

# Today

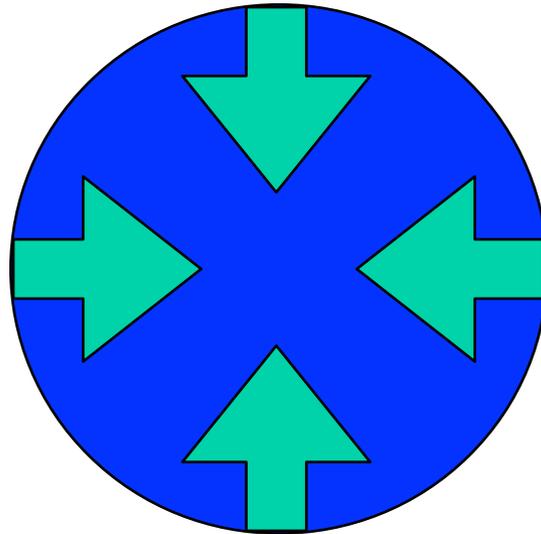
- Tides
- Light
  - the Electromagnetic Spectrum
  - Thermal Radiation

## EVENTS

- Homework Due Next time (Sept. 22)
- Exam I on Sept. 24

# Why are stars and planets spherical?

- Gravity pulls - it is an attractive force
- IF self-gravity is the most important force holding an object together, it must be spherical.



# Example: Earth

- Diameter of Earth: 12,756 km
- Mt. Everest: 8.848 km above sea level
- Mariana Trench: 10.934 km below
- Maximum variation: 19.782 km

$$\frac{\text{maximum variation}}{\text{diameter}} = \frac{19.782}{12,756} = 0.0015$$

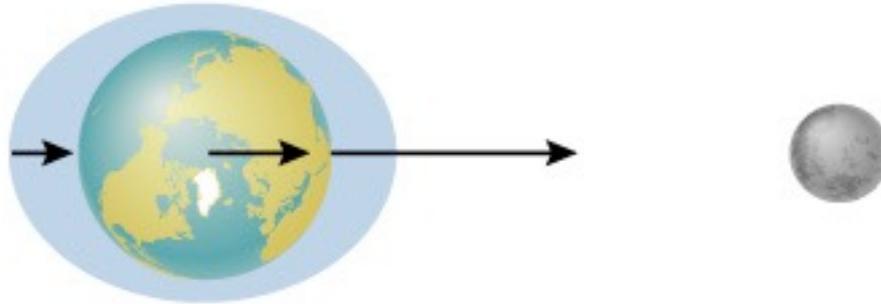
- a very smooth sphere!

- Gravity makes individual objects round
  - about 100 km in diameter is where objects start to become dominated by self-gravity
    - planets round
    - asteroids still lumpy

This holds for individual objects.  
What about multiple objects?



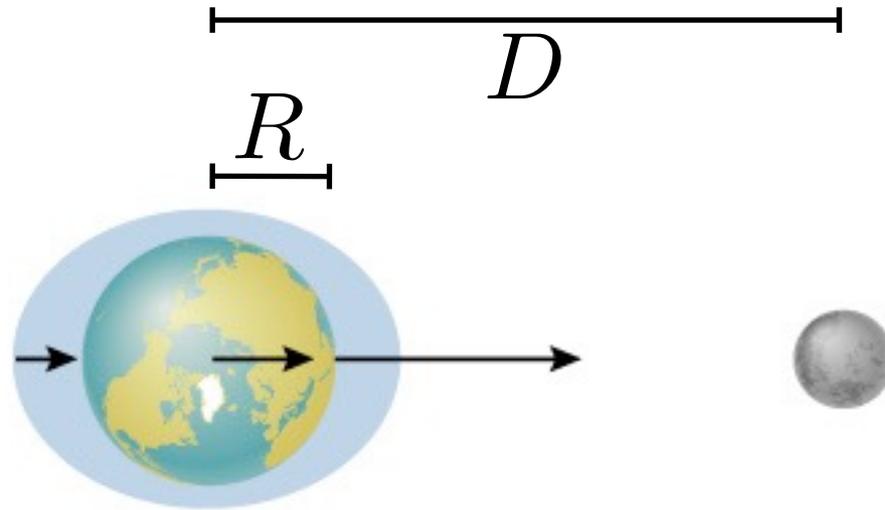
# Tides



*Not to scale!*

Tides are the result of differential gravity

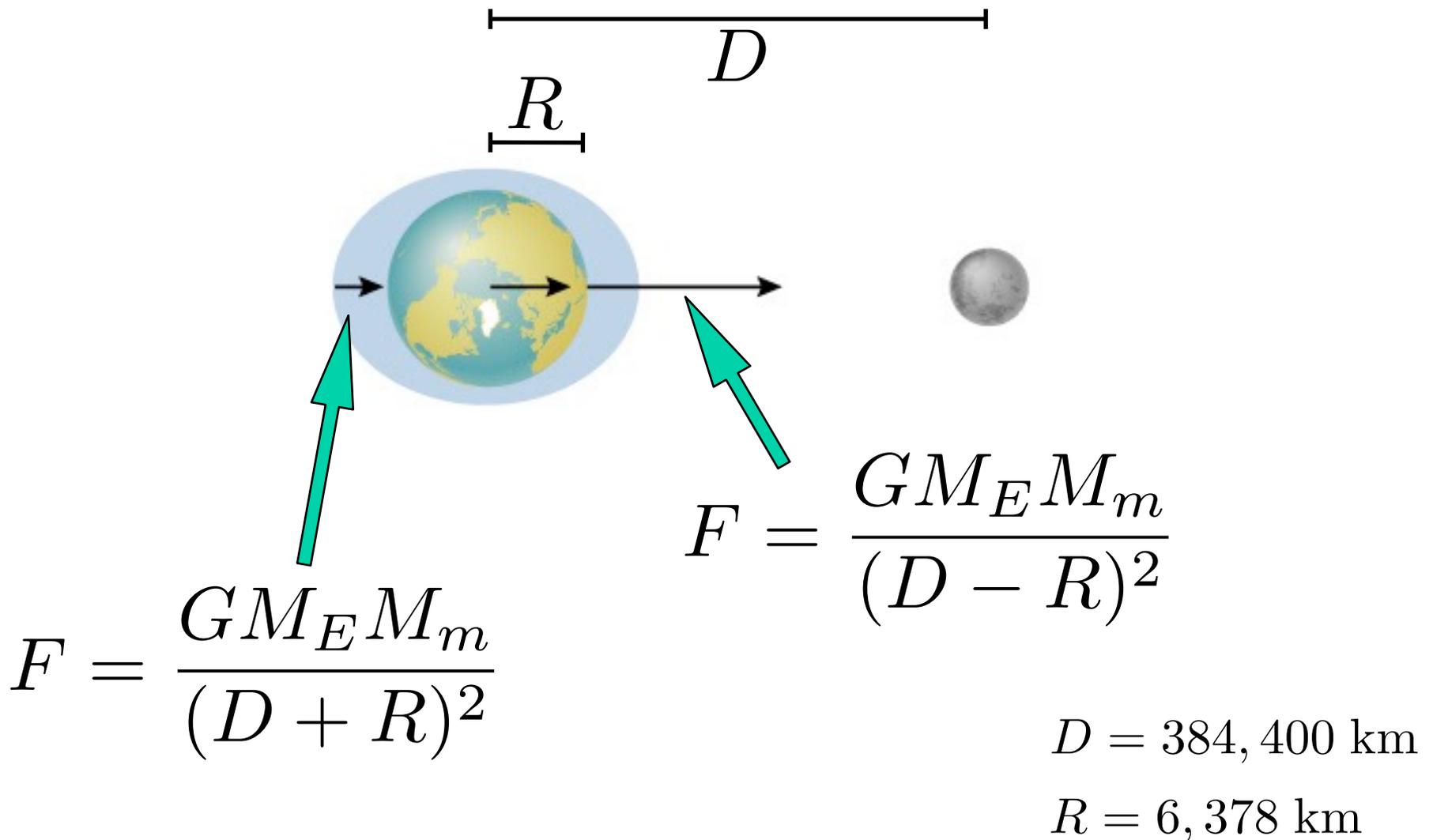
- The Moon's gravity pulls harder on near side of Earth than on far side (inverse square law).
- The difference in the Moon's gravitational pull stretches Earth.



*Not to scale!*

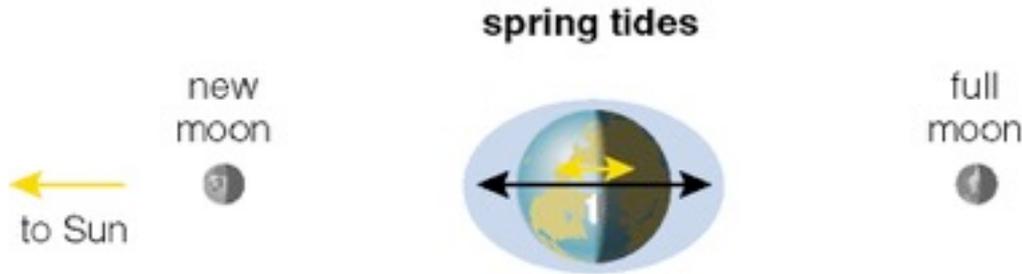
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So the gravitational attraction towards the moon is about 7% stronger on the near side of the Earth than on the far side.

# 2 Tides a day

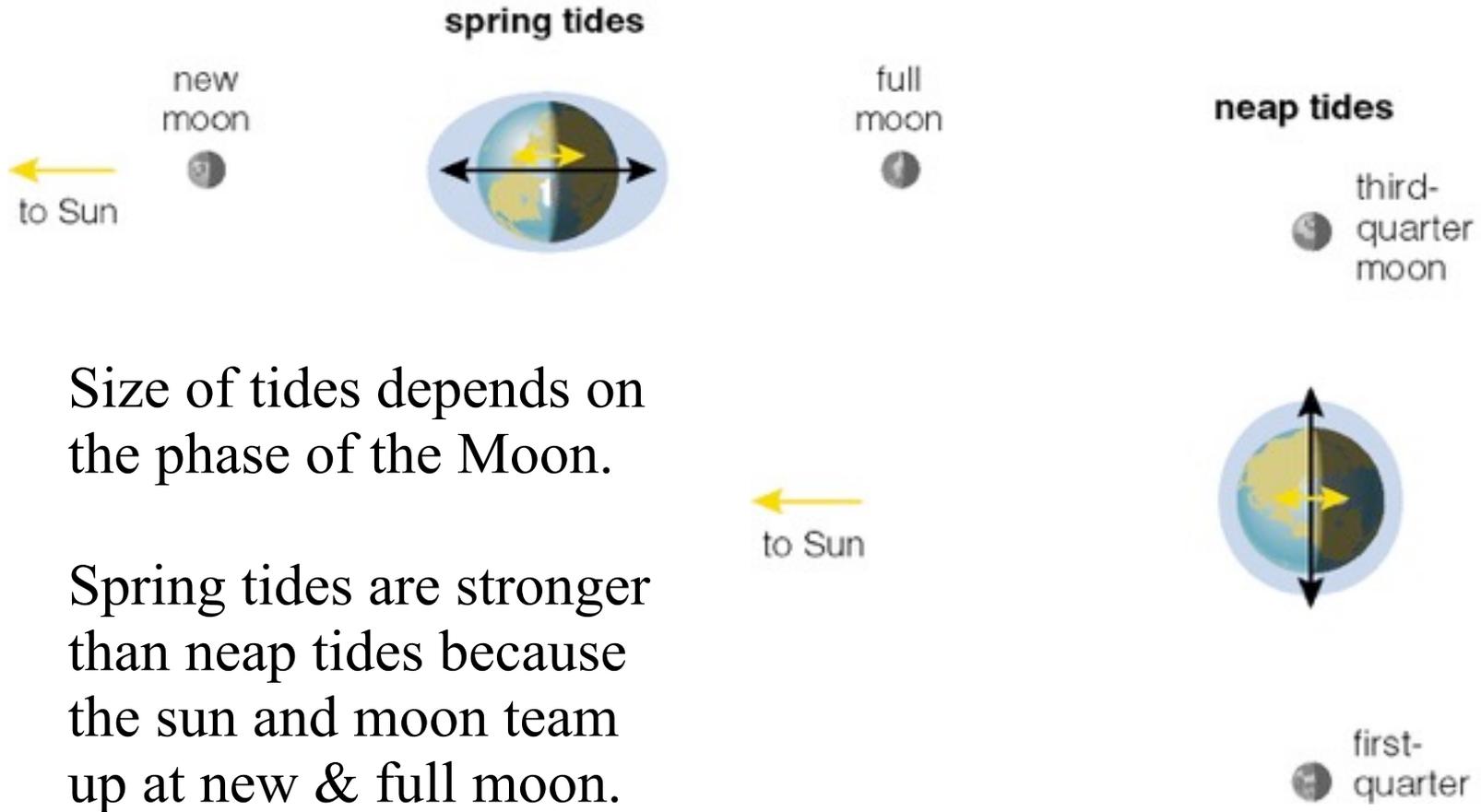


The combined force of the sun and moon causes the ideal gravitational surface to be slightly non-spherical.

