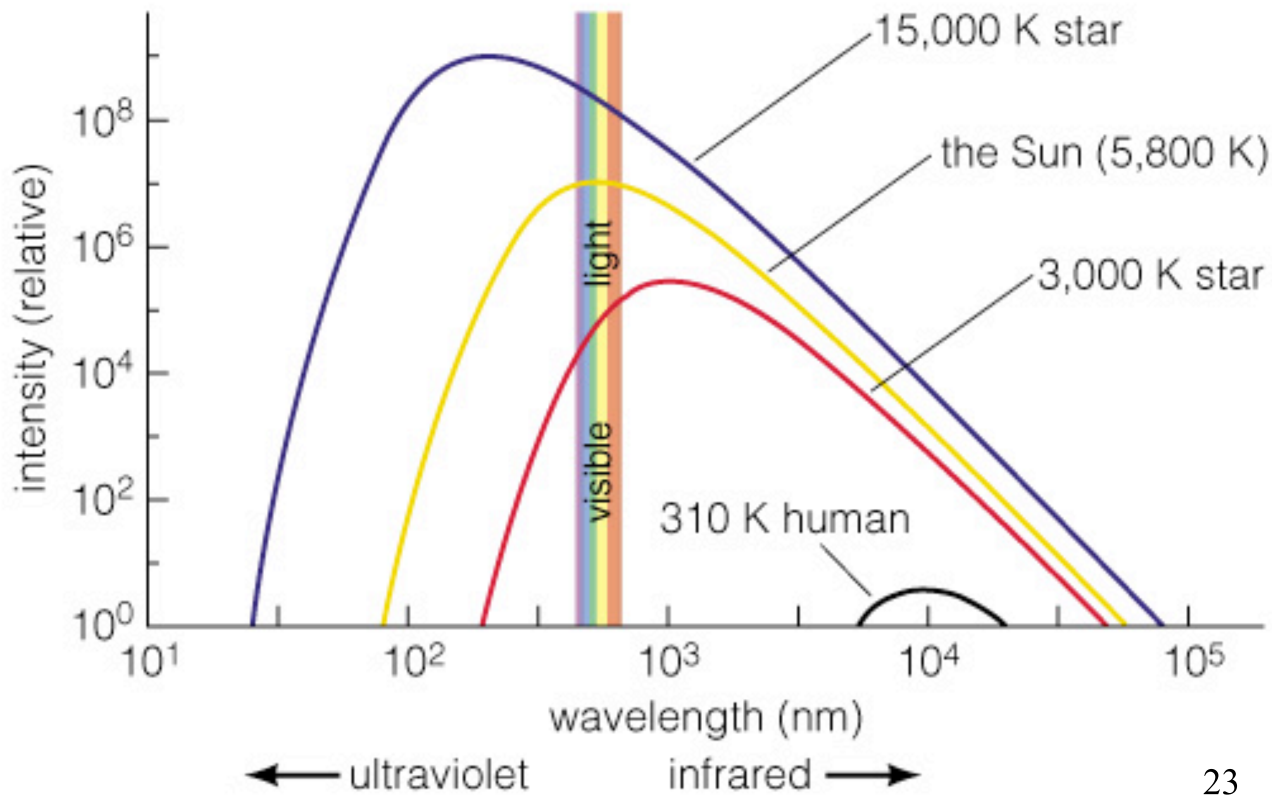
surface area of a sphere

- Suppose you have a star with some luminosity and you double its radius R while keeping the temperature T fixed. What happens to L?
- L goes up by a factor of 2x2, or 4
- What if you double the temperature T while keeping the radius R fixed?
- L goes up by a factor of 2x2x2x2, or 16
- Note that the other constants are always fixed, so we don't have to worry about them when taking a ratio

