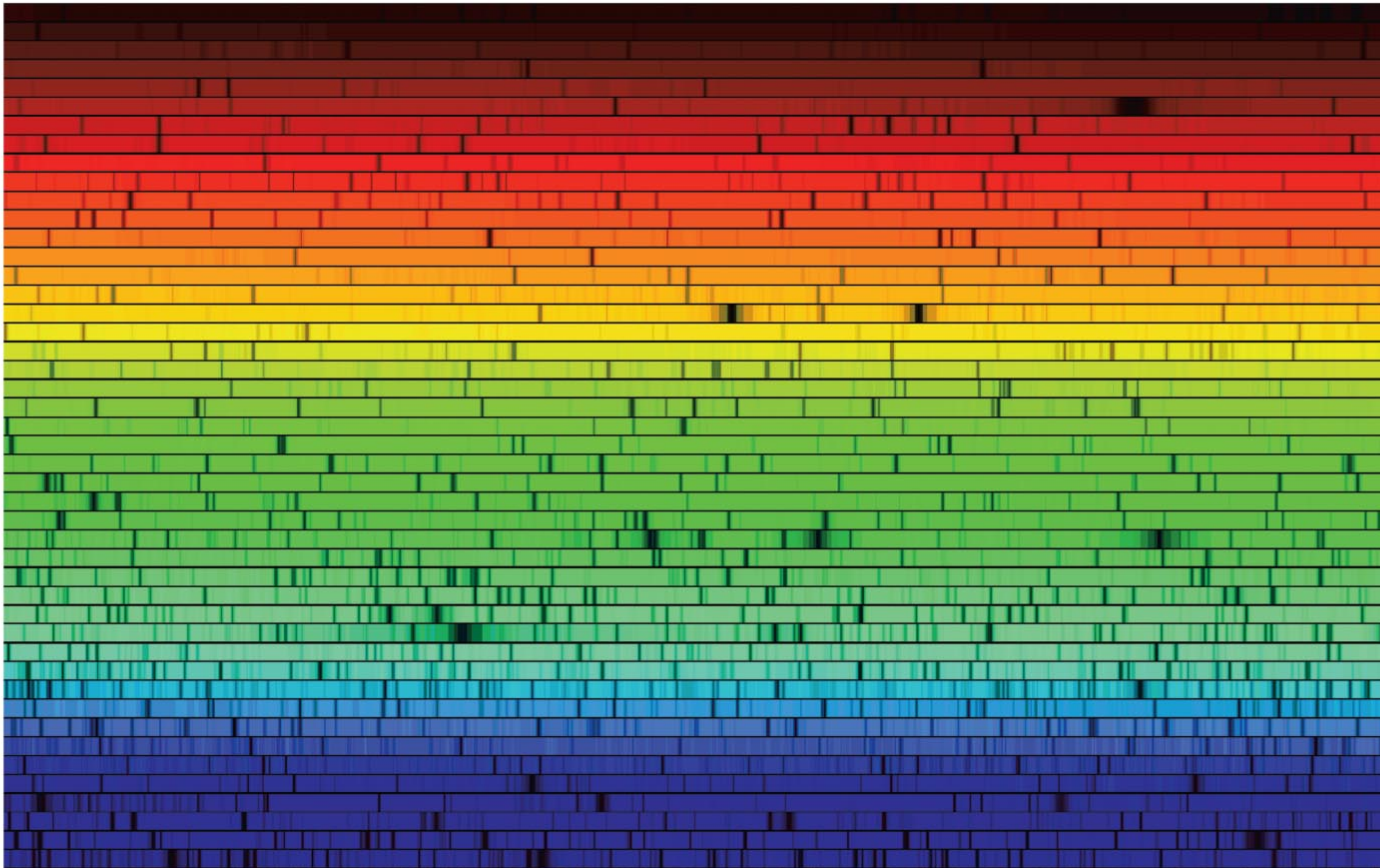
Electromagnetic Radiation



Electromagnetic Radiation

also known as 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.

