Stars, Galaxies & Universe
Lecture #4

- Electromagnetic radiation
  - Why we study it
  - What we can learn from it
  - Basic properties: speed, wavelength/frequency
  - The electromagnetic spectrum
  - The photoelectric effect
    (energy = frequency)
  - The Doppler effect

Basics of Electromagnetic Radiation (or "Light")

➢ What we can learn from observing EM radiation from an astronomical object
- ***Temperature***
- **Energy**
- ***Line-of-sight motion***

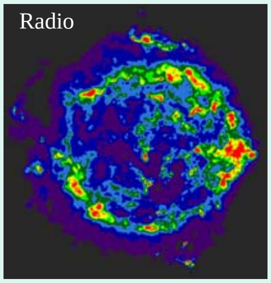
➢ Properties of EM Radiation
- ***How it interacts with matter***
- ***Wavelike properties (wavelength, frequency; Doppler Effect)***
- ***Particle-like properties (how light carries energy & how much: photoelectric effect, Wien's Law)***

Optical telescopes in the Canary Islands, Spain

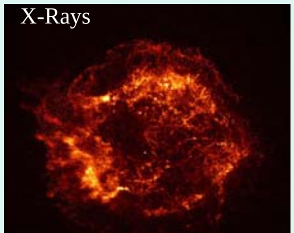
Arecibo Radio Telescope, Puerto Rico

VLA radio telescope, New Mexico

Radio



X-Rays



Cas A: Supernova Remnant
Distance: 10,000 light years (our Galaxy)

- Astronomers collect “light” from astronomical objects
  - *- “light” usually refers to VISIBLE electromagnetic radiation*
  - *- radio and x-rays are two other types of EM radiation*
- We derive physical properties of objects: energetics, size, velocities

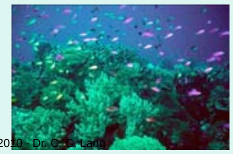
Physical properties of EM radiation

• EM radiation travels at a constant speed IN A VACUUM

c = 299,792.458 km/s (186,282.397 miles/s)
c (practical) = 3×10^5 km/s = 3×10^8 m/s

• EM radiation travels slower in air, water, glass, etc.

→ *space is nearly a vacuum, so mostly we use the value c*



• "light" from astronomical objects tells us about the physical properties when the light was emitted

• in this way, we are looking 'back in time'

• the further away, the 'older' the view

Light from the	Travel time
Earth to the moon	1.28 seconds
Sun to Earth	8.5 minutes
Sun to Mercury	3 minutes
Sun to Venus	6 minutes
Sun to Mars	12.5 minutes
Sun to Jupiter	43 minutes
Sun to Saturn	1 hour
Sun to Uranus	2.6 hours
Sun to Neptune	4 hours
Sun to Pluto	5.4 hours
Sun to the nearest star	4.3 years
Sun to the most distant stars	14 billion years

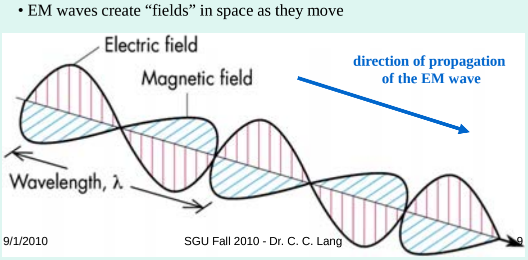
• **EM radiation has wave-like properties**

-waves travel through space
-waves are a disturbance in space

• **What is doing the "waving"?**

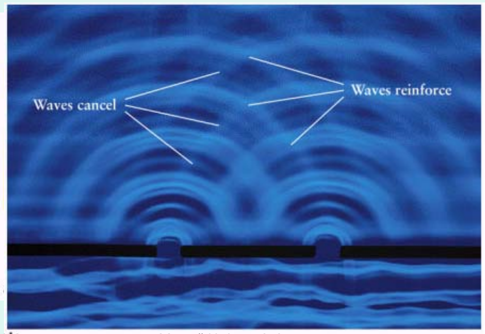
An EM wave is both an electric and magnetic disturbance

• EM wave emitted when charged particle (i.e. electron) accelerates
• EM waves create "fields" in space as they move

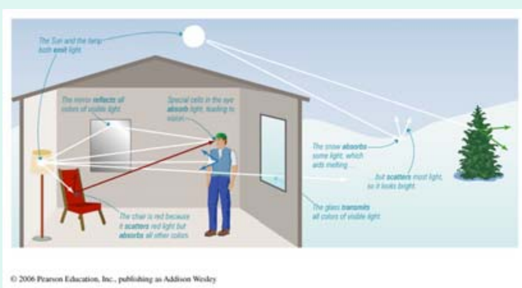


Thomas Young’s Double Slit Experiment: 1801

- *showed that EM radiation had wave-like properties*



How does “light” (or EM radiation) interact with matter?

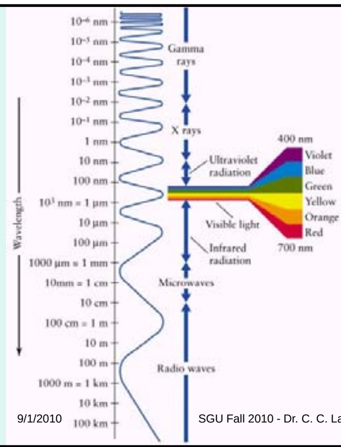


Emit – electric current in lightbulb
Transmit/Pass through - window
Absorb – hand absorbing light from bulb
Reflect/Scatter – off snow, dust

- EM waves are characterized by their wavelengths (λ) or their frequencies (ν)

A prism, or “spectrometer”, splits visible light ‘white light’ up into its different components

Much more sophisticated spectrometers are a main tool of astronomers - used at all different wavelengths.



The FULL Electromagnetic Spectrum

- Which one has the **longest wavelength**?

Microwaves

Visible light

X-rays

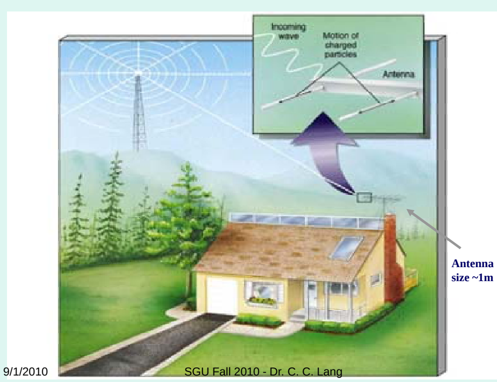
Ultraviolet radiation

Gamma-rays

Radio Waves

Infrared radiation

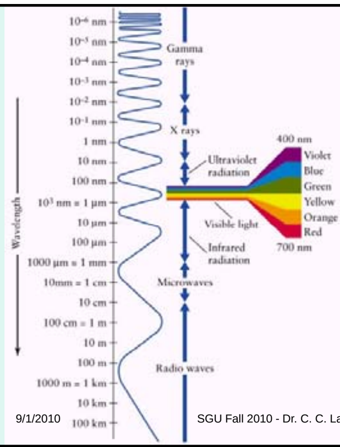
Electromagnetic Radiation: Radio Waves (TV, $\lambda \sim$ 1m)



Speed of light: relation between λ and v

- speed of light = c = λ x v
- c = constant = 3×10^8 m/s = 3×10^5 km/s
- λ has units of length (m)
- v has units of 1/s (Hz)

Example: what is the frequency of EM radiation with a wavelength (λ) of 50 micro-meters (μm)?



The FULL Electromagnetic Spectrum

- Which one carries the **most energy**?

Microwaves

Visible light

X-rays

Ultraviolet radiation

Gamma-rays

Radio Waves

Infrared radiation

EM radiation also has particle-like properties

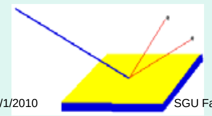
- study of wave/particle duality: quantum mechanics

• A "photon" is another way of referring to EM radiation

- used for describing its particle-like properties
- can think of a photon like a packet of EM radiation

• The photoelectric effect demonstrates particle properties

- "How we know EM radiation carries energy"
- experiments being done in late 1800's, Einstein 1905



- shine EM radiation on a metal plate (electrons)
- electrons will be ejected from metal plate if the energy of the incoming EM radiation is high enough

Photoelectric Effect:

• Outcome #1: if you increase **intensity** of light beam you get **more of the same electrons**

• Outcome #2: if you increase **frequency** of light beam you get **higher energy electrons**

→ Photons carry energy depending on their frequency (or wavelength)

$$\mathbf{E=h\nu = hc/\lambda}$$

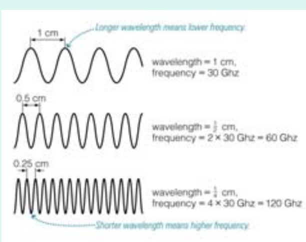
h is a physical constant, ν is frequency, E energy; c is speed of light and λ is wavelength

E is proportional to ν: if ν increases, E increases

Do X-rays or radio waves carry more energy?

X-rays have a higher frequency (shorter wavelength)

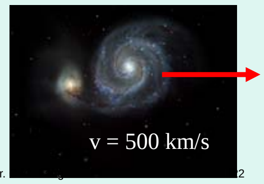
and therefore X-rays carry MORE ENERGY than radio waves



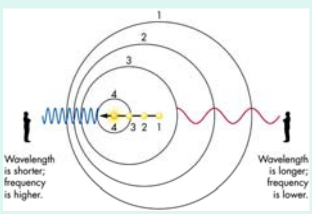
The Doppler Effect: wave-like property of EM radiation

The Doppler effect is an apparent *change in wavelength (or frequency) of an EM wave*.

This change occurs *because of motion of the object emitting the EM radiation*, i.e. a star, a galaxy



The Doppler Effect: wave property



If object is moving AWAY from YOU, the wavelength appears LONGER – “REDSHIFTED”

If object is moving TOWARD YOU, the wavelength appears SHORTER – “BLUESHIFTED”

Doppler Shift examples – used throughout Astronomy!

Venus’ rotation – discovered by the Doppler Shift of reflected radar waves

Doppler shift of sunlight Sun’s surface motions – entire Sun vibrates