Consequently, Earth's oceans fill a slightly oblate spheroid.

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

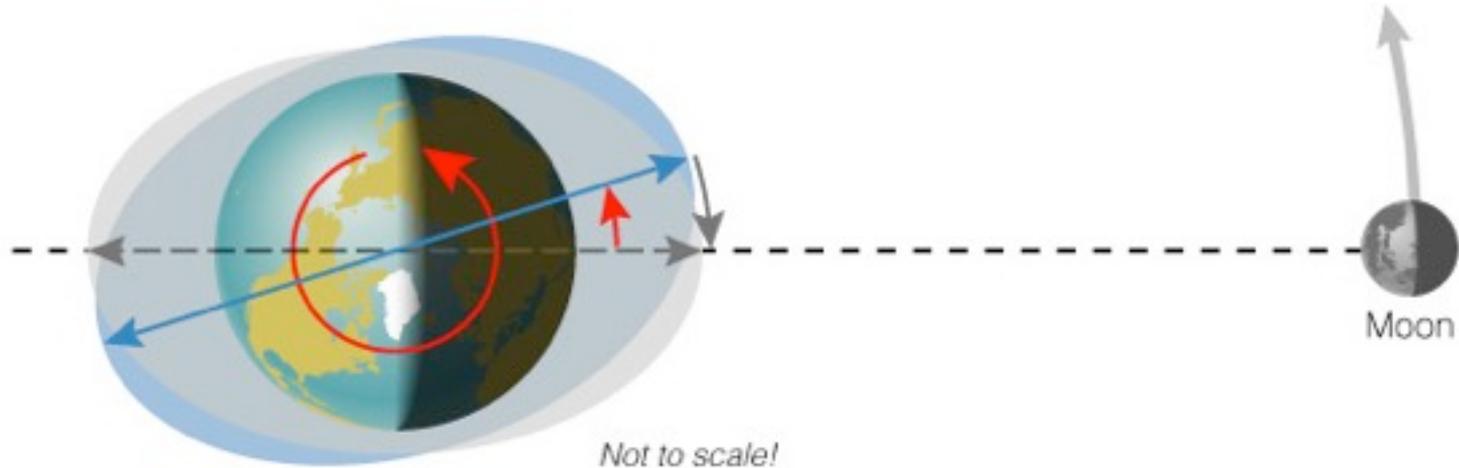
# Tides and Phases



Size of tides depends on the phase of the Moon.

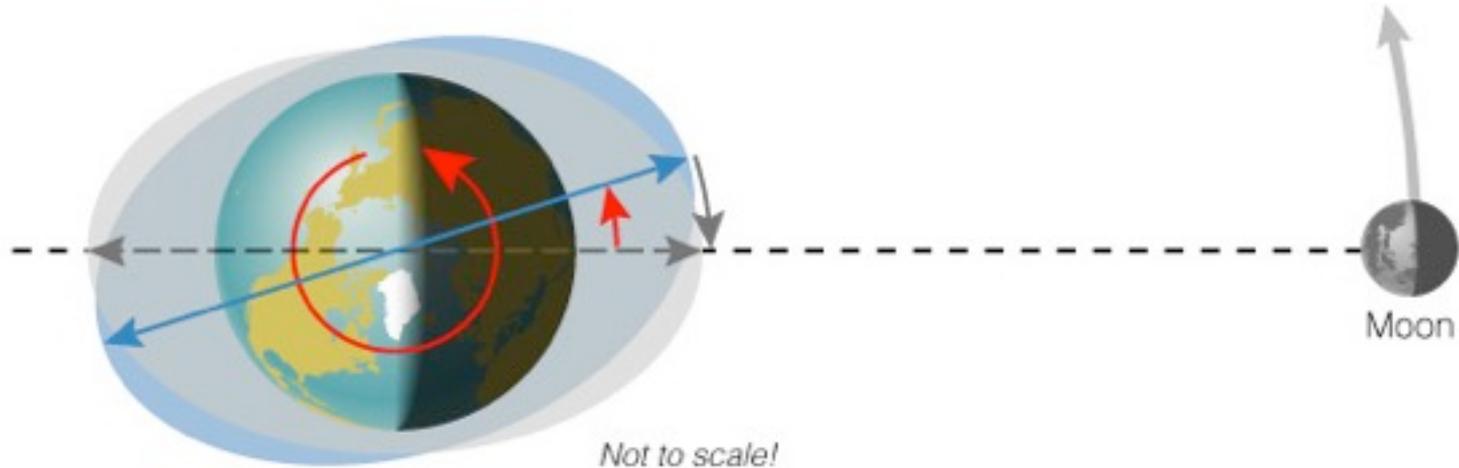
Spring tides are stronger than neap tides because the sun and moon team up at new & full moon.