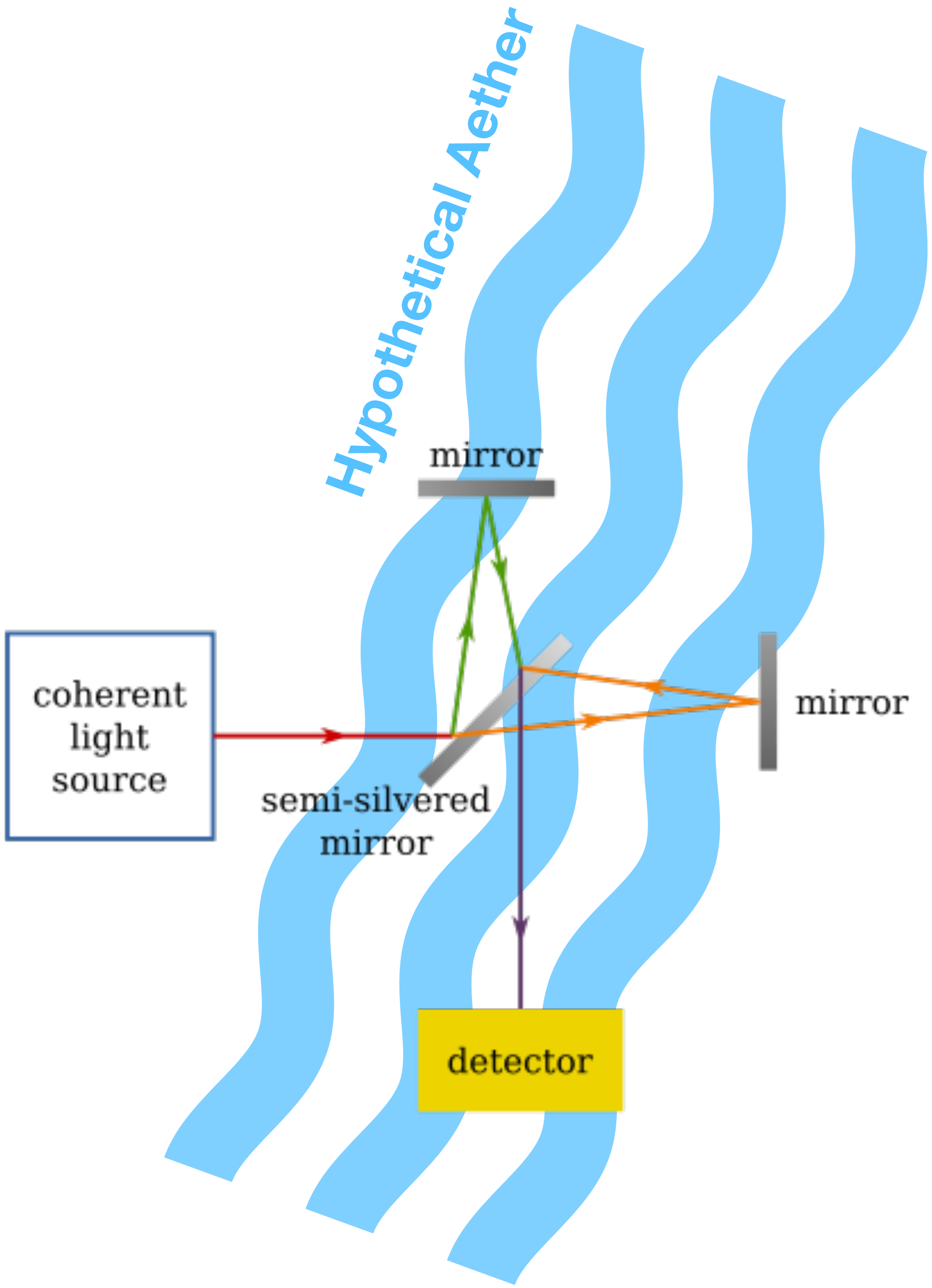
Electromagnetic Radiation

Light

- has properties that are wave-like

Sometimes light behaves like ripples on a pond (waves). Led physicists in the 19th century to hypothesize a "luminiferous aether" - an all pervasive substance that was the pond to light's ripples. As physics was understood at that time, collective, wave-like phenomena required that there being a medium (aether) in which the waves propagated.

Michelson-Morley Experiment
Performed on campus in 1887



If light was a wave in some ethereal medium, it's speed should depend on our motion through that medium, getting a boost from Earth's orbital speed (30 km/s) when parallel to it, and not when perpendicular.

Instead, Michelson & Morley measured the speed of light to be invariant at 300,000 km/s irrespective of direction. This led to Einstein's Special Relativity.

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).

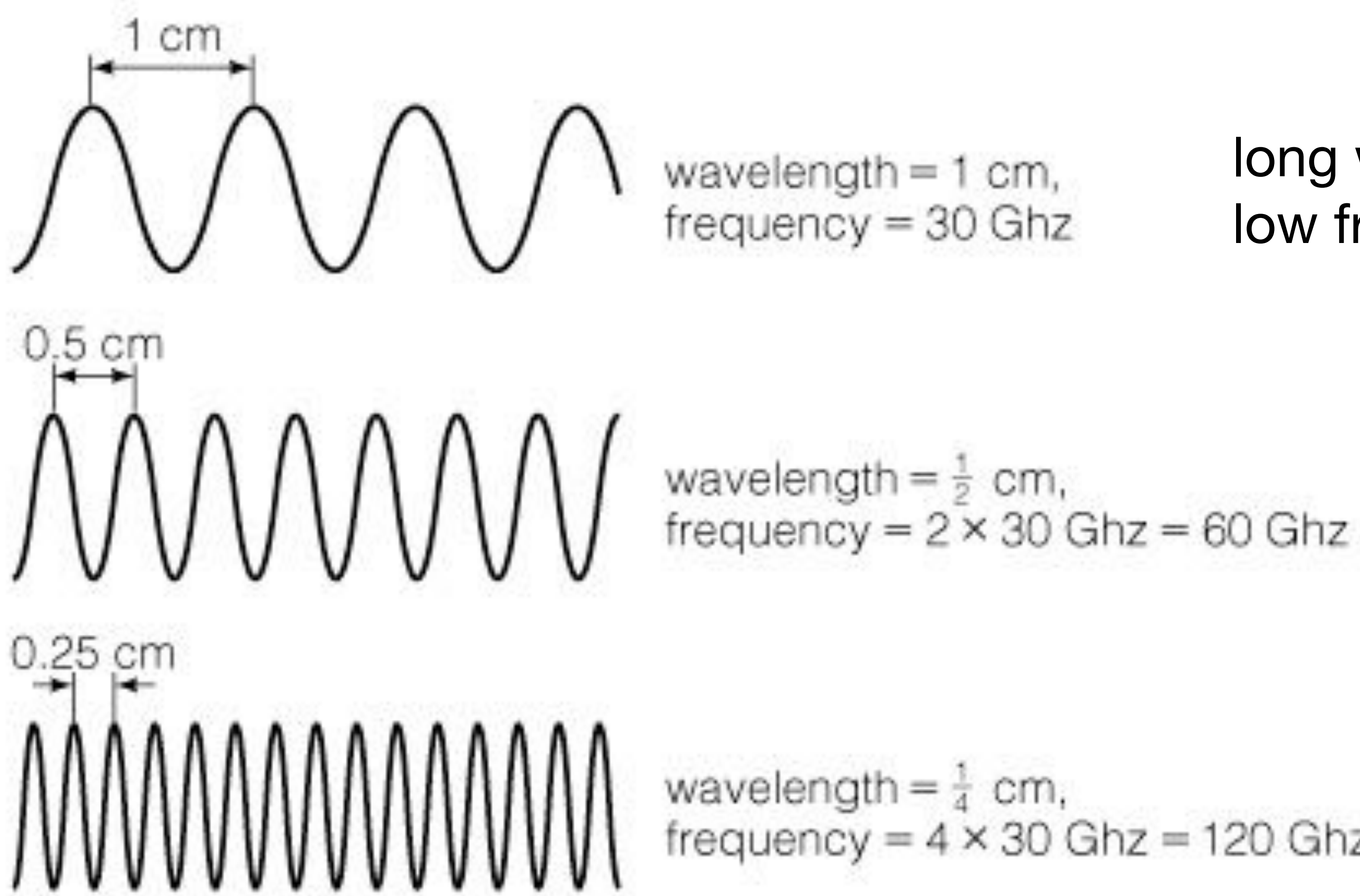
Called the "wave-particle" duality in quantum mechanics.

