



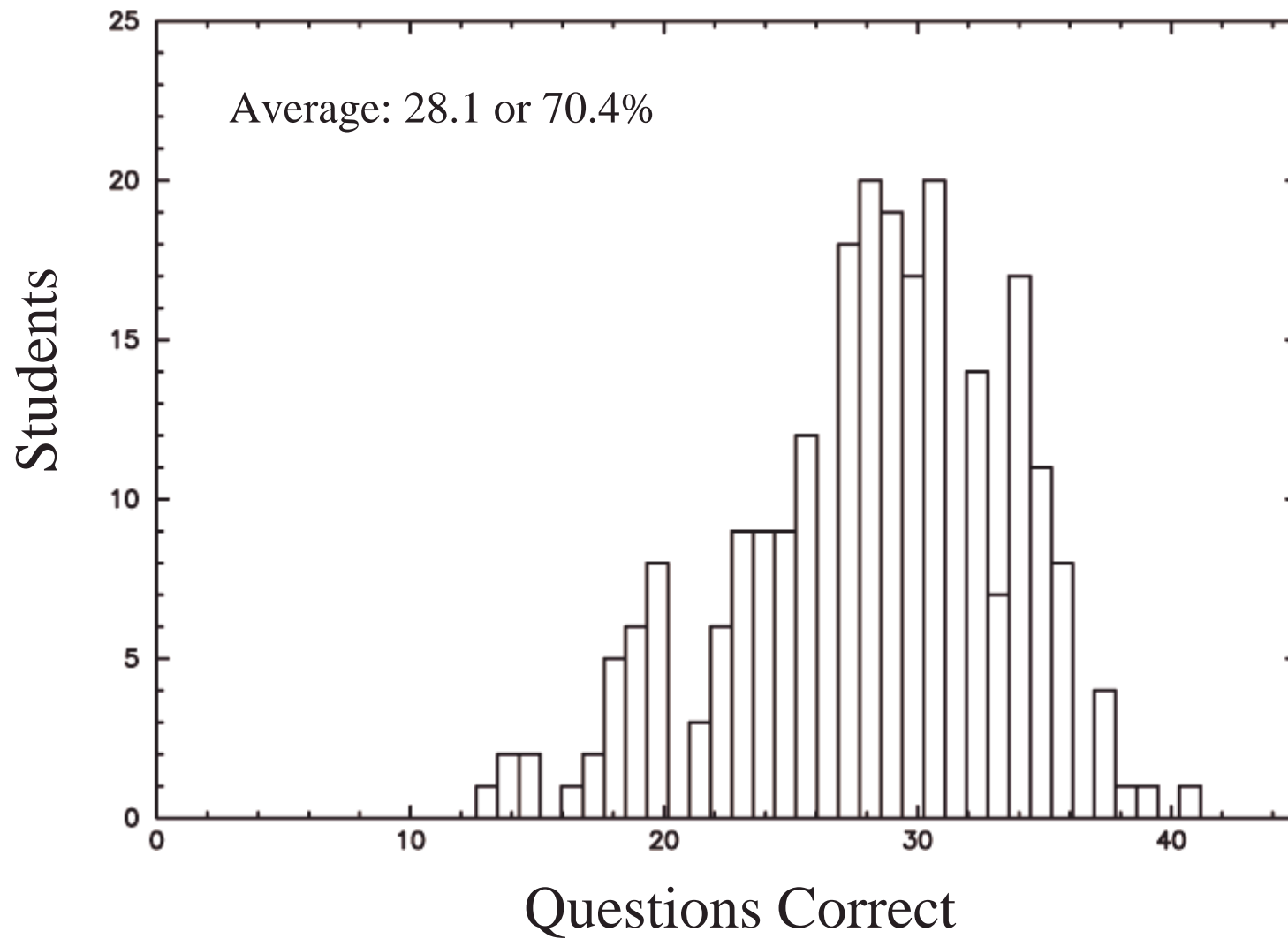
- Next homework due Oct 24th– this Friday at 11:50 am.
- Astronomy Club:
<http://www.astro.uiuc.edu/~uias/>

Outline



- Fusion reaction in the Sun
- Neutrino astronomy
- Switch Gears to Light– hmm... Light
- Rainbow of Light
- Why is the sky blue?
- Light speed– fast but not infinite
- Light is a wave and a particle
- The Electromagnetic Spectrum– Radio waves to Gamma rays

Exam 1 Results



Nuclear Reactions in the Sun



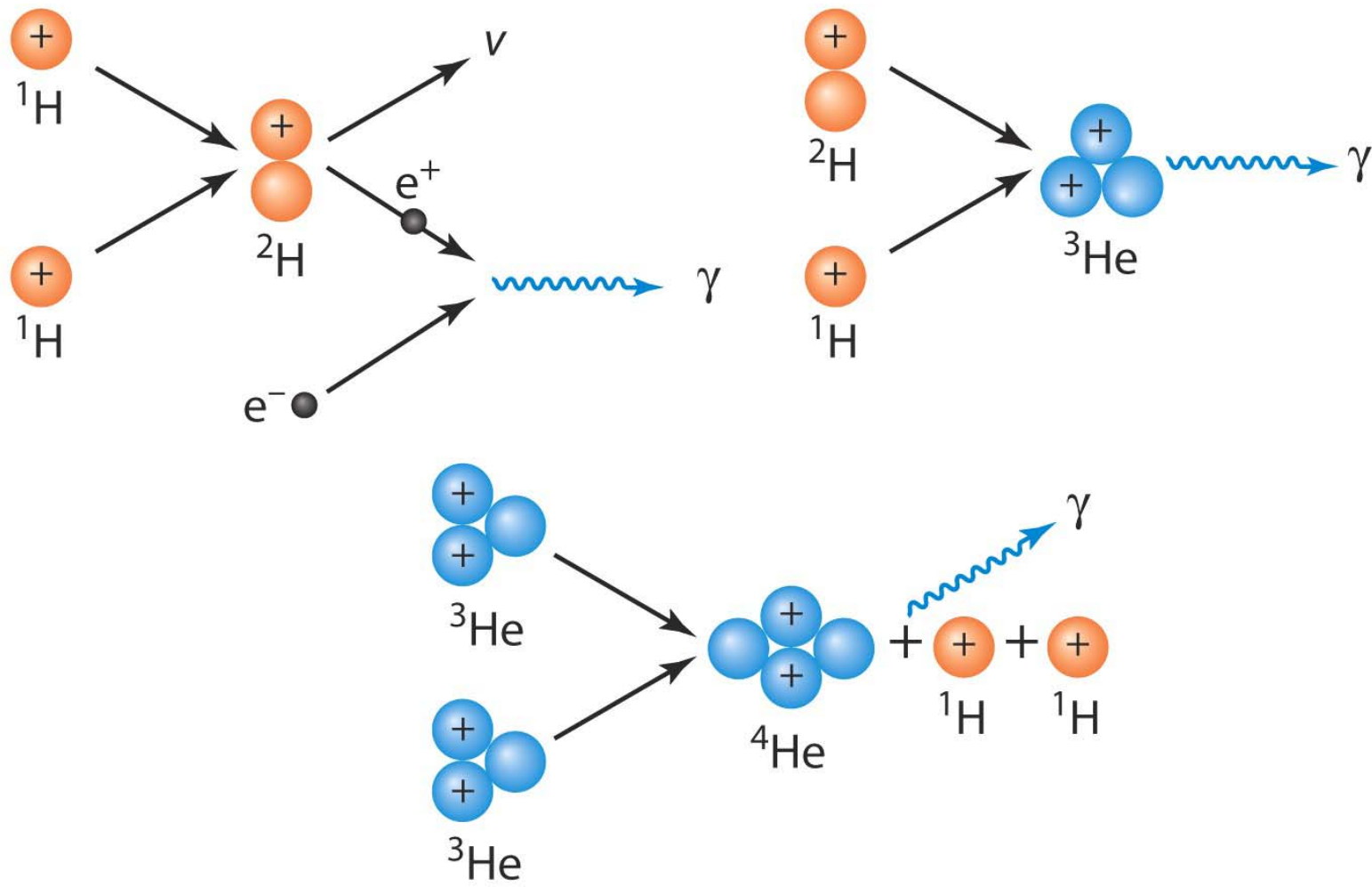
- Chain: 4 protons  helium

- first step in chain:



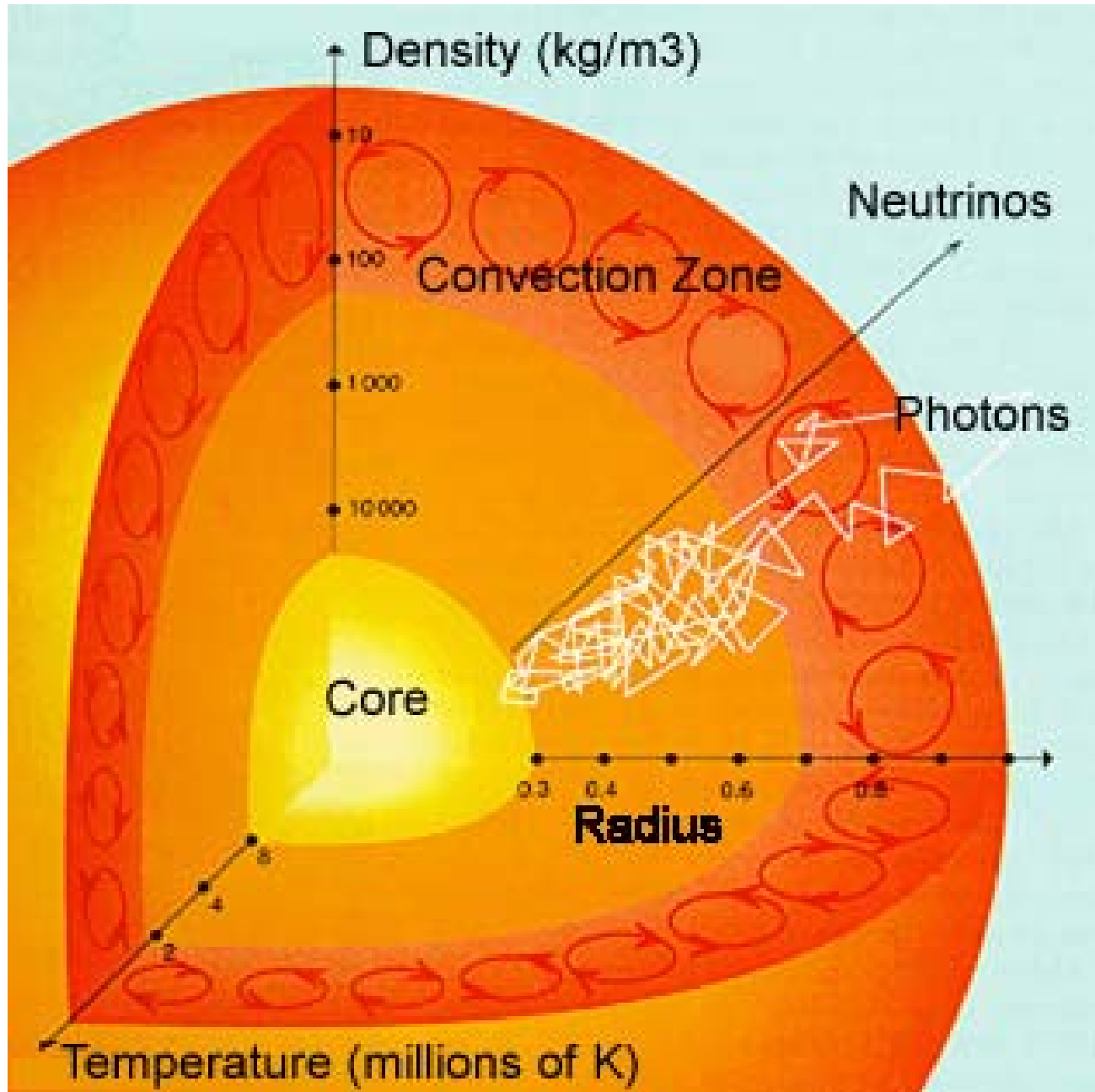
- start with 2 particles (Nuclei of hydrogen— 2 protons)
- end up with 4 particles (two of which are glued together)
- deuterium, positron, and neutrino

Nuclear Fusion in the Sun's Interior



The Proton-Proton Cycle

The Interior of the Sun





The Evidence

How do we know these nuclear reactions occur in the Sun?

Neutrinos from Sun are *observed*

Detect in huge underground experiments

- *Why huge?*
- *Why underground?*

Neutrino Observatories



- I. vats of chlorine
(cleaning fluid!) in
S. Dakota gold mine

ν + chlorine \rightarrow argon

collect argon atoms:
radioactive!



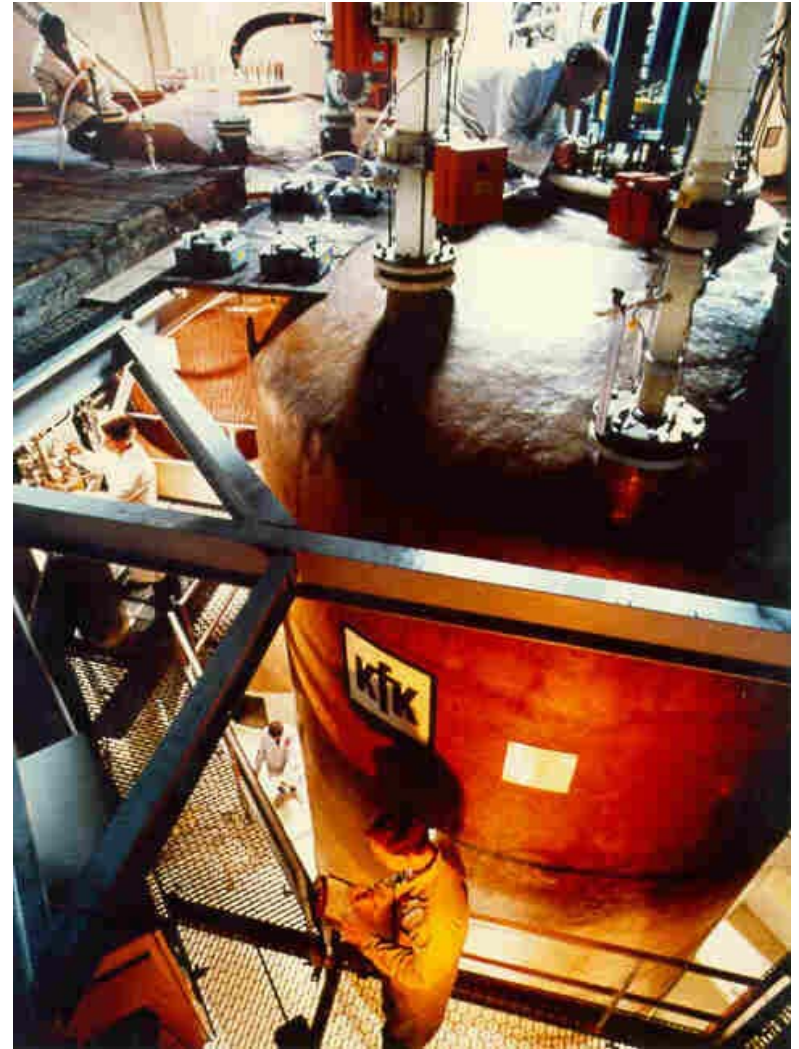
Neutrino Observatories



II. vats of gallium metal
under mountain in Italy

$\nu + \text{gallium} \rightarrow \text{germanium}$

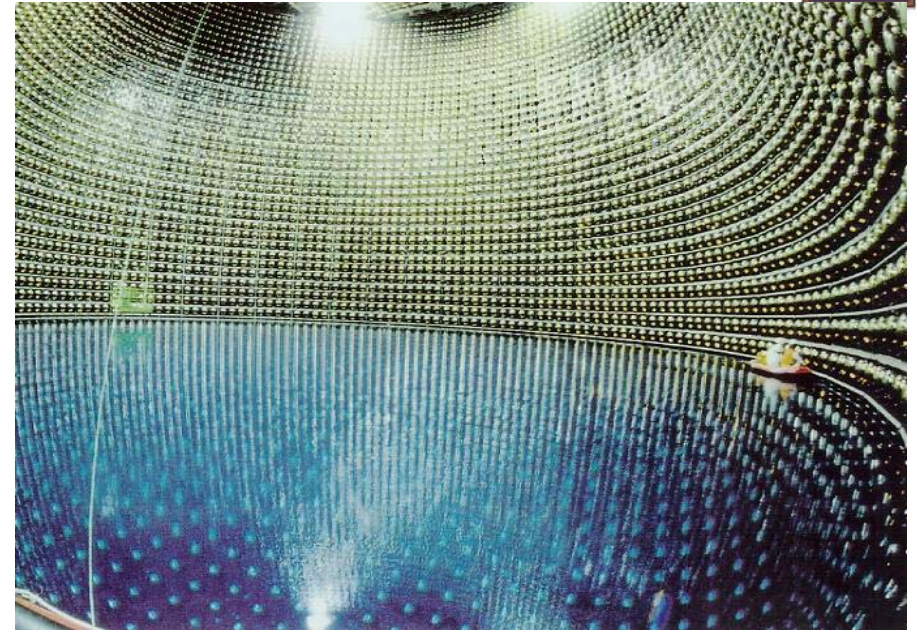
collect germanium atoms



Neutrino Observatories

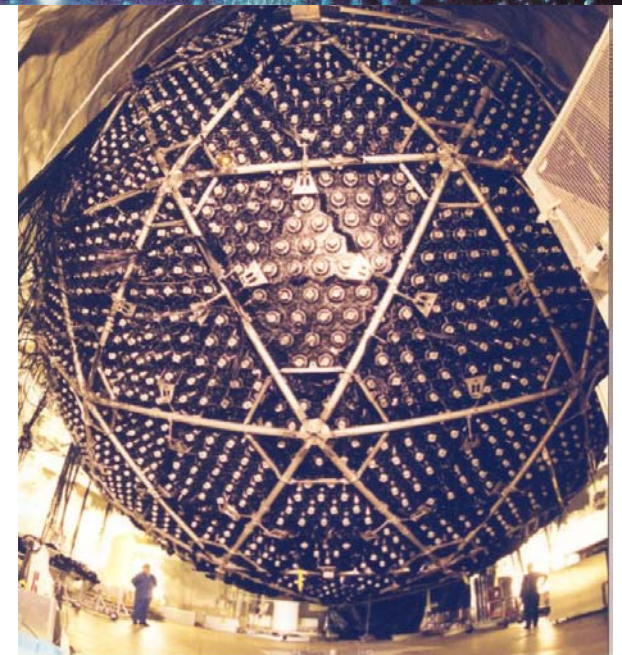


III. vats of pure water in Japanese, Canadian mines



$\nu + e$ at rest $\rightarrow e$ moving fast

- see tiny flashes of light from “kicked” electrons

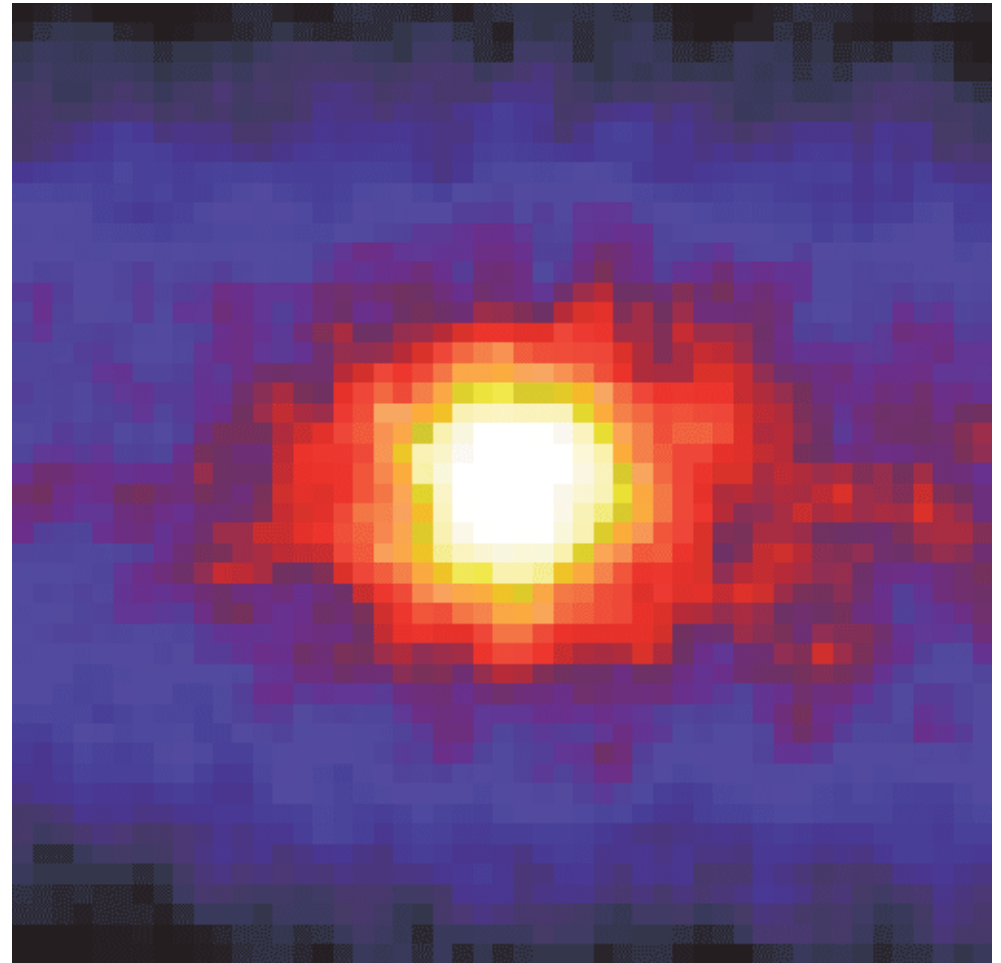


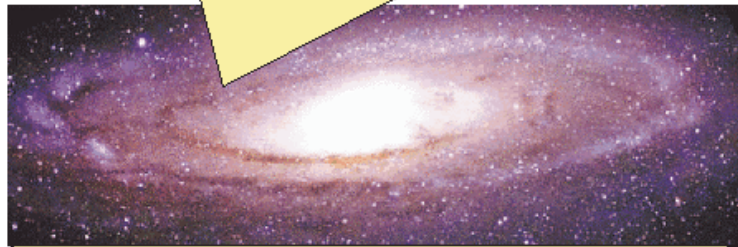
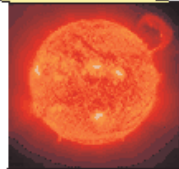
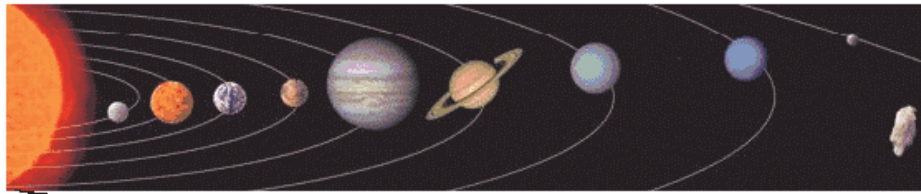
Results and Implications: *Neutrino Astronomy*



Results:

- All experiments detect neutrinos
 - Water experiments show they come from the Sun!
1. **Proof** that Sun powered by nuclear fusion
 - *Why?*
 2. Neutrino experiments are telescopes
 - Open new window to cosmos!





Astronomy: The Big Picture

We must better understand light,
how it is emitted, and how
astronomers collect and analysis it.

Back to Chapters 3 & 4!

Visible light is composed of all the colors of the rainbow



Name Some things that shine by (emit) their own light?



Light bulbs

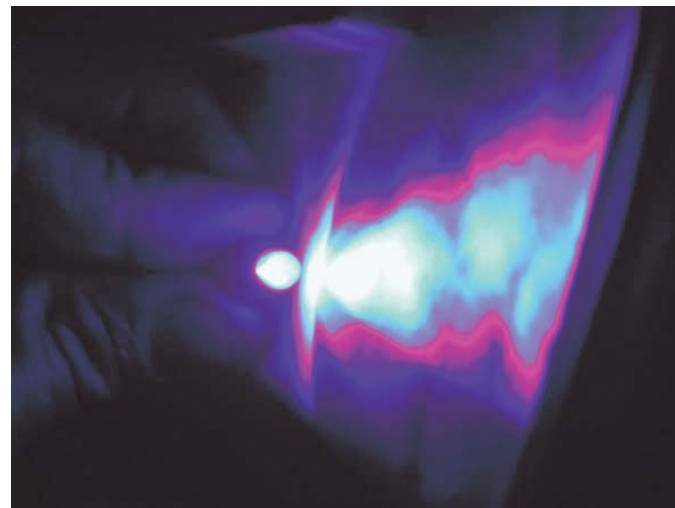


Stars



Nebulae

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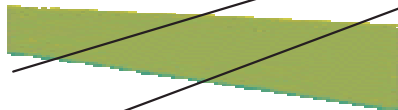
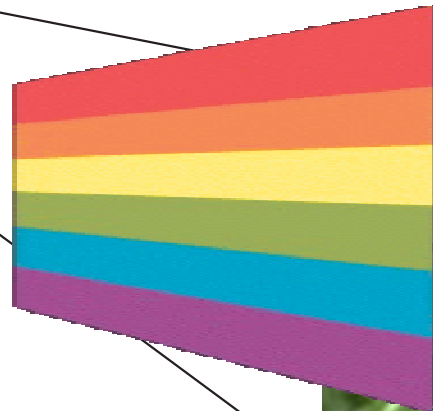


Light-emitting diodes (LEDs)

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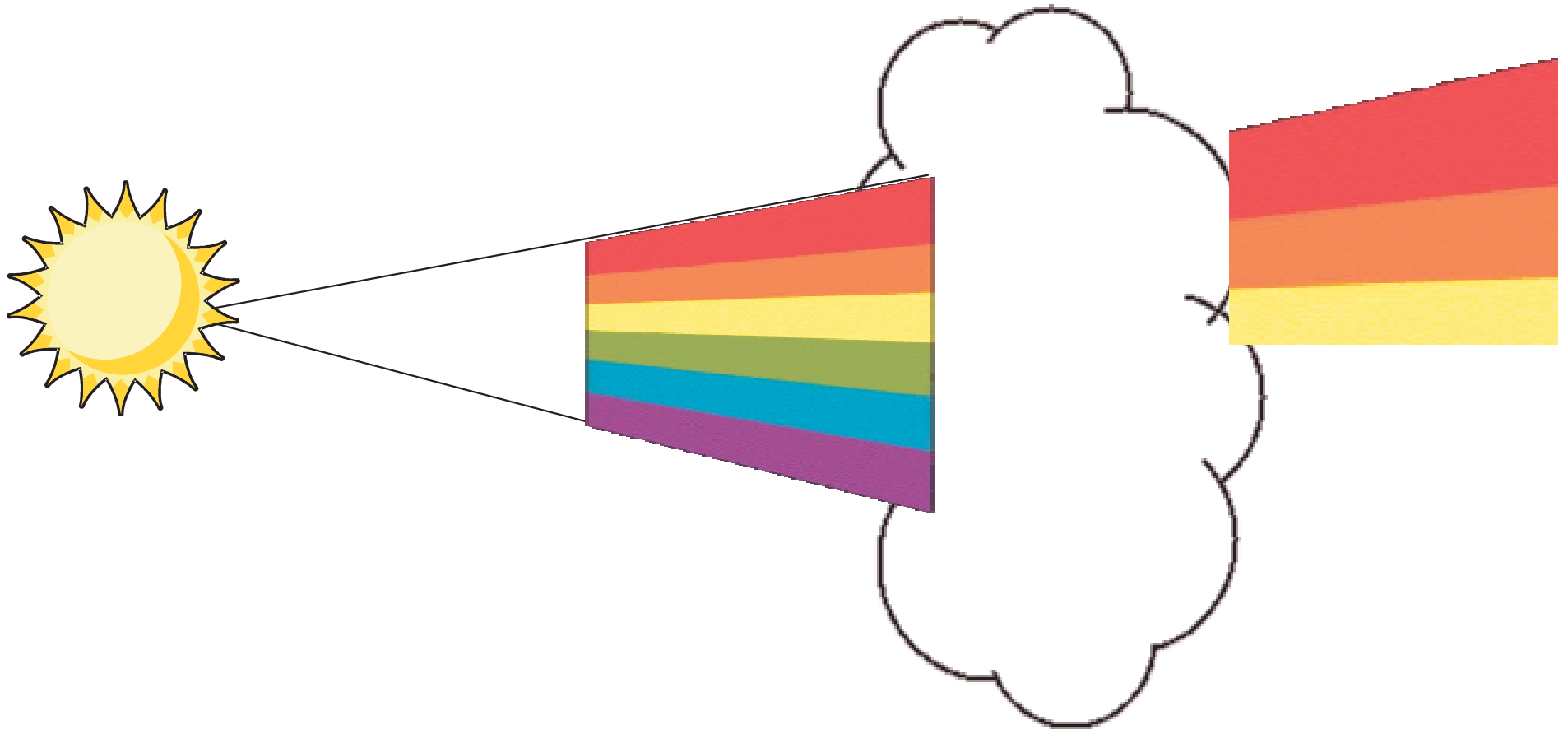


Matter interacts with light



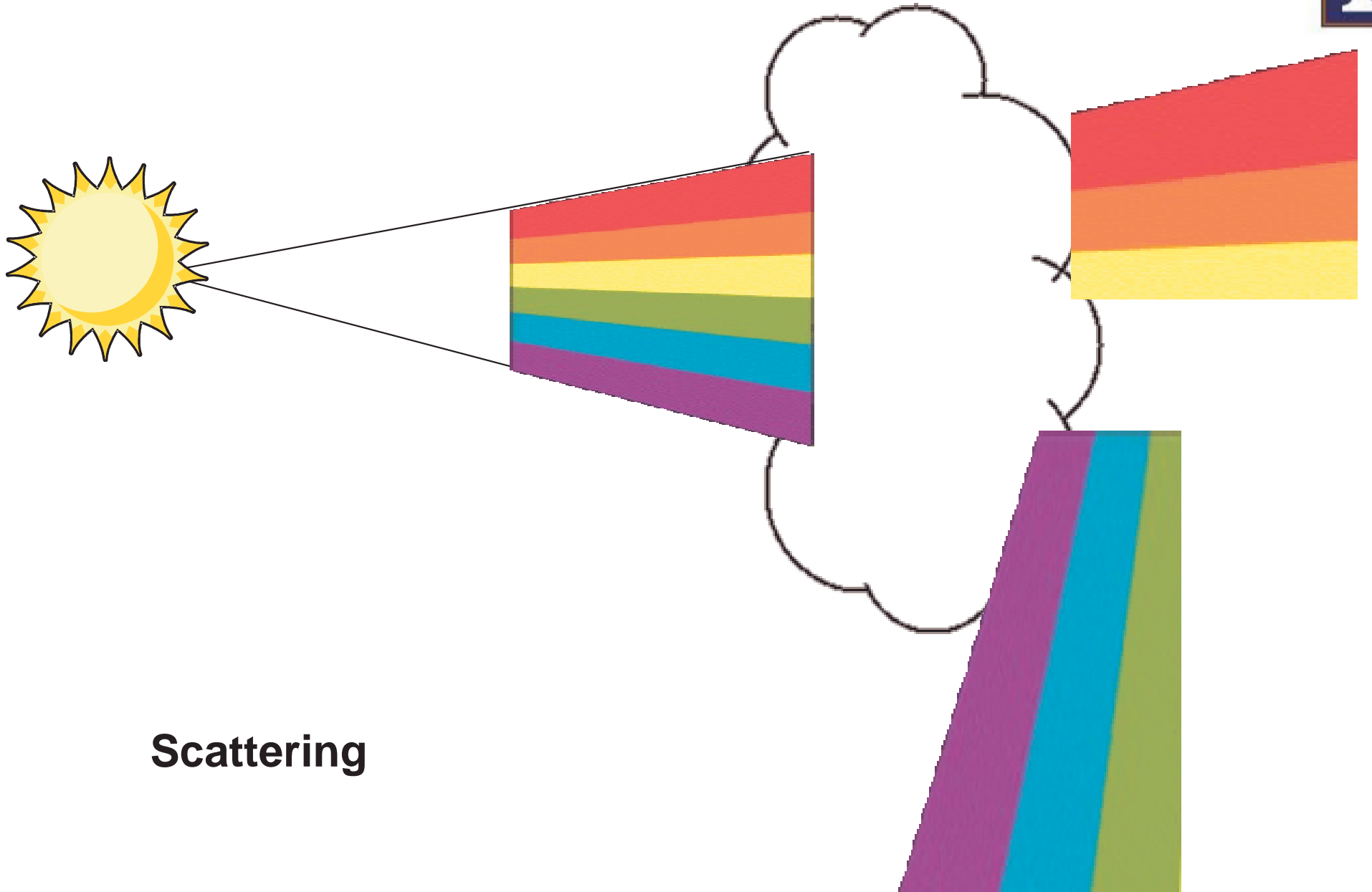
Reflection

Matter interacts with light



Absorption

Matter interacts with light



Scattering

Why is the Sky Blue?



Visible Light Spectrum

R O Y G B I V

long wavelength
low frequency

Least readily scattered
part of spectrum.

short wavelength
high frequency

Most readily scattered
part of spectrum.

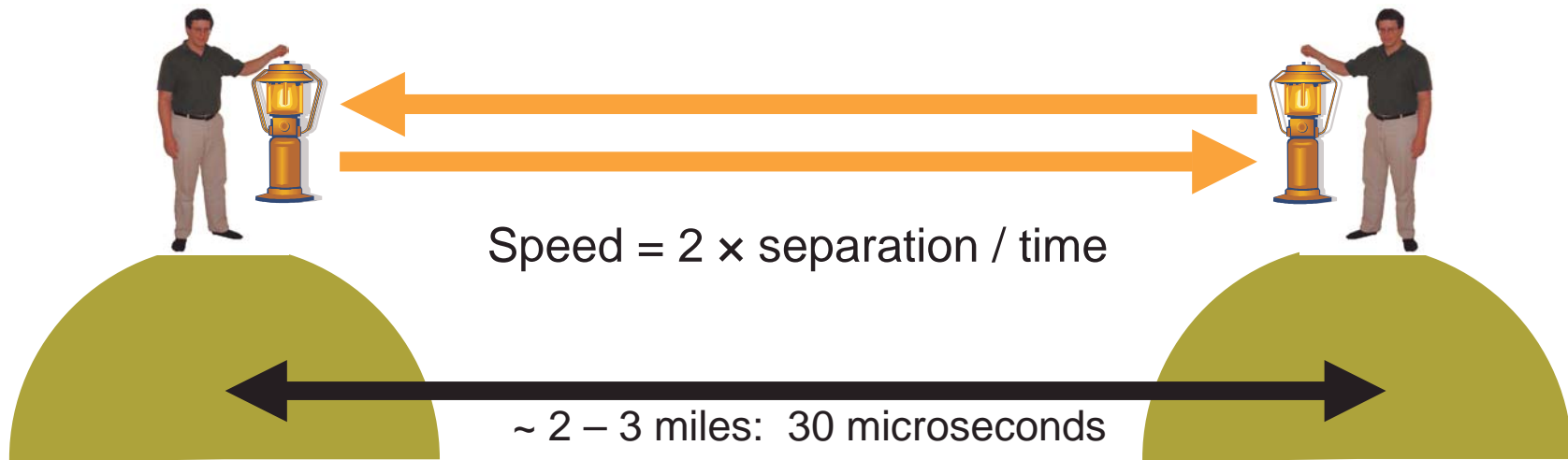
Atmospheric nitrogen and oxygen scatter violet light most easily, followed by blue light, green light, etc. But our eyes notice the blue scattered light the most.



Light travels with a finite speed

Ancient Greeks (except for Empedocles) believed speed of light was infinite

Galileo realized that “very fast” is not the same as “infinite”
– first to suggest an experiment to measure speed of light

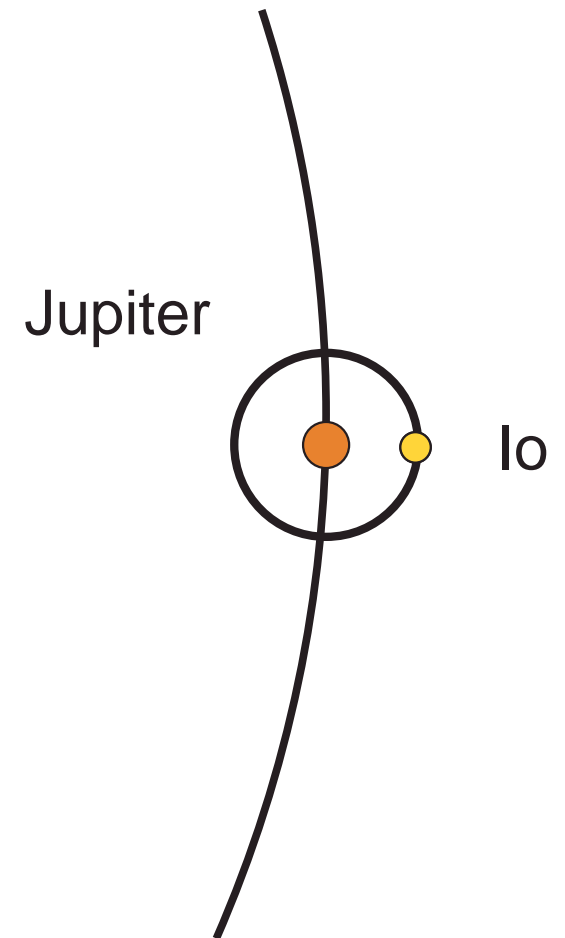
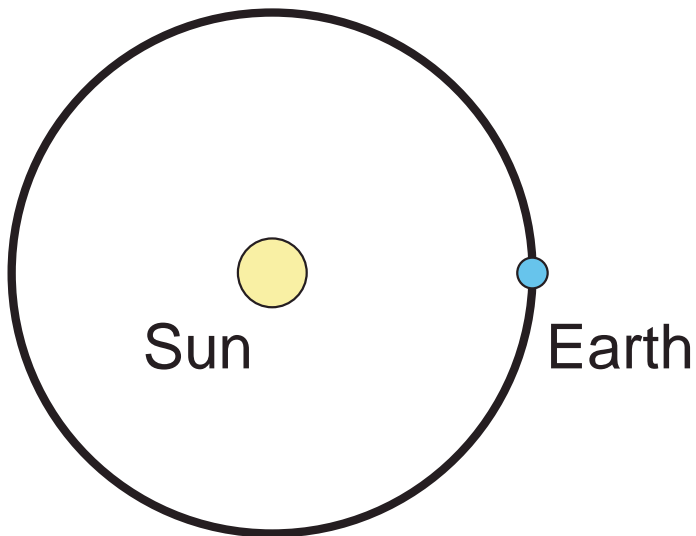


At least 10 times the speed of sound.

Light travels with a finite speed



First actual measurement by Ole Roemer in 1676 using Jupiter's moon Io – eclipses by Jupiter delayed by several minutes (16 mins) every six months because of extra light travel distance



Light travels with a finite speed



- Nowadays we **define** the speed of light to be 2.99792458×10^8 m/s
- The **second** is defined very precisely using atomic clocks (9.192631770×10^9 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom at 0 K, if you must know)
- Thus the **meter** is defined as the distance traveled by light in vacuum during $1/(2.99792458 \times 10^8)$ second

A Light Year



The **light-year**

- Distance that light travels in one year
- Speed of light: 3.00×10^5 km/sec
- Seconds in one year:

$$\left(60 \frac{\text{sec}}{\text{min}}\right) \times \left(60 \frac{\text{min}}{\text{hour}}\right) \times \left(24 \frac{\text{hour}}{\text{day}}\right) \times \left(365 \frac{\text{days}}{\text{year}}\right) = 3.16 \times 10^7 \text{ sec}$$

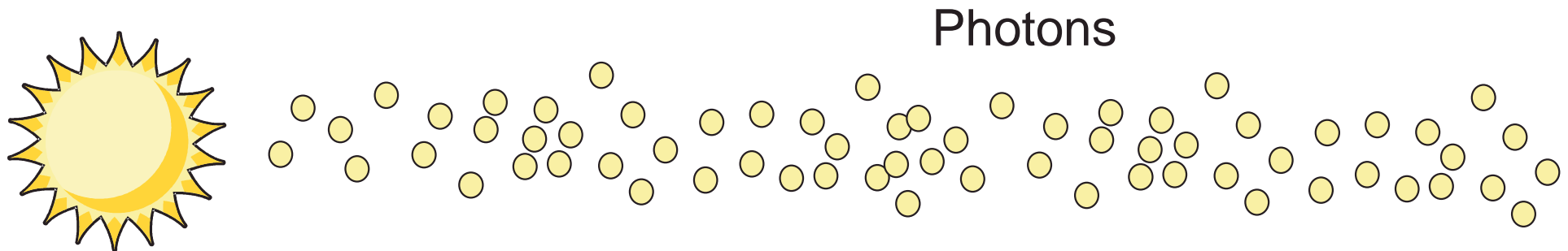
so 1 light year = $(3.00 \times 10^5 \text{ km/sec}) \times (3.16 \times 10^7 \text{ sec}) = 9.42 \times 10^{12} \text{ km}$

- Nearest star (Proxima Centauri) is about 4.2 light years away.
- Analogous to saying: Chicago is about 2 hours away.

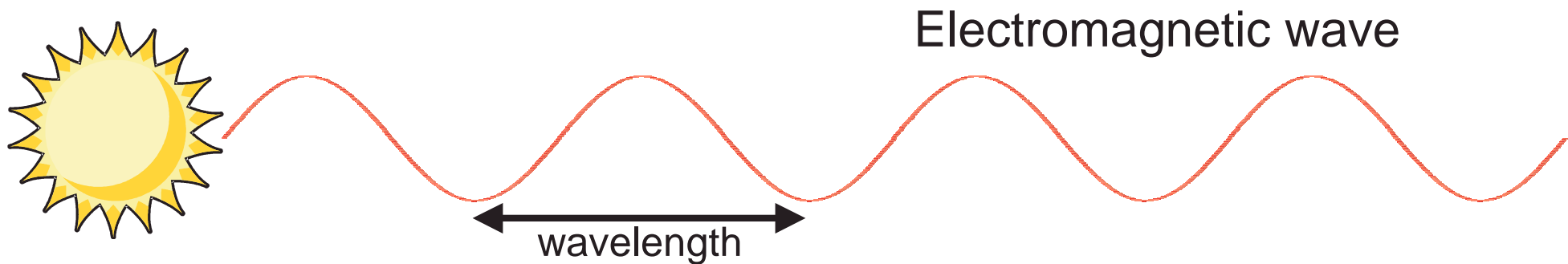
What is light?



Newton: light is composed of a large number of particles



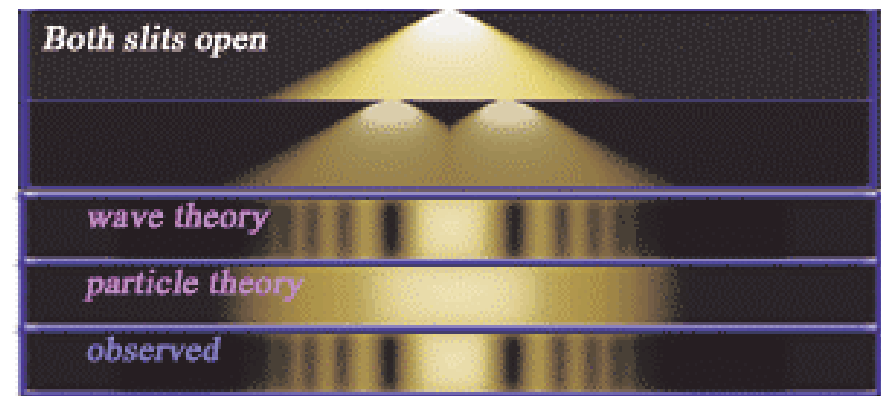
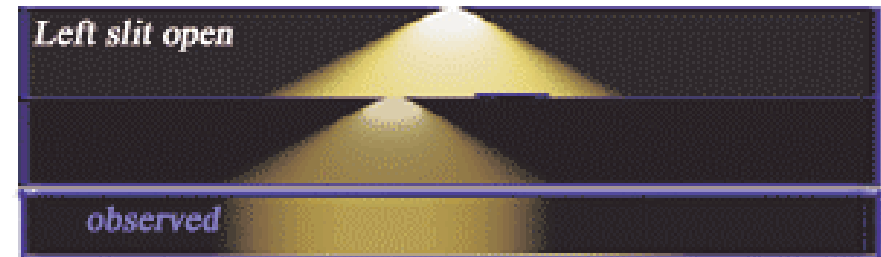
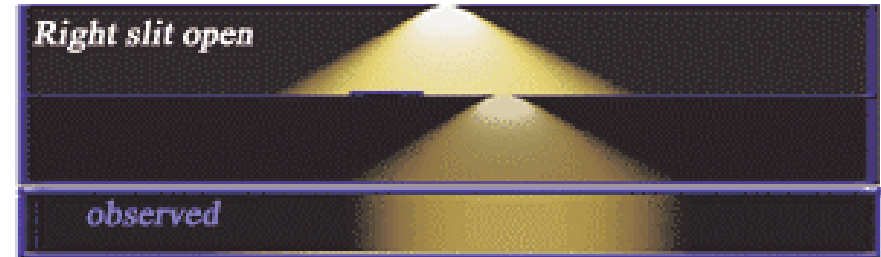
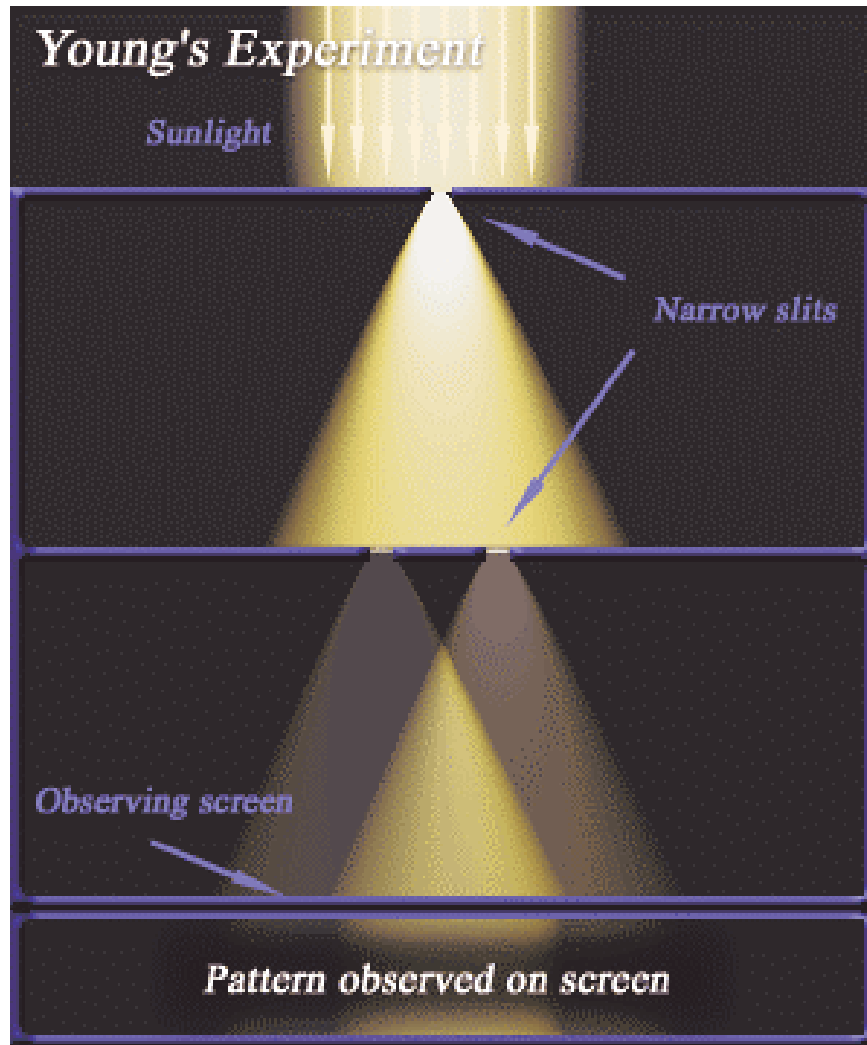
Hooke and Huygens: light is composed of waves



It turns out that both viewpoints are correct.

Thomas Young: Light is a wave

Double-slit experiment (1801)

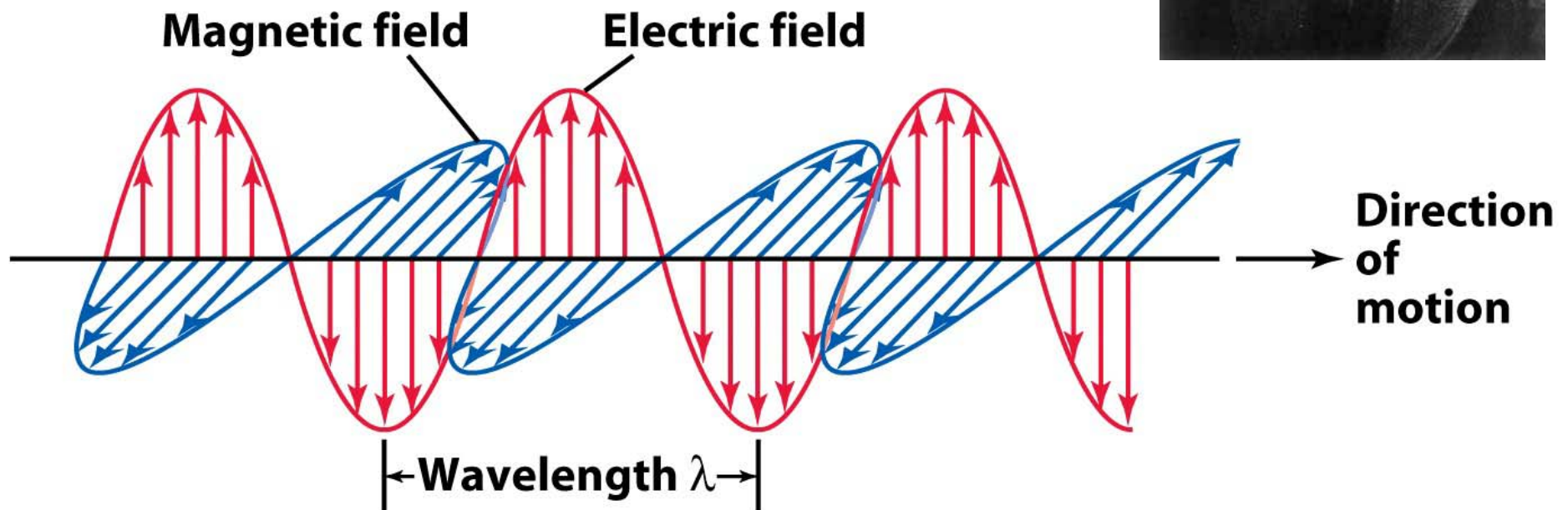
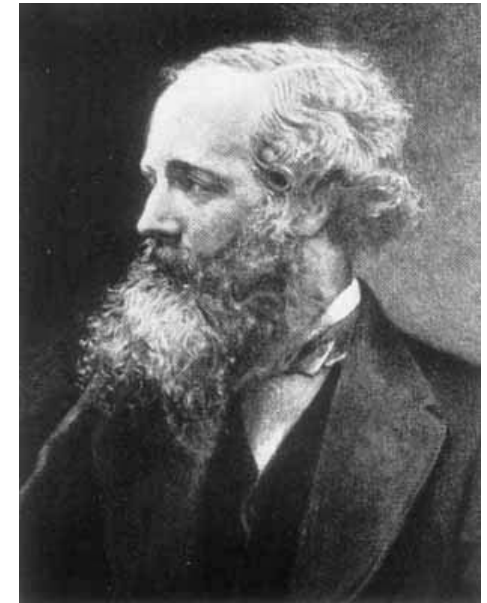


Wikipedia

James Clerk Maxwell: Light is a traveling electromagnetic wave (1862)



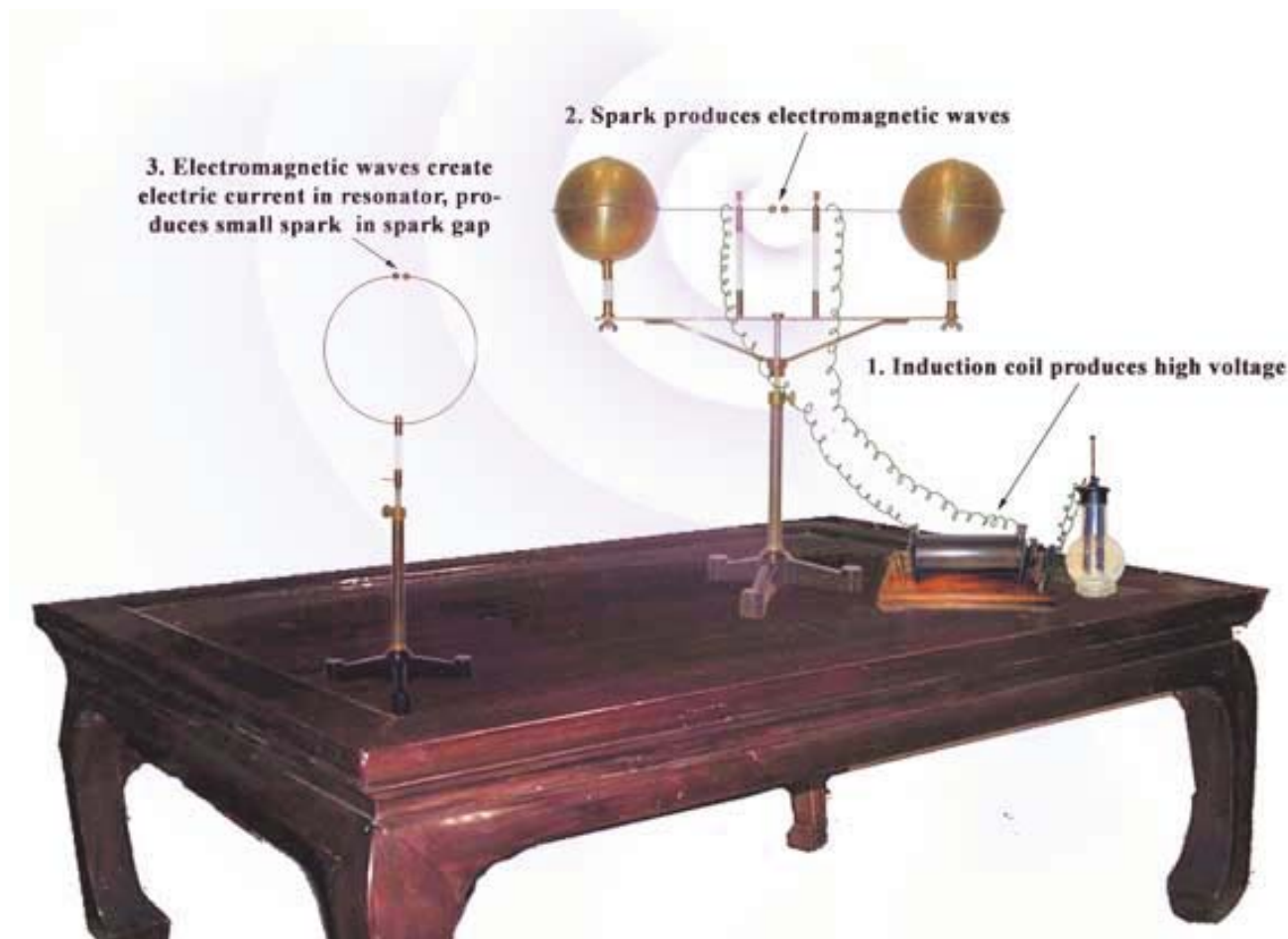
- ▶ Unified electromagnetism and optics
- ▶ Predicted the existence of invisible forms of light



The discovery of radio waves



Heinrich Hertz's experiment (1885)



The discovery of X-rays

Wilhelm Roentgen (1895)



Radiograph of the hand of the anatomist Privy Councillor von Koelliker in Würzburg, taken by W. C. Röntgen in Würzburg on January 23, 1896

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Light is also made of particles!



- **Photoelectric effect:** if we shine light onto a metal surface, electrons pop out
- Only happens if the **frequency** of the light is high enough
- Increasing the **intensity** of the light doesn't help

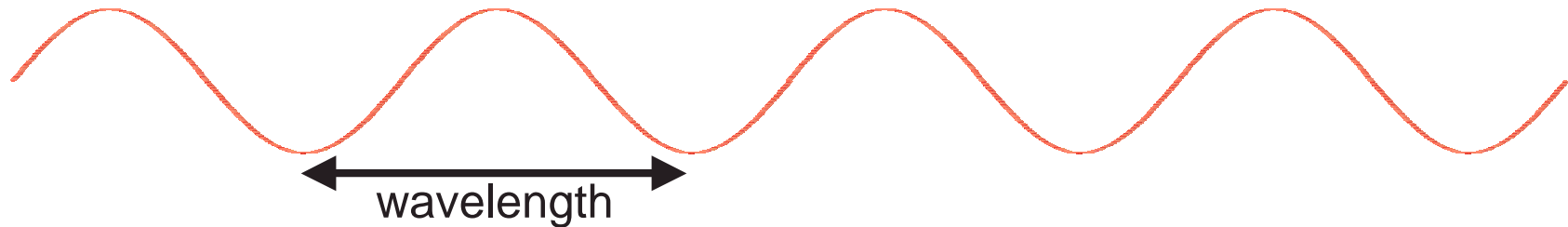
<http://www.dac.neu.edu/physics/b.maheswaran/phy1121/data/ch08/anim/anim0801.htm>

Albert Einstein interpreted this to mean: light can also behave like a particle – the low-frequency light particles (**photons**) don't have enough energy to knock out electrons. He won the Nobel Prize for this work.,

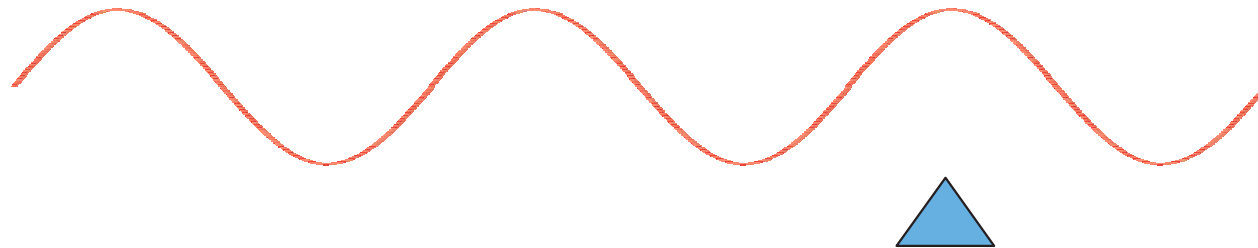
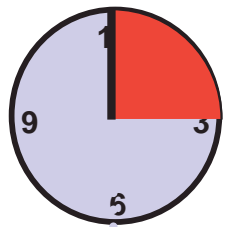
Light is both particle and wave



Wavelength is the distance between successive crests (or troughs) of a wave



Frequency is the reciprocal of the time between successive crests for an observer standing still as the wave goes by.

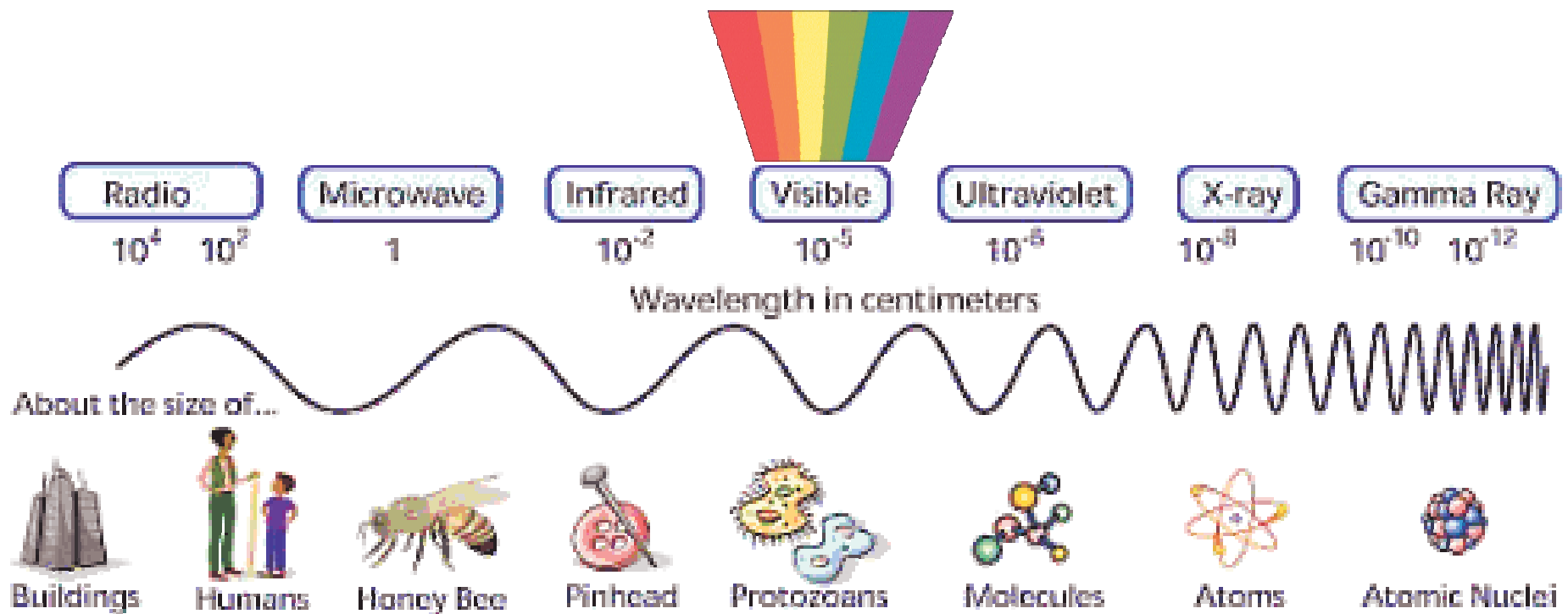


The **energy** of light particles (photons) increases as their frequency increases.

The electromagnetic spectrum



- ▶ Visible light is only a tiny portion of the full electromagnetic spectrum
- ▶ Red light has longer wavelength/lower frequency/lower energy than blue light

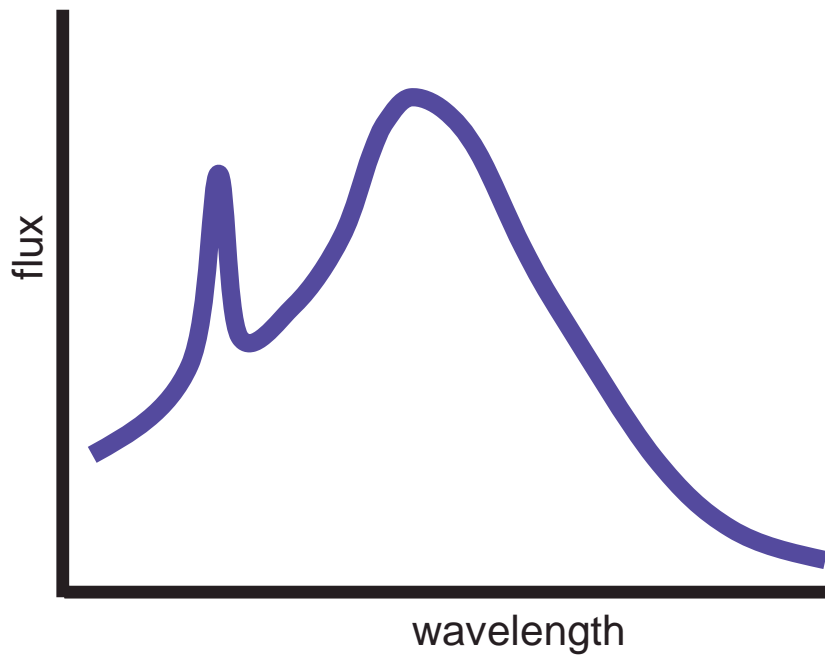


NASA

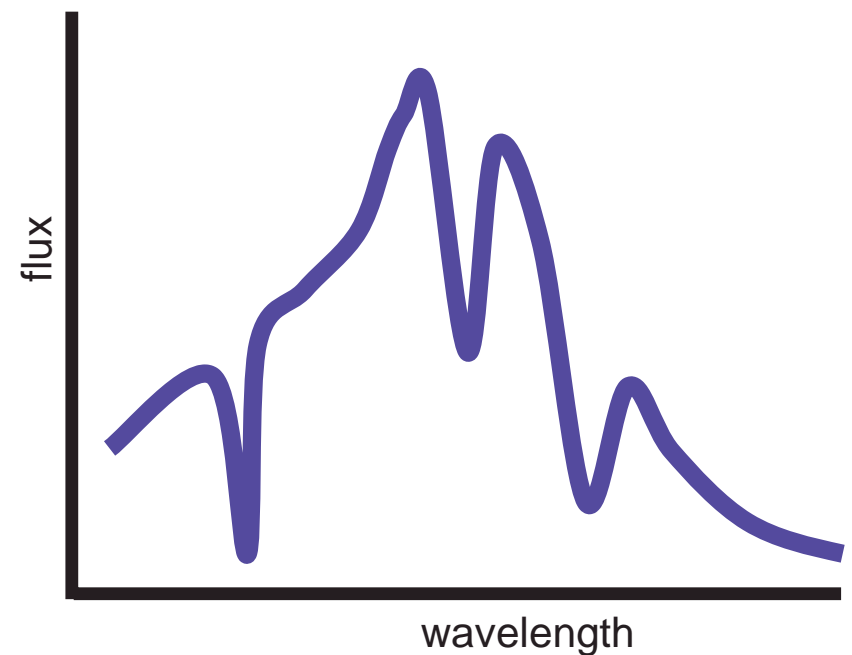
The spectrum



The “spectrum” of a light source also refers to the fractional contribution of all of the different wavelengths to its total light output.

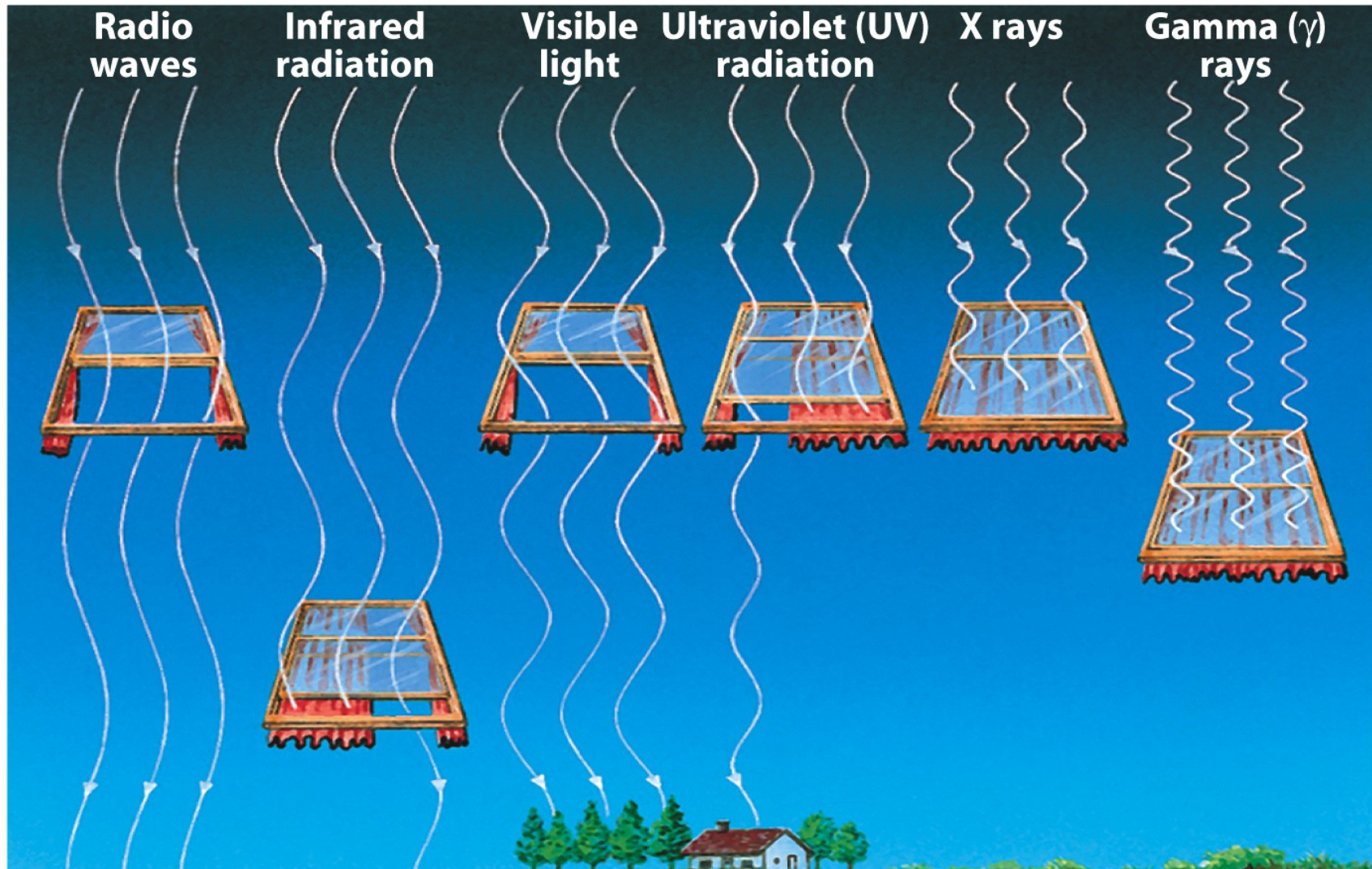


Emission



Absorption

The atmosphere absorbs some wavelengths and not others



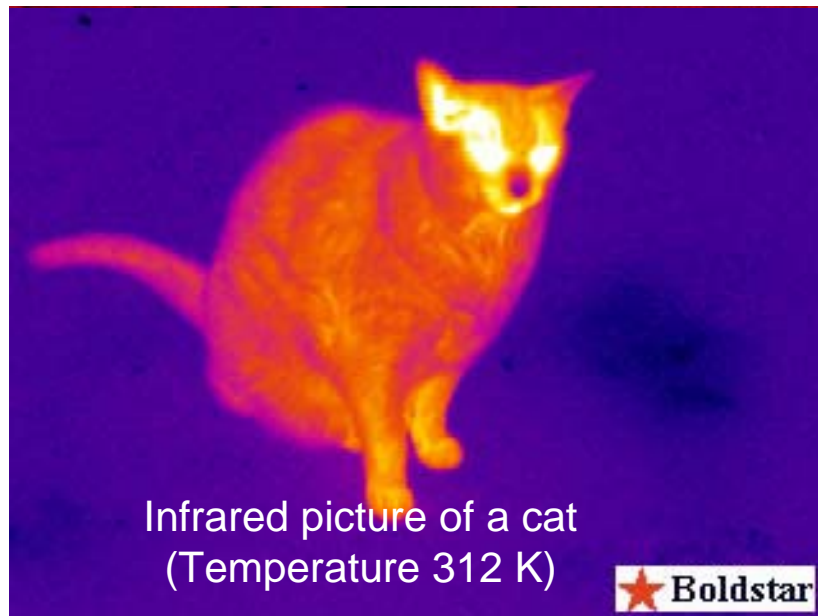
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Blackbody Radiation



- Light that objects emit because of their temperature is called **blackbody radiation**
- Blackbody radiation is composed of a continuous spectrum of wavelengths
- The **hotter** an object gets, the **more intense** and **shorter wavelength** (bluer) its blackbody radiation becomes



Infrared picture of a cat
(Temperature 312 K)

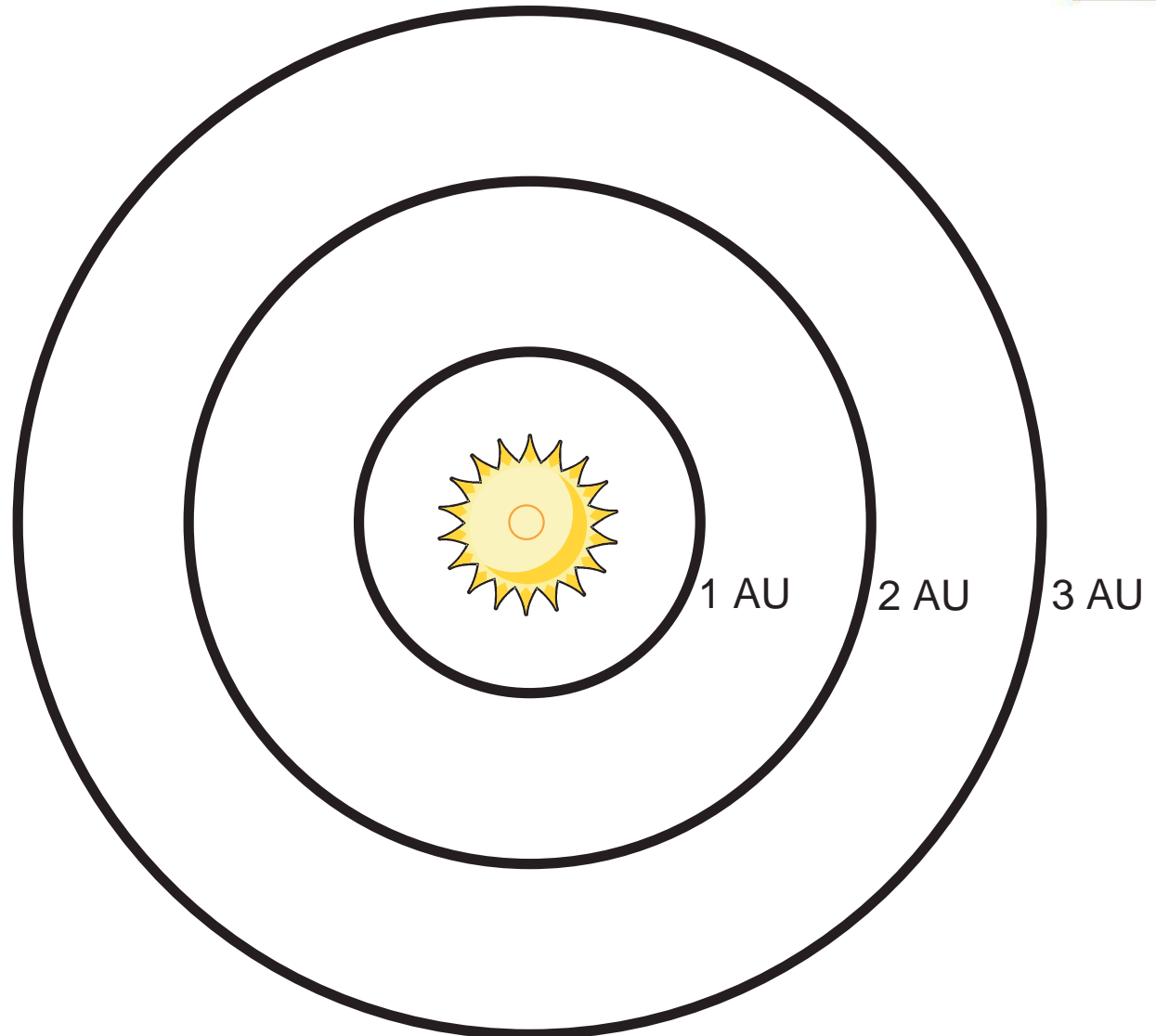


Visible-light picture of a stove element
(Temperature ~ 400 K)

Flux and distance



- ▶ Area of concentric spheres increases as the square of their radii
- ▶ Same amount of light passes through each sphere
- ▶ So amount of light per unit area (ie. **flux**) decreases as the inverse square of the distance



Radius	Area/ 4π	Flux
1 AU	1 AU ²	1.00
2 AU	4 AU ²	0.25
3 AU	9 AU ²	0.11