Properties of Thermal Radiation

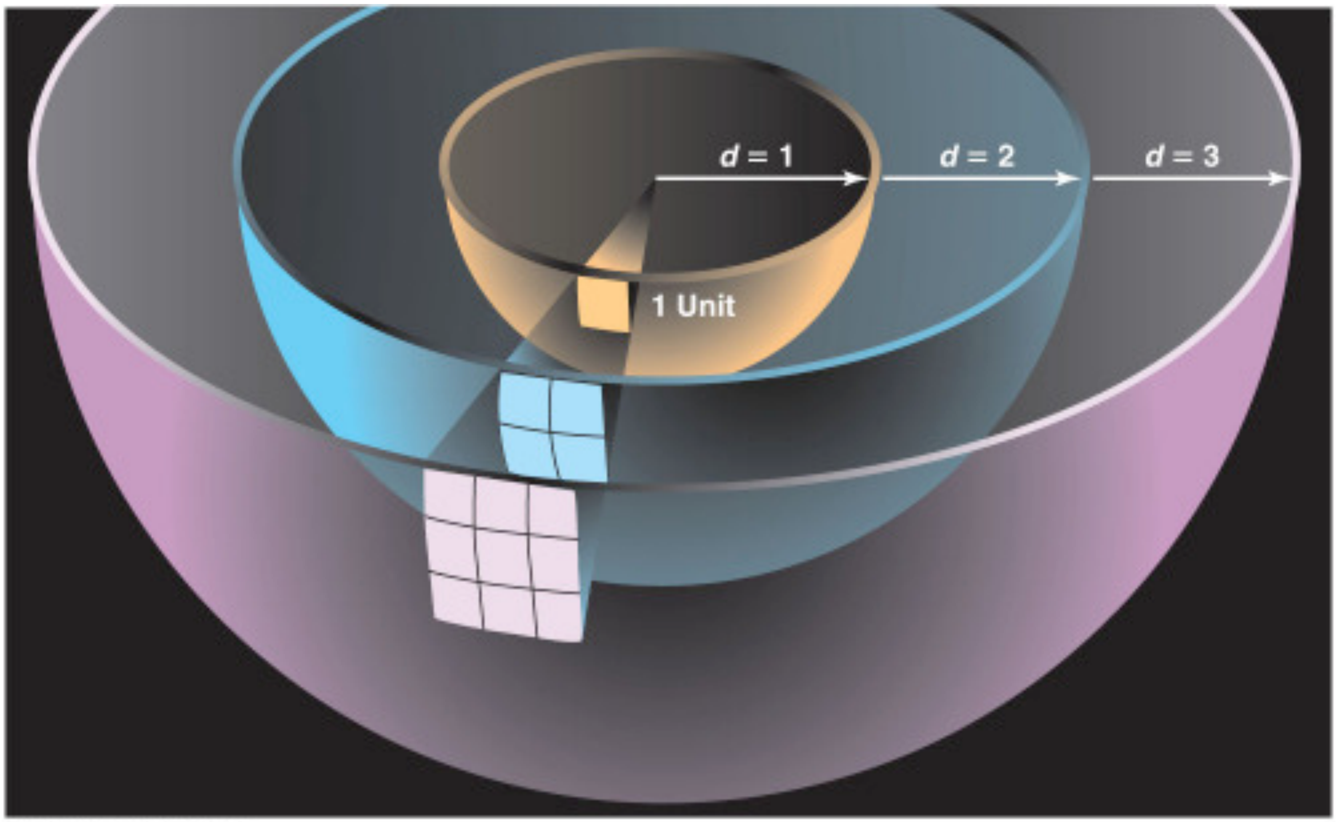
Hotter objects emit more light at all frequencies per unit area.

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

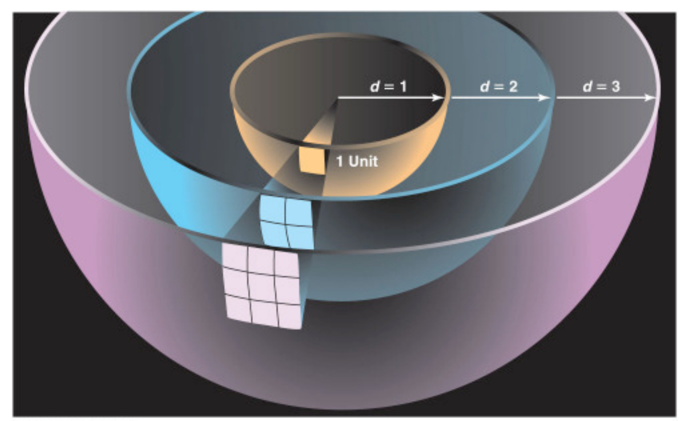


Inverse square law

- 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

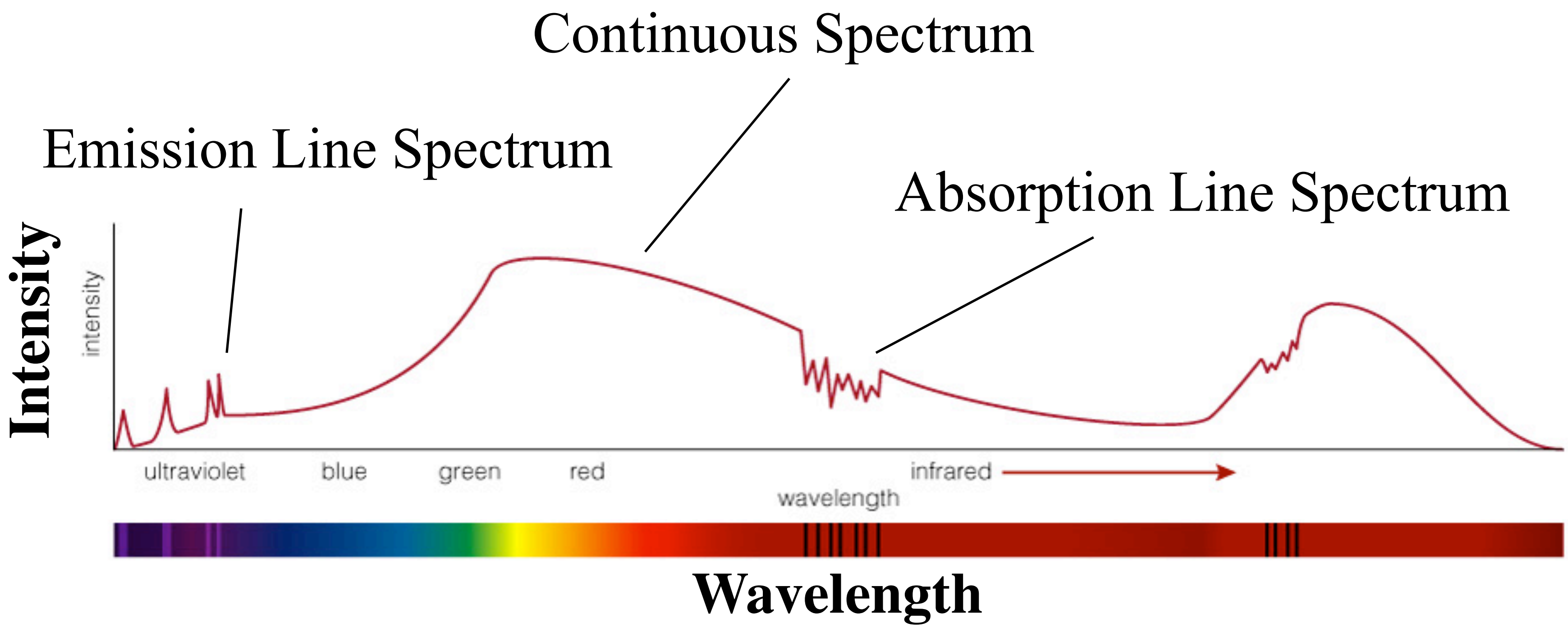
apparent brightness

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



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 & Stefan-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