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

inversely related



long wavelength,
low frequency

short wavelength,
high frequency

Wavelength & Frequency

λ = wavelength (separation between crests)

f = frequency (rate of oscillation)

c = speed of light = 300,000 km/s

$$\lambda f = c$$

Wavelength, Frequency, and Energy

photon energy:

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

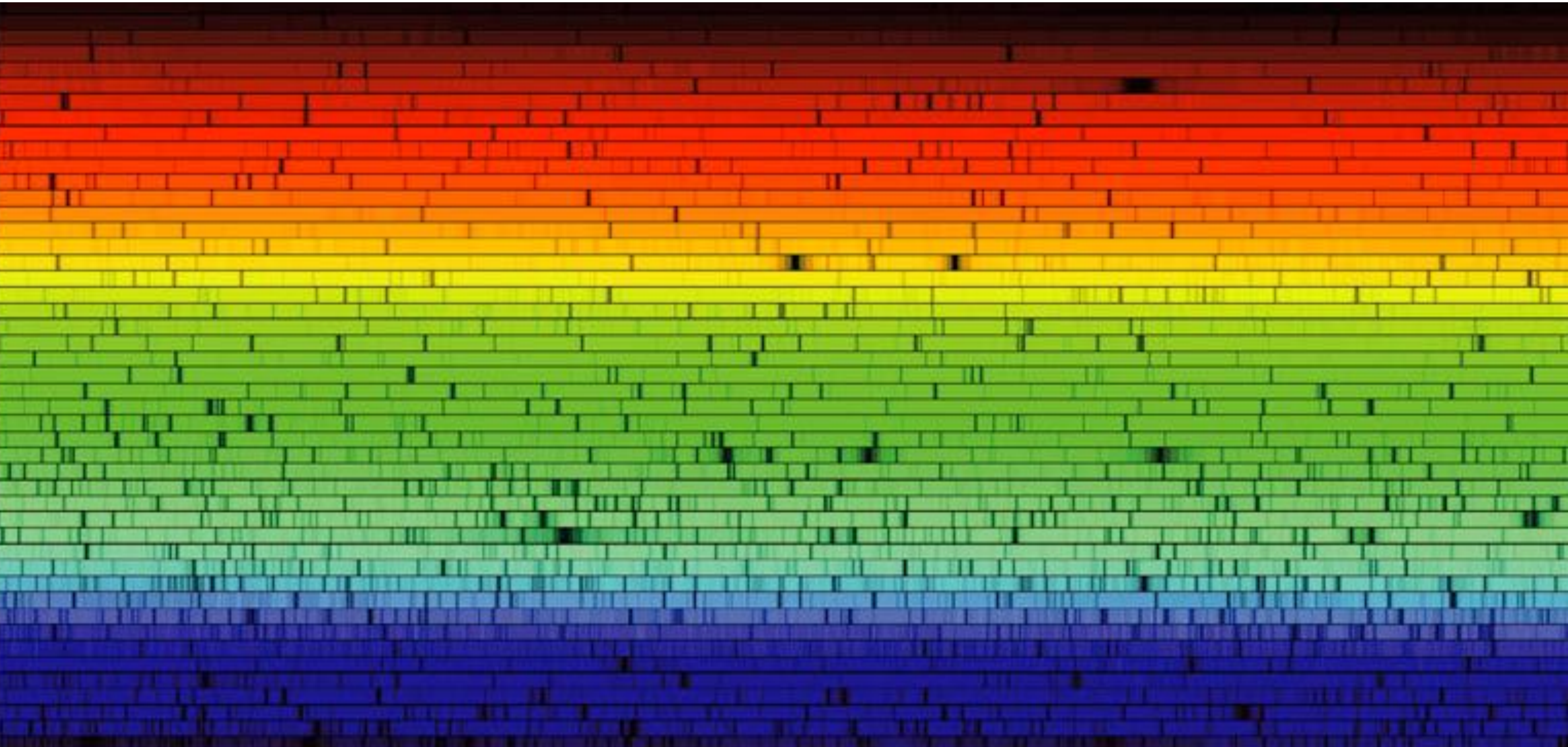
$$h = 6.626 \times 10^{-34} \text{ joule} \times \text{s}$$

(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 (led to quantum mechanics).