# 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

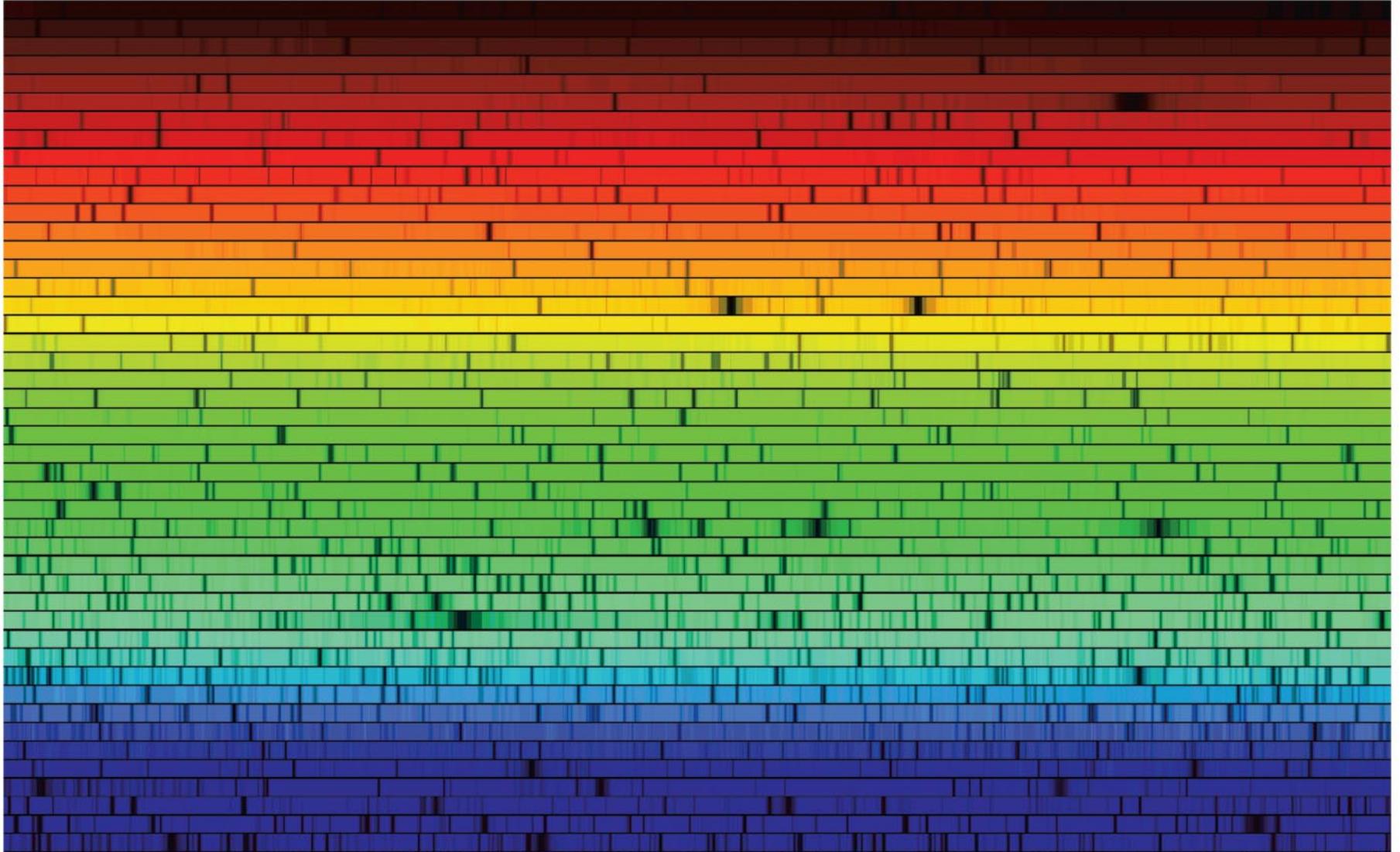
The length of Earth's day increases 2 milliseconds per century

- Moon once spun faster; tidal friction caused it to “lock” in synchronous rotation
  - orbit period:spin period = 1:1
  - keeps same face towards us all the time

# 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 caused 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**

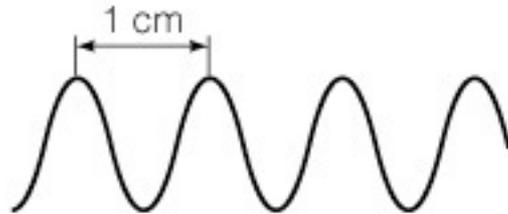
Sometimes it behaves like ripples on a pond (waves).  
Sometimes it behaves like billiard balls (particles).

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

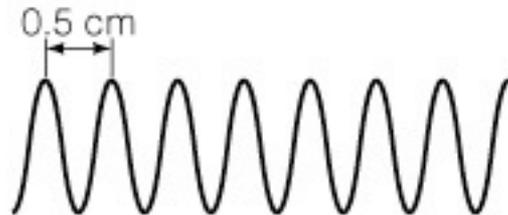
# Particles of Light

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

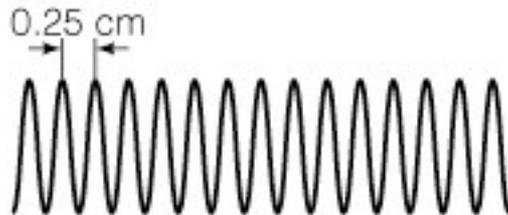
# Wavelength and Frequency



wavelength = 1 cm,  
frequency = 30 Ghz



wavelength =  $\frac{1}{2}$  cm,  
frequency =  $2 \times 30$  Ghz = 60 Ghz



wavelength =  $\frac{1}{4}$  cm,  
frequency =  $4 \times 30$  Ghz = 120 Ghz

# Wavelength & Frequency

$\lambda$  = wavelength (separation between crests)

$f$  = frequency (rate of oscillation)

$c$  = speed of light =  $3 \times 10^8$  m/s

$$\lambda f = c$$

# Wavelength, Frequency, and Energy

photon energy:

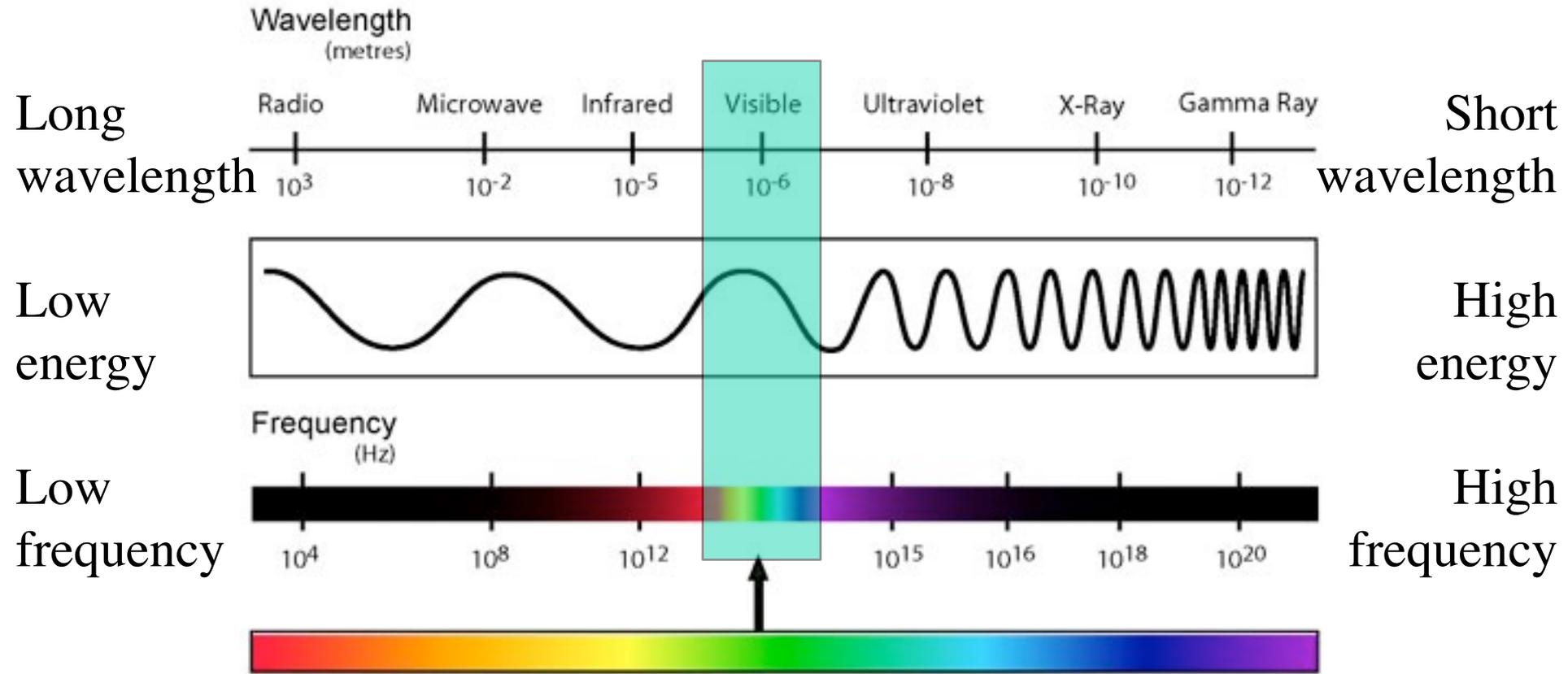
$$E = hf = hc/\lambda$$

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

(Planck's constant)

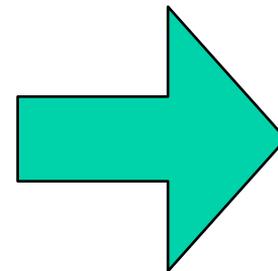
The frequency  $f$  can be arbitrarily high or low, so the energy carried by an individual photon can be arbitrarily high or low. However, the energy always comes in a finite unit of one photon at a time, not continuously.

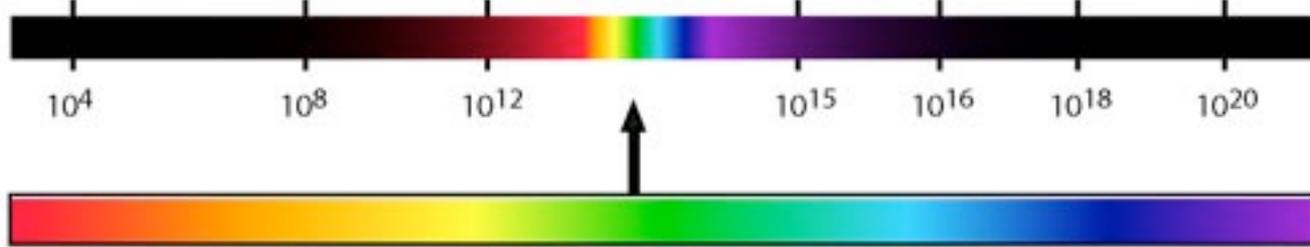
# THE ELECTRO MAGNETIC SPECTRUM



*E, f increasing*

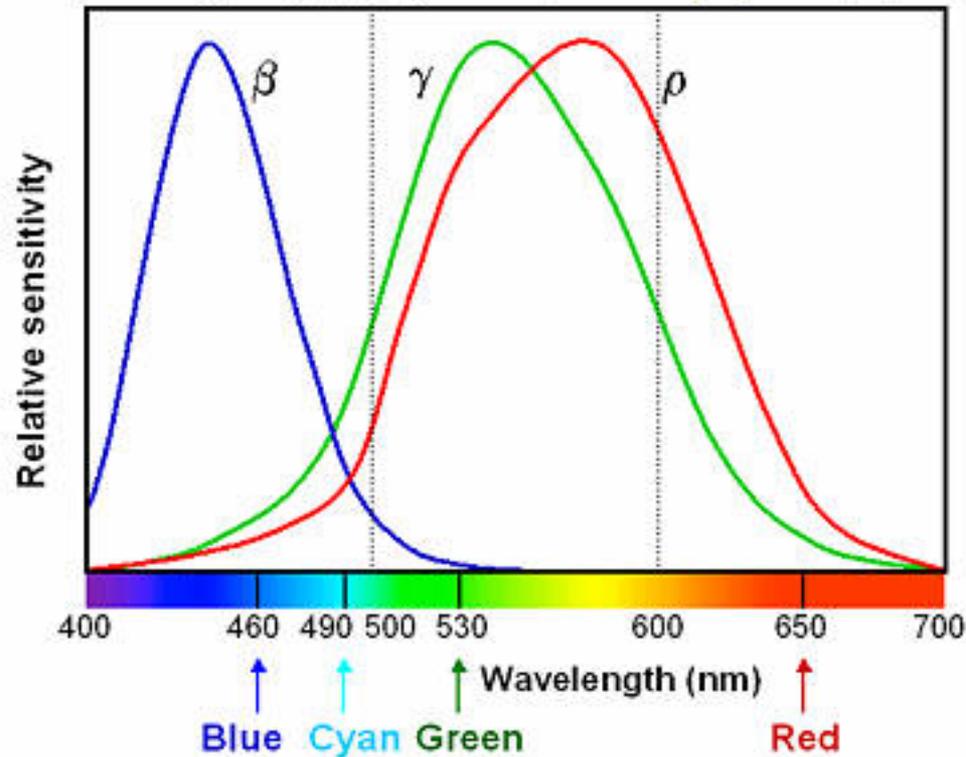
*$\lambda$  decreasing*





### Human spectral sensitivity to color

Three cone types ( $\rho$ ,  $\gamma$ ,  $\beta$ ) correspond *roughly* to R, G, B.



