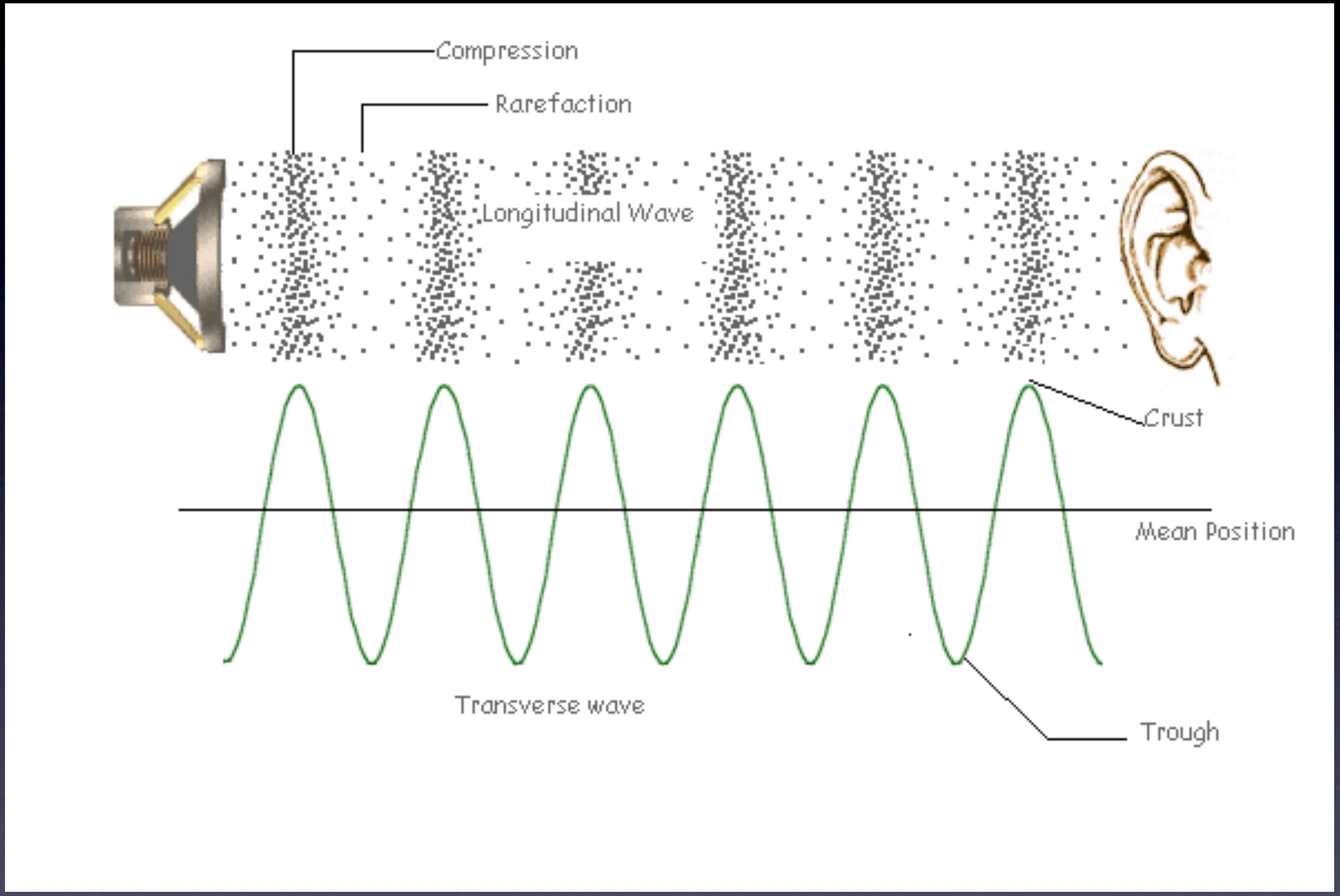
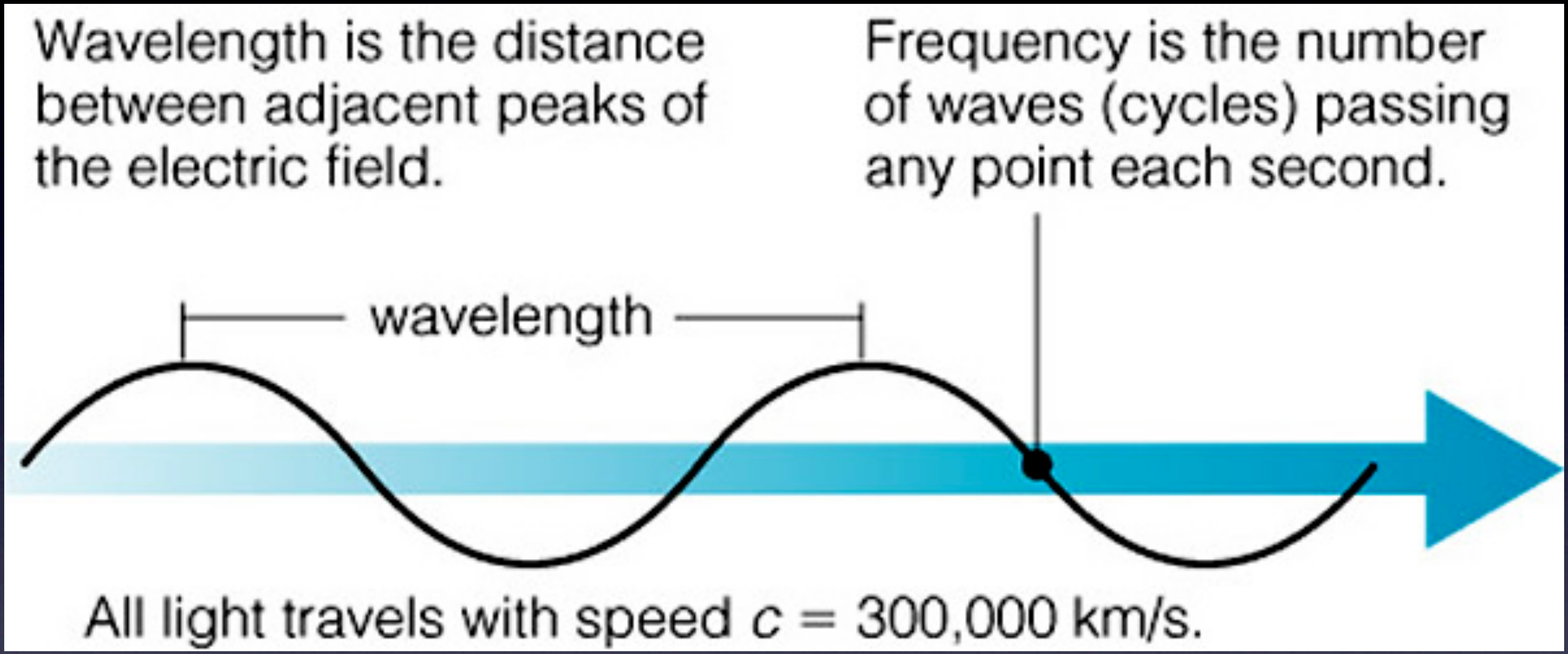
Light

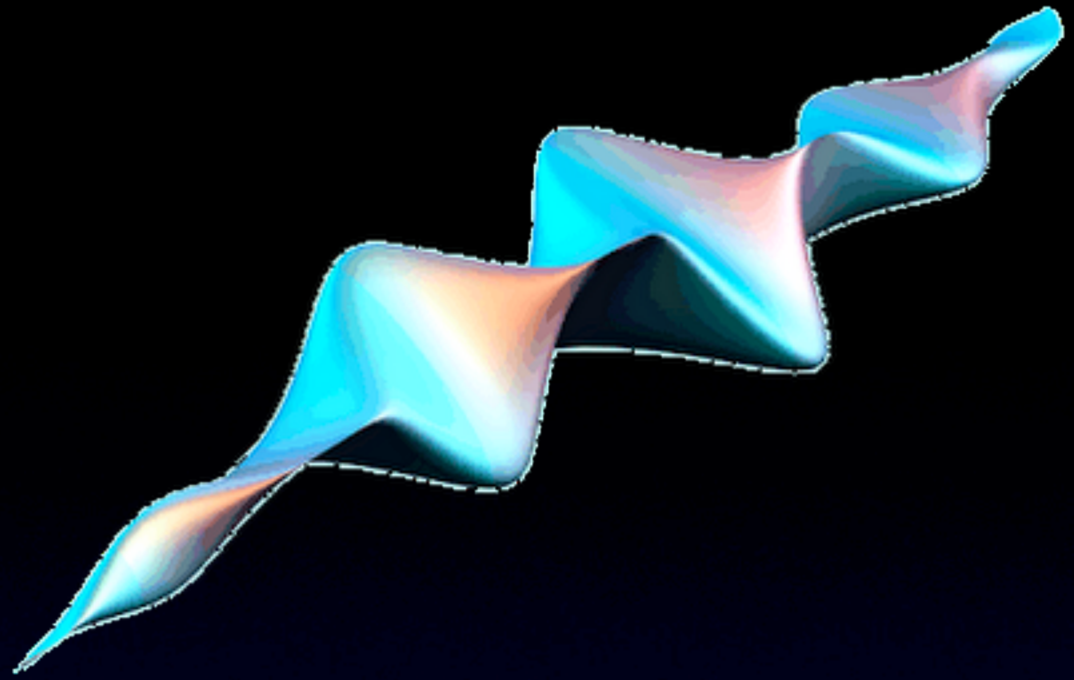
Longitudinal WAVES

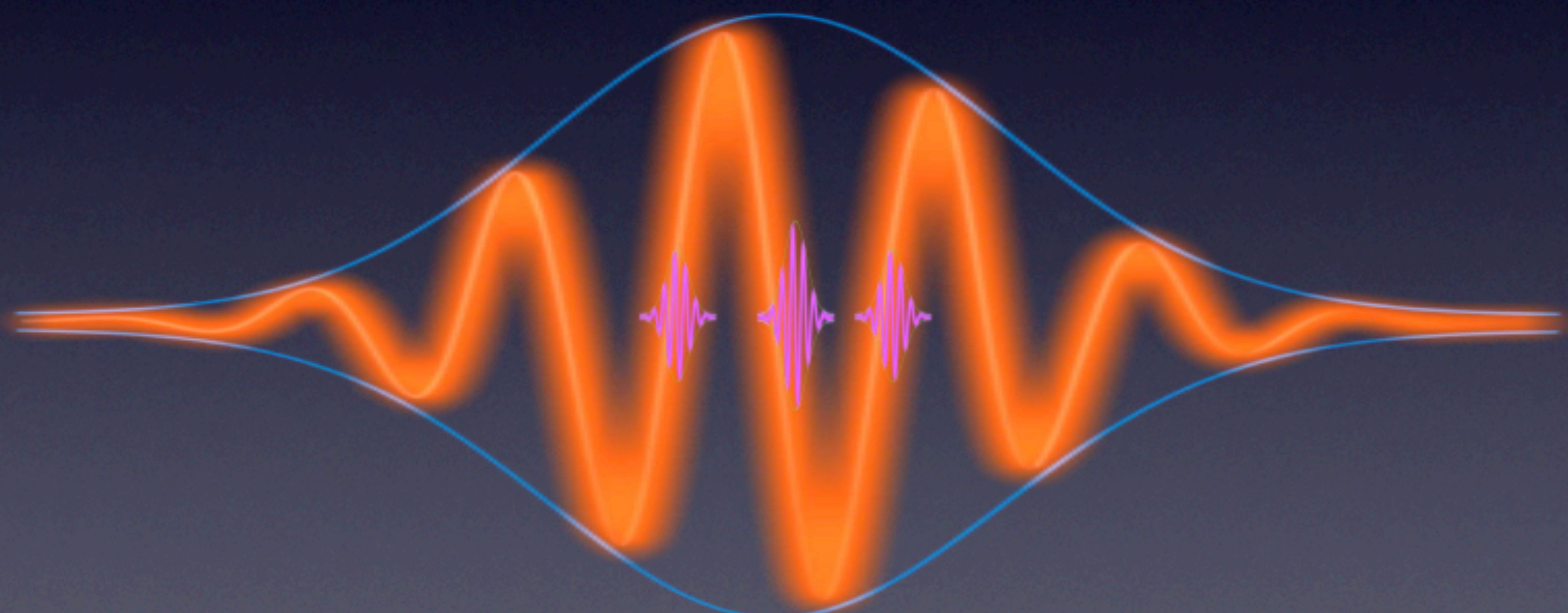


Light: Transverse WAVE



Light: Particle or wave
Photon





The Wave Nature of Light

1. Unlike other branches of science, astronomers cannot touch or do field work on their samples. The only information that we have is from the light that is imaged by our telescopes. Fortunately, light contains a wealth of physical information about the Universe.

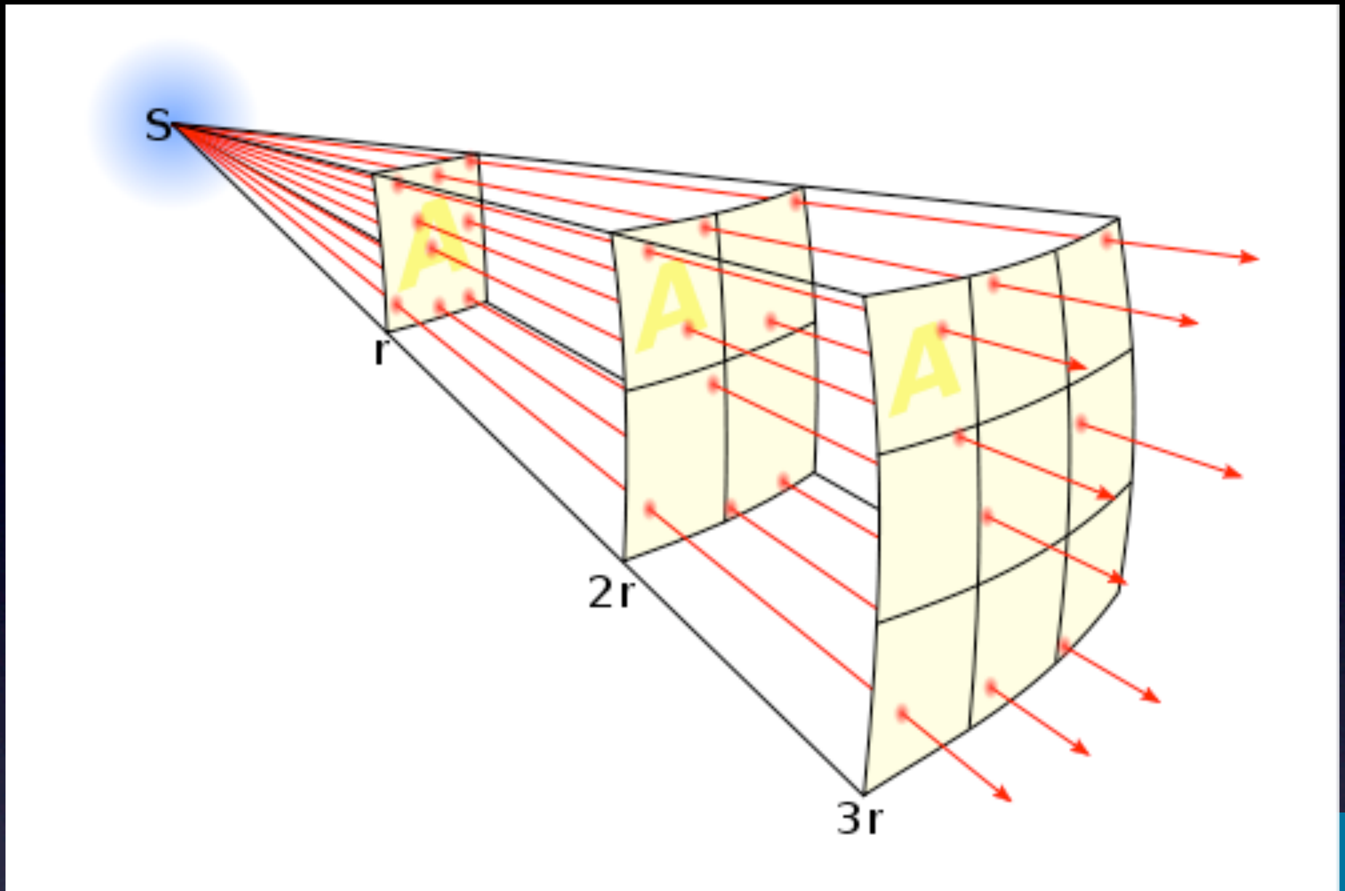
2. Light can be viewed as a traveling wave (like an ocean wave). It is made up of electric & magnetic fields so light is referred to as *electromagnetic radiation*.

3. The *wavelength* is the distance between wave crests (units are length). For optical light, a shorthand notation of *angstroms* (Å) is used such that 1 Å meters. So, visible wavelength light is about 5000 Å.

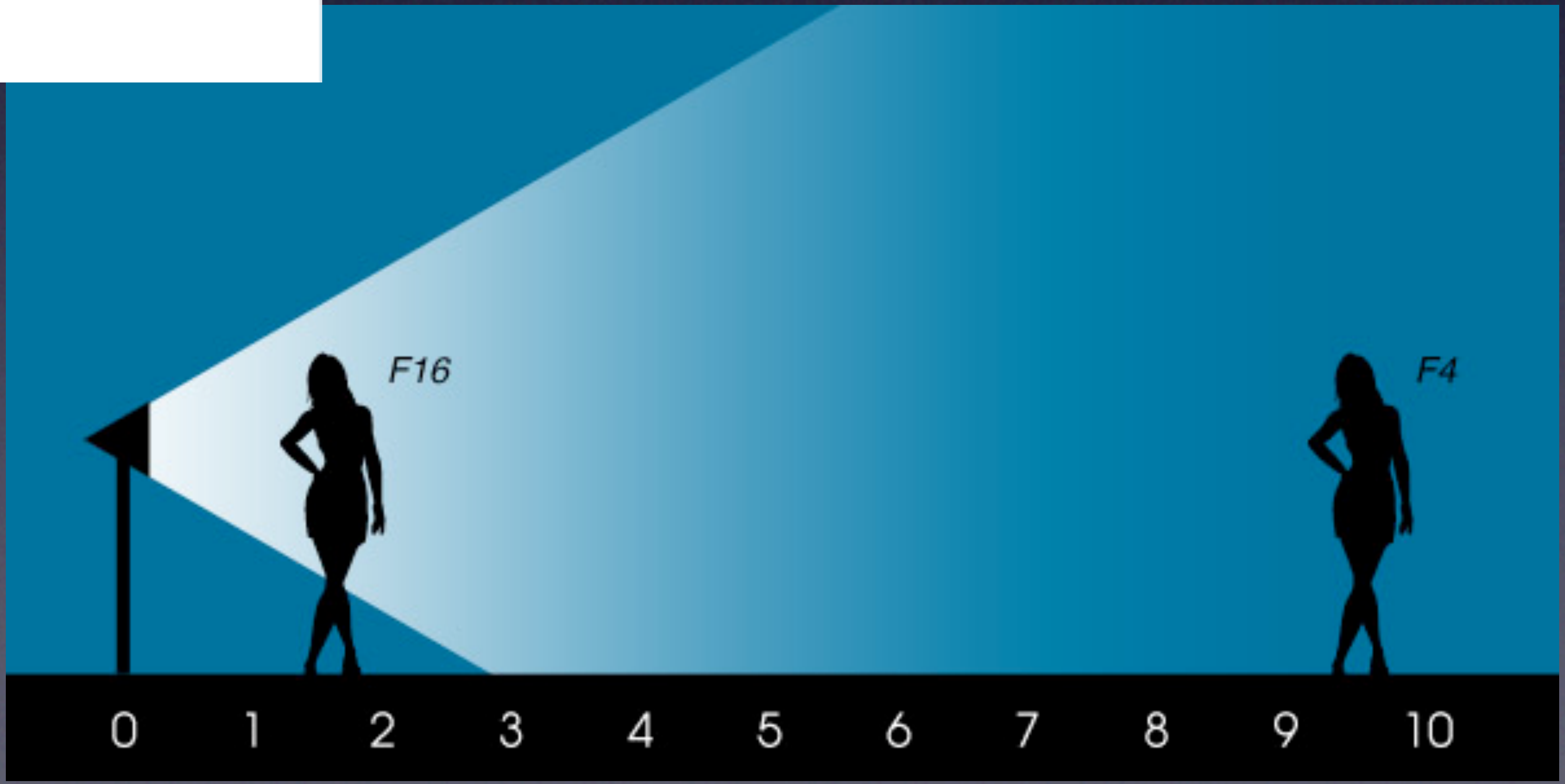
4. The *frequency* is the number of wave crests that pass by a detector per second of time. The units are *Hertz* (Hz), where 1 Hz is 1 cycle/sec. A typical radio frequency is 100 MHz (where MHz is a million Hz).

5. Light travels very fast at c = 300,000 km/sec. This speed is constant throughout space for all wavelengths.

Inverse Square Law: Intensity declines with the distance from the source of light



$$1/R^2$$



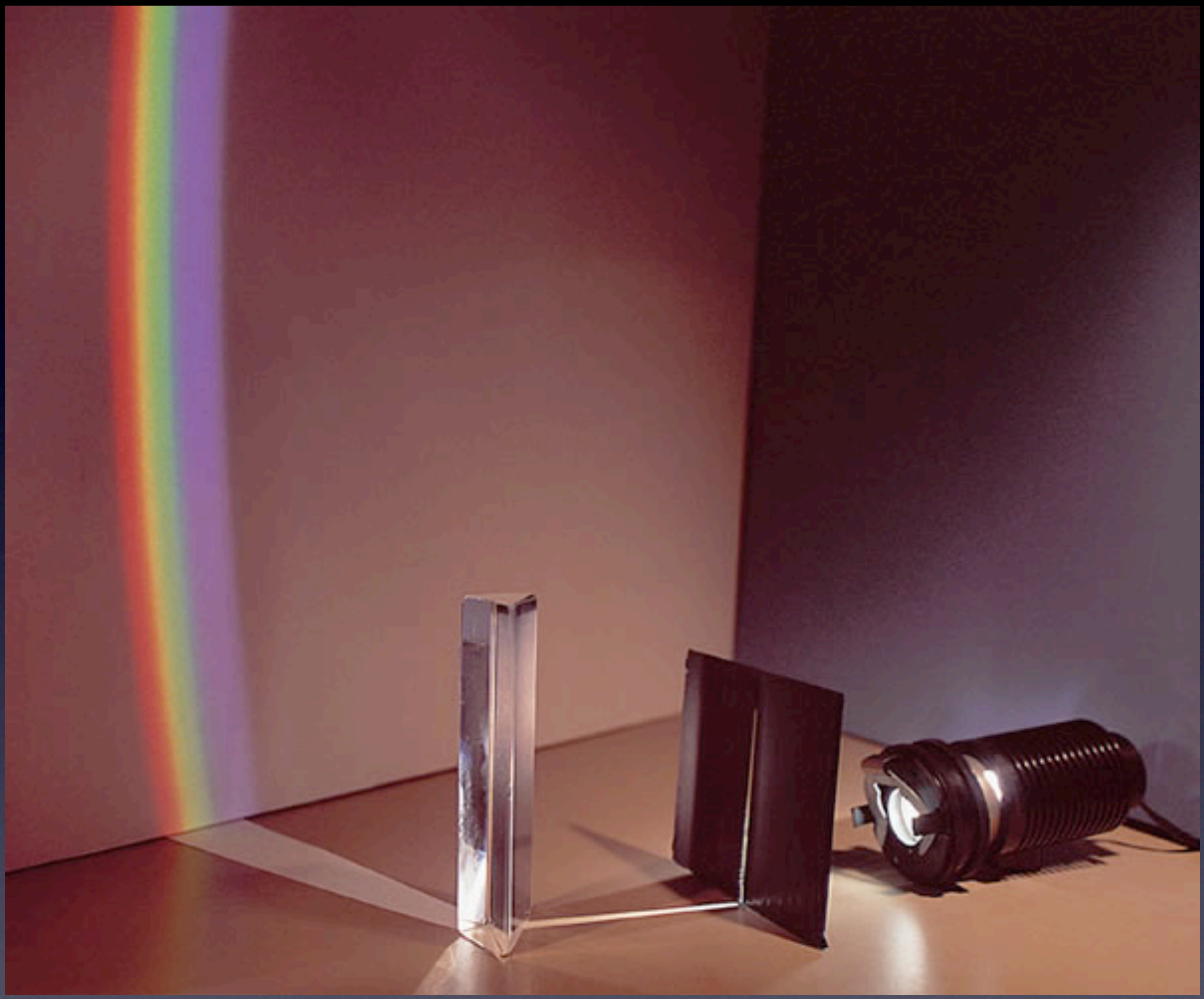
The Inverse Square Law

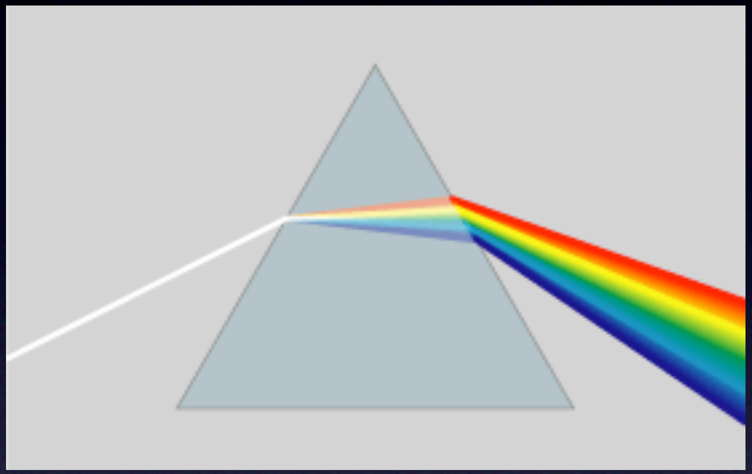
1. When we look at the night sky, we see that all stars are not the same color or brightness. ***Brightness*** is the amount of energy per second per area that falls on a detector such as a photographic plate or on the retina of our eyes. Brightness depends upon two factors:
   - The total energy per second or ***luminosity*** emitted by a star or other object. For example, a 200 Watt light bulb appears brighter than a 100 Watt light bulb if they are side by side.
   - The distance of the light source from the observer. The further away the light source, the less bright it appears.

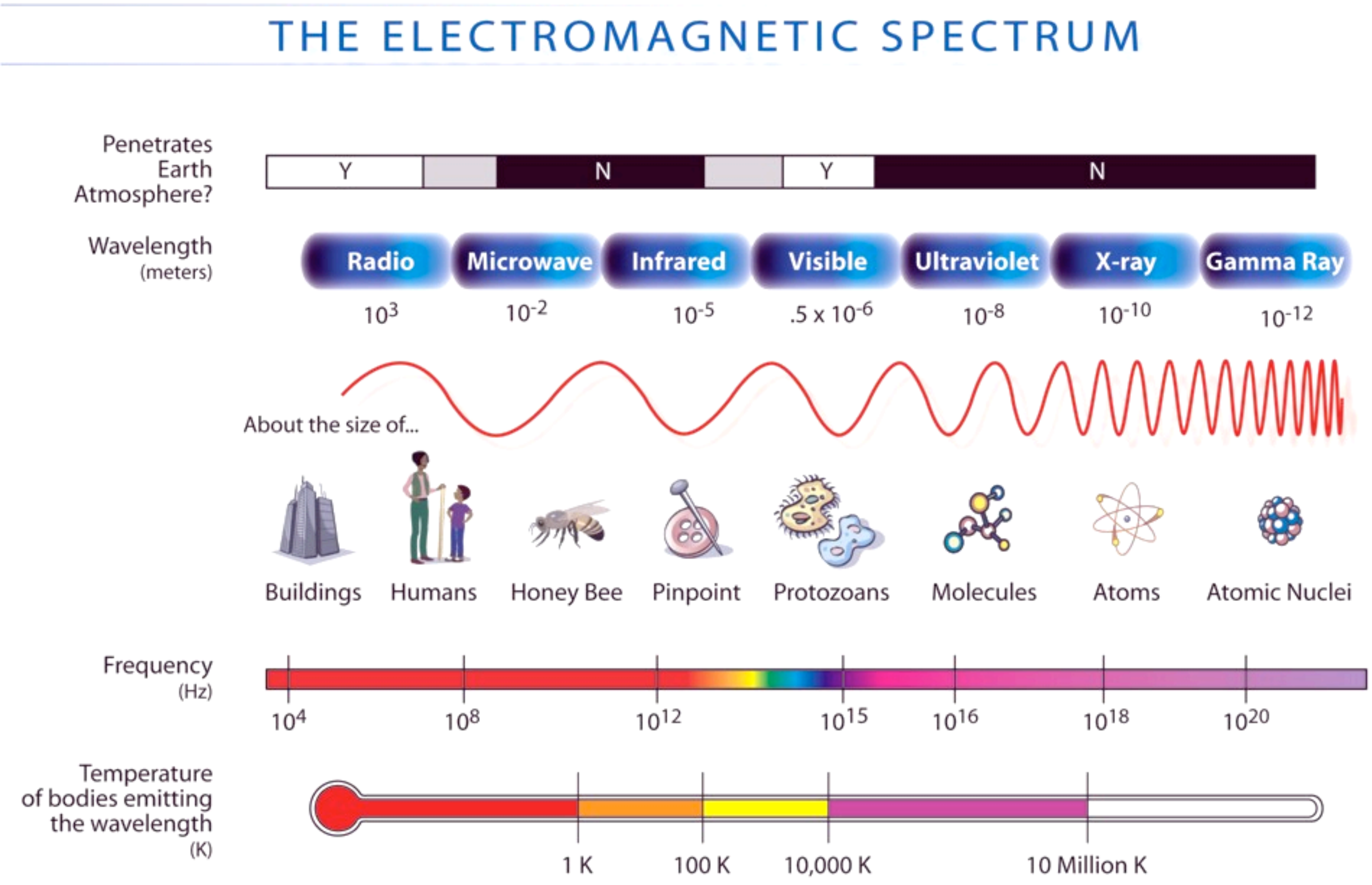
2. This dependence of brightness upon distance is called the *Inverse Square Law*. Once again, it is very much like the Gravity Force Law in that the brightness of a light source is proportional to $1/R^2$, where R is the distance between the light source and the observer.

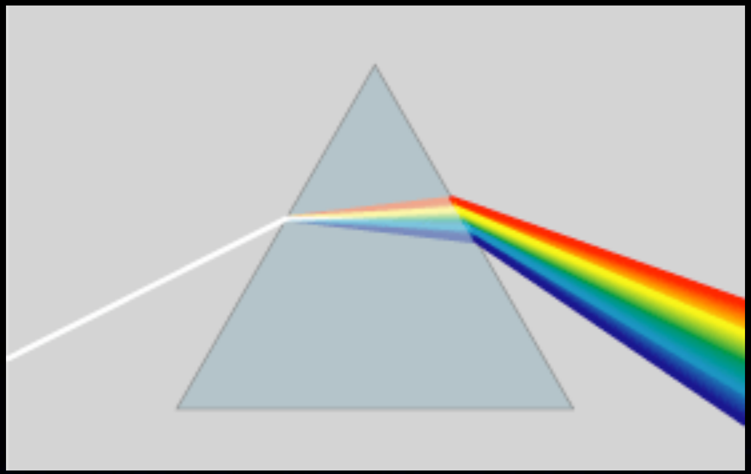
3. So, when we look at a star, it may be faint because it is far away or it is low luminosity or a combination of the two.

Electromagnetic Spectrum



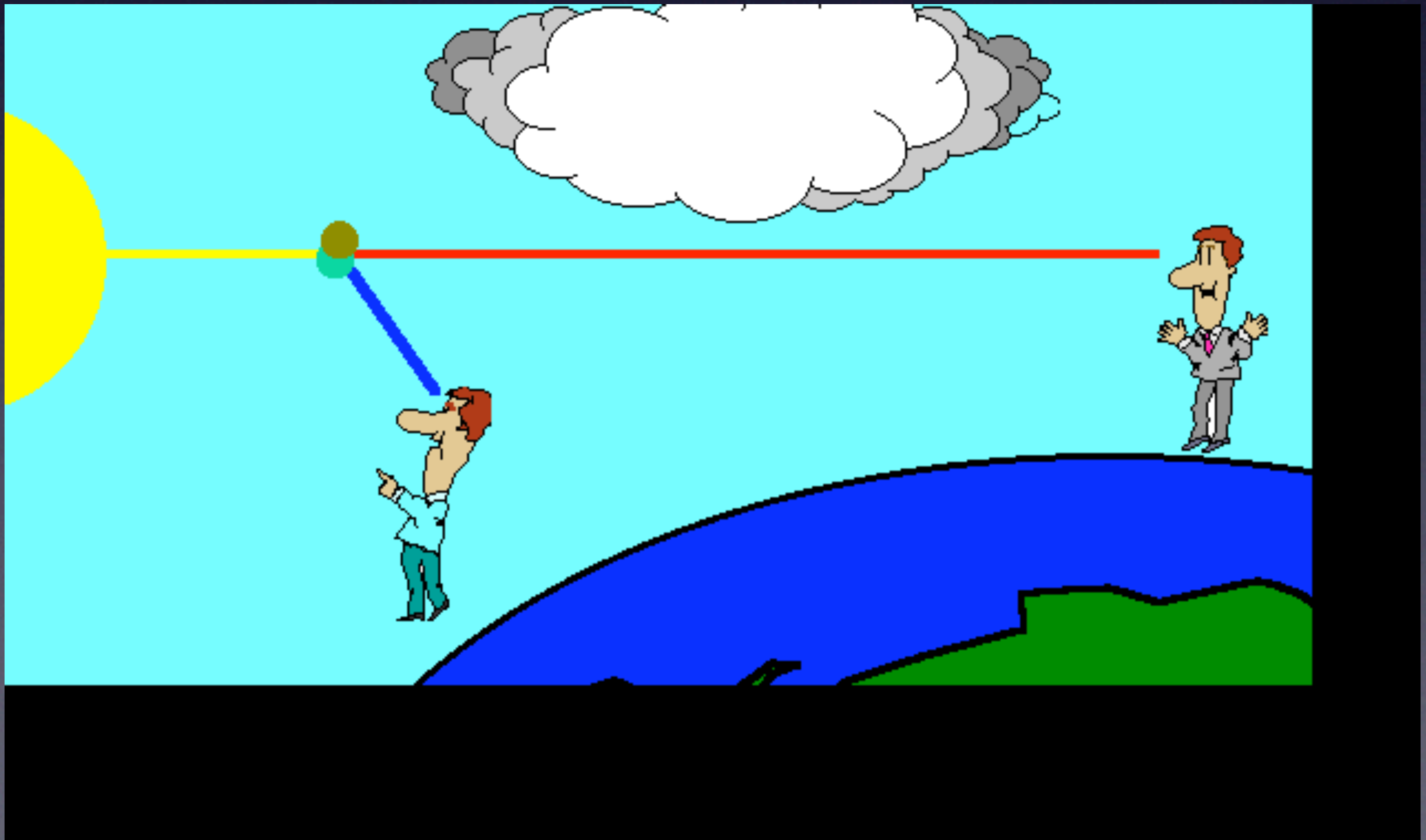


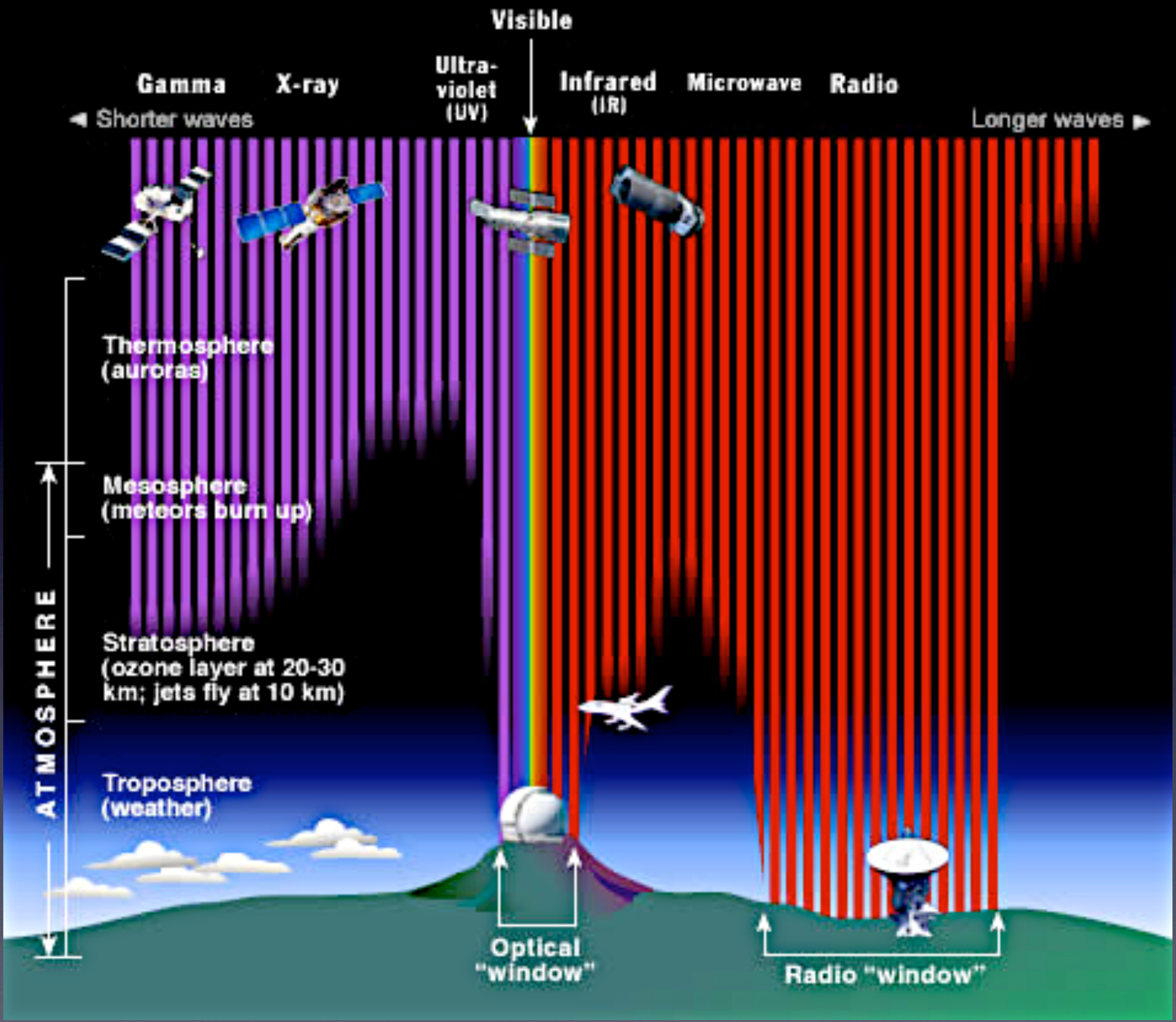

THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K



Short (blue) waves are deflected more than red ones

This is the reason why the sky is blue and sunset is red





Visible
Gamma
X-ray
Ultra-
violet
(UV)
Infrared
(IR)
Microwave
Radio
◄ Shorter waves
Longer waves ►
Thermosphere
(auroras)
Mesosphere
(meteors burn up)
Stratosphere
(ozone layer at 20-30
km; jets fly at 10 km)
Troposphere
(weather)
ATMOSPHERE
Optical
"window"
Radio "window"

The Electromagnetic Spectrum

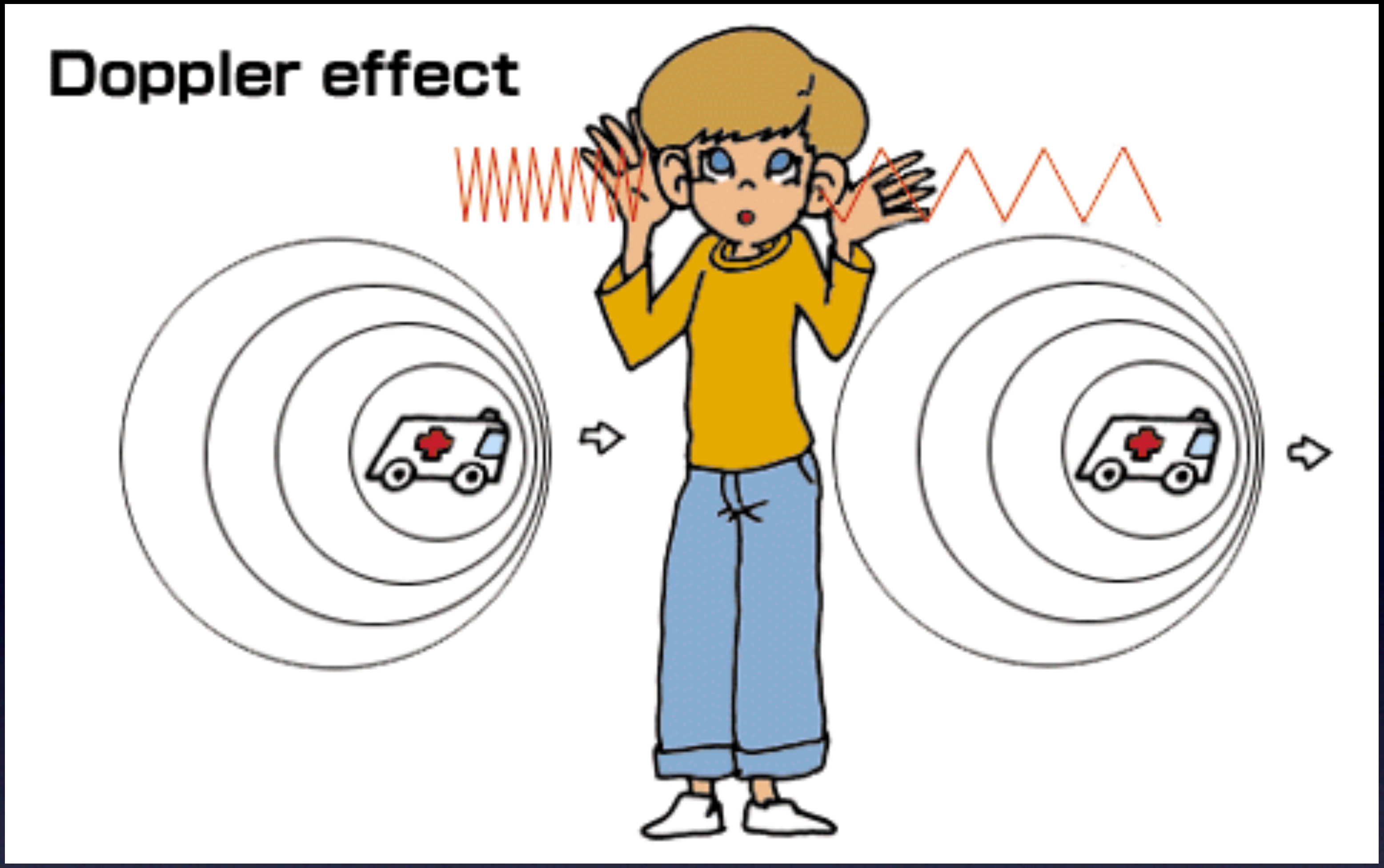
- In the visible, the rainbow of colors make up the spectrum. *Color is the same as wavelength*. Blue light has the shortest wavelength and red light has the longest.

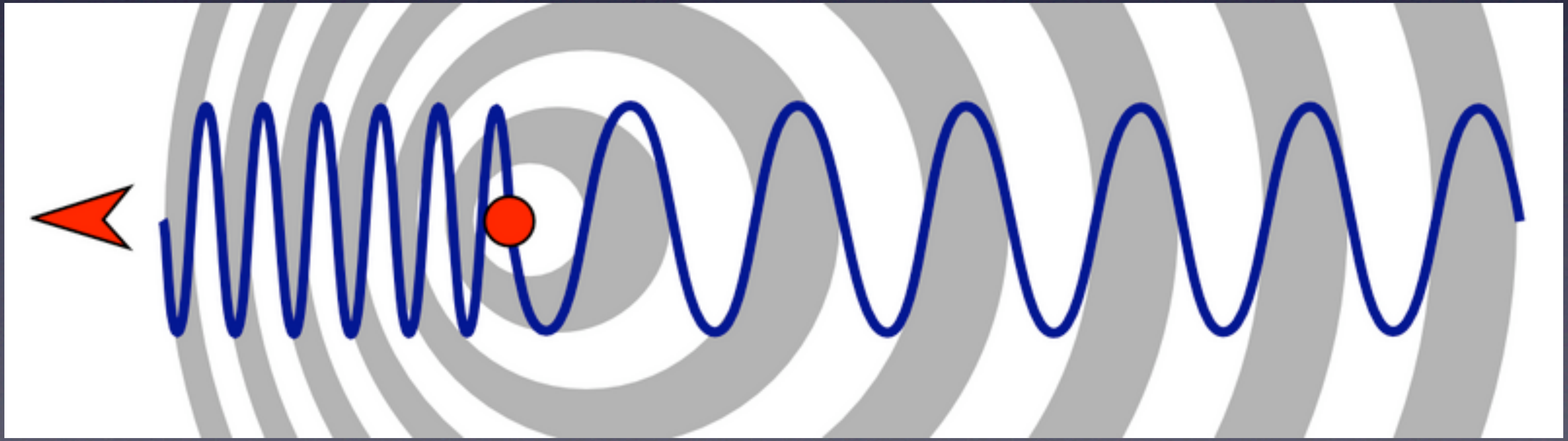
- The only difference between various parts of the electromagnetic spectrum (such as radio and x-rays) is the wavelength. In order of increasing wavelength: gamma-rays, x-rays, ultraviolet, visible, infrared, and radio. Gamma-rays have wavelengths Å and radio waves have wavelengths of meters.

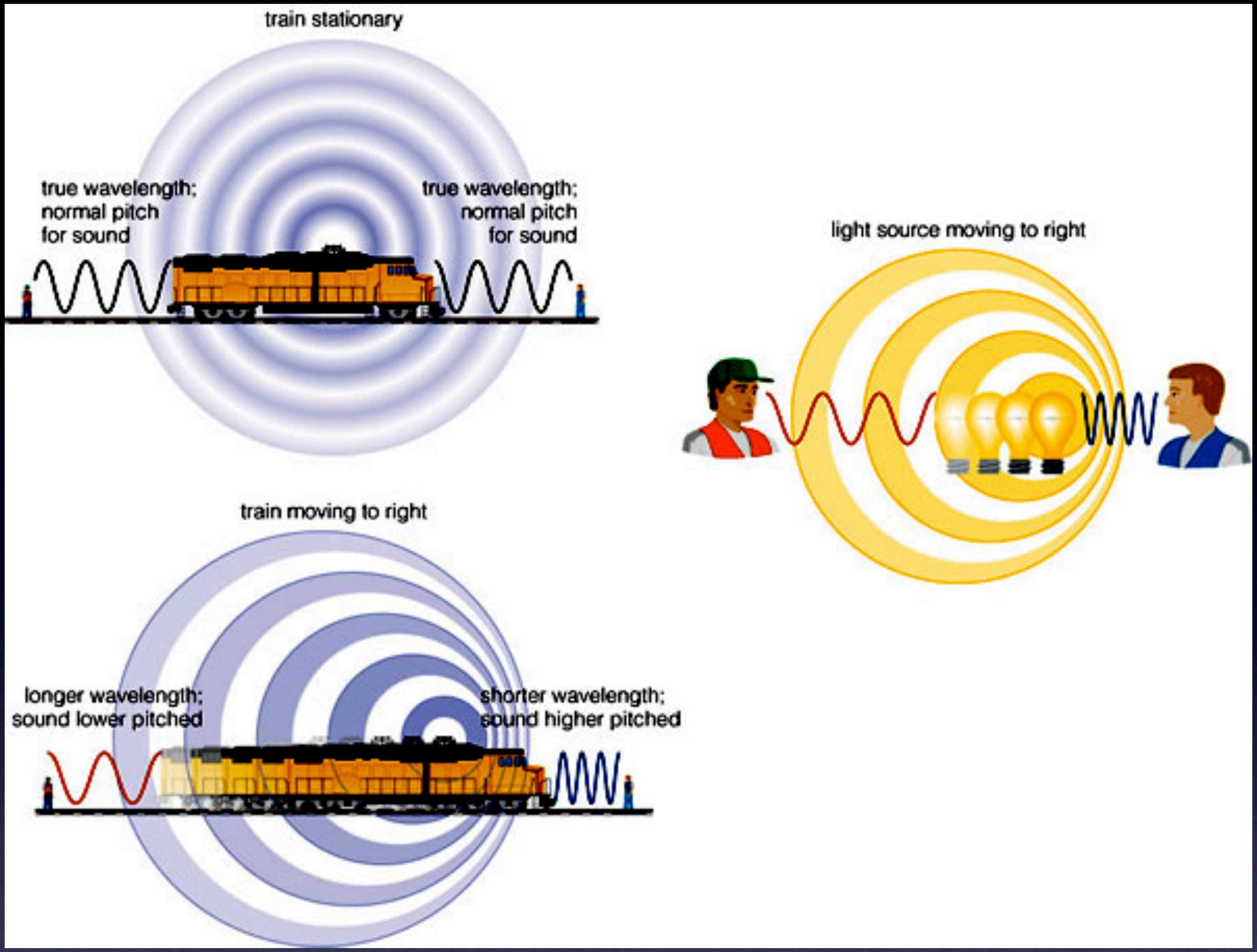
- The atmosphere is mostly opaque to the electromagnetic spectrum. Only visible and radio waves easily penetrate the atmosphere with a bit of ultraviolet & infrared as well. This means ground-based telescopes operate in the visible & the radio, whereas space-based telescopes (above the atmosphere) function at other wavelengths.

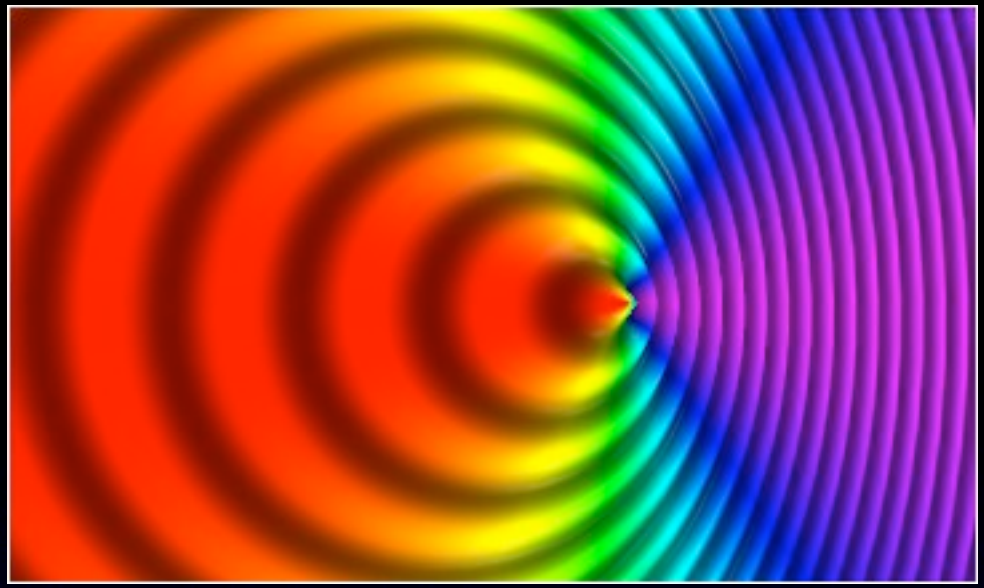
The Doppler Effect

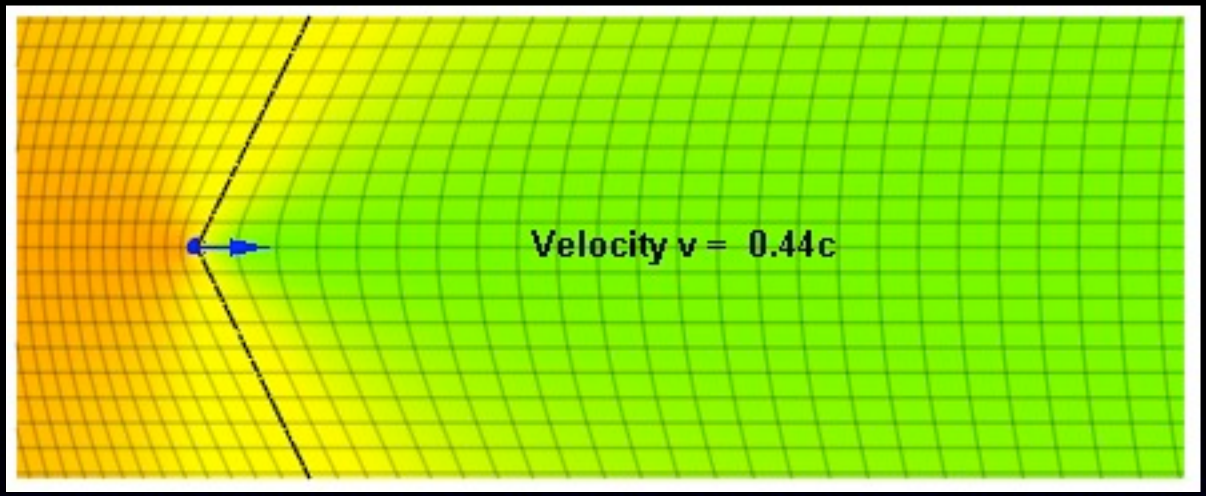
- The *Doppler Effect* is the shift of the wavelength of light produced by motion of an object toward or away from us. We experience a similar effect with sound when a train approaches us & then moves away from us - the pitch or the wavelength of the sound changes.

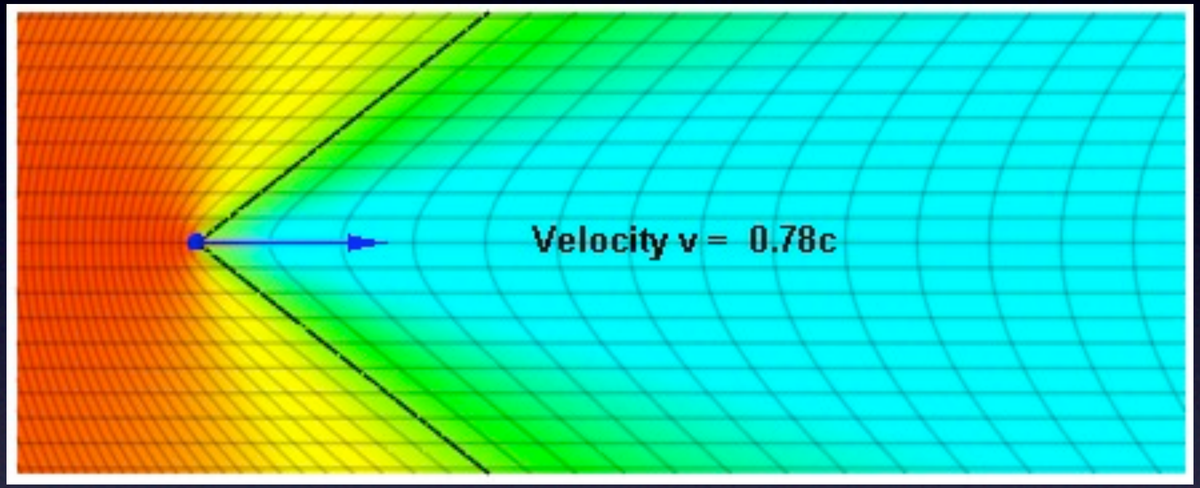

Doppler effect



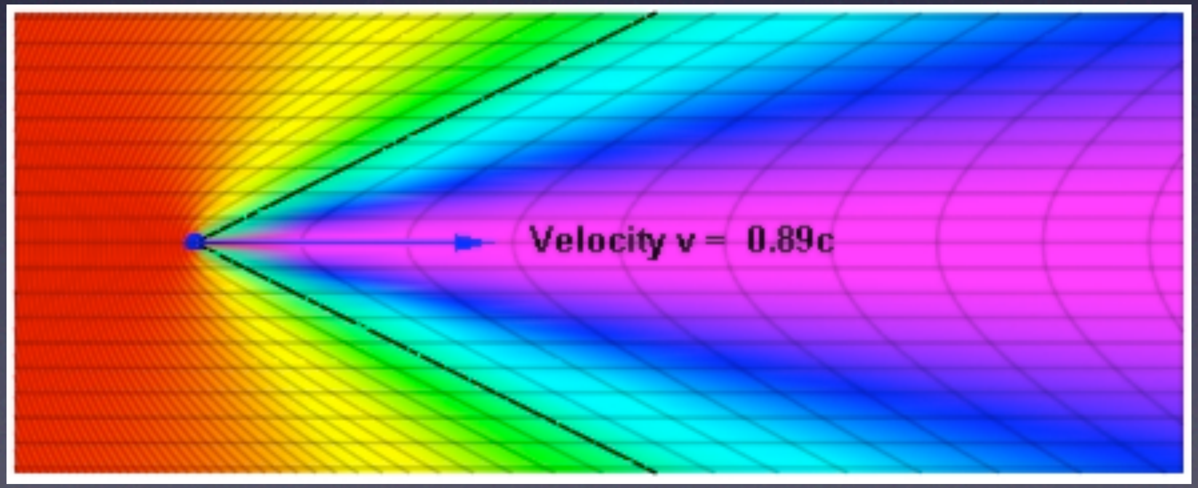

train stationary
true wavelength;
normal pitch
for sound
true wavelength;
normal pitch
for sound
light source moving to right
train moving to right
longer wavelength;
sound lower pitched
shorter wavelength;
sound higher pitched



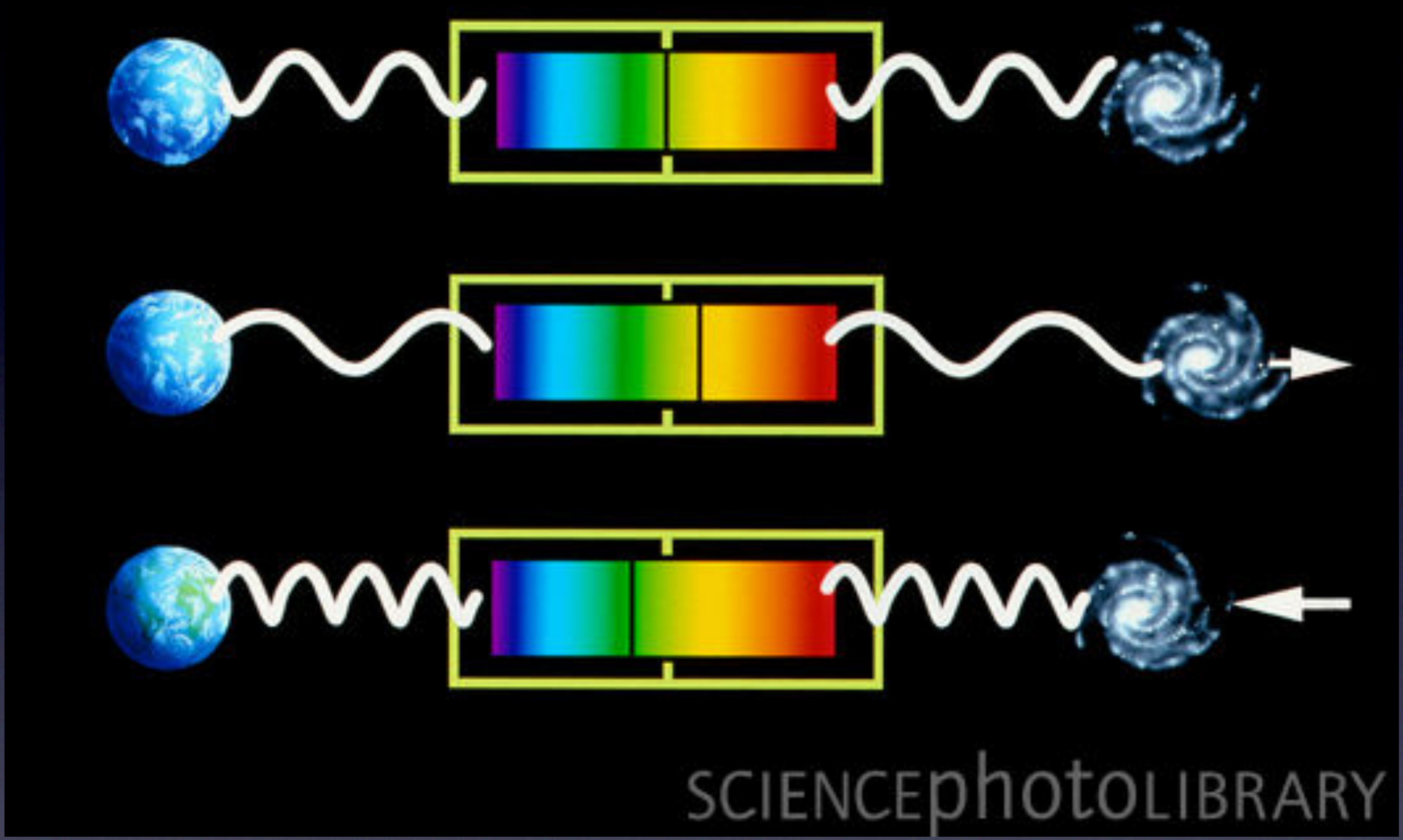


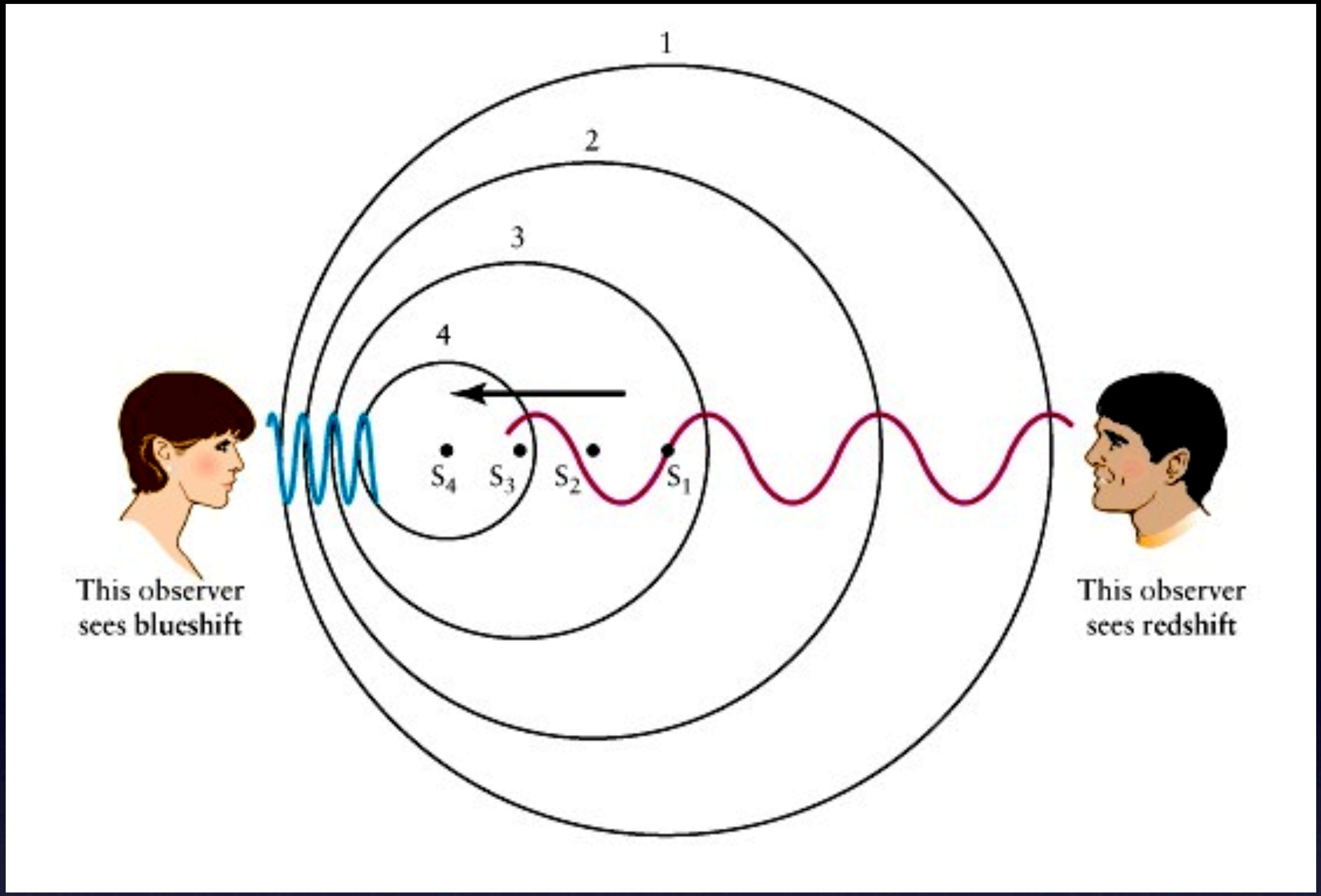


In this diagram, the blue point represents the observer. The x,y-plane is represented by yellow graph paper. As the observer accelerates, he sees the graph paper change colors. Also he sees the distortion of the x,y-grid due to the aberration of light. The black vertical line is the y-axis. The observer accelerates along the x-axis.



Relativistic Doppler Effect


SCIENCEphotoLIBRARY



$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

The Doppler Effect

- The *Doppler Effect* is the shift of the wavelength of light produced by motion of an object toward or away from us. We experience a similar effect with sound when a train approaches us & then moves away from us - the pitch or the wavelength of the sound changes.

- The change in the wavelength between that observed for a moving object and that measured when the light source is at rest is directly proportional to the wavelength. For stars **moving away from us**, the wavelength change is toward the red and is called a *redshift*. For stars **moving toward us**, it is a **blueshift**.

- The Doppler Effect provides astronomers with a powerful **tool for measuring radial velocities** of planets, stars, & galaxies. All we need to do is measure the difference between the observed wavelength and the wavelength measured in the laboratory.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$