Spectrum

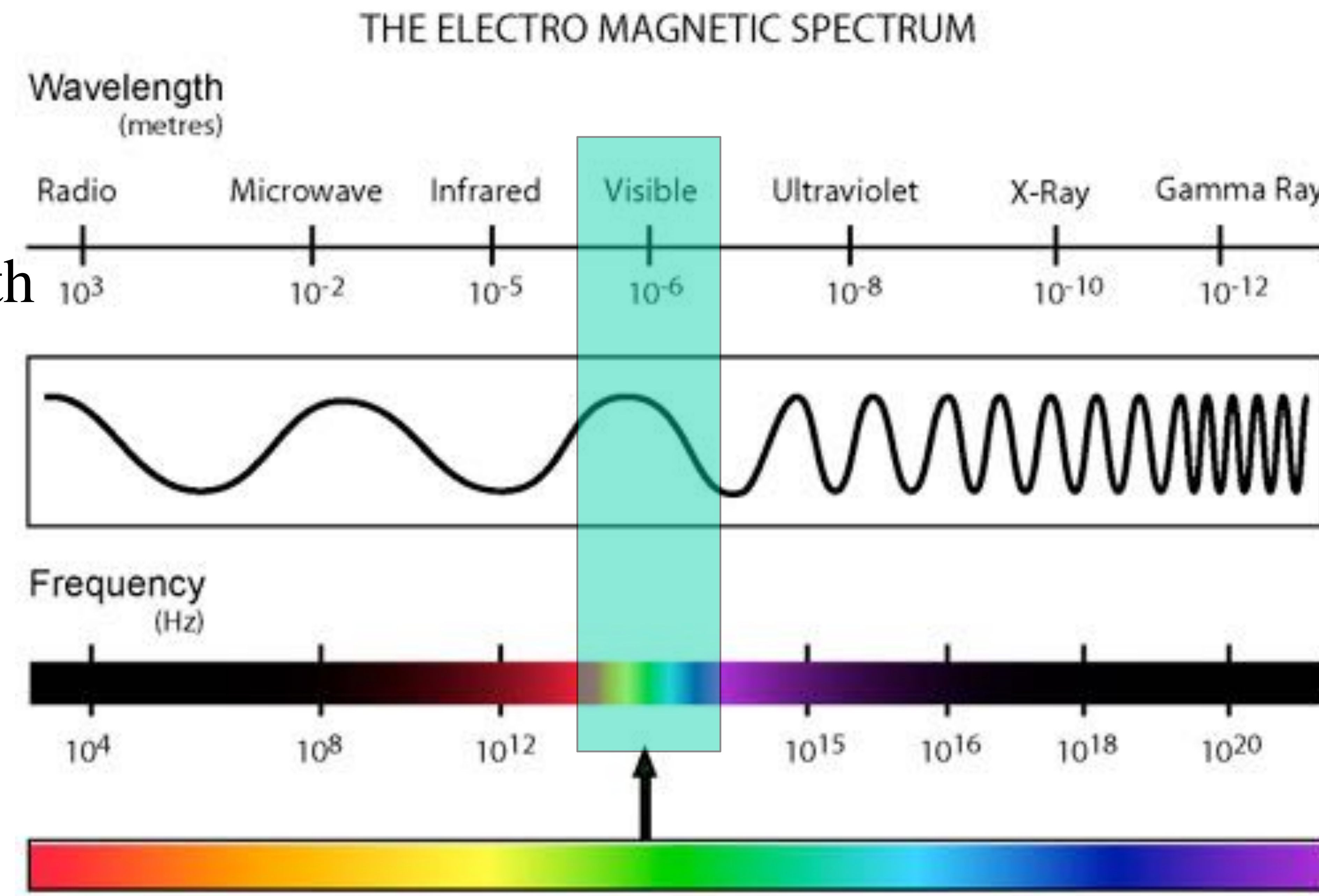
- Originally, "the range of colors obtained by passing sunlight through a glass prism"
- Quantitatively, the Intensity of electromagnetic radiation as a function of wavelength