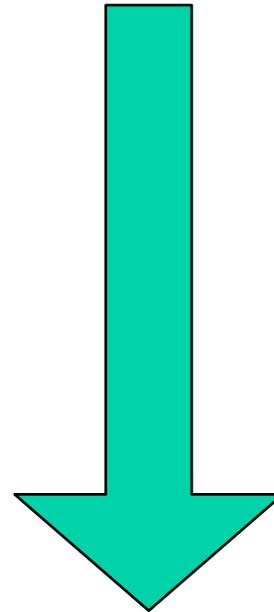
Our eyes are only sensitive to a factor of two range in wavelength, from 380nm (violet) to 700nm (deep red).

# Same stuff, different Energy:

## Electromagnetic Radiation

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

Energy per photon  
increasing



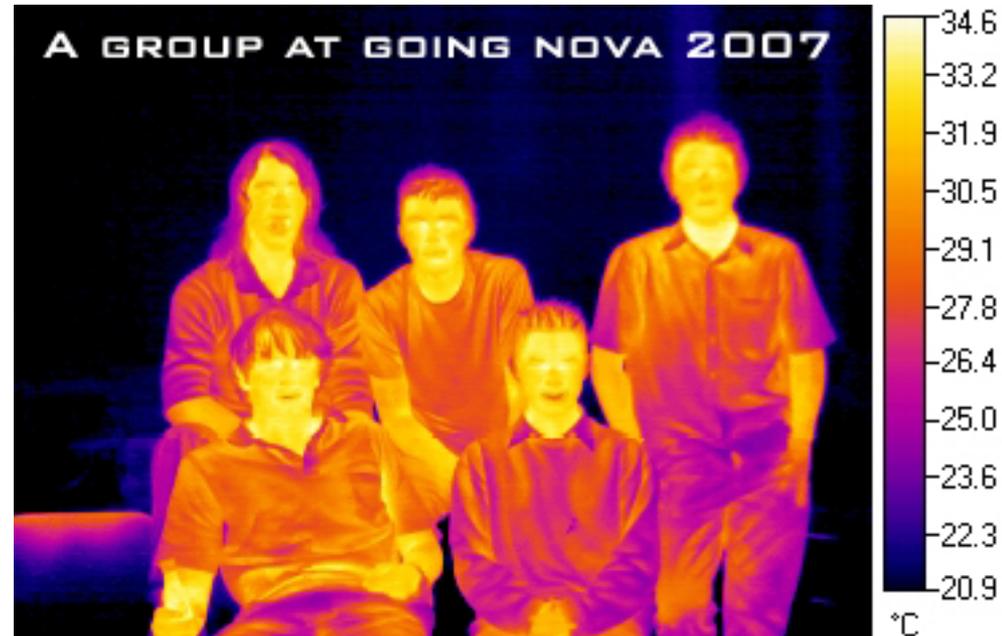
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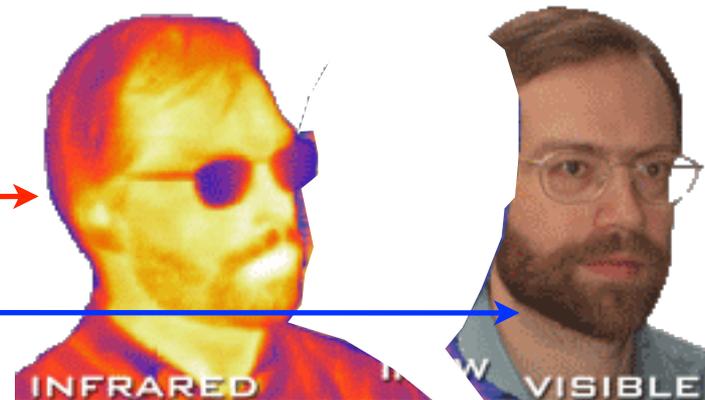
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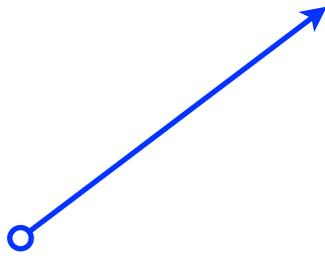
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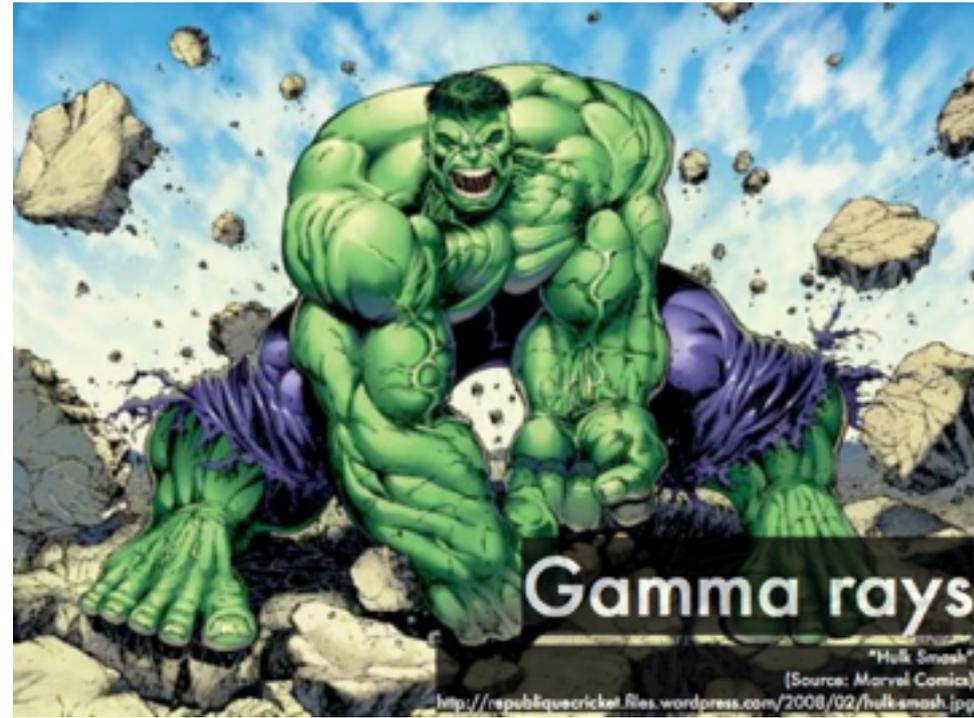
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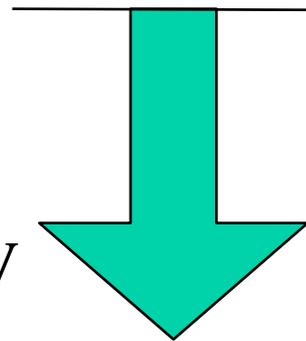
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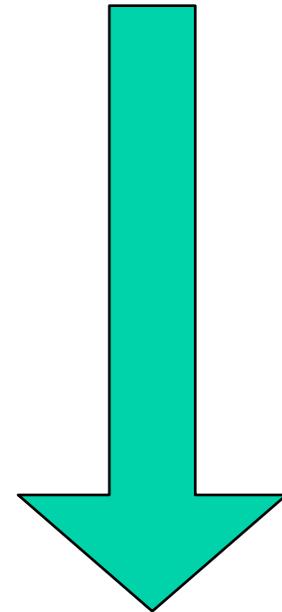
Ionizing  
radiation

benign



potentially  
dangerous

Energy per photon  
increasing

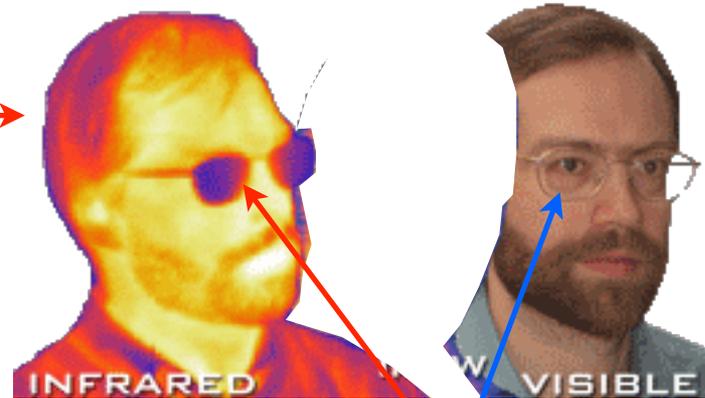


# How do light and matter interact?

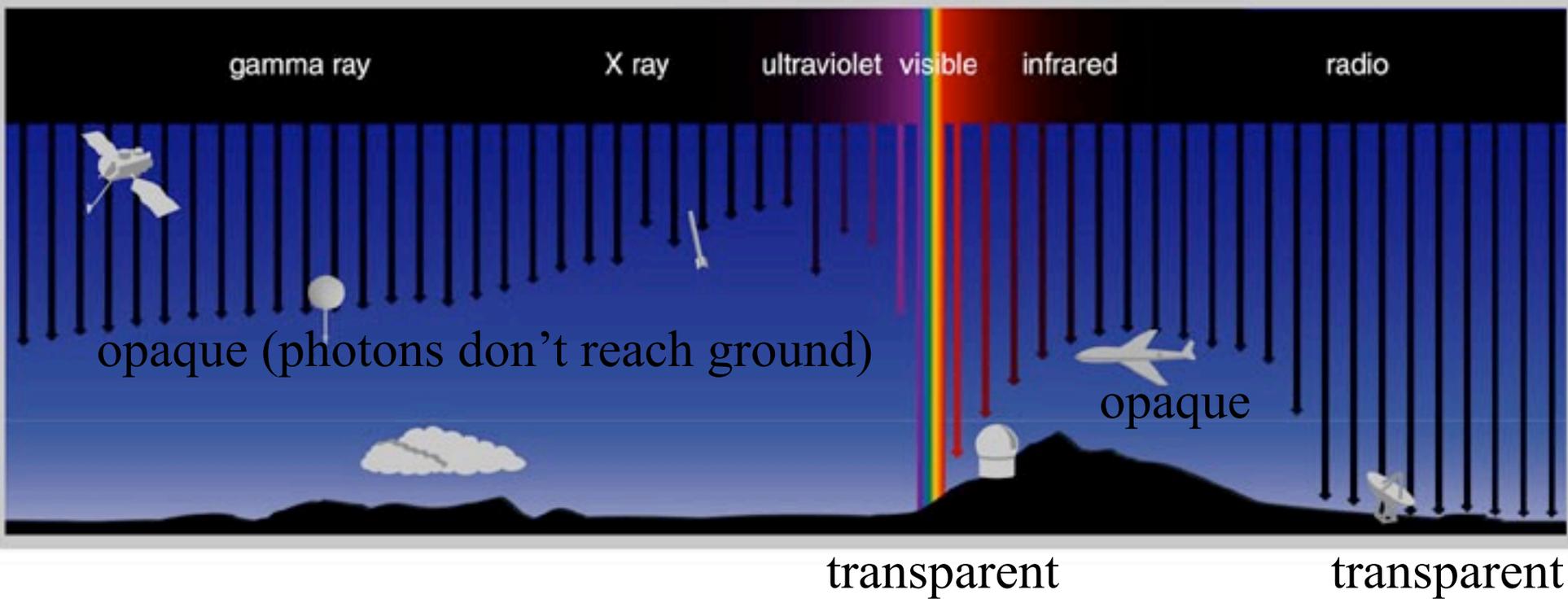
- Emission
- Absorption
- Transmission:
  - Transparent objects transmit light.
  - Opaque objects block (absorb) light.
- Reflection or scattering
  - we see by scattered light

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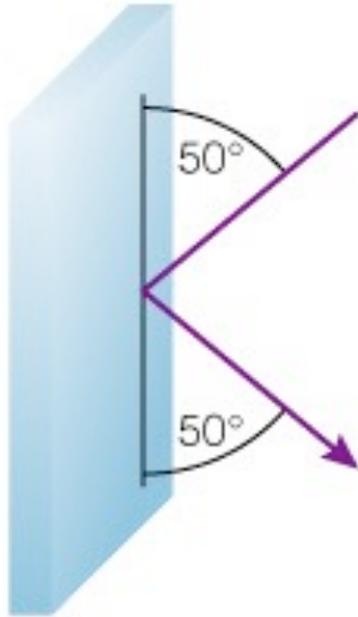


# transmission & absorption

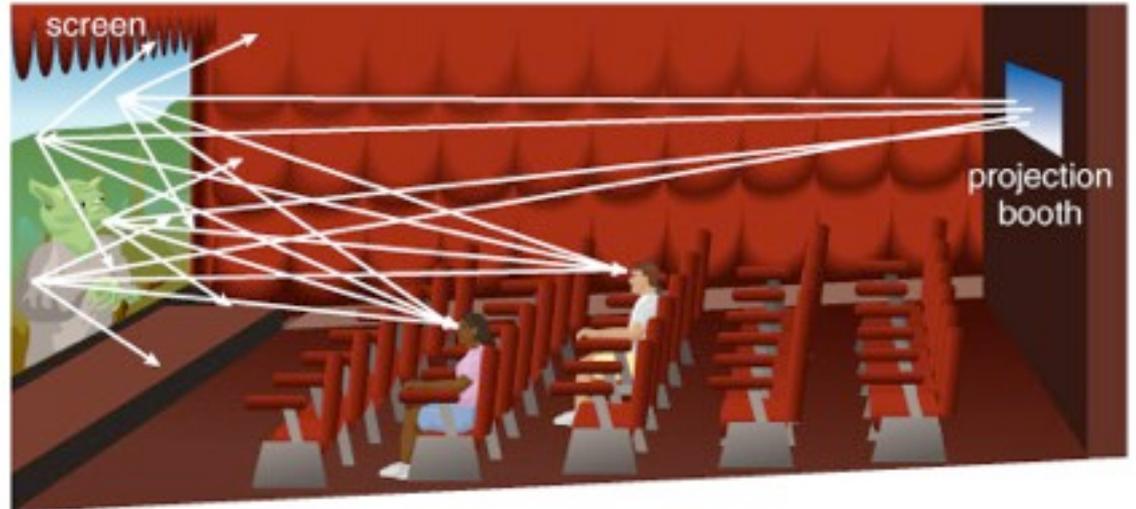


Earth's atmosphere is opaque to light at most wavelengths. It is transparent only to visible light and radio waves.

# Reflection and Scattering

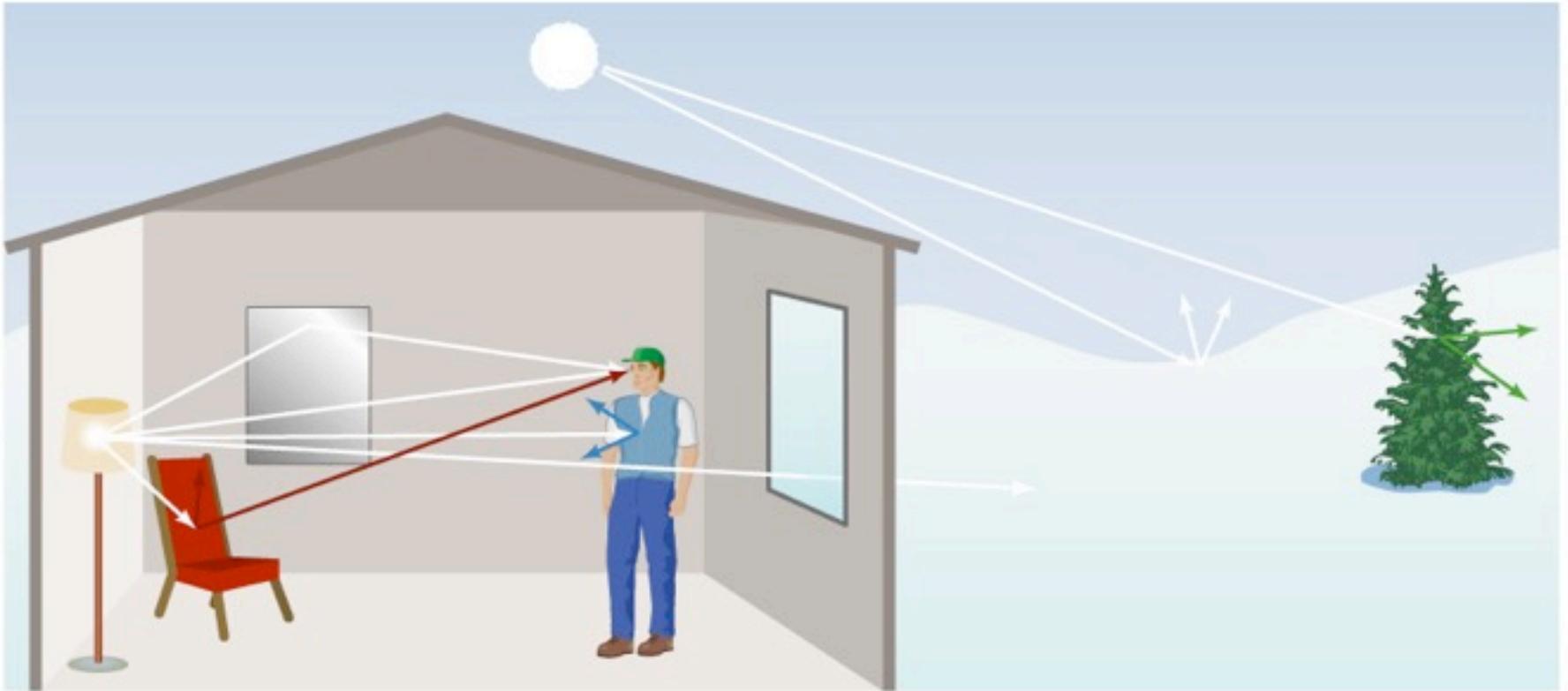


Mirror reflects light in a particular direction.



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:

