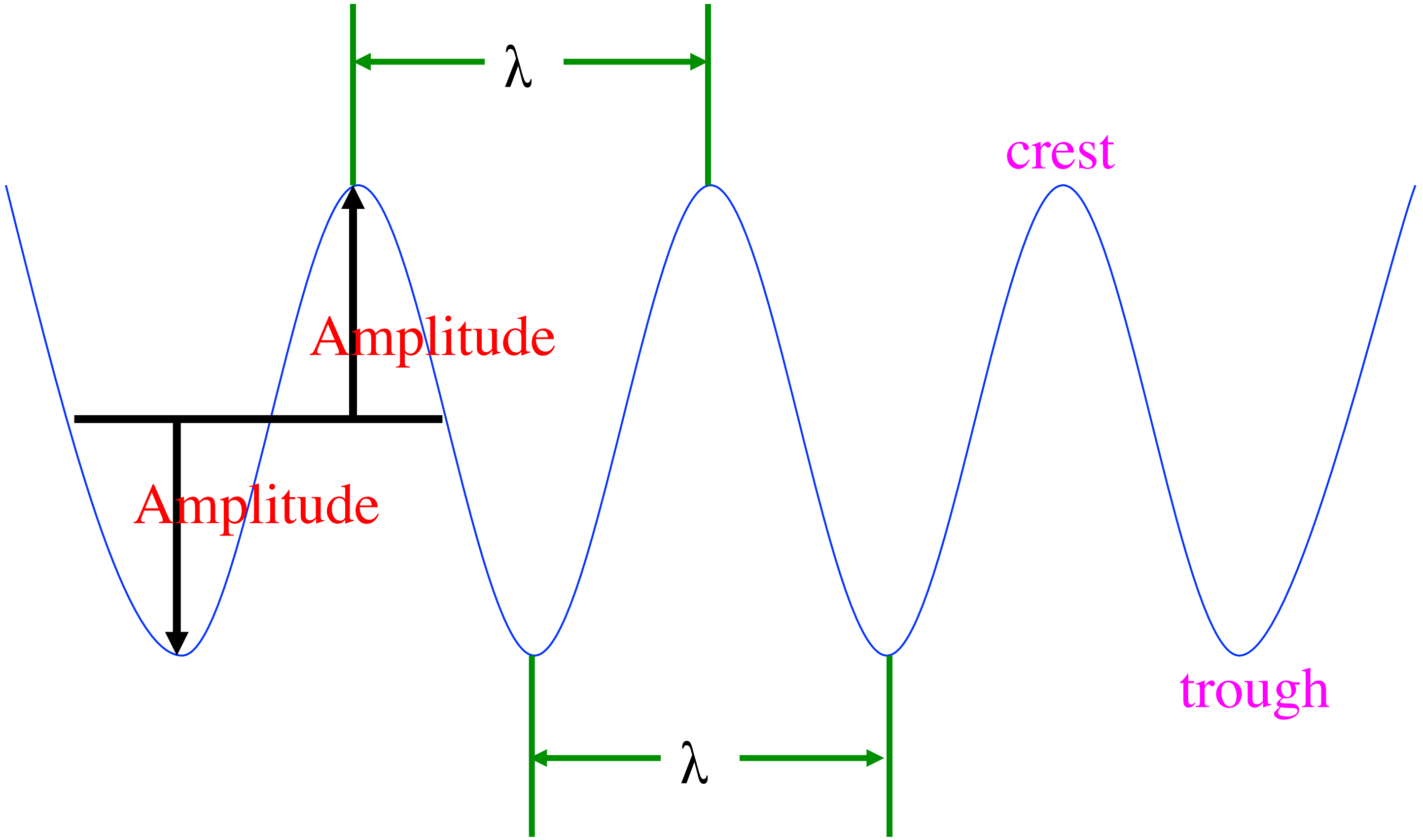
Astronomy & Light

- Astronomy is a science
- In science we “know” by doing experiments
- When multiple experiments give the same results we develop theories and laws
- In astronomy many of the “experiments” are done by collecting data from distant objects by using telescopes to collect light.
- Telescopes become our “time machines” to measure changes over time.

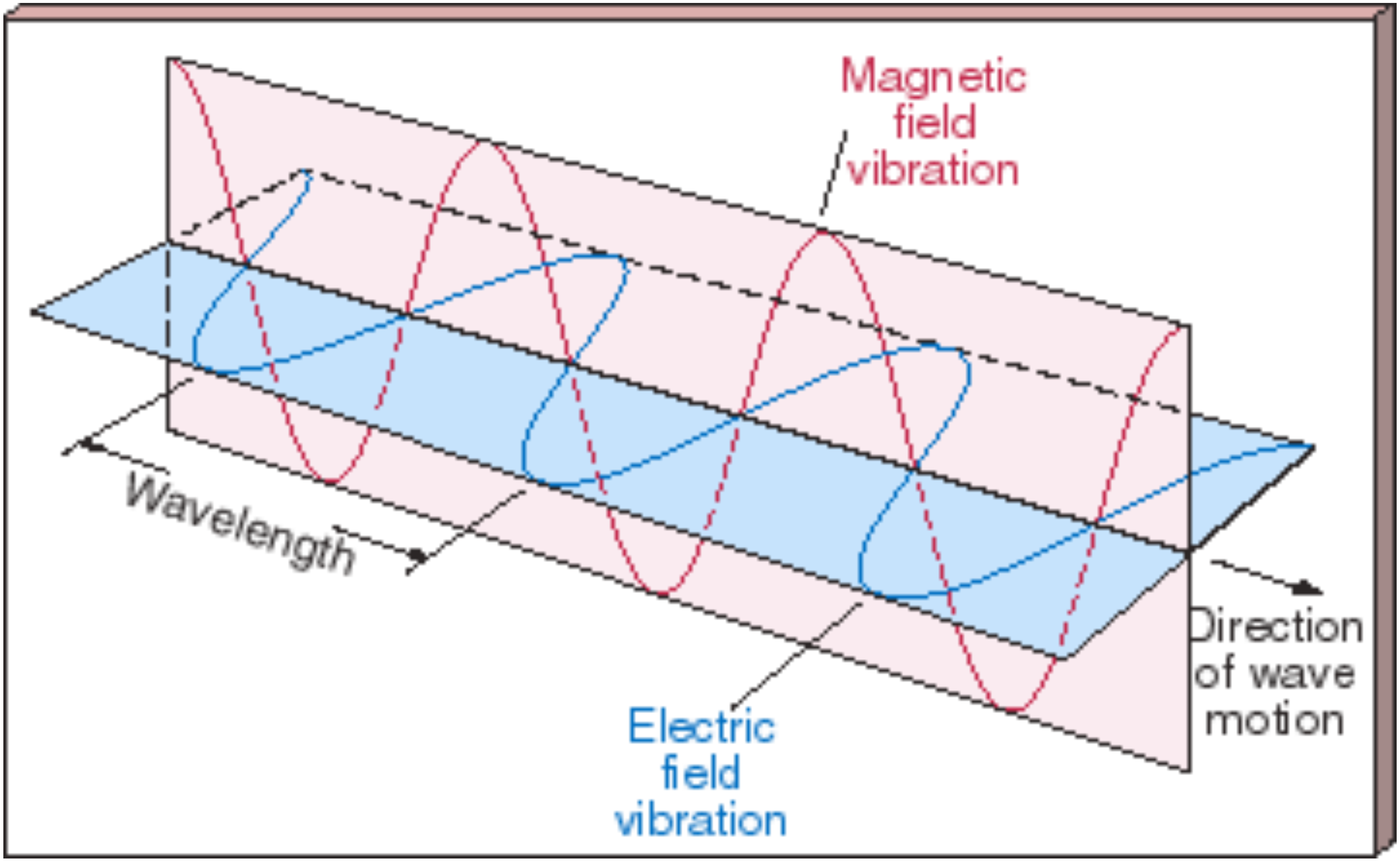
Light - electromagnetic radiation

- Electromagnetic radiation is a result of interactions of electricity and magnetism.
- Light travels as a transverse wave with crests and troughs.
- NASA Electromagnetic Spectrum