Long wavelength

Low energy

Low frequency



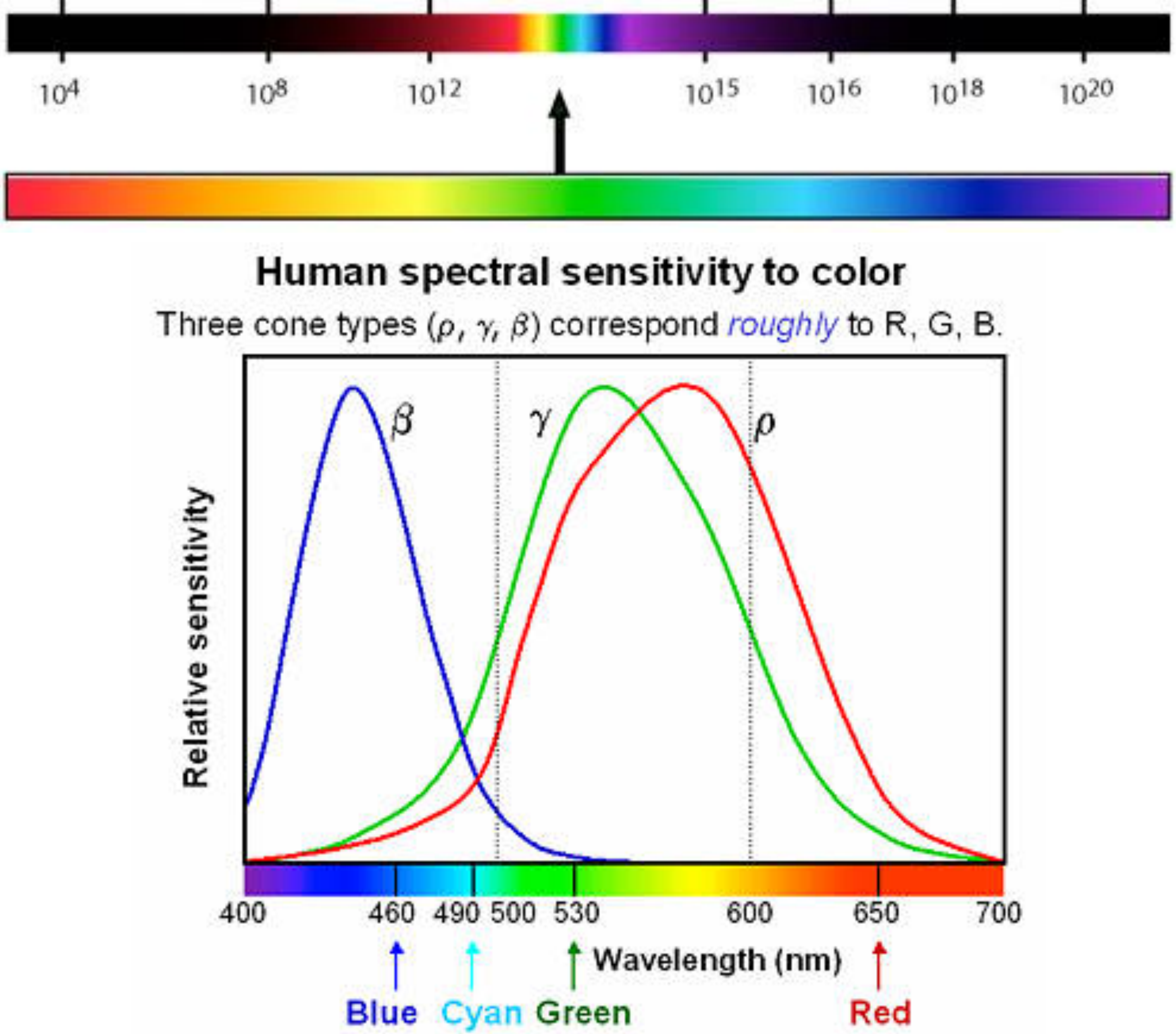
Short wavelength

High energy

High frequency

$E\ ,f$ *increasing*

λ *decreasing*



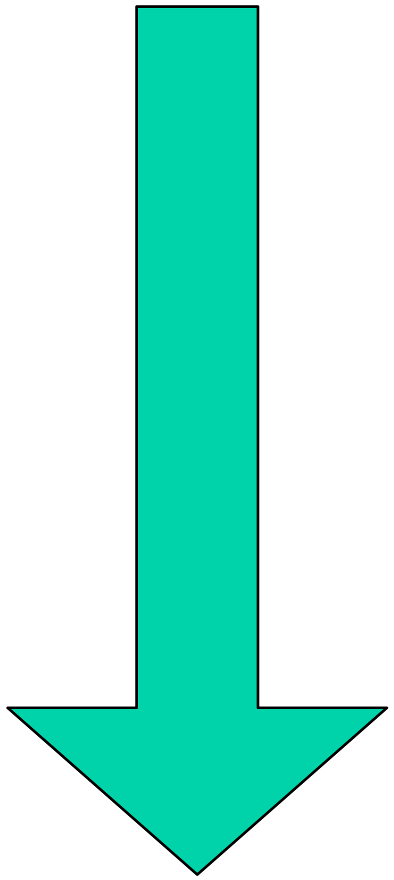
Our eyes are only sensitive to a factor of two range in wavelength, from 380nm (violet) to 700nm (deep red).

Same stuff, different Energy:

<u>Electromagnetic Radiation</u>

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

Energy per photon increasing



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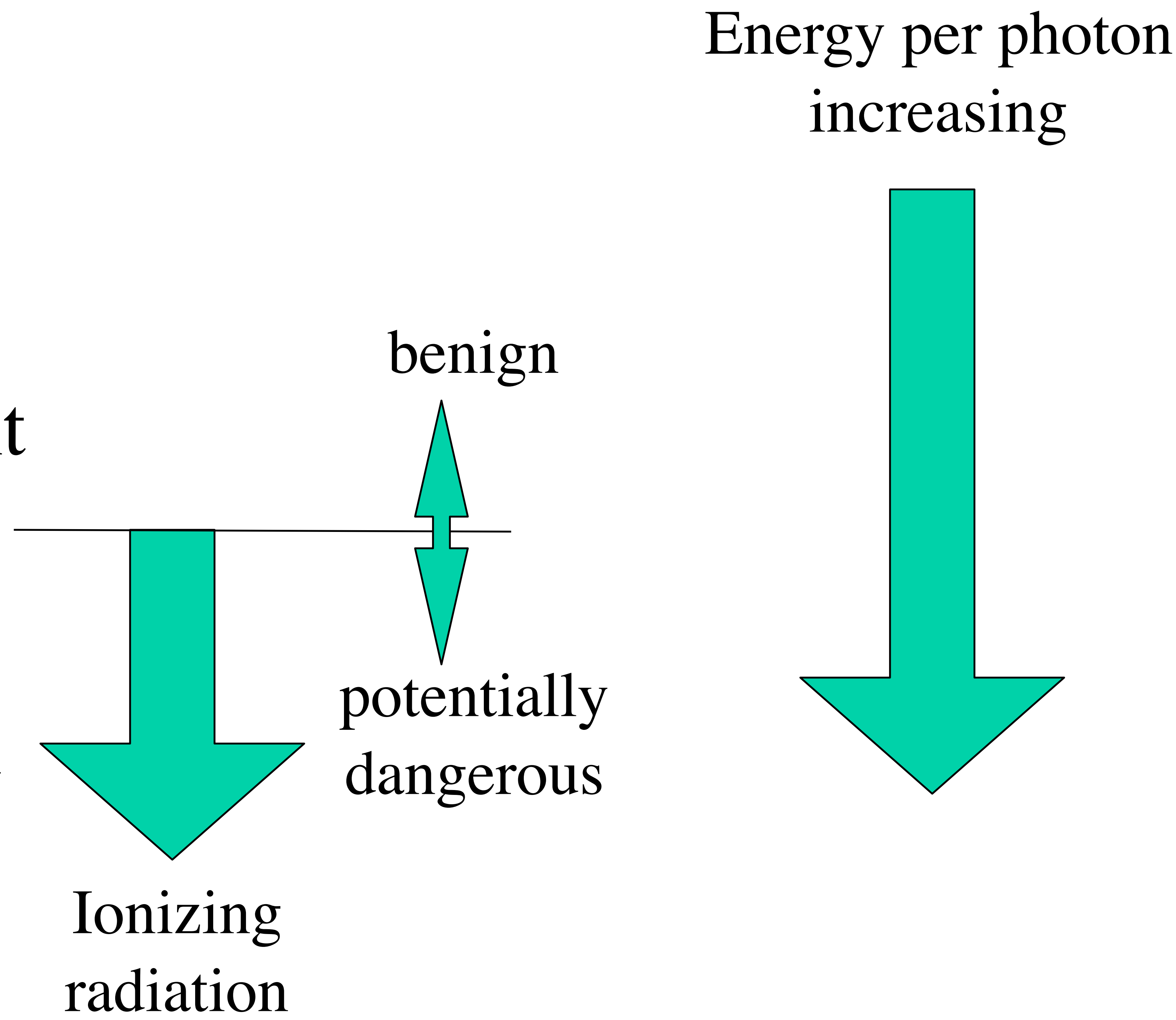

How do light and matter interact?

