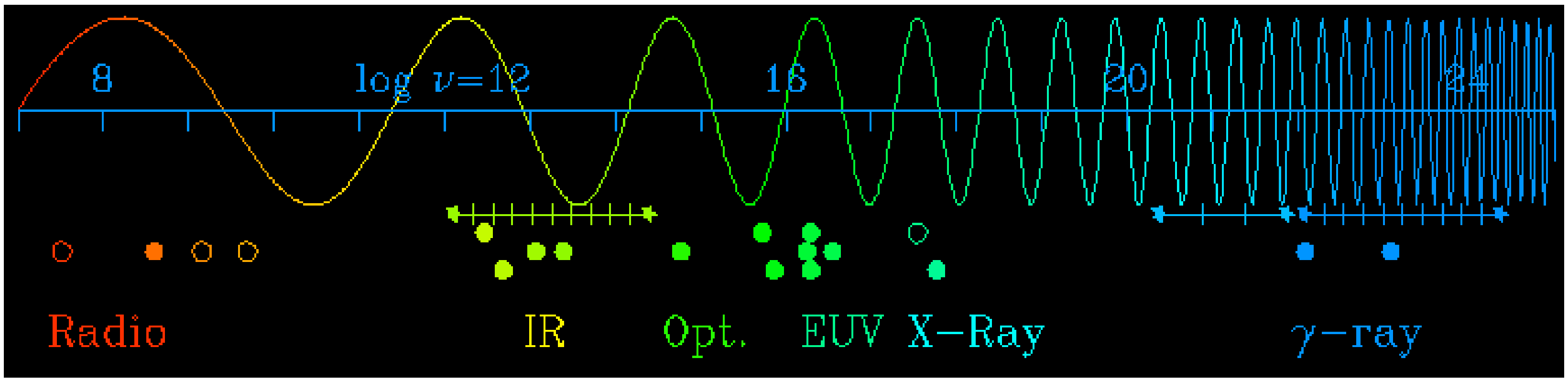
Reminders 28 Sept 2004

- http://www.ucolick.org/~bolte/AY4_04

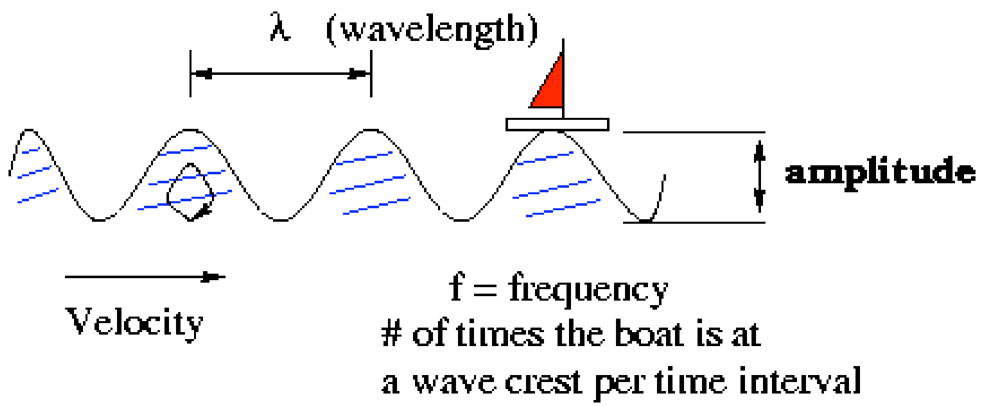
  Has all the class info. Lectures, homework, sections times/places, office hours and contact info.
- Note: by far the best way to contact me is via bolte@ucolick.org
- Note: Next week attend a section to take your lab data and get a copy of the lab assignment.

Let there be Electromagnetic Radiation



- Light, radio waves, x-rays, ultra-violet radiation are all forms of a type of wave composed of oscillating electric and magnetic fields

Waves



- Think about water waves. They are characterized by their amplitude (height) and three related quantities: wavelength (λ), frequency (*f*) and speed (v).

$$v = f \times \lambda$$

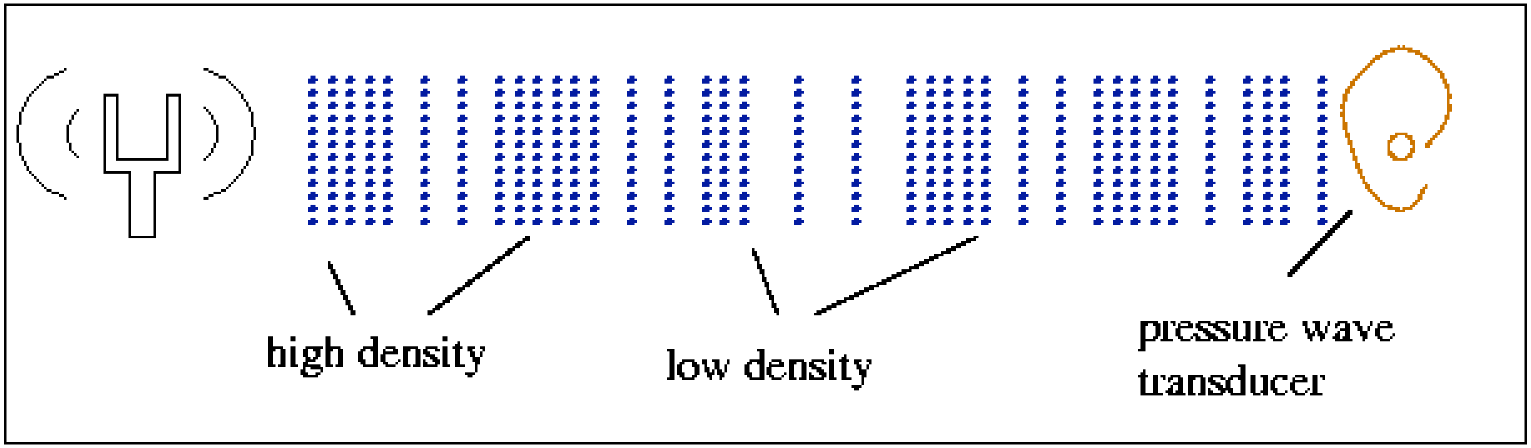
- Wavelength has units of distance
- Frequency, the number of times the boat goes up and down per unit time, has units of 1/time, e.g. 1/second.
- Speed has units of distance/time.

Q. What moves at the wave speed?

ENERGY

Other waves

- There are other kinds of waves. Ocean waves are sometimes called `gravity' waves.
- Sound waves are density/pressure waves

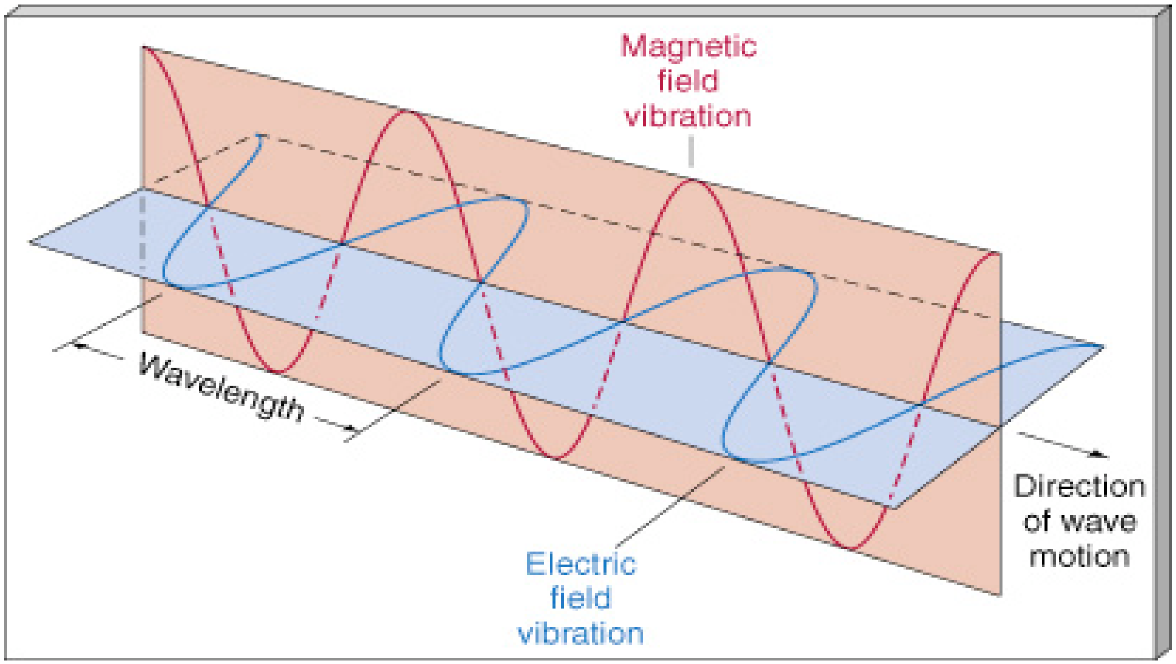


Sound waves

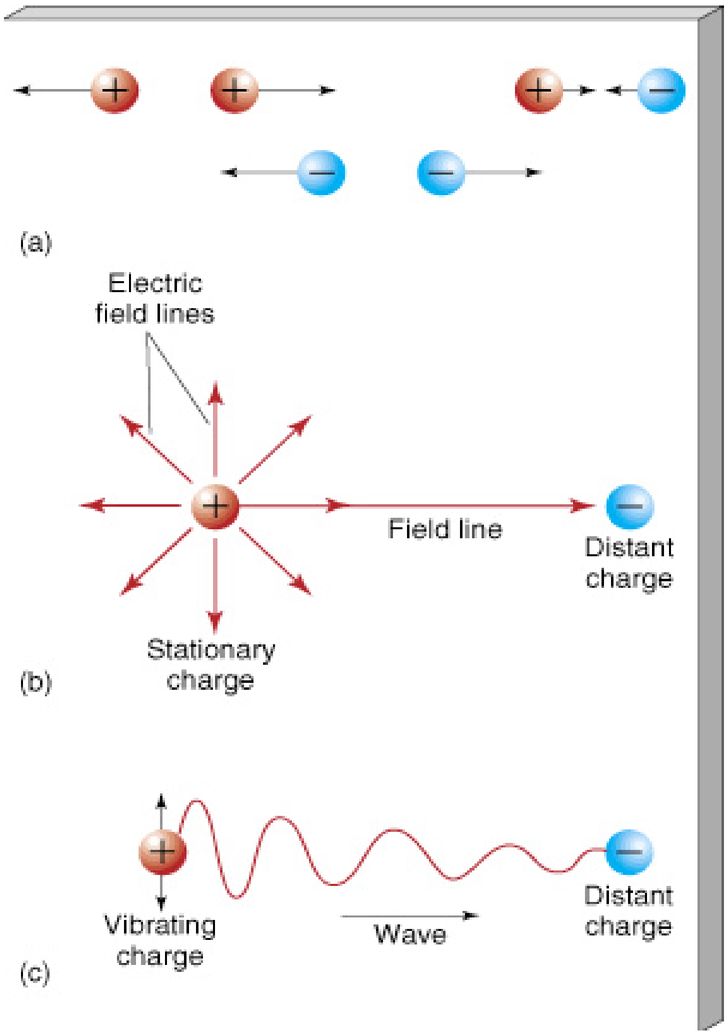
- Sound waves only travel at 1000 ft/sec in air. This is the basis of the old thunderstorm trick.
  - The light from lightning travels at the speed of light (it arrives almost instantaneously).
  - Thunder is a pressure wave triggered by the rapid expansion of the heated air near the lightning bolt. This travels at the speed of sound in air.
- So, for every second delay between seeing the lightning and hearing the thunder the storm is 1000ft away (5280 feet/mile)

E-M Radiation

- Light is a type of wave composed of oscillating electric and magnetic fields propogating through space.



E-M radiation



- This diagram is not quite right, but gives you the idea.
- Any charged particle has a radial electric field extending to infinity. If the charge moves, the center of the field has changed.
- This information propogates outward as a `kink' in the field lines. This changing electric field induces a changing magnetic field.