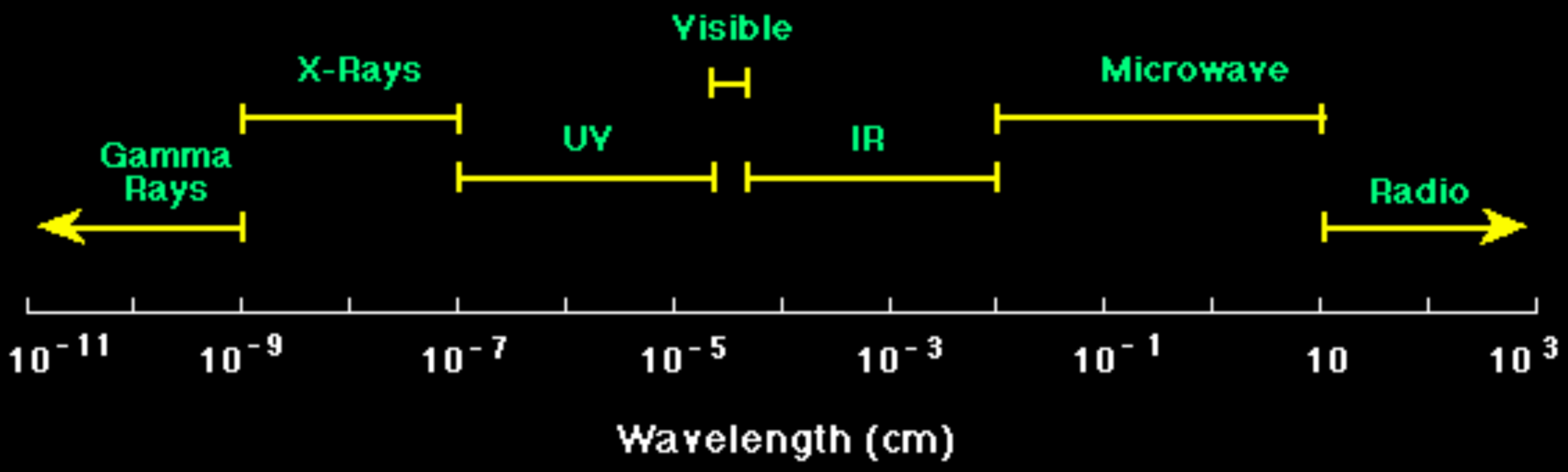
Transverse Waves



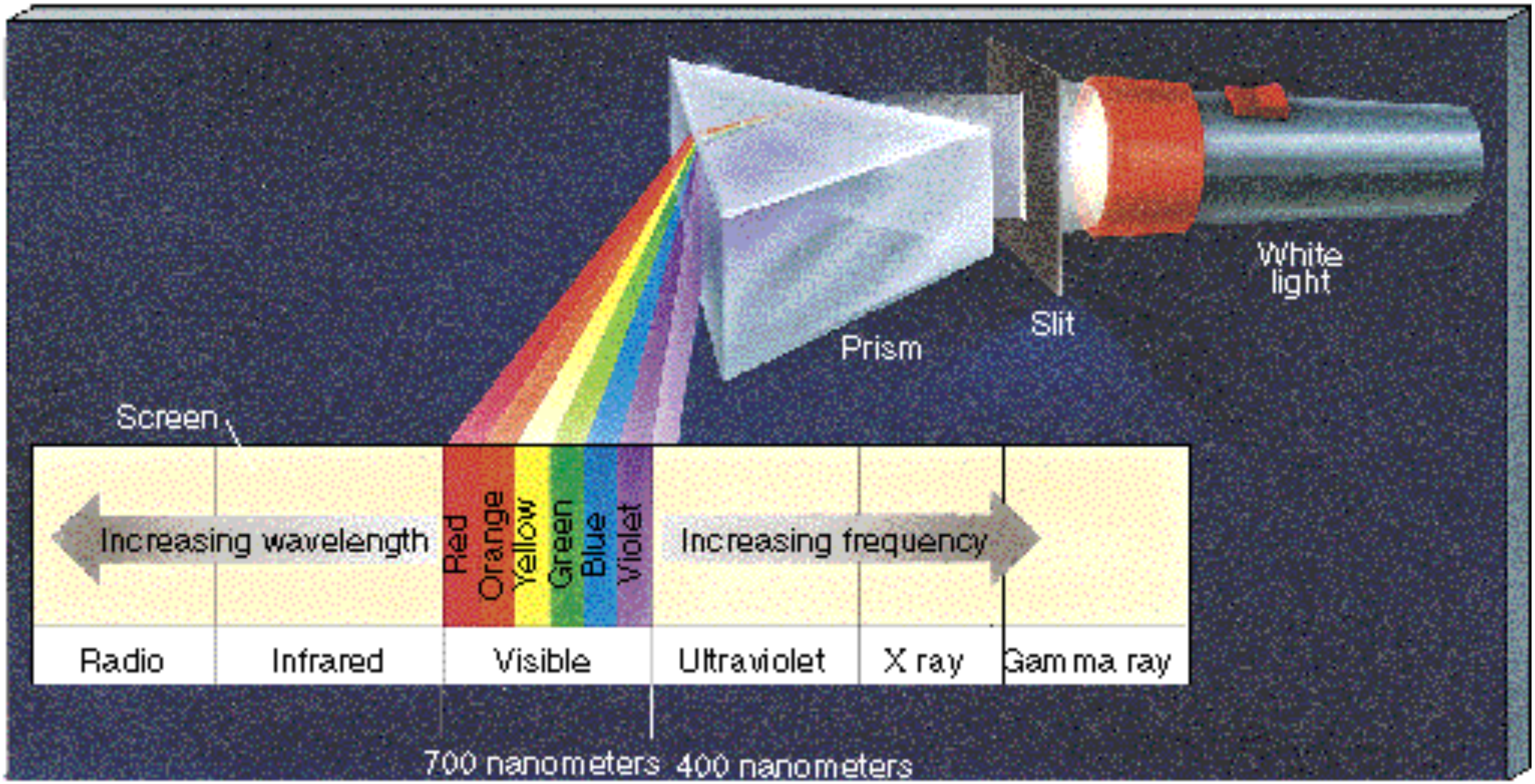
Electromagnetic Wave

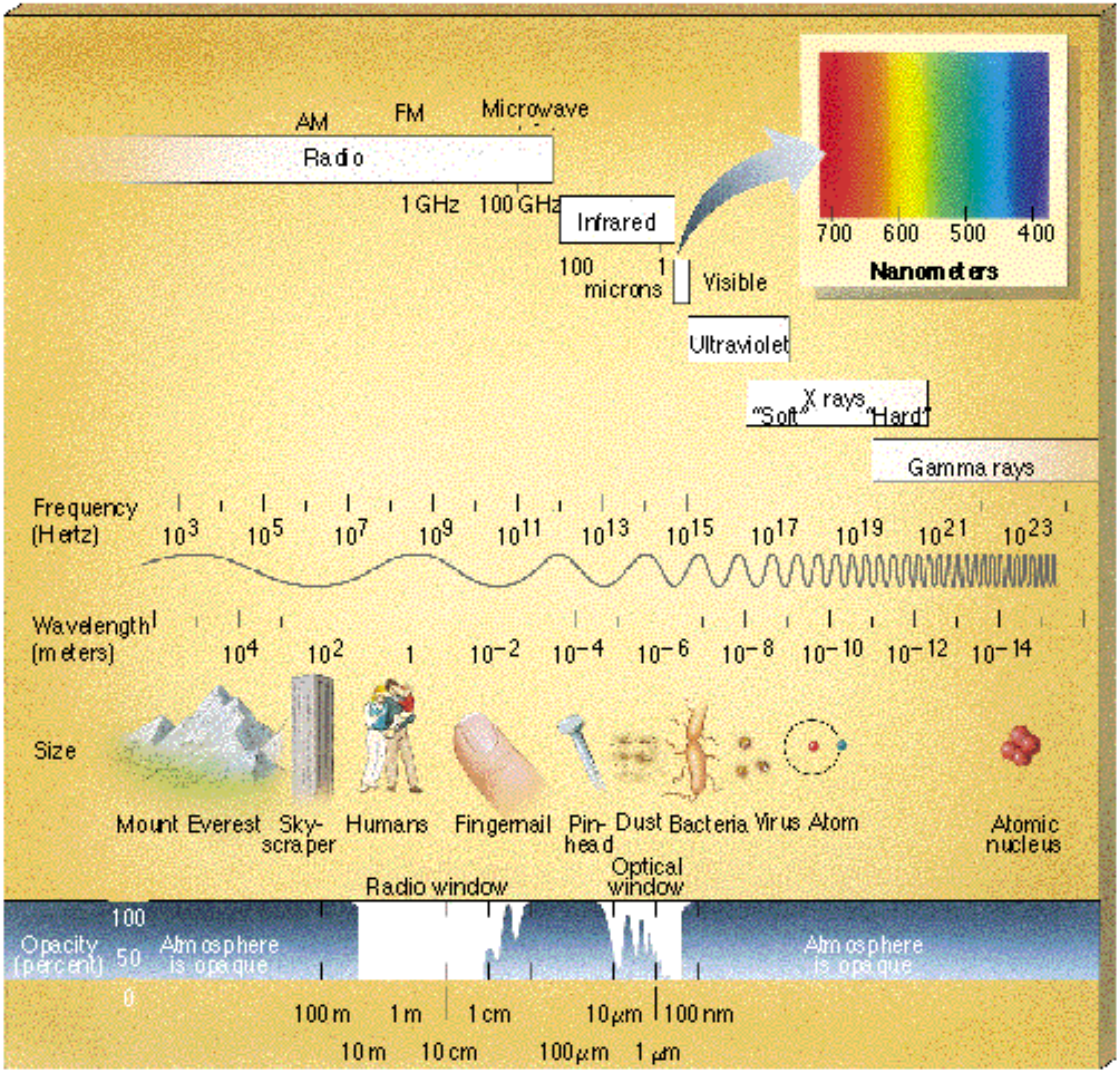


Electromagnetic Spectrum



Electromagnetic Radiation





AM
FM
Microwave
Radio
1 GHz
100 GHz
Infrared
100 microns
1
Visible
700
600
500
400
Nanometers
Ultraviolet
"Soft"
X rays
"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
Size
Mount Everest
Sky-scraper
Humans
Fingernail
Pin-head
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 μm
100 nm
10 m
10 cm
100 μm
1 μm

The Speed of Light

- The speed of light through space is constant, 3.00×10^8 m/s.
- The speed of a wave depends only on the kind of wave and the kind of material it travels through.
- The speed of light is the speed limit of the universe. The speed of light is the same in all reference frames.

Color, wavelength, frequency

- The frequency and wavelength of a wave are inversely proportional.
- Changing the frequency or the wavelength do not change the speed of the wave.
- Wavelength and Frequency

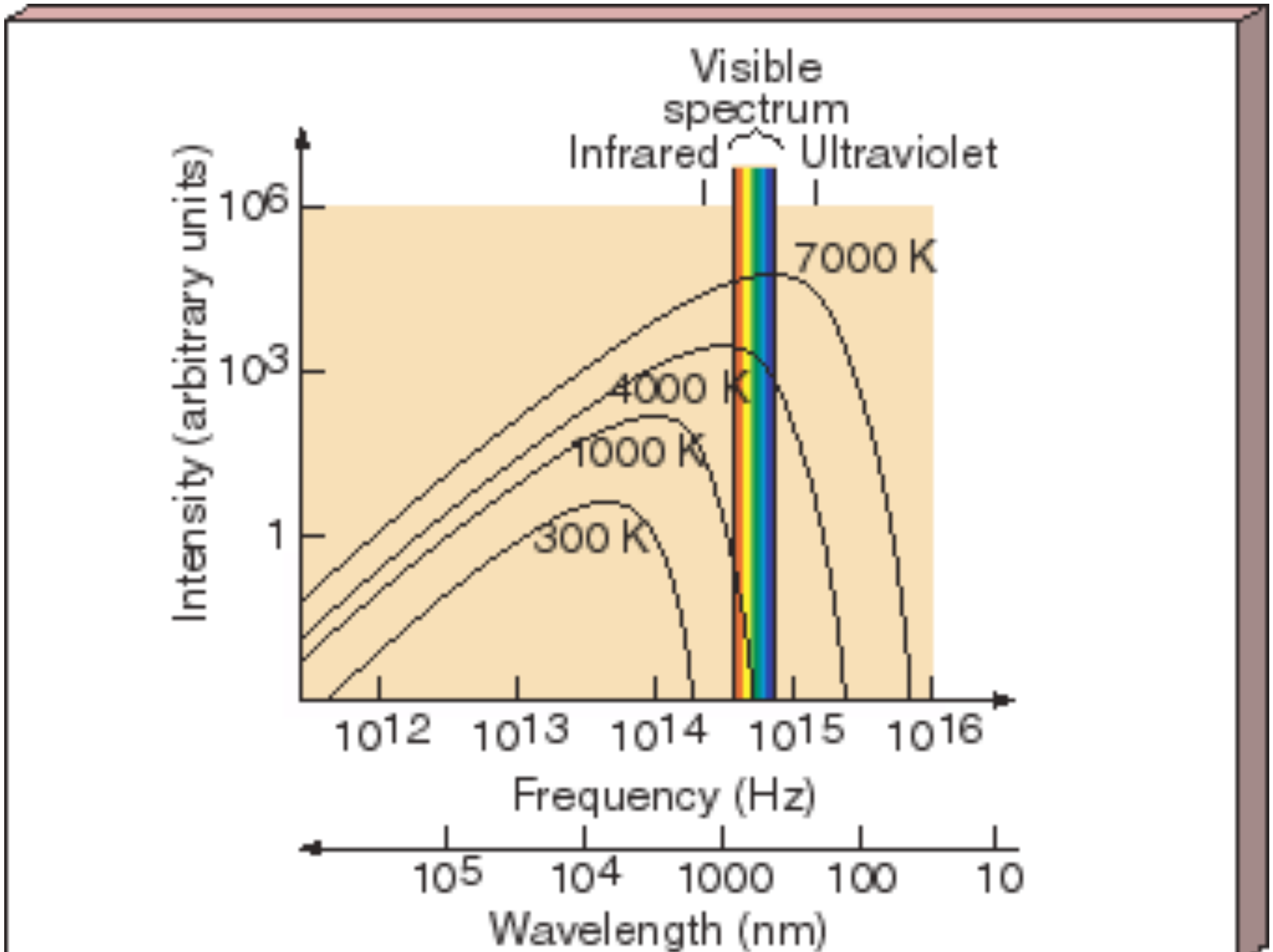
Light is a form of Energy

- The energy of the light depends on the frequency ⇨ $E=hf$ where h is Plank's constant.
- The frequency of the light depends on the wavelength λ $c=f\lambda$
- The wavelength determines the color.
- The color of the light is related to the energy.
- The energy is released as light temperature or black body radiation.

Black Body Radiation

- As the temperature of an object increases the energy it releases also increases.
- The energy is released in the form of light.
- The greater the energy the higher the frequency ($E=hf$), the shorter the wavelength ($c=f\lambda$), the bluer the light.
- Cooler objects give off redder light.

Color Temperature



Black Body Radiation

The wavelength of the light is inversely proportional to the temperature in Kelvin.

K=°C + 273.15

Kelvin is the absolute temperature scale - there are no negative numbers on this scale. The coldest possible temperature is 0 K.

Wien's law relates the wavelength to the Kelvin temperature

$\lambda_{max} = 0.29$ cm/T

Black Body Radiation

A star like our sun that gives off visible light might have a λ_{max} of 550 nm. This means that the greatest amount of light has a wavelength of 550 nm.

To calculate the temperature we must first convert the wavelength from nm to cm because

$\lambda_{max} = 0.29$ cm/T

Black Body Radiation

550 nm

$\lambda_{max} = 0.29 \text{ cm}/T$ or $T = 0.29\text{cm}/\lambda_{max}$

$$550 \text{ nm} \times \frac{1 \text{ m}}{1\times10^{9} \text{ nm}} \times \frac{100 \text{ cm}}{1 \text{ m}} = 5.5\times10^{-5} \text{ cm}$$

$$T = \frac{0.29 \text{ cm}}{5.5\times10^{-5} \text{ cm}} = 5272 \text{ K}$$

Black Body Radiation

The color of the light tells us the temperature of the surface of any object (especially stars).

The more “blue” (shorter wavelength) the star, the higher the temperature

The more “red” (longer wavelength) the lower the temperature.

Black Body Radiation

The total amount of energy that an object releases also depends on the temperature.

Josef Stefan determined that the *energy flux* (symbol of F in the equation), the amount of energy emitted per square meter depends on the temperature to the 4th power.

$F=\sigma T^4$

Where σ is called the Stefan-Boltzmann constant = 5.67×10^{-8} W/ m^2 K^4

Black Body Radiation

A human being has a normal body temperature of 37°C (or 310 K)

$F=\sigma T^4$

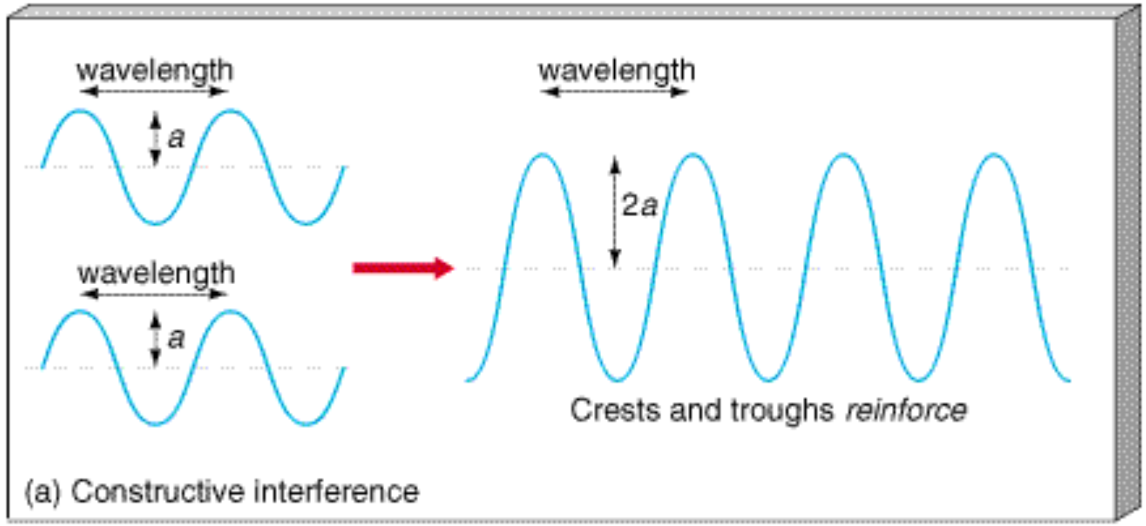
$F= (5.67 x 10^{-8}\ W/\ m^2\ K^4)\ (310\ K)^4 = 524\ W/m^2$

The sun at about 5500 K

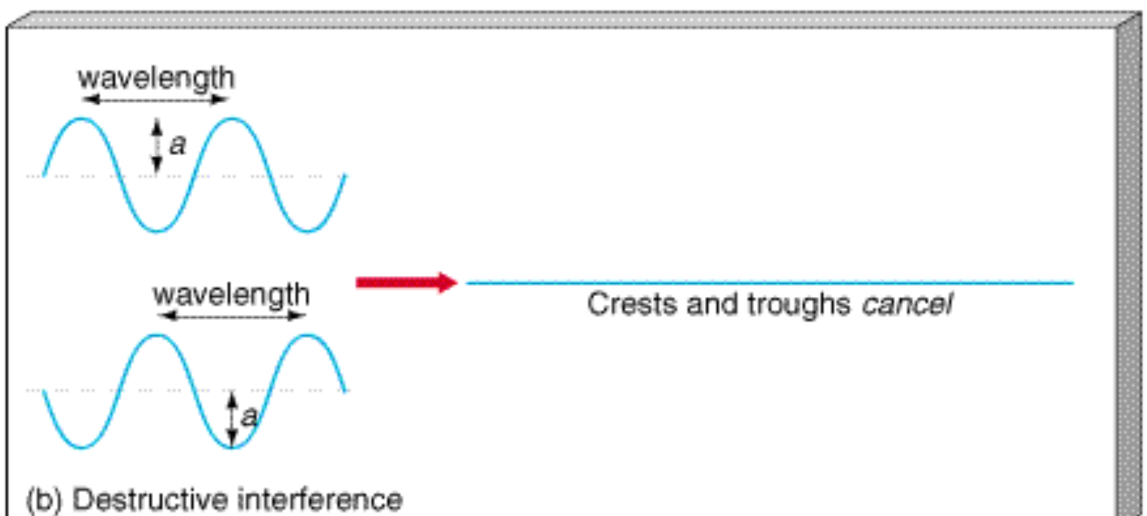
$F= (5.67 x 10^{-8}\ W/\ m^2\ K^4)\ (5500\ K)^4 =$ 51,840,000 W/m^2 or 51.8 megawatts/square meter

Interference

- Interference happens when two waves run into each other.
- When the wave increases in amplitude because of crests and troughs of one wave are on the same side as crests and troughs of another wave it is constructive interference.
- When the wave decreases in amplitude because of crests and troughs of different waves are on the opposite side it is destructive interference.



(a) Constructive interference

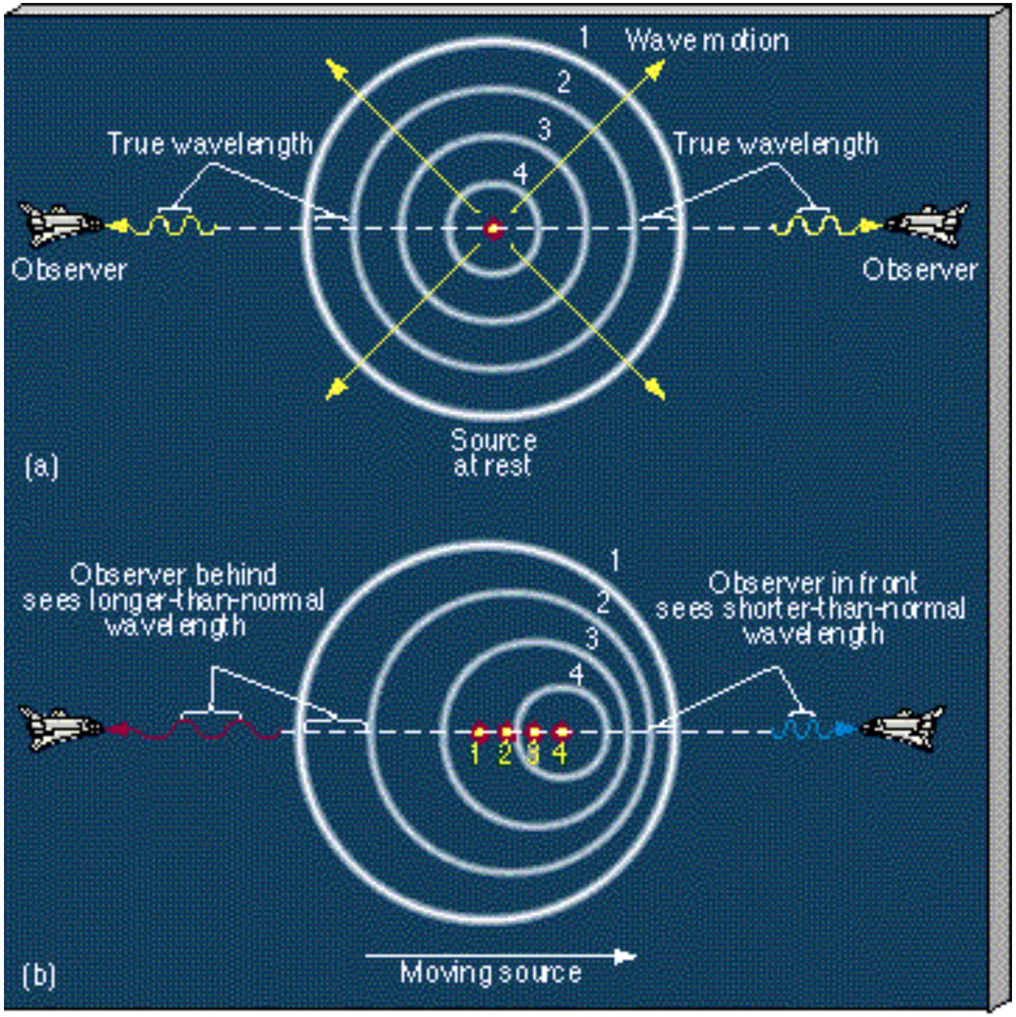


(b) Destructive interference

Doppler Effect

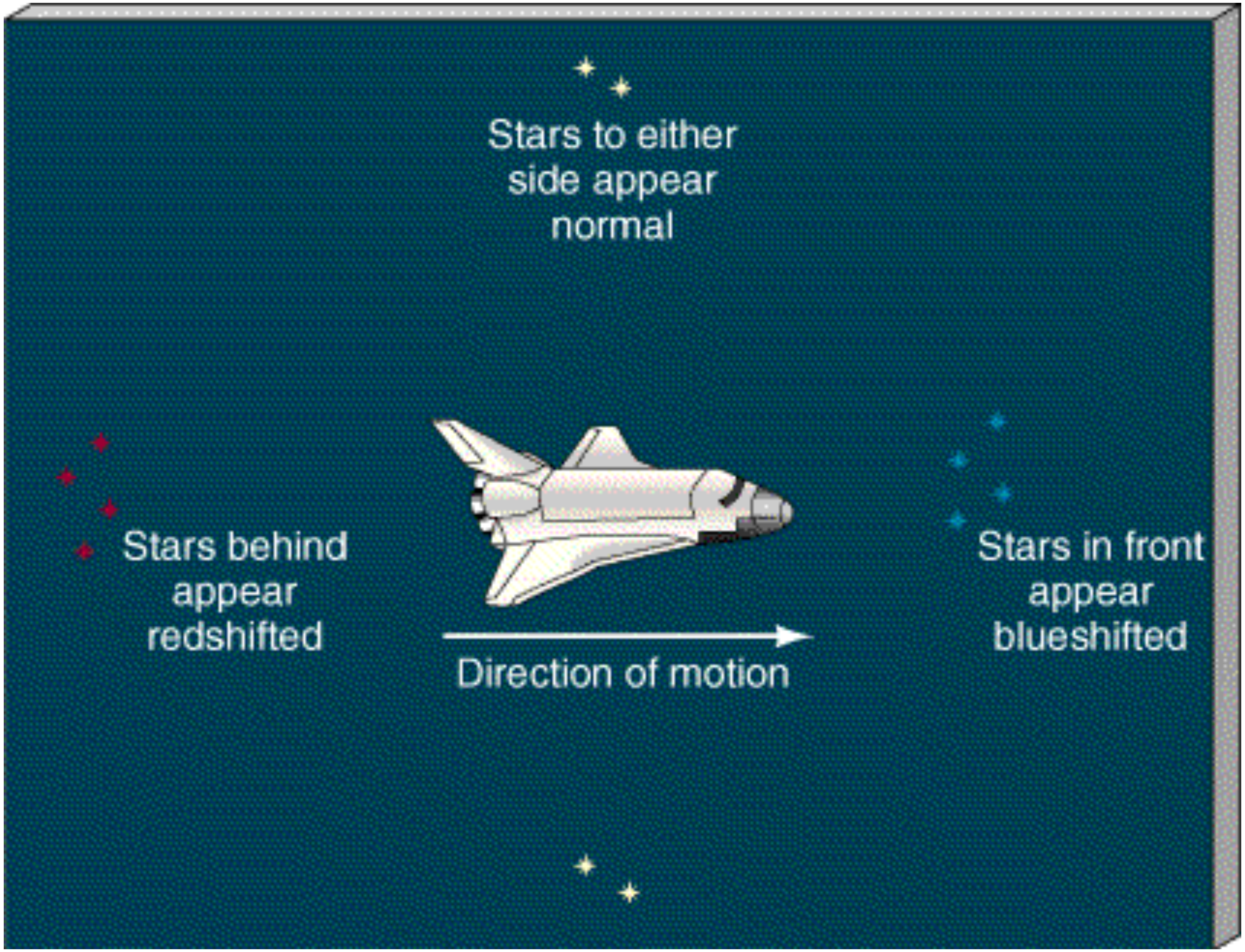
- The speed of a wave is determined **ONLY** by the kind of wave and the material it is traveling through.
- If the source of the wave is moving, the wave doesn't change speed, it changes the wavelength and frequency.
- The change in the frequency of a wave because of the motion of the source is called the Doppler Effect.

Doppler Effect



Sound Doppler Effect

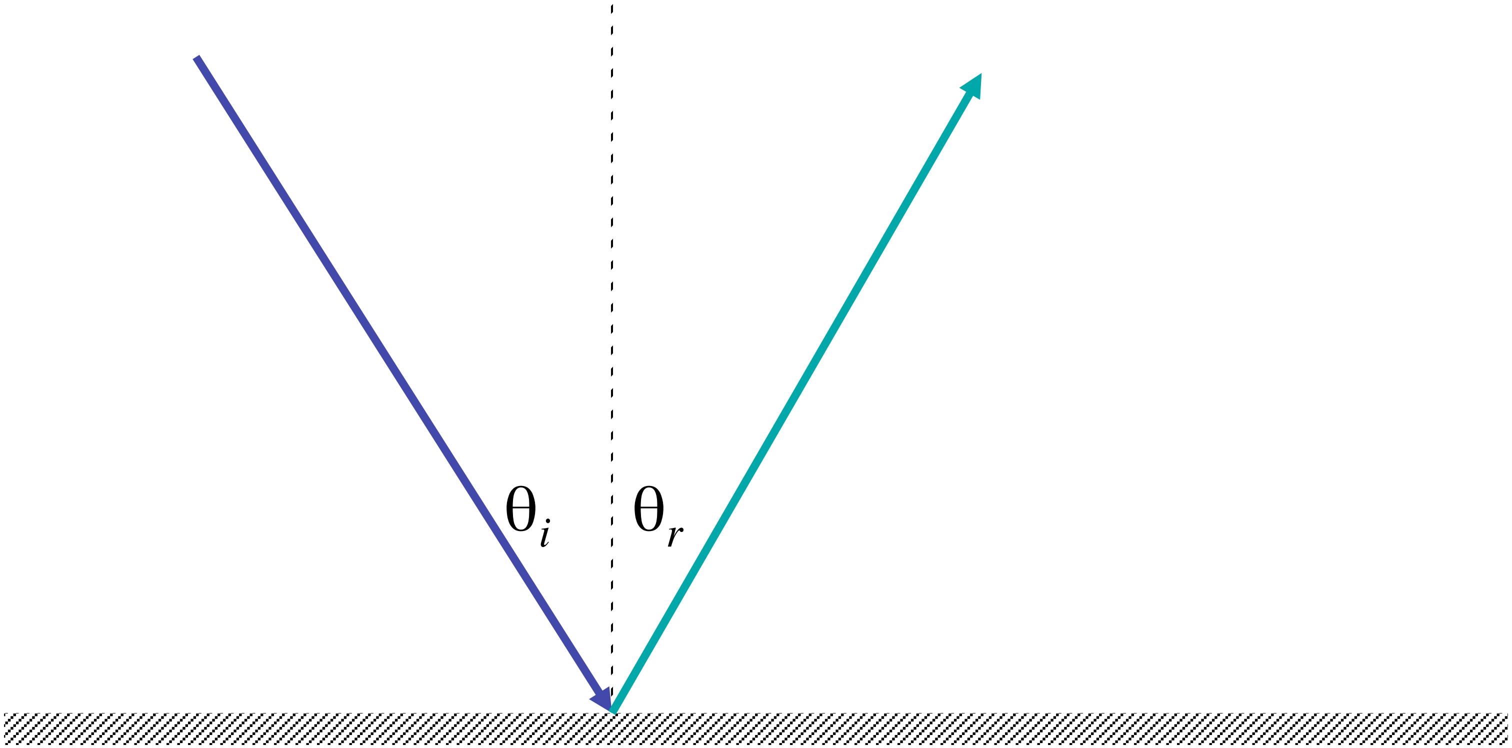
Doppler Effect



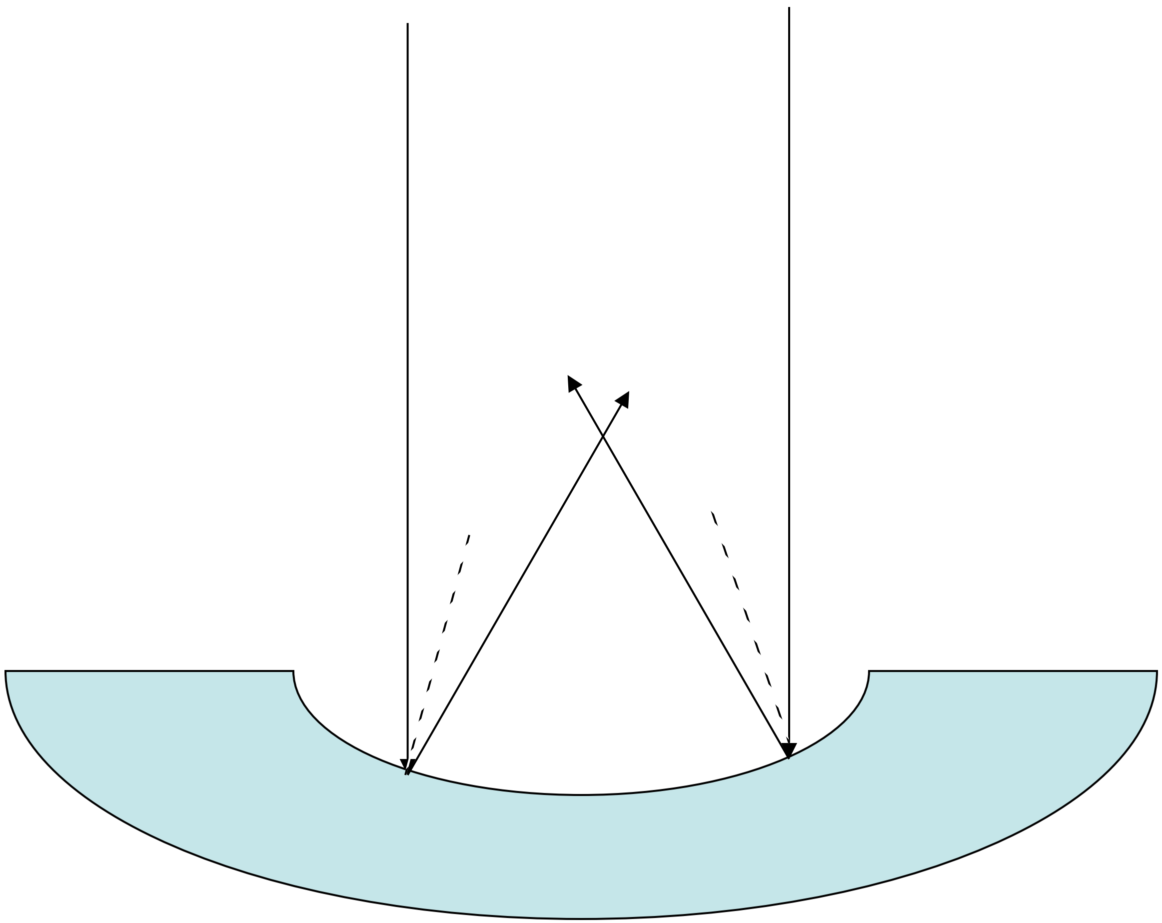
Law of Reflection

- Waves bounce off (reflect) following the law of reflection.
- The angle of incidence is equal to the angle of reflection.
- The angles are measured from the normal line.
- A normal line is defined as the line perpendicular (90 degrees) to the surface.

The law of reflection



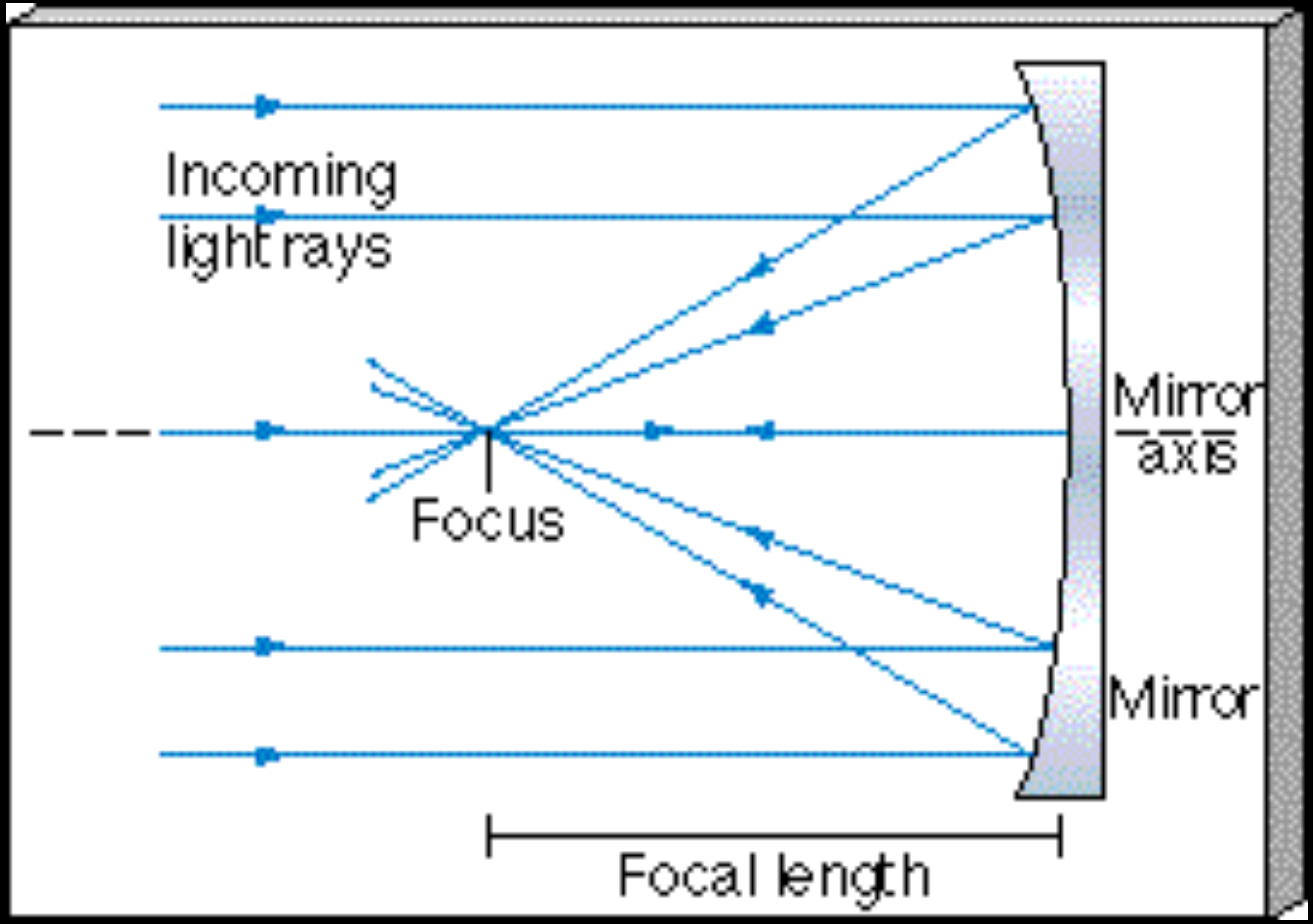
Curved Surfaces also follow the law of reflection



Concave mirrors

- Concave mirrors can gather and “focus” light.
- By gathering more light we have more light information.

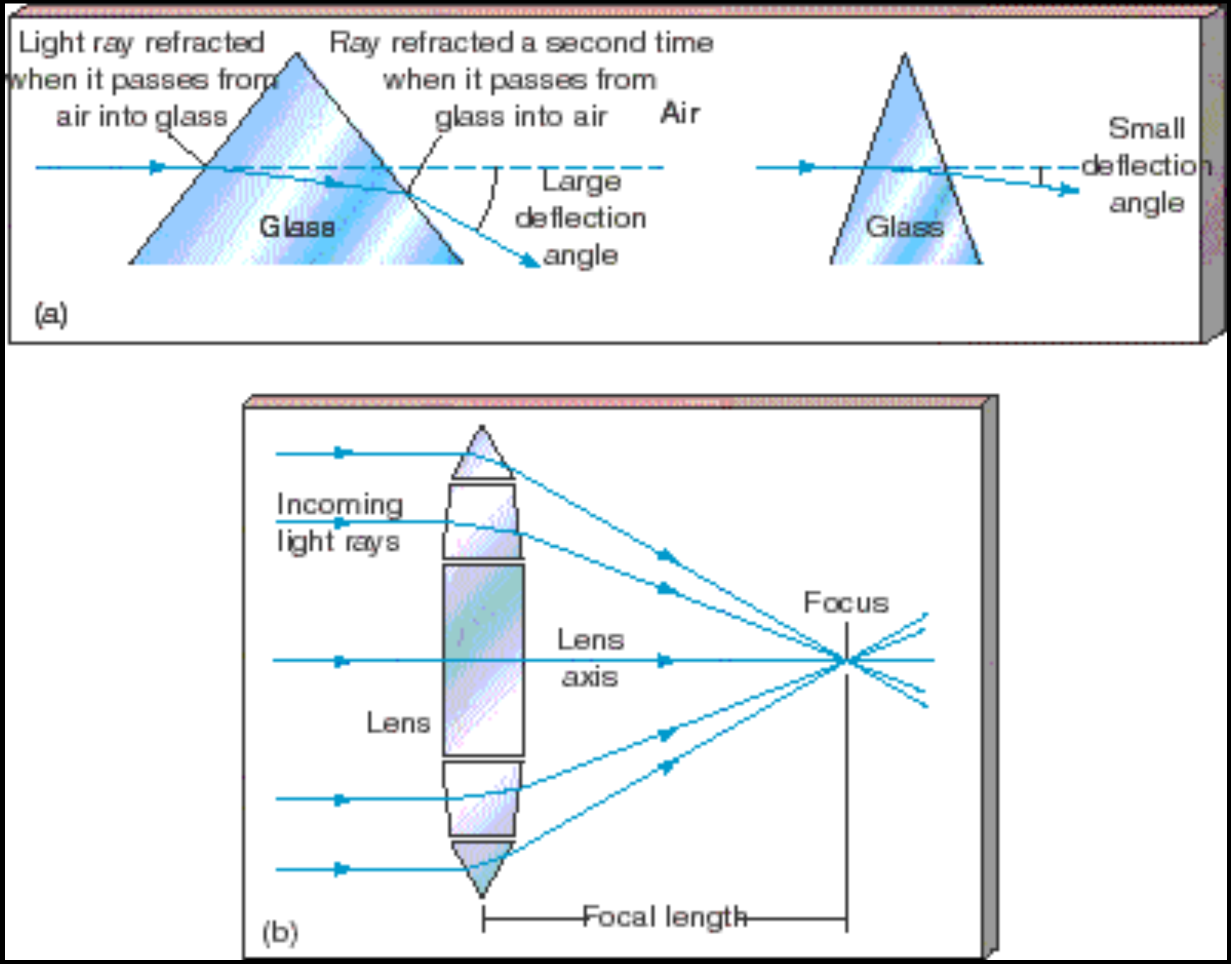
Reflector



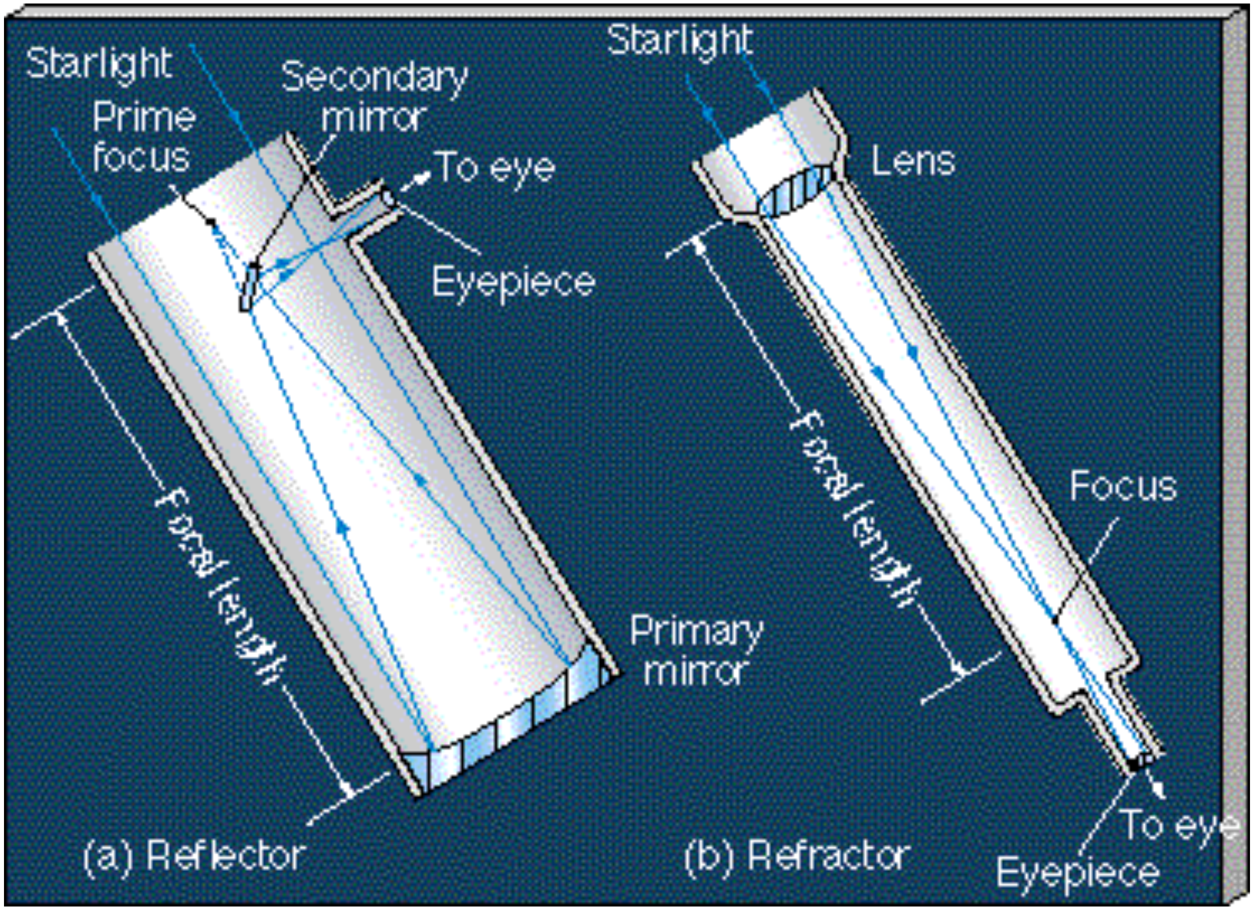
Light Refraction

- Waves bend when going from one kind of material into another because the speed of the wave changes.
- This bending of light can also be used to gather and “focus” light.
- The relationship follows Snell’s Law.
- $n_1 \sin\theta_1 = n_2 \sin\theta_2$

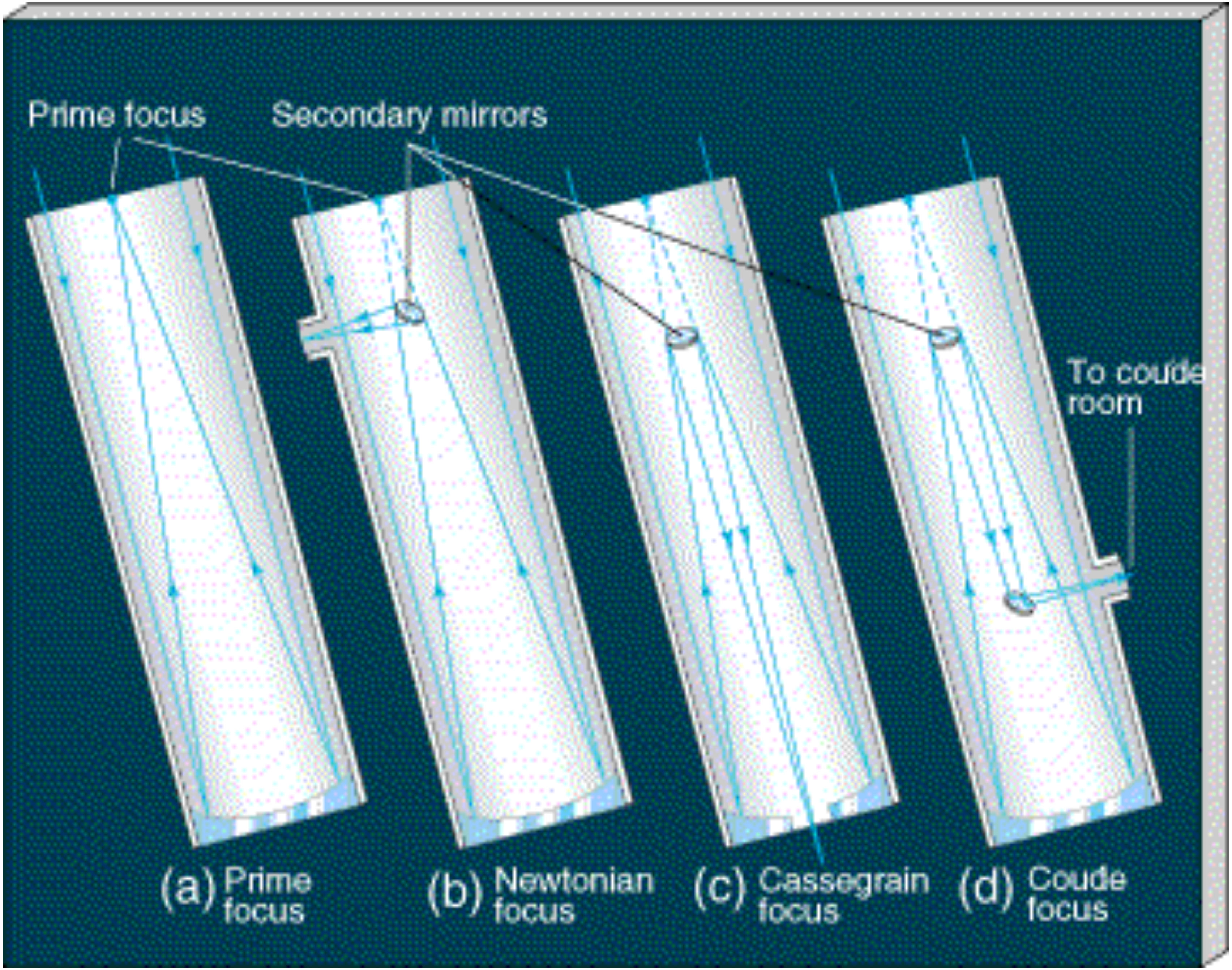
Refraction


Light ray refracted when it passes from air into glass
Ray refracted a second time when it passes from glass into air
Air
Glass
Large deflection angle
Glass
Small deflection angle
(a)
Incoming light rays
Lens
Lens axis
Focus
Focal length
(b)

Telescopes



Starlight
Prime focus
Secondary mirror
To eye
Eyepiece
Focal length
Primary mirror
(a) Reflector
Starlight
Lens
Focal length
Focus
To eye
Eyepiece
(b) Refractor



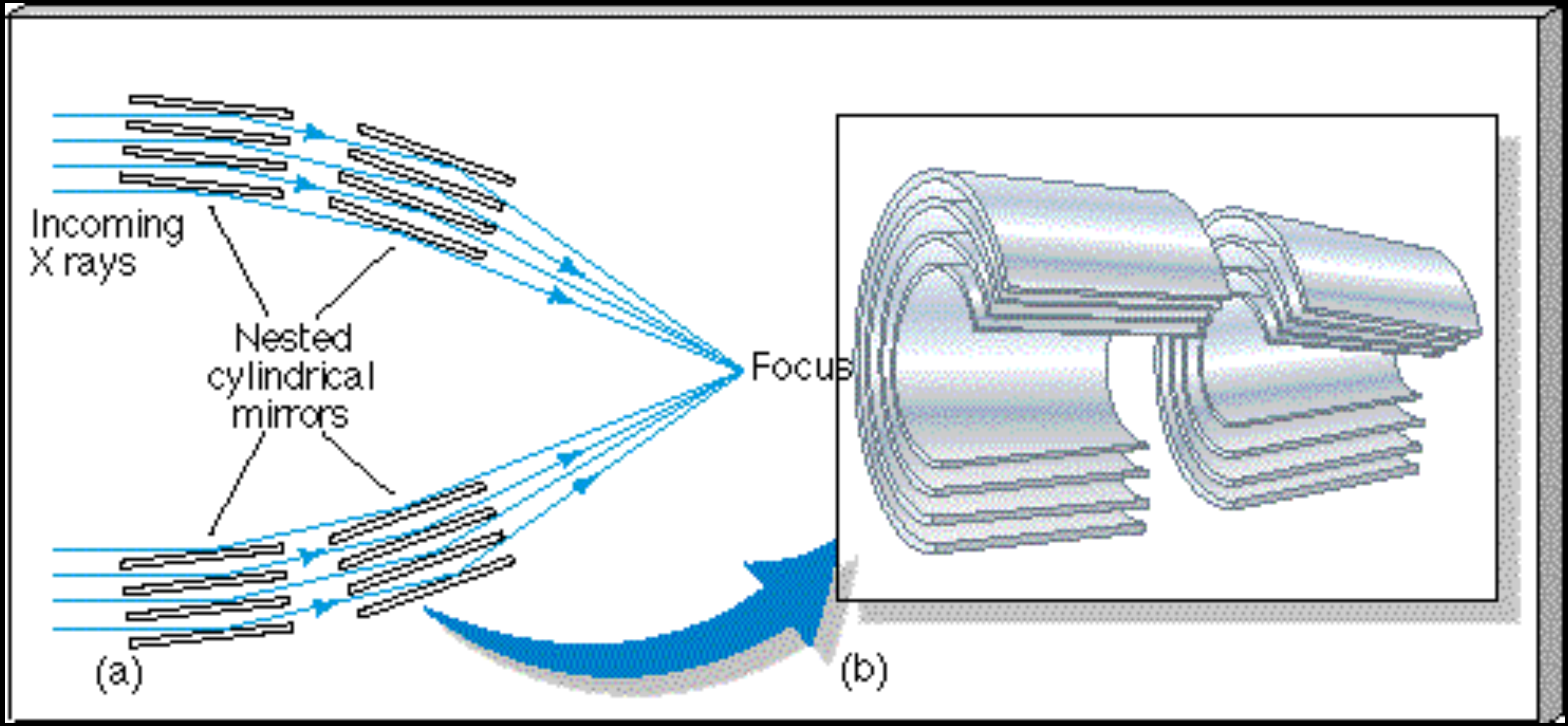
Prime focus
Secondary mirrors
To coude room
(a) Prime focus
(b) Newtonian focus
(c) Cassegrain focus
(d) Coude focus

Radio Telescopes

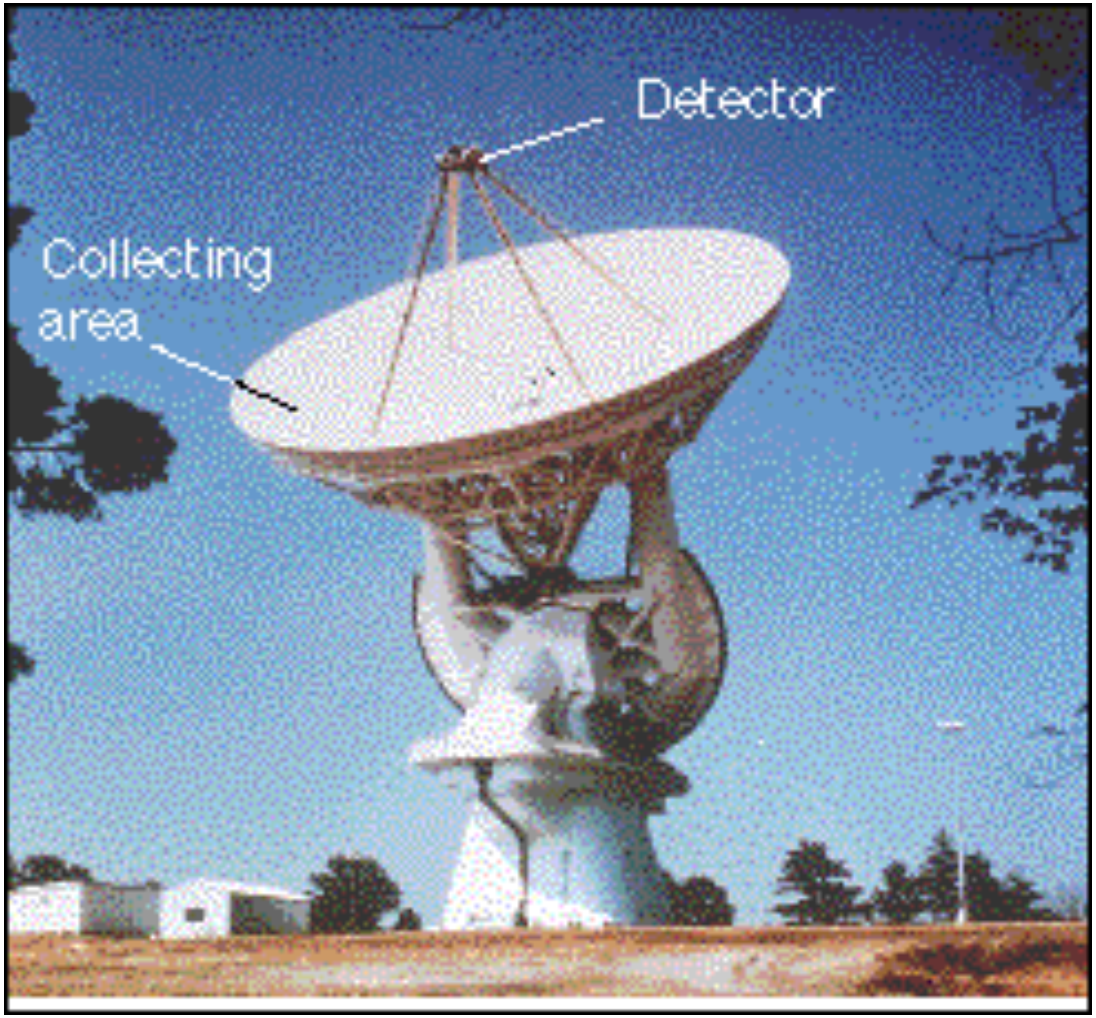
(a)

(b)

X-Ray Telescope



Radio Telescope



Purpose of Telescopes

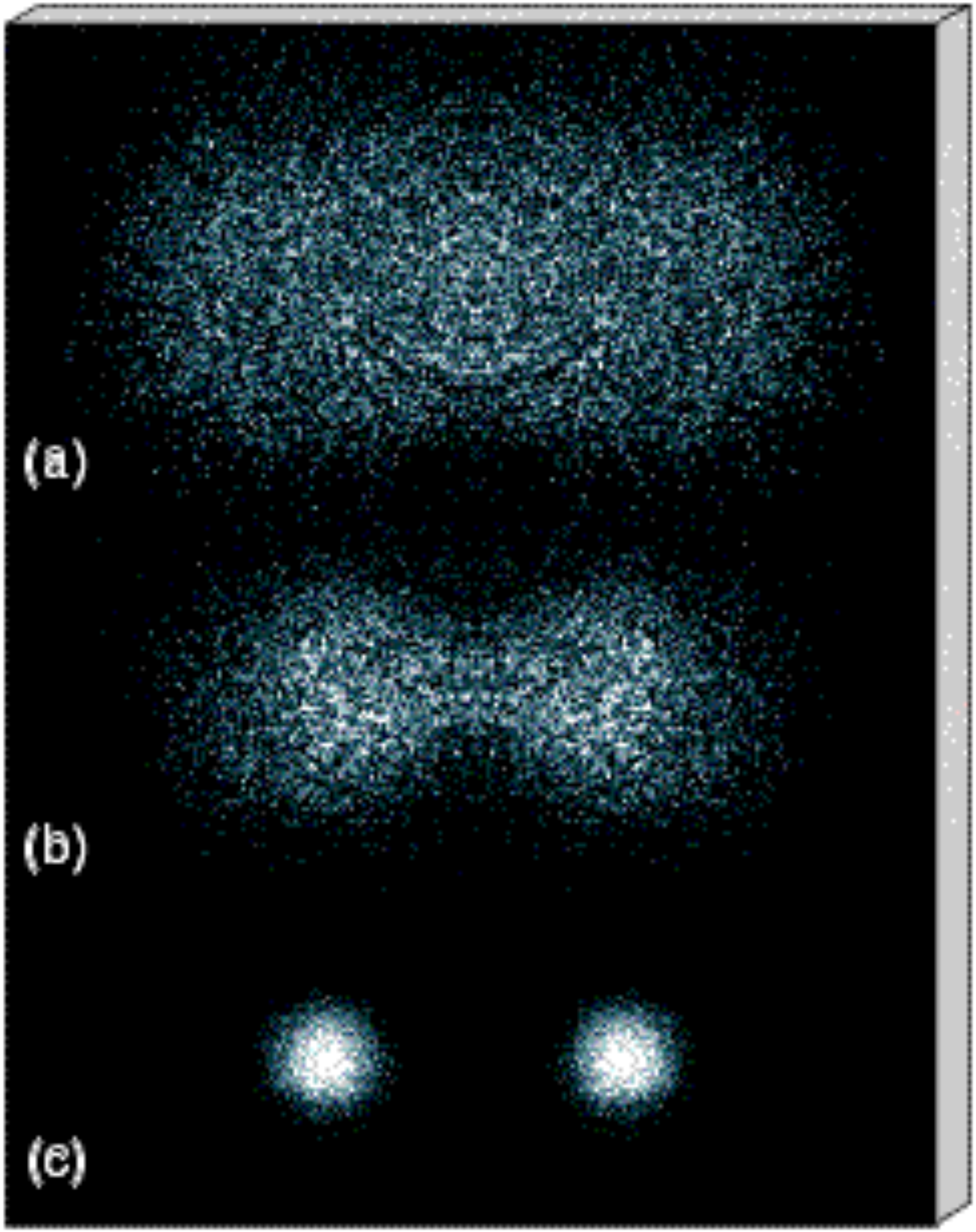
- The purpose of telescopes is to gather more light.
- While it is possible to enlarge or magnify images with mirrors and lenses for objects outside of our solar system the magnification does little to improve our information.
- To get more information we need more light.
- More light means bigger objectives on the telescope.

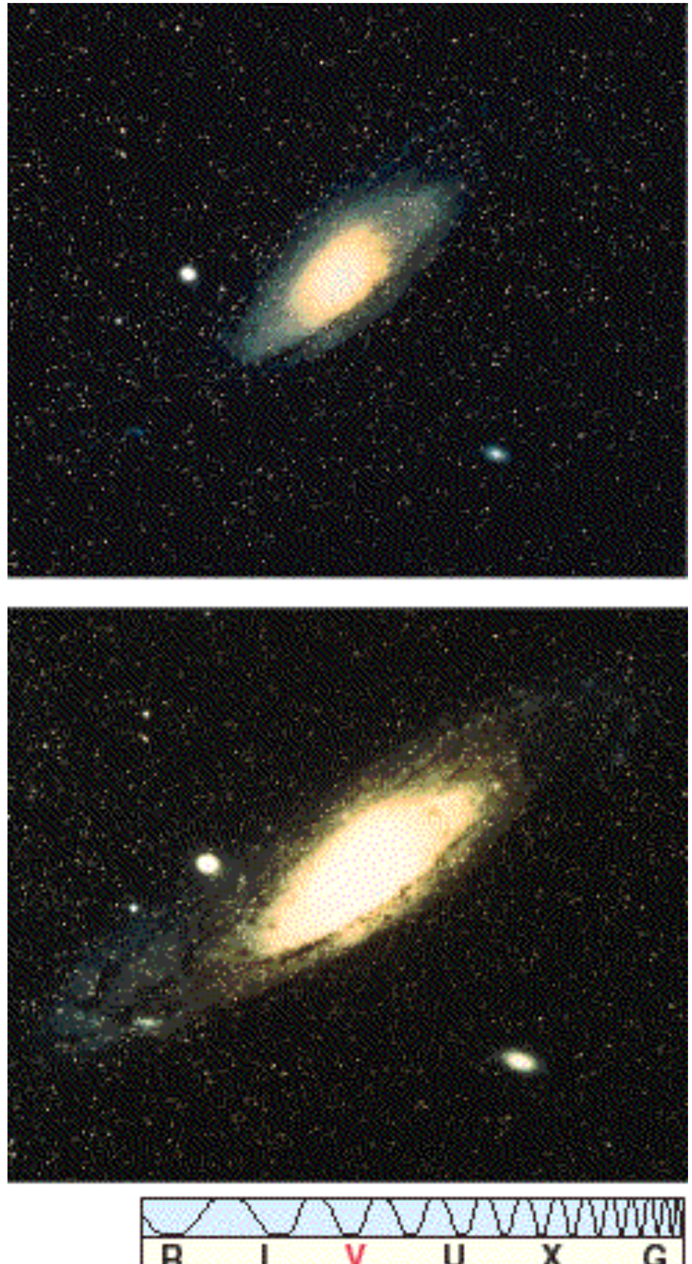
Telescope Resolution

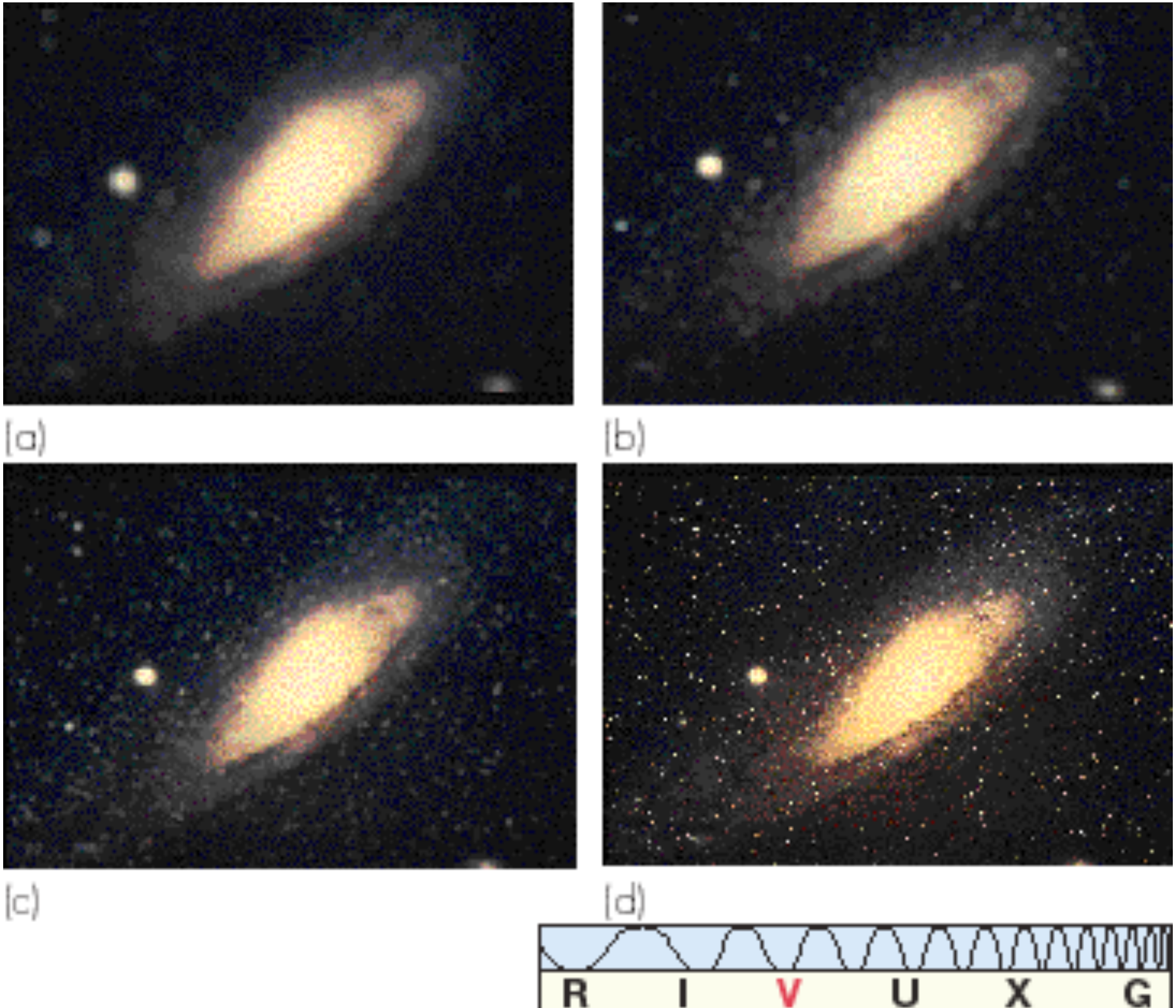
$$\text{angular resolution in arc seconds} = .25 \, \frac{\text{wavelength in } \mu\text{m}}{\text{telescope objective diameter in meters}}$$

1 meter = $1 \times 10^6 \, \mu$m

- The larger the diameter of the objective lens of a telescope the smaller the object it can "resolve".
- Resolution is the ability to form a distinct image.




R I V U X G


(a)
(b)
(c)
(d)
R I V U X G