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

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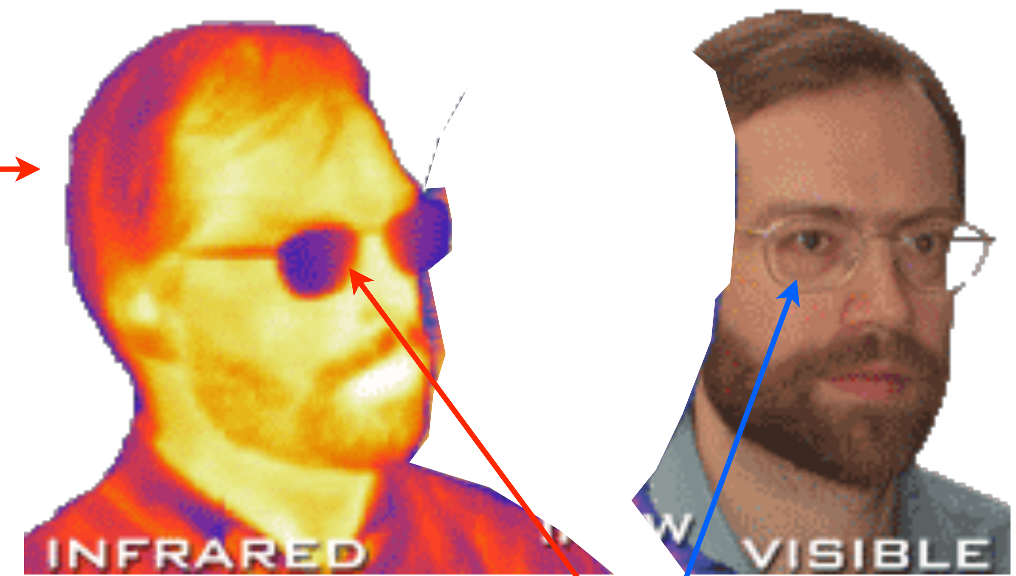
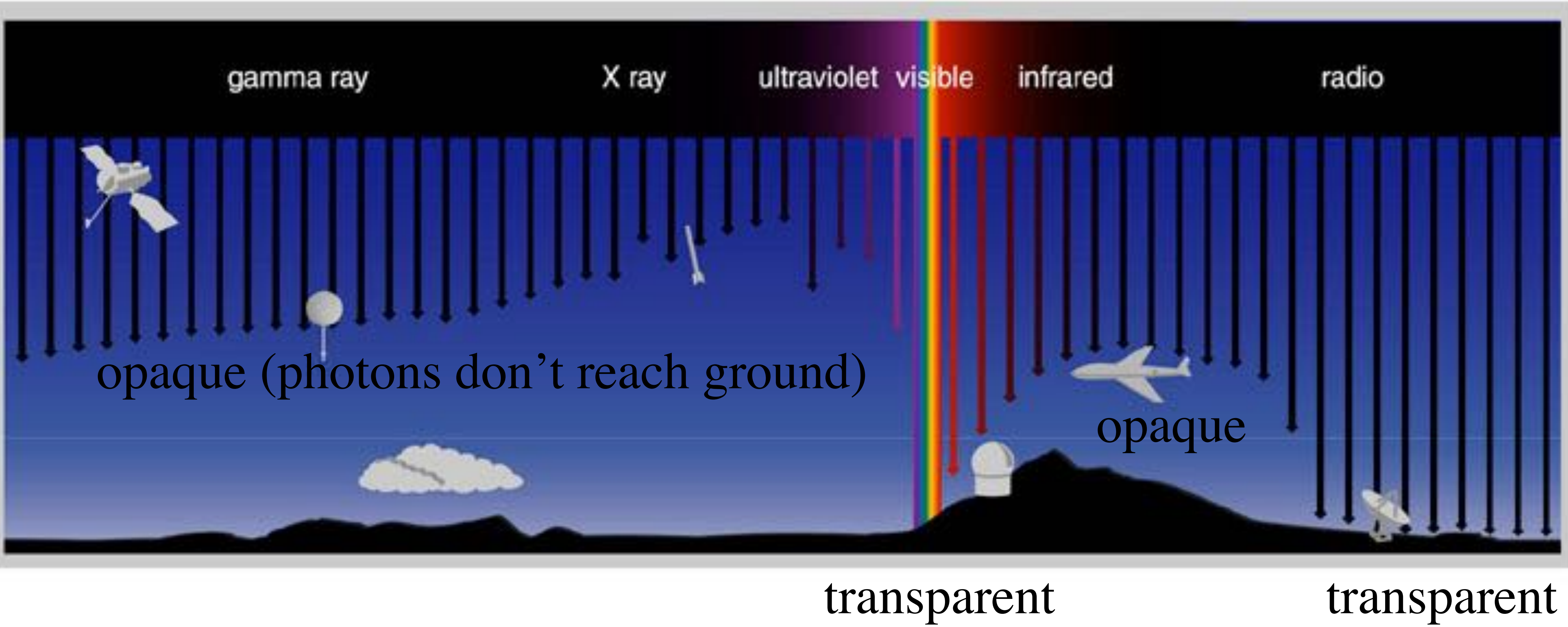
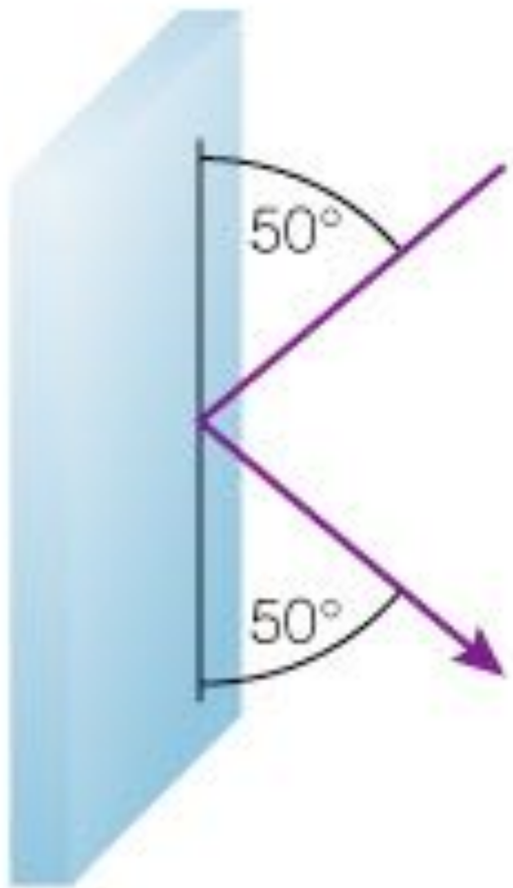


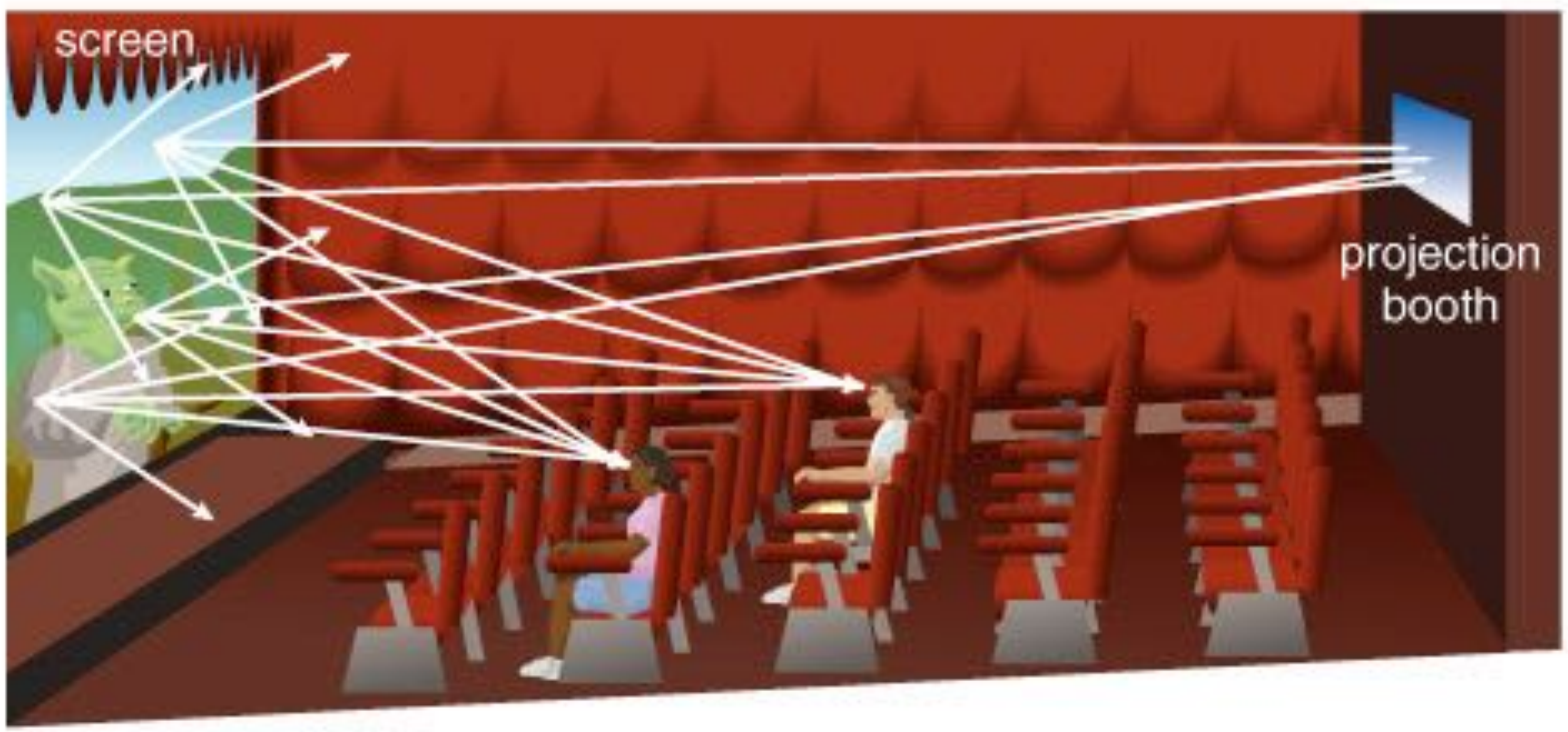
transmission & absorption



Earth's atmosphere is opaque to light at most wavelengths.
It is transparent only to visible light and radio waves - and is only completely transparent to visible light when it isn't cloudy.