- The varying electric and magnetic fields move outward at the speed of light.
- In a vacuum, this speed is:

$$c = 300{,}000\,\text{kilometers/second}$$

$$c = 3 \times 10^{5}\,\text{km/s}$$

Q. What is the speed of light in miles/hour?

$$c = 3 \times 10^5 \frac{\cancel{km}}{\sec} \times \frac{0.62\,miles}{1\,\cancel{km}} = 186{,}000 \frac{miles}{\sec}$$

$$186{,}000 \frac{miles}{\cancel{\sec}} \times \frac{60\,\cancel{\sec}}{1\,\cancel{\min}} \times \frac{60\,\cancel{\min}}{1\,hr} = 6.7 \times 10^8 \frac{mile}{hr}$$

Q. The Sun is 93,000,00 miles away. How long does it take for the light that leaves the Sun to reach the Earth?

$$t = D/S$$

$$t = \frac{9300000\,miles}{186{,}000\,\frac{miles}{\text{sec}}} = 500\,\text{sec} \times \frac{1\,\text{min}}{60\,\text{sec}} = 8.3\,\text{min}$$

Q. What is a Light Year?

First, this is a unit of ***distance***, not time. It is the distance light travels in a vacuum in one year.

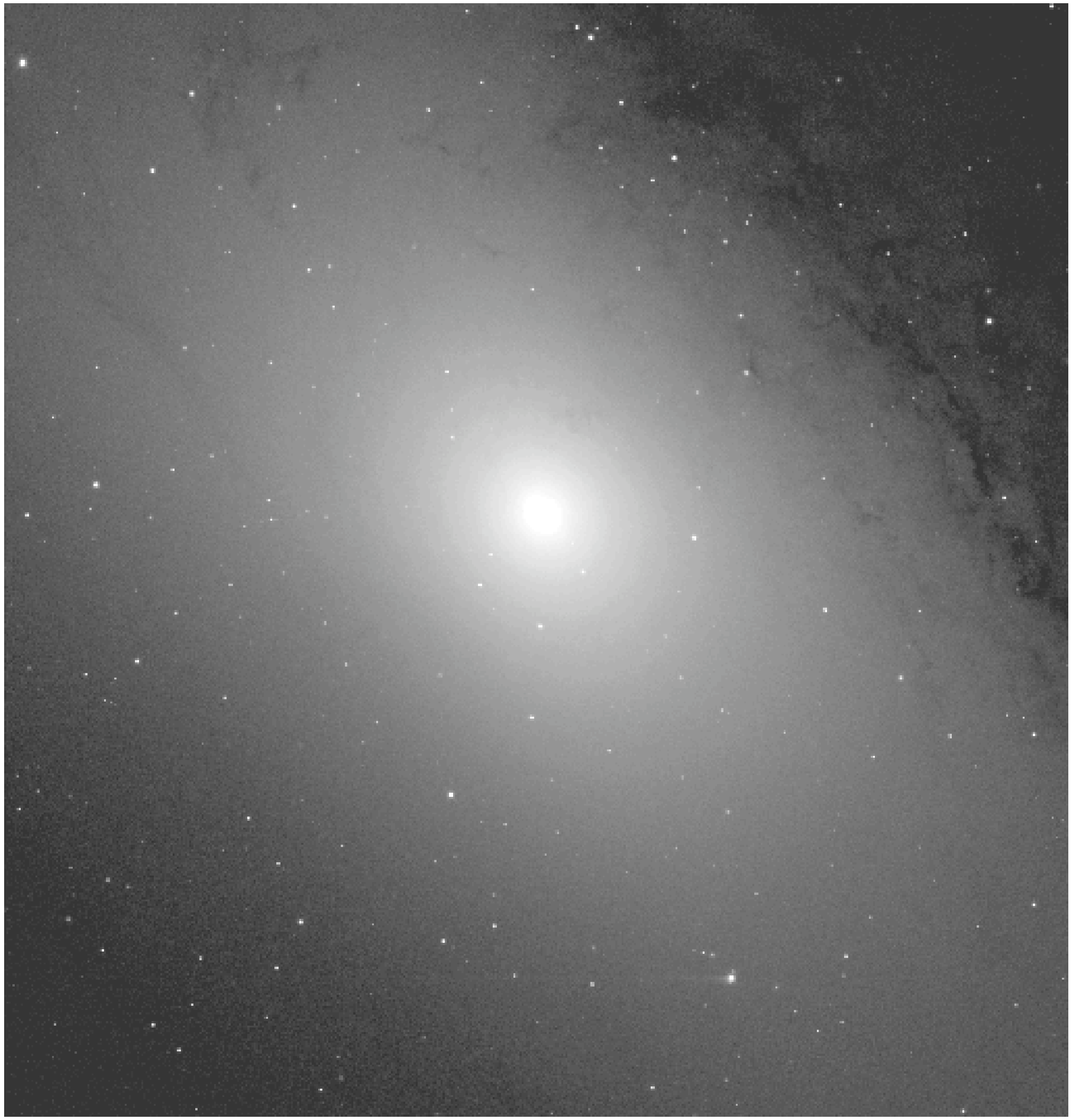
$$186{,}000\,\frac{miles}{\sec} \times \frac{60\sec}{1\min} \times \ldots$$

$$= 5.86 \times 10^{12}\,miles/year$$

$$\Rightarrow 1LY = 5.86 \times 10^{12}\,miles$$

Lookback Time

- Because of the finite speed of light, we see all objects with a time delay.
- The Sun we see as it was 8.3 minutes in the past.
- The nearest big galaxy, the Andromeda galaxy is two million light years away -- we see it as it appeared two million years ago.



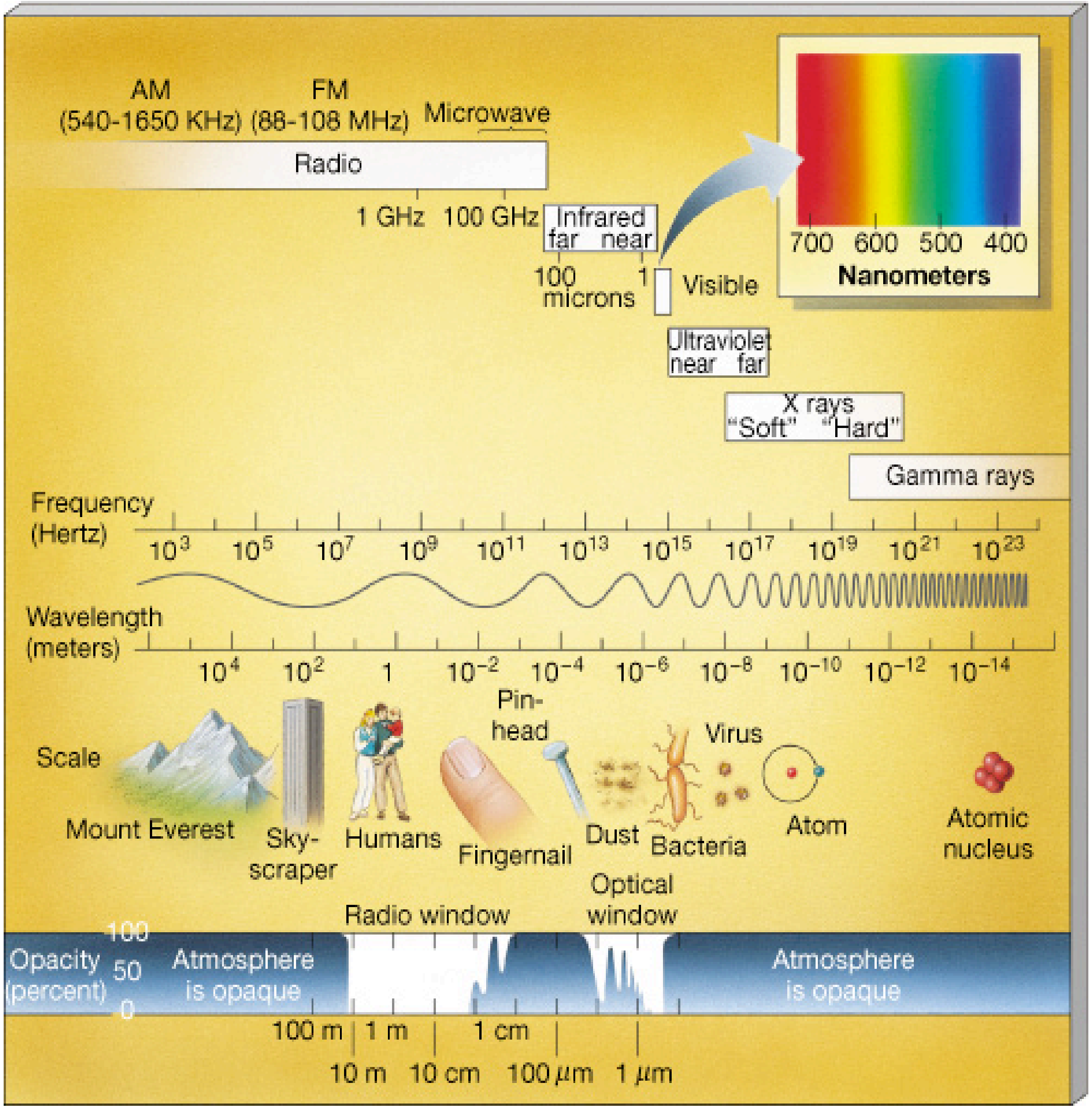
Lookback Times

In the Hubble Ultra Deep Field, some of the objects have lookback times > 12 billion LY. This provides an opportunity to view the Universe at different times in its evolution (!)

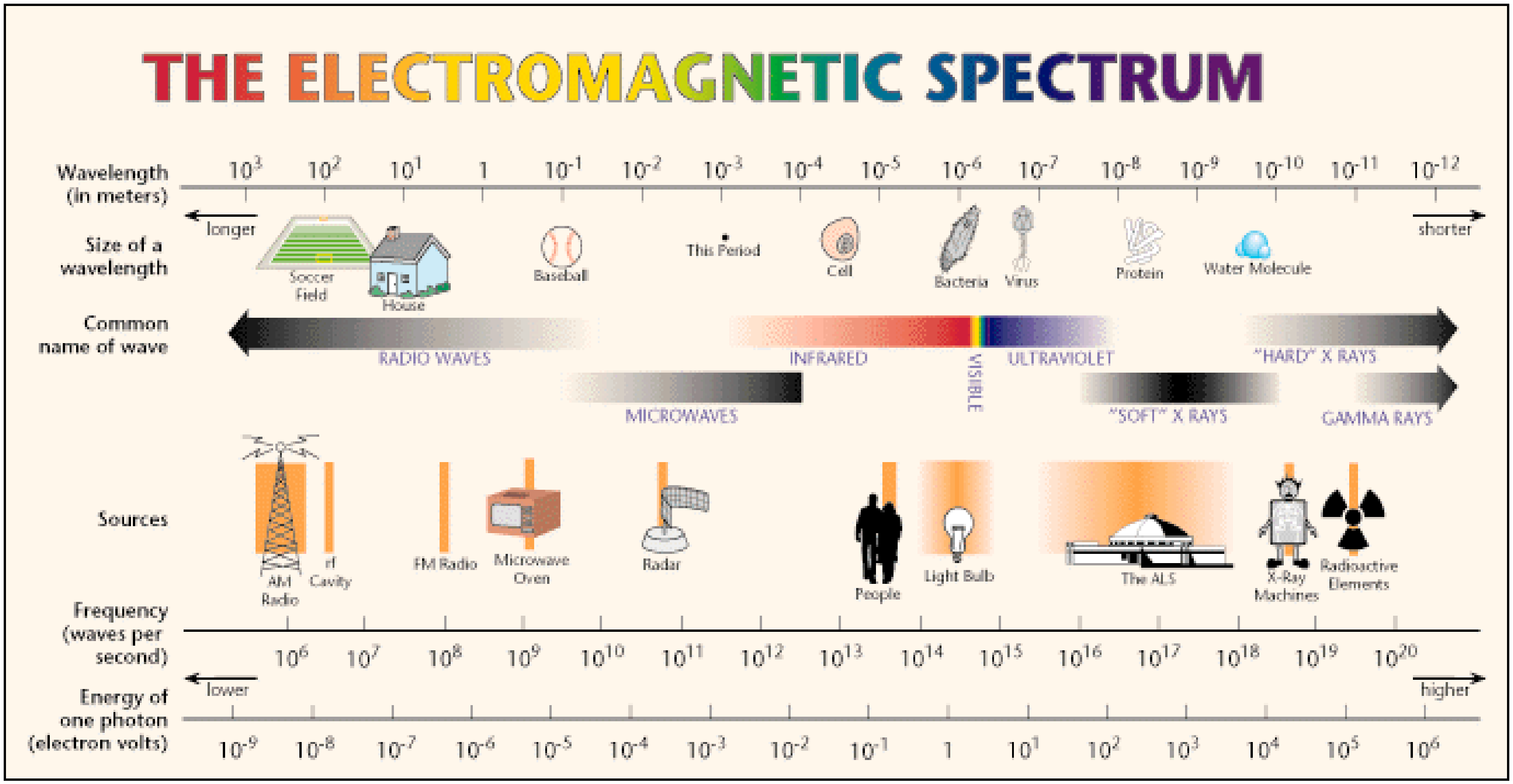
E-M Radiation

- Light is only one form of E-M radiation. There are different names for E-M radiation with different wavelength (or frequency).

X-rays
Ultraviolet
Microwaves
Infrared
Radio



AM
(540-1650 KHz)
FM
(88-108 MHz)
Microwave
Radio
1 GHz
100 GHz
Infrared
far near
100 microns
1
Visible
700 600 500 400
Nanometers
Ultraviolet
near far
X rays
"Soft" "Hard"
Gamma rays
Frequency (Hertz)
10^3 10^5 10^7 10^9 10^11 10^13 10^15 10^17 10^19 10^21 10^23
Wavelength (meters)
10^4 10^2 1 10^-2 10^-4 10^-6 10^-8 10^-10 10^-12 10^-14
Scale
Mount Everest
Sky-scraper
Humans
Pin-head
Fingernail
Dust
Bacteria
Virus
Atom
Atomic nucleus
Radio window
Optical window
Opacity (percent)
100
50
0
Atmosphere is opaque
Atmosphere is opaque
100 m
1 m
1 cm
10 m
10 cm
100 µm
1 µm



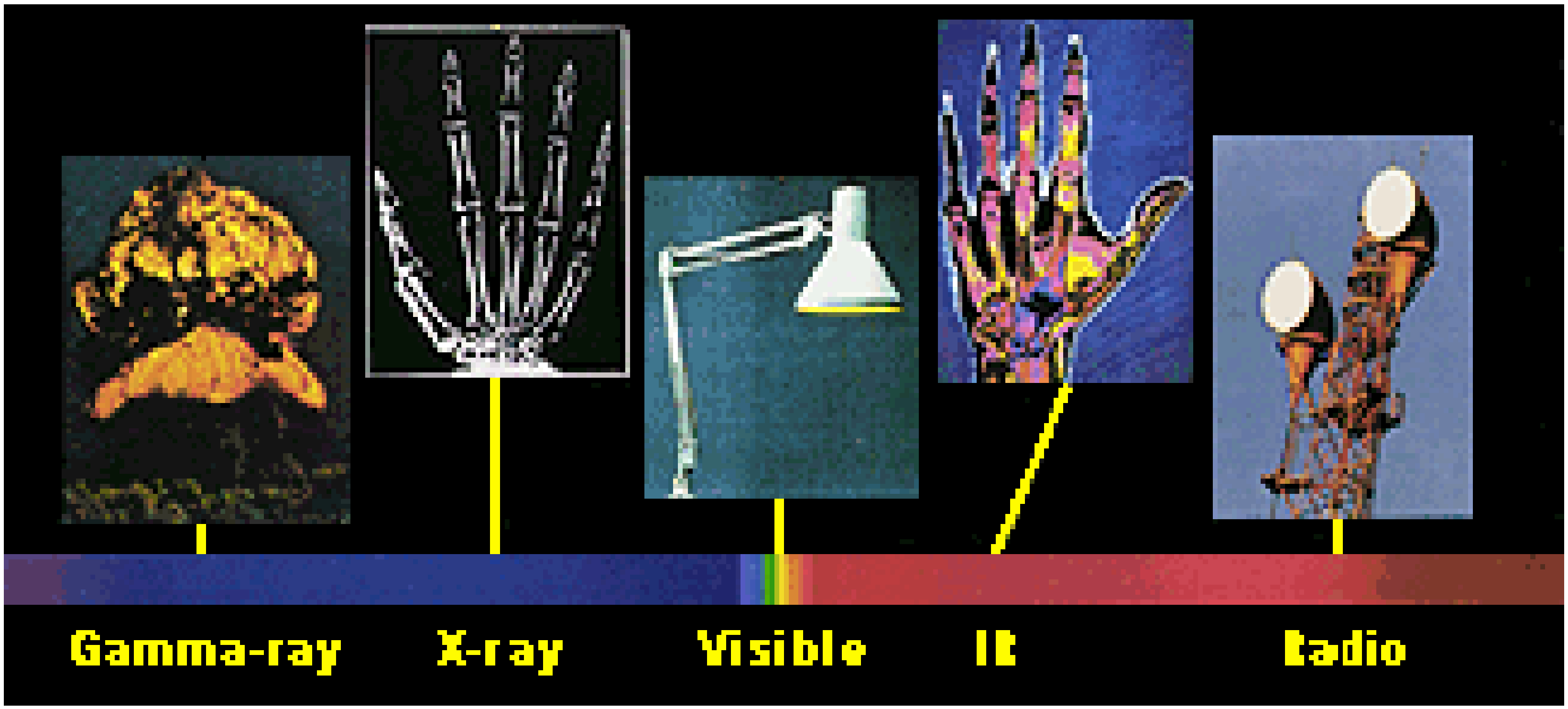
Wavelength increases, frequency decreases, energy decreases

E-M radiation

- E-M radiation with wavelength= 10^{-7} m can be detected by cells in the retina of your eye.
- E-M R between 0.5m and 1000m is used to transmit radio and television signals.
- E-M R with wavelength ~10^{-3}m (*microwaves*) is absorbed by water molecules (i.e. the energy of the E-M R is transferred to the water molecules, they heat up and your burrito in the microwave oven gets warm).

More E-M Radiation

- E-M R with wavelength ~10^{-5}m (*infrared*) can be sensed with your skin (but not eyes)
- E-M R with wavelength ~10^{-8}m (*ultraviolet*) activates pigments in your skin which causes you to tan (and triggers skin cancer).
- E-M R with wavelength ~10^{-9}m (*X-rays*) can penetrate flesh but not bones.


Gamma-ray
X-ray
Visible
IR
Radio

Q. What is the wavelength of 810 Kilohertz on your AM dial?

`kilo' > 1000; `hertz' > 1/second

$$\lambda = \frac{c}{f} = \frac{3 \times 10^5}{810{,}000} \frac{km/\sec}{1/\sec} = 0.37\,km = 1214\,ft$$

More Waves: Energy

- Radio wave, light, Infrared radiation, UV and X-rays are all E-M radiation and travel at the speed of light .
- They differ in ***wavelength*** and ***frequency.***
- Each wavelength of E-M radiation also has a unique Energy given by:

$$E = hf = \frac{hc}{\lambda}$$

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h is called `Planck's constant. For a given wavelength or frequency of E-M radiation this is the `unit' energy. This is not the same as the intensity of the radiation, put rather it is the energy of a single `***photon***'.

h=6.626068 x 10^{-34}Joules·sec (=m^2kg/s)

Photons

- The photon model of E-M radiation is different than the wave model.
- A photon is like a tiny E-M bullet with characteristic wavelength, frequency and energy.
- Both models are right and this is the source of many discussions on the wave-particle duality of light.

Visible Light: Some Details

- The shortest wavelength of E-M Radiation our eyes can sense is 4×10^{-7} meters (400 nm) which is interpreted by our brain as blue light. The longest wavelength our eyes are sensitive to is 700nm -- this is interpreted as red light