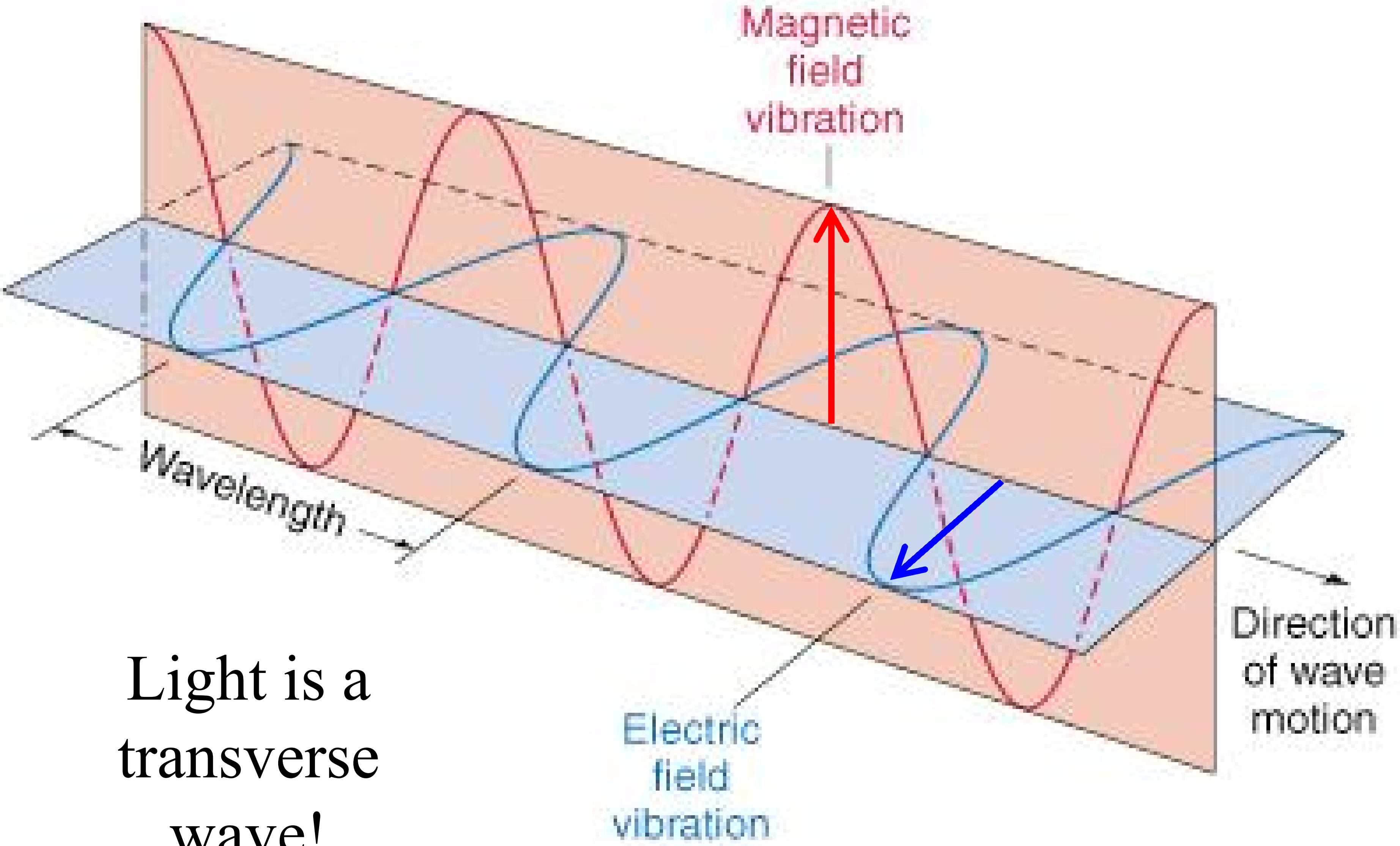
Electromagnetic Radiation

EMR

What *is* Light?

- Visible light is one example of what scientists call electromagnetic radiation.
- It is called this because its medium consists of oscillating electric and magnetic fields.
- An electron or proton will experience force when subject to fields such as these.
- Therefore light can be viewed as a disturbance of electric and magnetic force.



Light is a
transverse
wave!

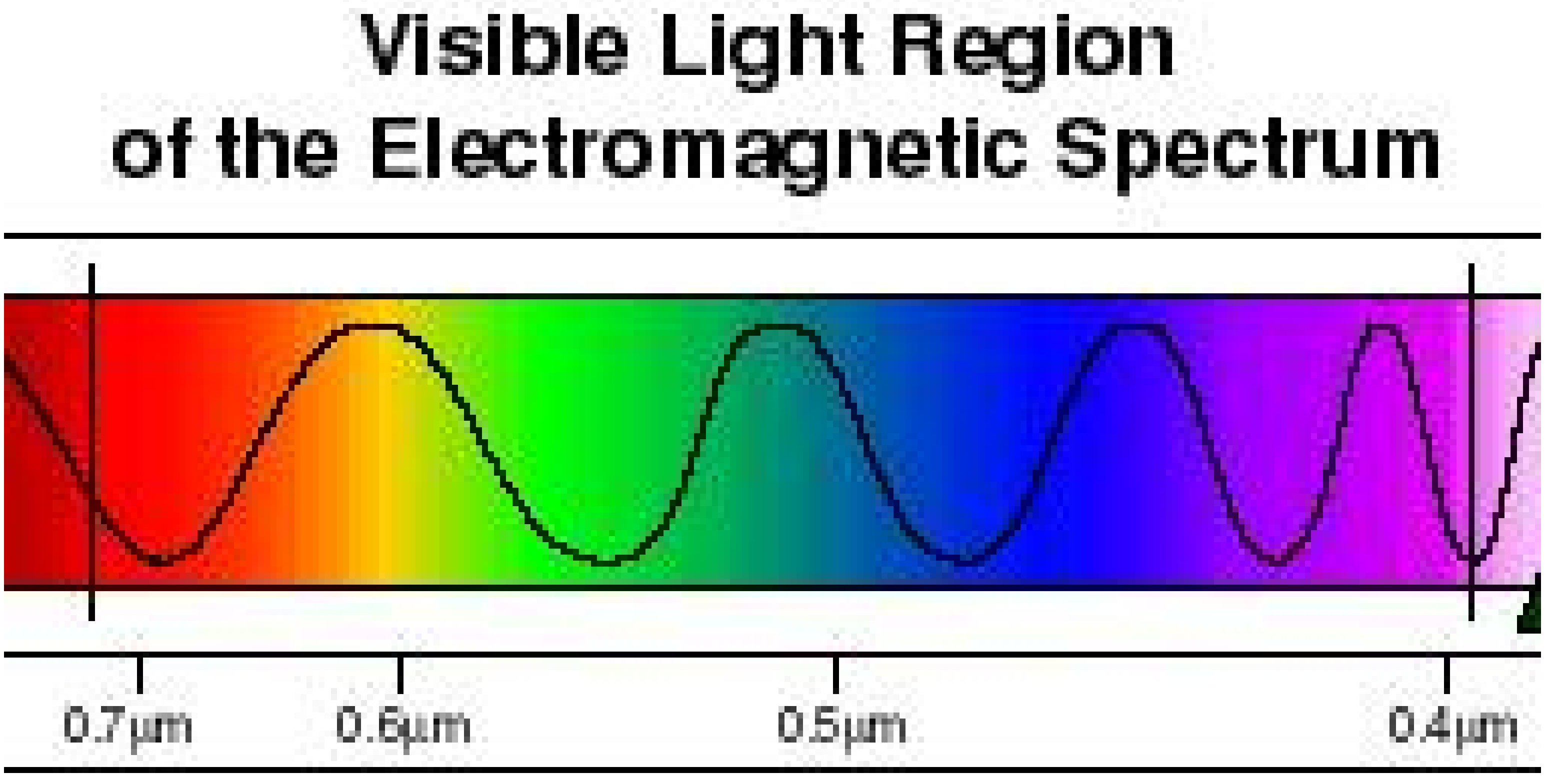
Speed of Light

- Light can exist in a vacuum (such as "outer space") or within certain gases, liquids or solids.
- The speed of light in a vacuum is: c = 299,792,458 m/s
- This is an important "constant" in physics.
- However, the speed of light *can vary*, depending upon the material through which is travels…

Speed of Light	
Vacuum	2.998×10^8 m/s
Air	2.997×10^8 m/s
Water	2.25×10^8 m/s
Glass	2.00×10^8 m/s

(Typically use 3.00×10^8 m/s!)

What makes red light
different from blue light?

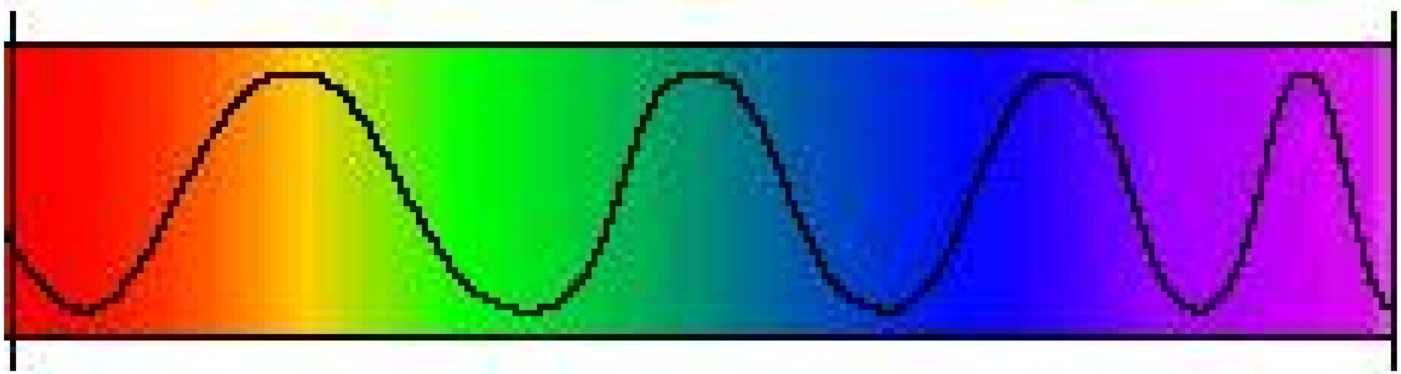


decreasing wavelength

increasing frequency

The range of visible wavelengths of light is from 400 nm to 750 nm (approximately). Determine the range of visible *frequencies*.

750 nm - - - - - wavelength - - - - - 400 nm



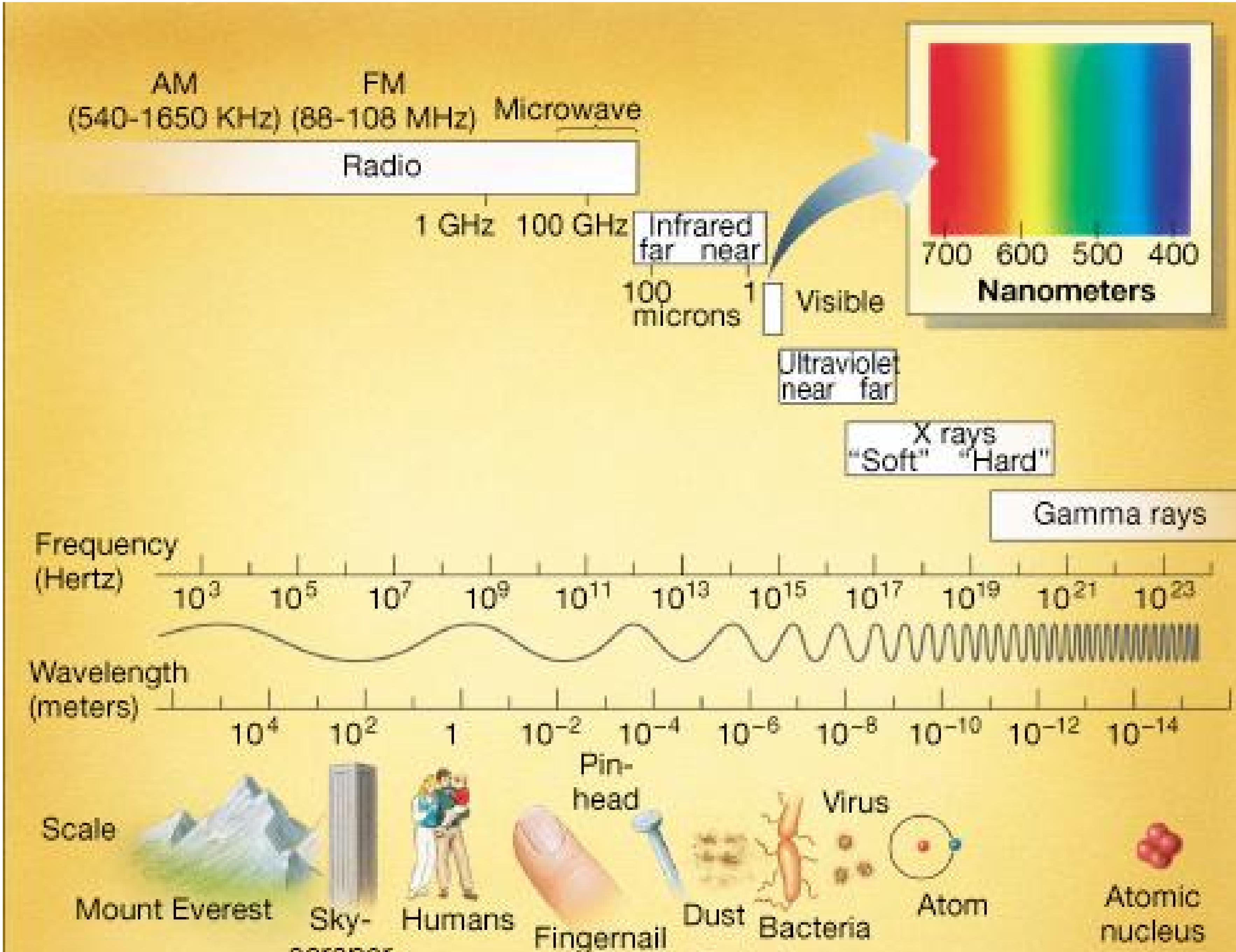
4.0×10^{14} Hz - - - - frequency - - - - 7.5×10^{14} Hz

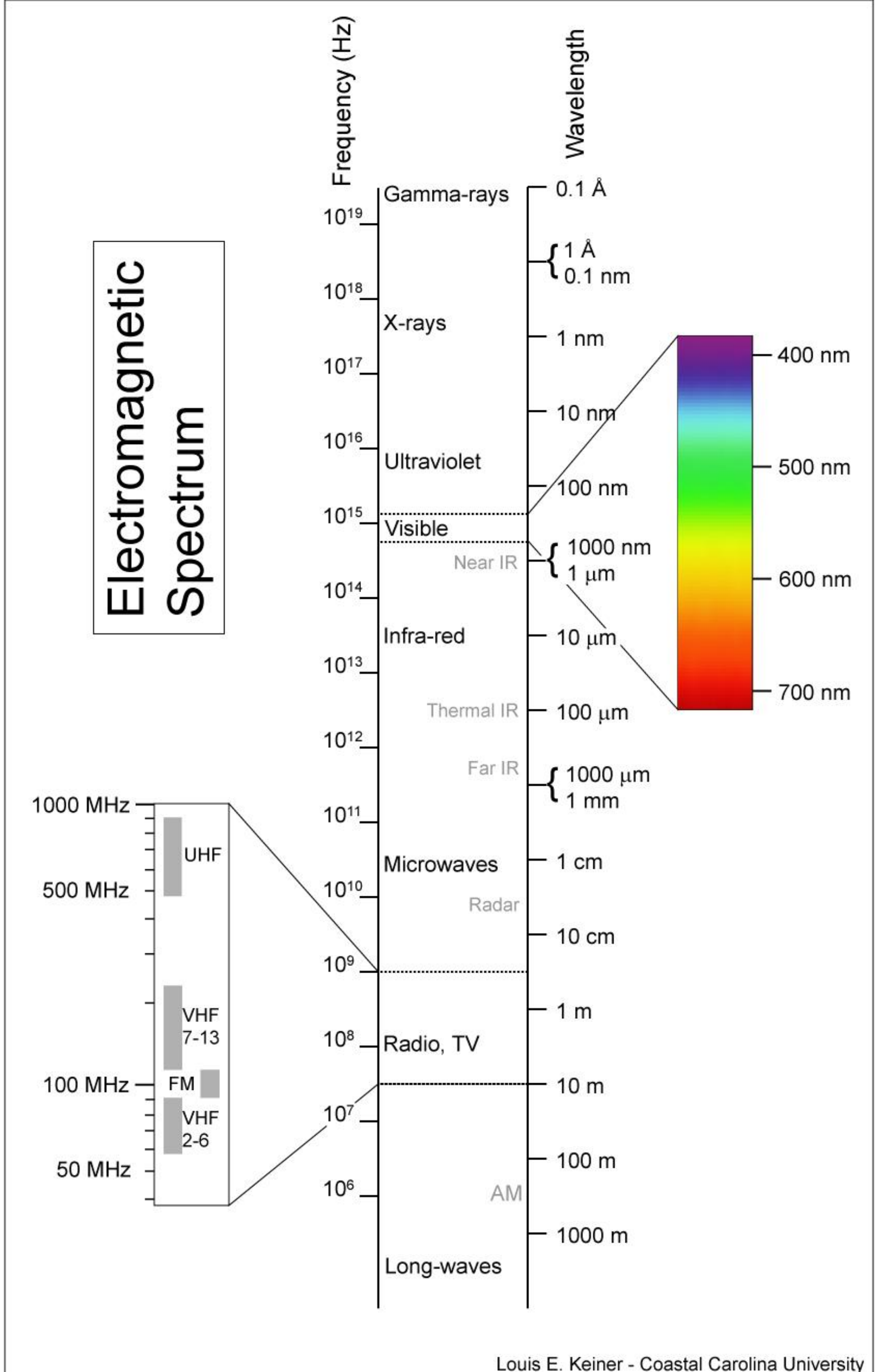
Beyond Light

- Electromagnetic waves can exist at virtually any frequency or wavelength.
- Our eyes are only sensitive to a certain range of wavelengths.
- EMR with wavelengths outside this range can *exist* but cannot be *seen*.

What is the speed of infrared?

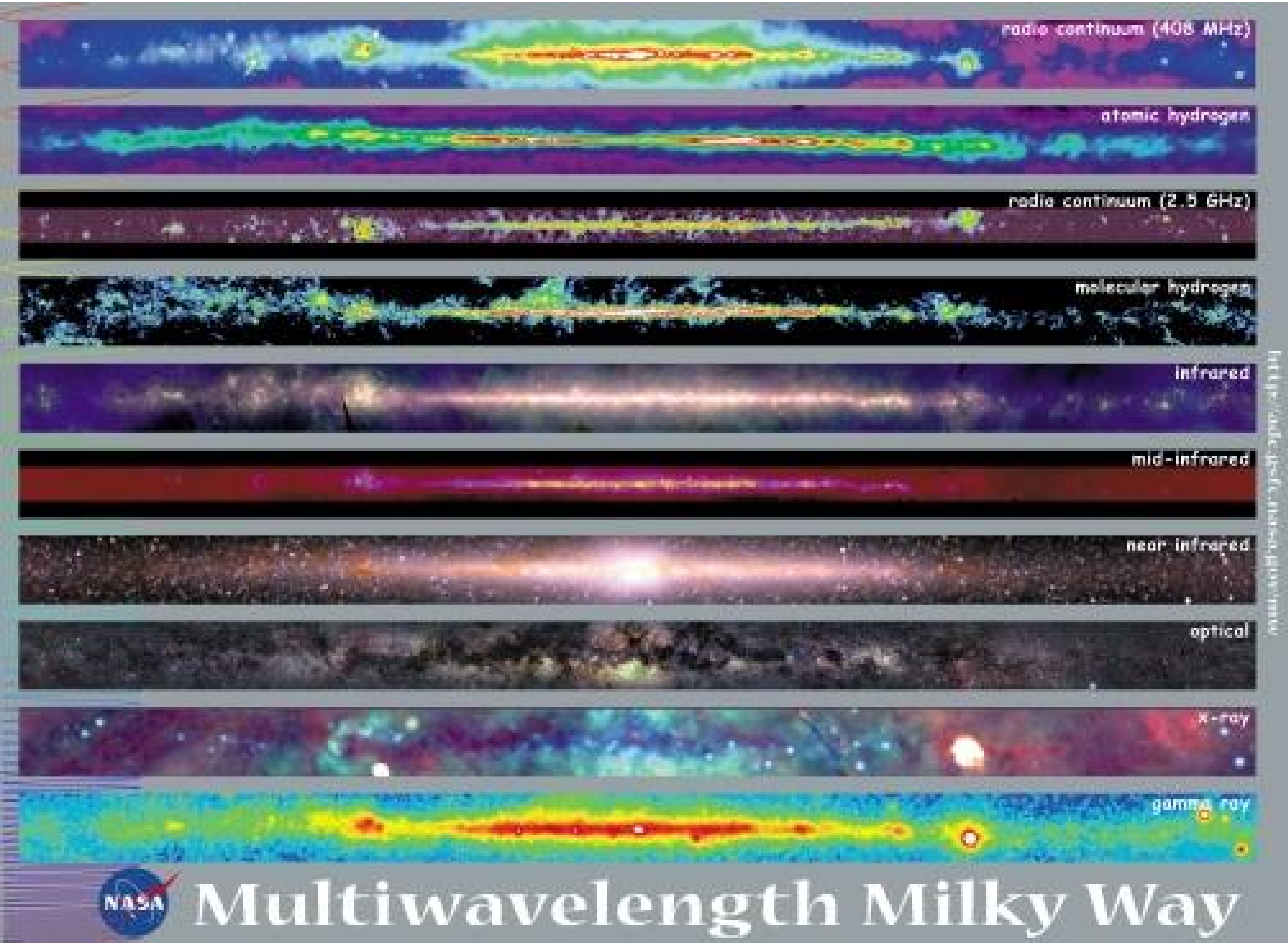
- Because all EMR is essentially the same kind of wave it all travels at the same speed through a vacuum (or air).
- The speed of infrared is the same as the speed of light or the speed of radio or the speed of any EMR: 3.00×10^8 m/s


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
Fingernail
Pin-head
Dust
Bacteria
Virus
Atom
Atomic nucleus

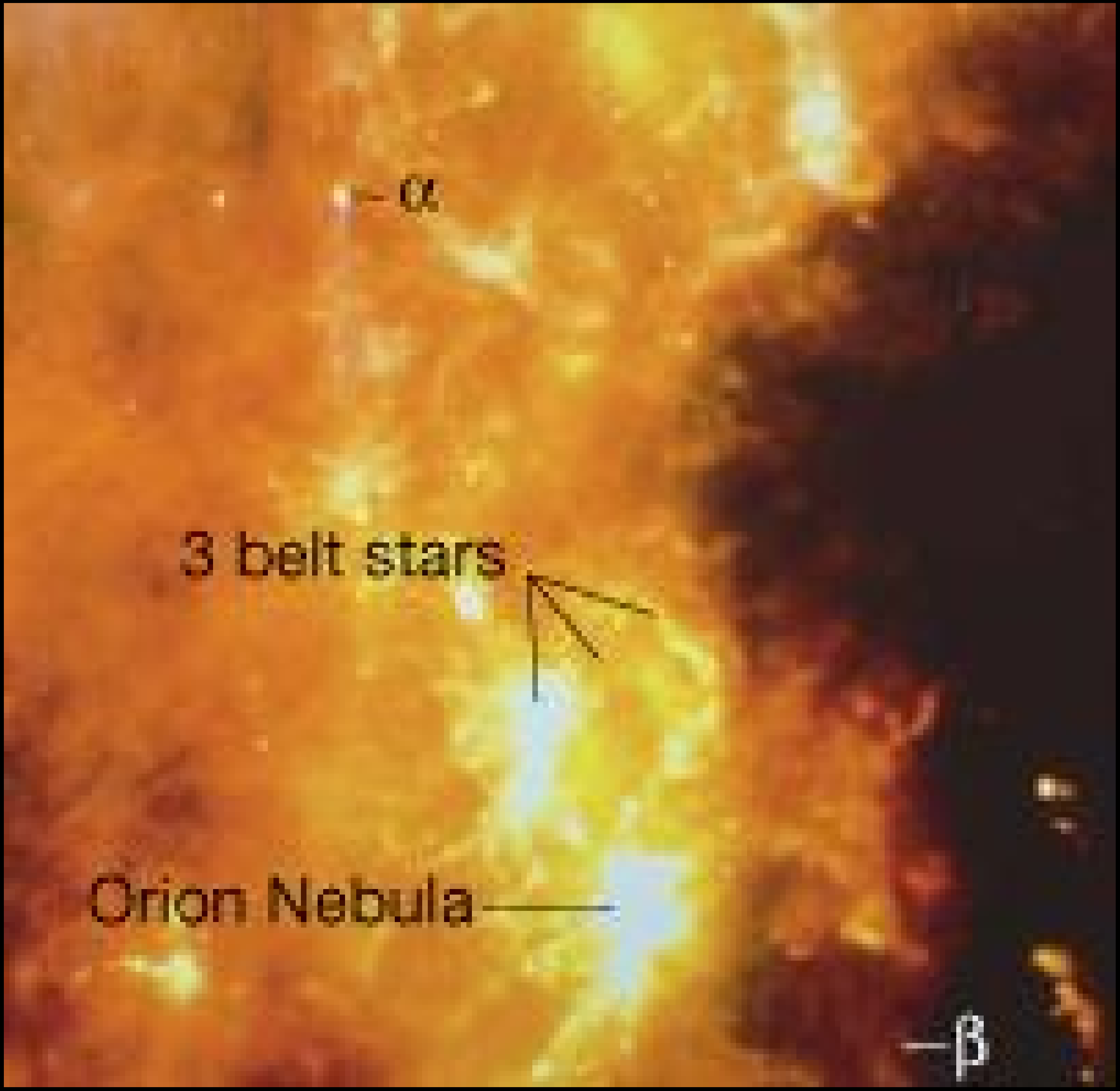

Electromagnetic Spectrum
Frequency (Hz)
Wavelength
Gamma-rays
X-rays
Ultraviolet
Visible
Near IR
Infra-red
Thermal IR
Far IR
Microwaves
Radar
Radio, TV
AM
Long-waves
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
0.1 Å
1 Å
0.1 nm
1 nm
10 nm
100 nm
1000 nm
1 µm
10 µm
100 µm
1000 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1000 m
400 nm
500 nm
600 nm
700 nm
1000 MHz
500 MHz
100 MHz
50 MHz
UHF
VHF
7-13
FM
VHF
2-6
Louis E. Keiner - Coastal Carolina University

	Example	Frequency	Wavelength
Radio	AM (WNOX)	990 kHz	303 m
	FM (WIMZ)	103.5 MHz	2.897 m
	TV (VHF ch 10)	195 MHz	1.54 m
	TV (UHF ch 43)	647 MHz	0.463 m
Microwave	microwave oven	2450 MHz	0.122 m
	classroom generator	10.525 GHz	0.0285 m
Infrared	human (98.6 °F)	3.21×10^{13} Hz	9.35 µm
	hot oven (300 °F)	4.36×10^{13} Hz	6.87 µm
	remote control	3.19×10^{14} Hz	940 nm

Visible Light	far red	4.00×10^{14} Hz	750 nm
	red laser pointer	4.61×10^{14} Hz	650 nm
	green laser pointer	5.64×10^{14} Hz	532 nm
	deep violet	7.50×10^{14} Hz	400 nm
Ultraviolet	UVA	8.21×10^{14} Hz	365 nm
	UVC	3.00×10^{15} Hz	100 nm
X-ray	"soft"	3×10^{17} Hz	1 nm
	"hard" (medical)	1.21×10^{19} Hz	2.48×10^{-11} m
Gamma	radioactive cobalt-60	3.22×10^{20} Hz	9.31×10^{-13} m

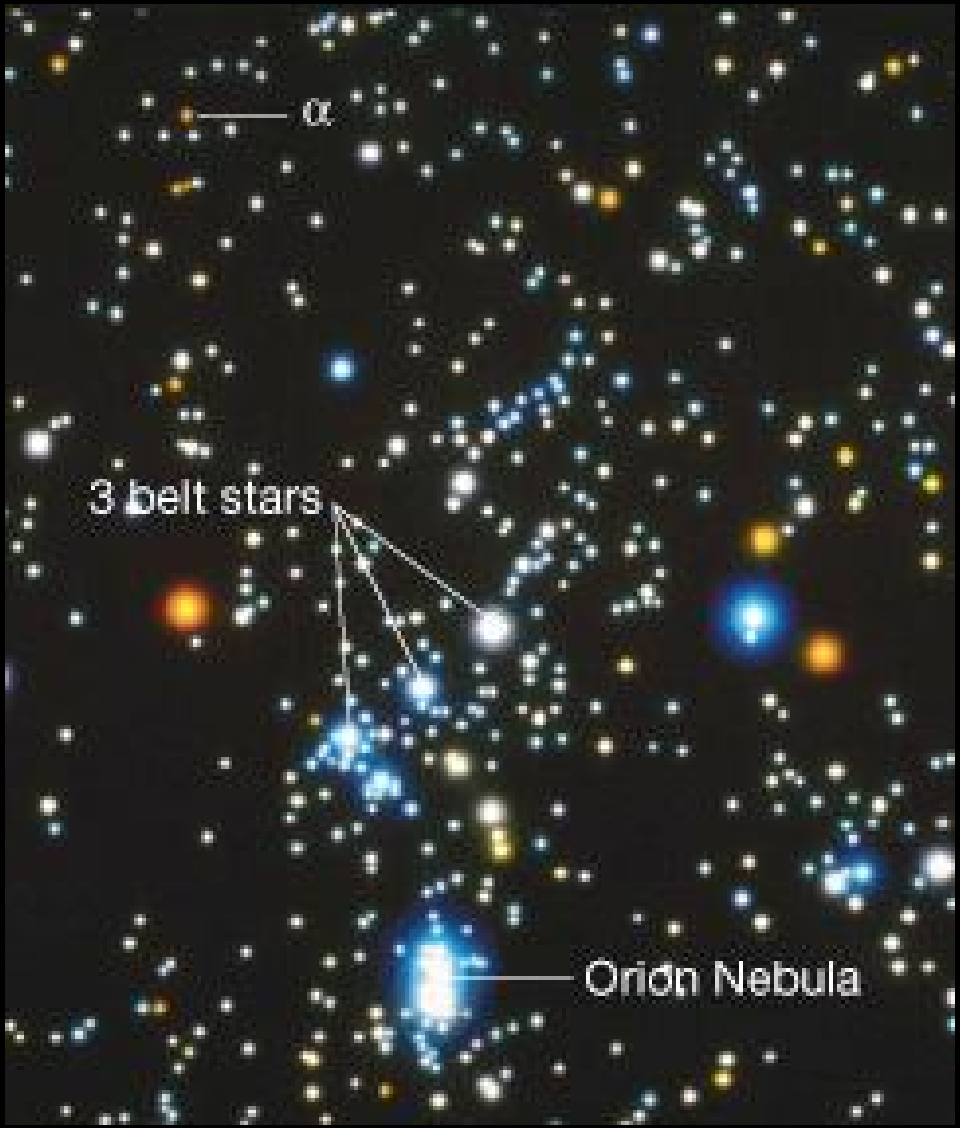

radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
NASA
Multiwavelength Milky Way

Orion in visible light



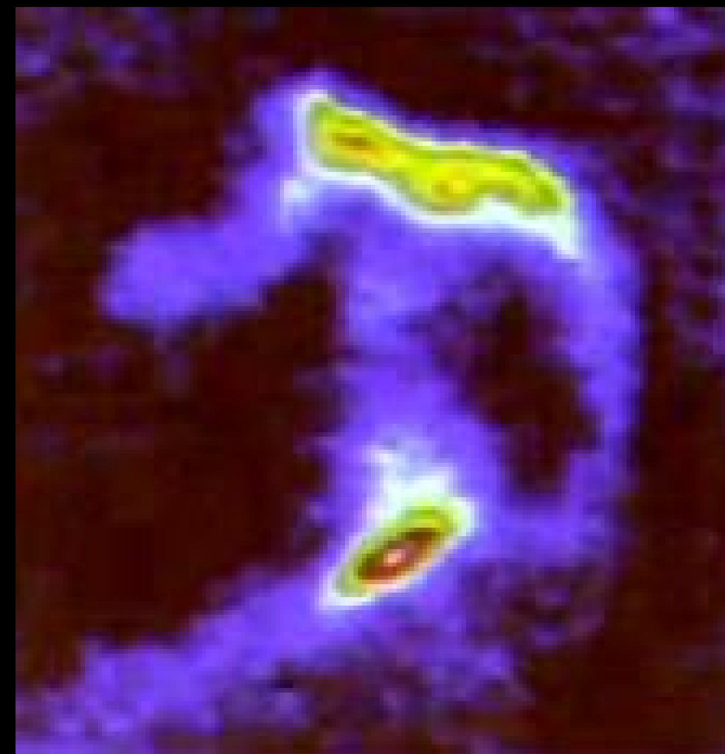
Orion in infrared

Orion in visible light



Orion X-ray

The Horsehead Nebula



Visible
(0.4 – 0.75 μm)

Infrared
(55 – 670 μm)

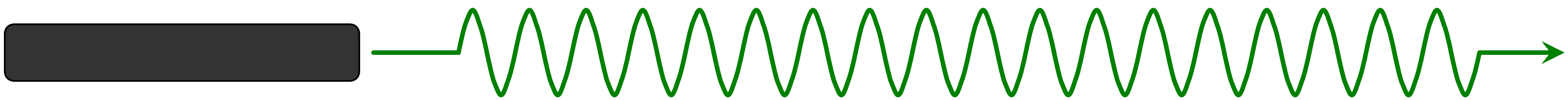
What determines frequency?

- Like all wave forms, frequency is determined by the source.
- In the case of light and other forms of EMR, atoms and/or subatomic particles are the source.
- When an atom or particle undergoes an energy change it either emits or absorbs EMR.
- The greater the change in energy the greater the frequency of the EMR.

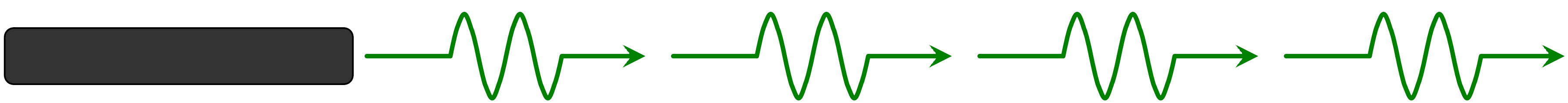
Particles of Light?

- Although light can be clearly demonstrated to behave as a wave, certain experiments show it to be like a stream of particles.
- These “particles of light” are called **photons**. A photon may be thought of as a “wave packet” or a tiny burst of wave energy.
- The energy of a photon is proportional to its frequency. Higher frequency = more energy per photon.

Visualizing Photons…

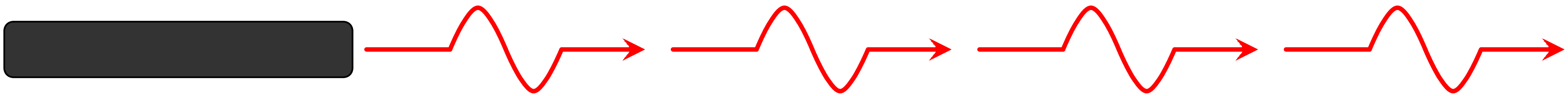


Instead of a *continuous* wave pattern in the beam of a laser pointer…

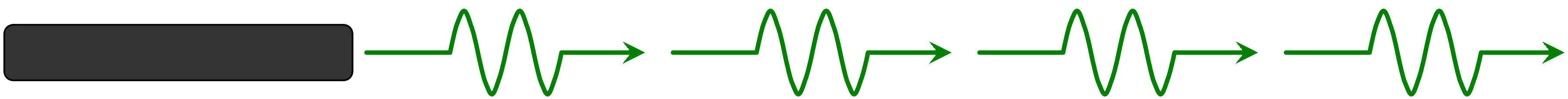


…imagine a series of “wave bursts” or *photons*, each of which has a particular frequency, wavelength, and energy.

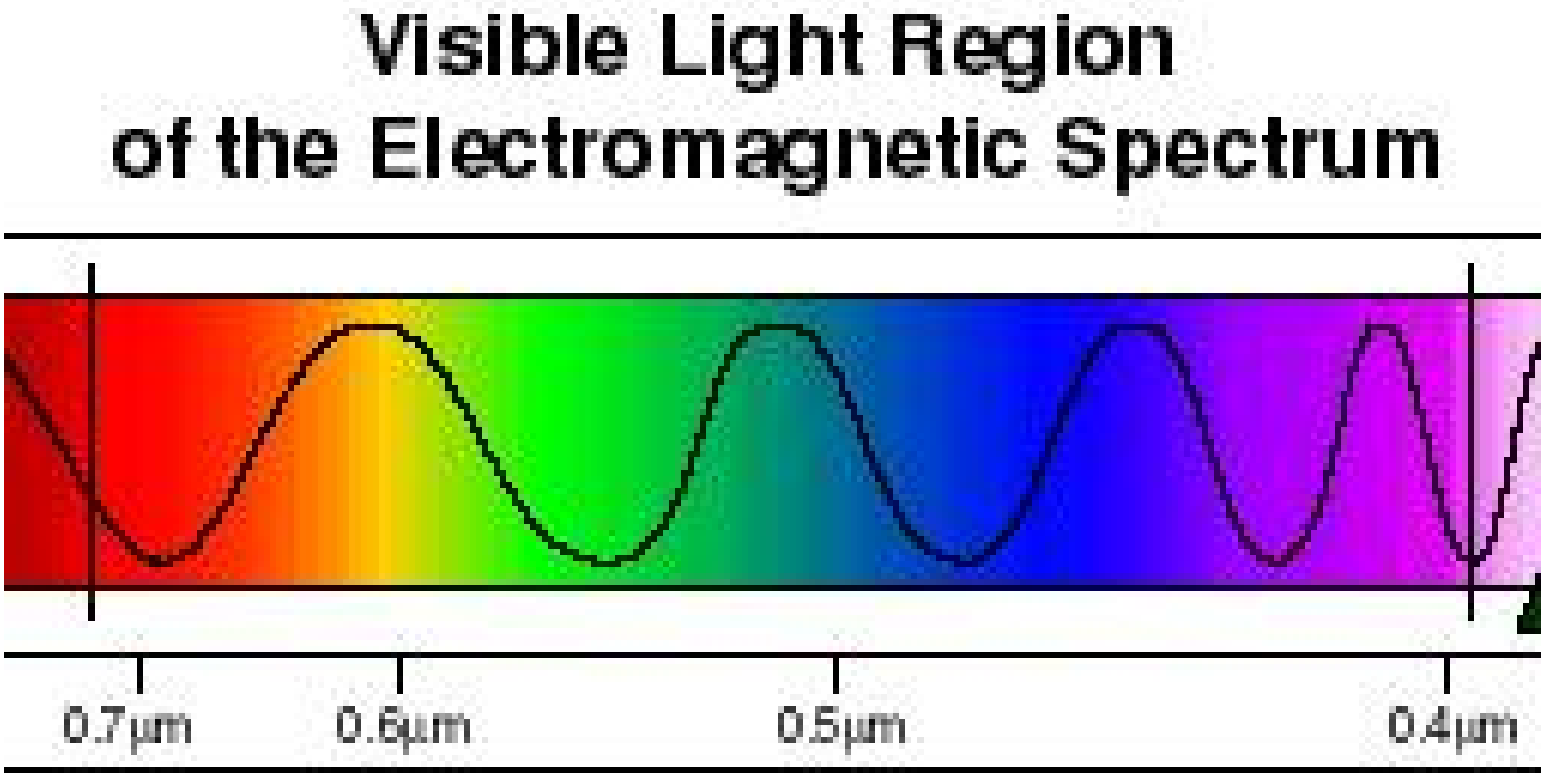
Visualizing Photons…



The red laser pointer's photons each have longer wavelength, lower frequency, and lower energy…



…than the green laser pointer's photons, each of which have shorter wavelength, higher frequency, and greater energy.



increasing frequency

increasing energy per photon