Reflection and Scattering

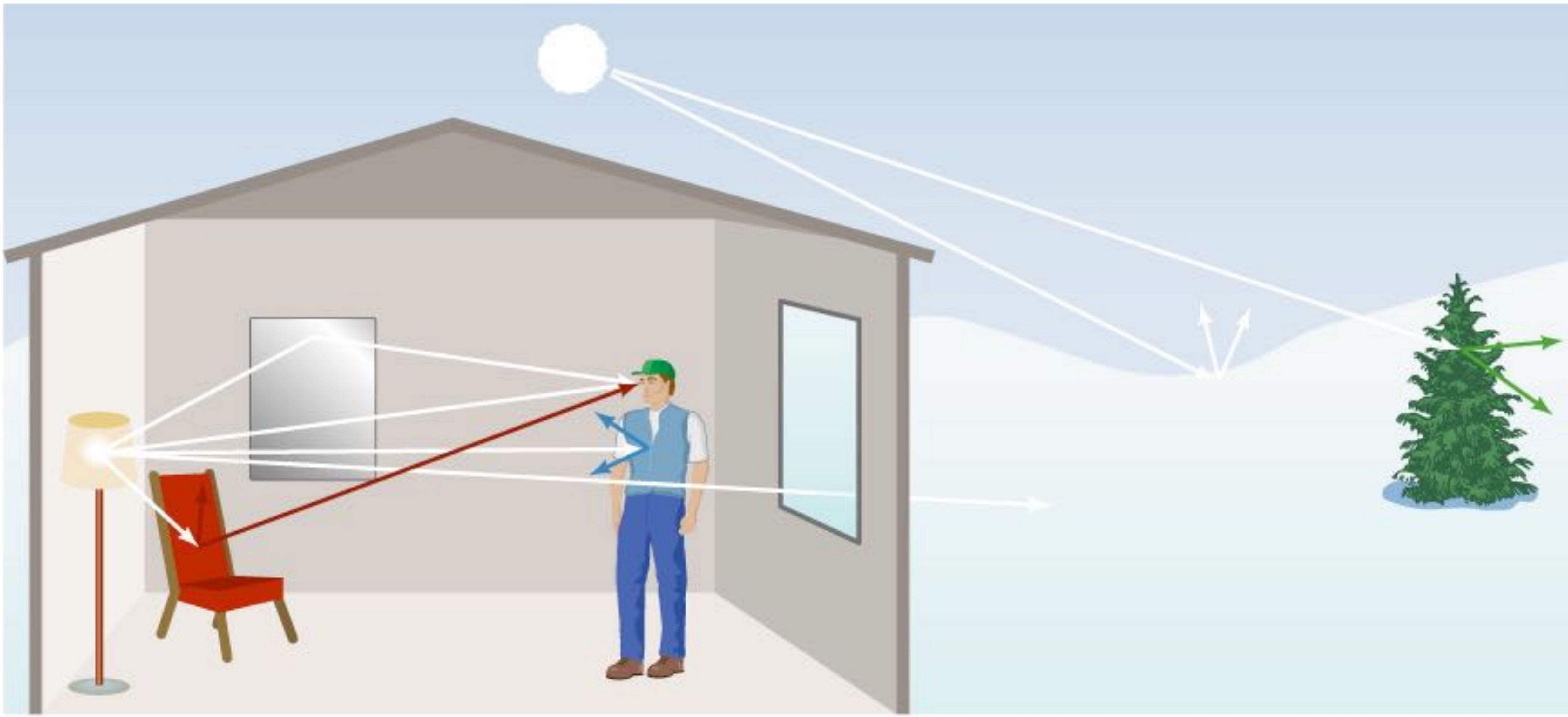




Mirror reflects light in a particular direction.

Movie screen scatters light in all directions.

We see by scattered light



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

optical **infrared**

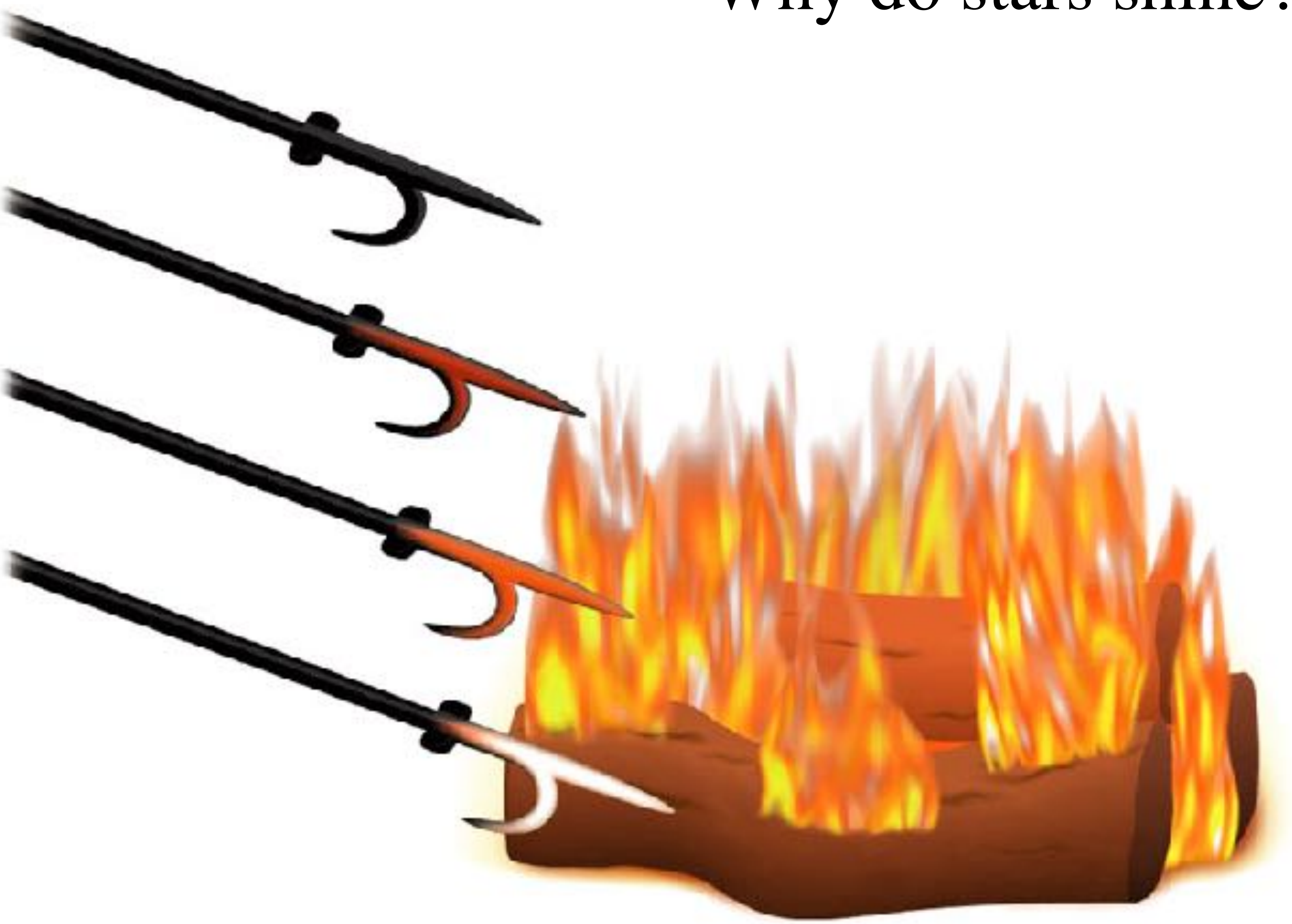
optical photons
scattered
ambient light

infrared photons
emitted
by warm object

Temperature scale illustrated by false color

Production of light

Why do stars shine?



They're hot!

Thermal Radiation

- Hot, dense objects emit thermal radiation
  - includes stars, planets, and you.

- An object's thermal radiation spectrum depends on 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: