Electromagnetic Radiation and Telescopes

I. Waves (chpt. 3)
Speed, frequency, wavelength, light, EMR etc.

II. Spectroscopy (chpt. 4)
Wein's Law, Doppler effect, spectral lines, etc.

III. Telescopes (chpt. 5)
Refractors, reflectors, resolution, magnification, etc.

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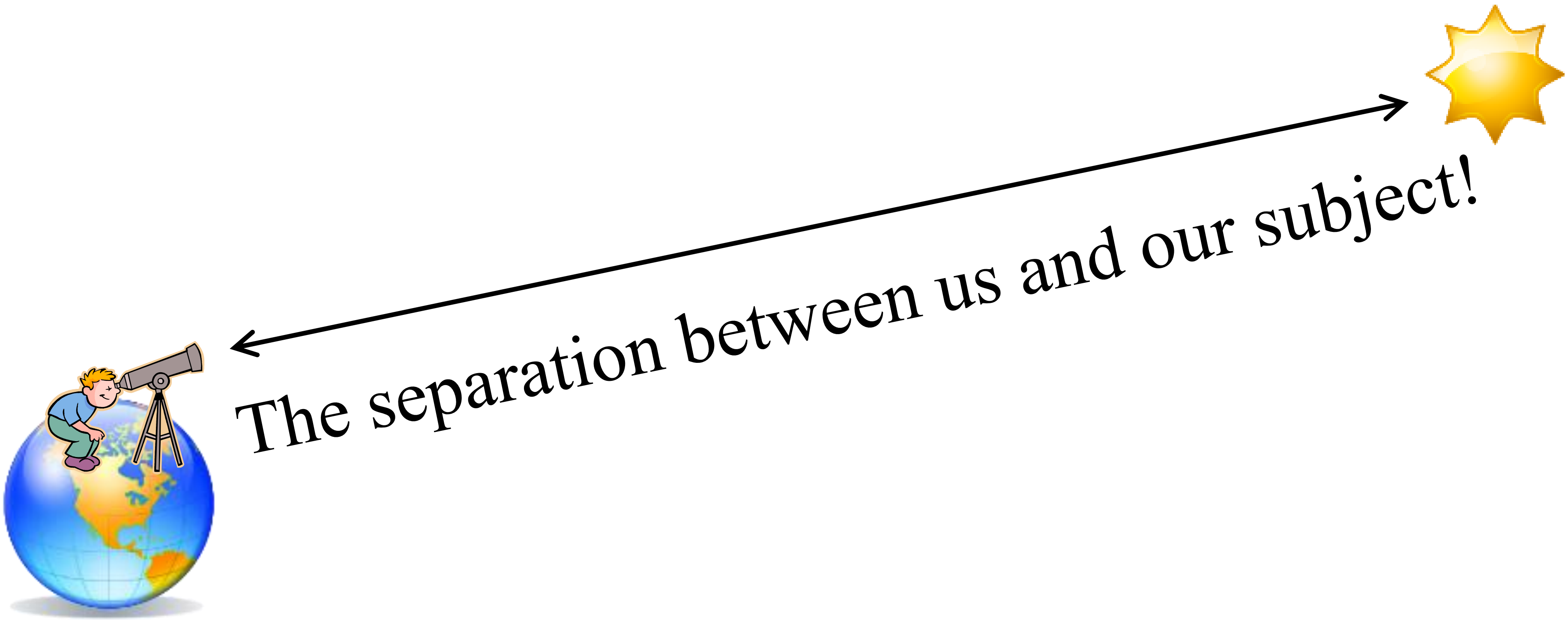
What separates astronomy from other sciences?



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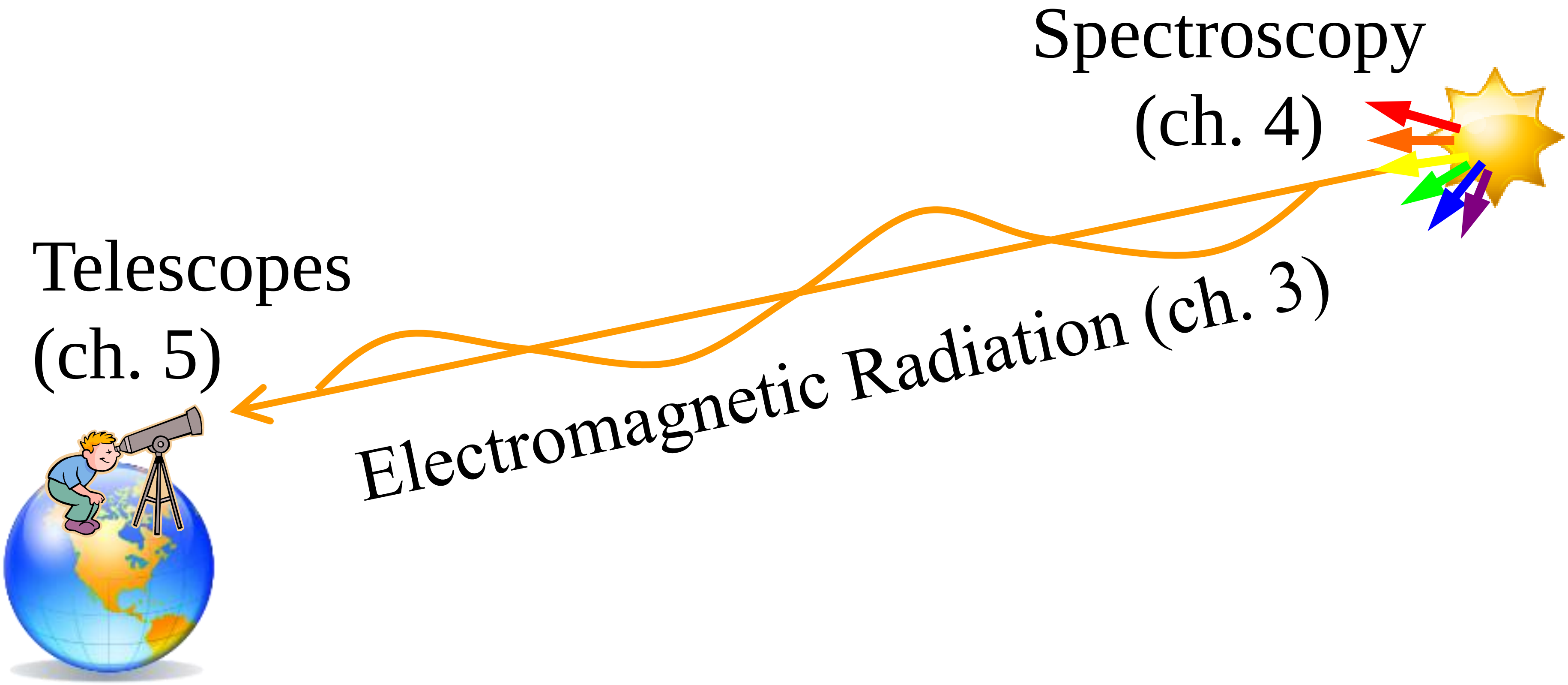
This unit of study is about methods of analyzing the very distant objects in the universe.



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	The student will be able to:	HW:
1	Define, illustrate, and apply the basic wave concepts of frequency, wavelength, and speed and relate these to source and medium.	1
2	Solve mathematical problems involving speed, frequency, and wavelength.	2 – 4
3	Describe and illustrate the nature of electromagnetic radiation.	5
4	State the six major regions of the electromagnetic spectrum in order of frequency and/or wavelength.	6 – 8
5	State the colors of the visible spectrum in order of frequency and/or wavelength.	
6	Define, illustrate, and apply the concepts of diffraction, interference, opacity and transparency.	9 – 10
7	Explain, illustrate, and apply the basic concepts of blackbody radiation.	11 – 12
8	Solve mathematical problems using Wein's law.	13 – 15
9	Explain, illustrate, and apply the concept of the Doppler effect and the astronomical terms of redshift and blueshift.	16 – 17
10	Describe the characteristics of continuous, emission, and absorption spectra and the conditions under which each is produced.	Chpt 4 R&D 1 – 4, 11 – 20
11	Explain how spectral lines and the width and intensity of those lines are related to properties of atoms and or molecules.	
12	Describe and illustrate the two main types of optical telescopes – refracting and reflecting and contrast in terms of resolution, light gathering, and aberrations.	Chpt 5 R&D 1, 2, 4 – 8, 10 – 13, 15, 16, 19, 20
13	Describe how the Earth's atmosphere affects astronomical observations and current efforts to improve ground-based astronomy.	
14	Compare and contrast telescopes that create images using nonvisible radiation.	
15	Solve mathematical problems relating magnification to focal lengths of objective and ocular.	18 – 19
16	Solve mathematical problems relating angular resolution to wavelength and diameter.	20 – 23
17	Solve mathematical problems involving light gathering capacities.	24 – 27

A **wave** is a disturbance propagating through a medium.

- Whatever it is that is being disturbed is called the **medium**.
- A **disturbance** is a change in the equilibrium state of the medium.
- **Propagation** implies that the wave is "self sustaining" and that the pattern of disturbance is reproduced at progressive points through the medium.
- All waves involve the transfer of energy and require a **source** that initiates the wave and supplies energy to the medium.

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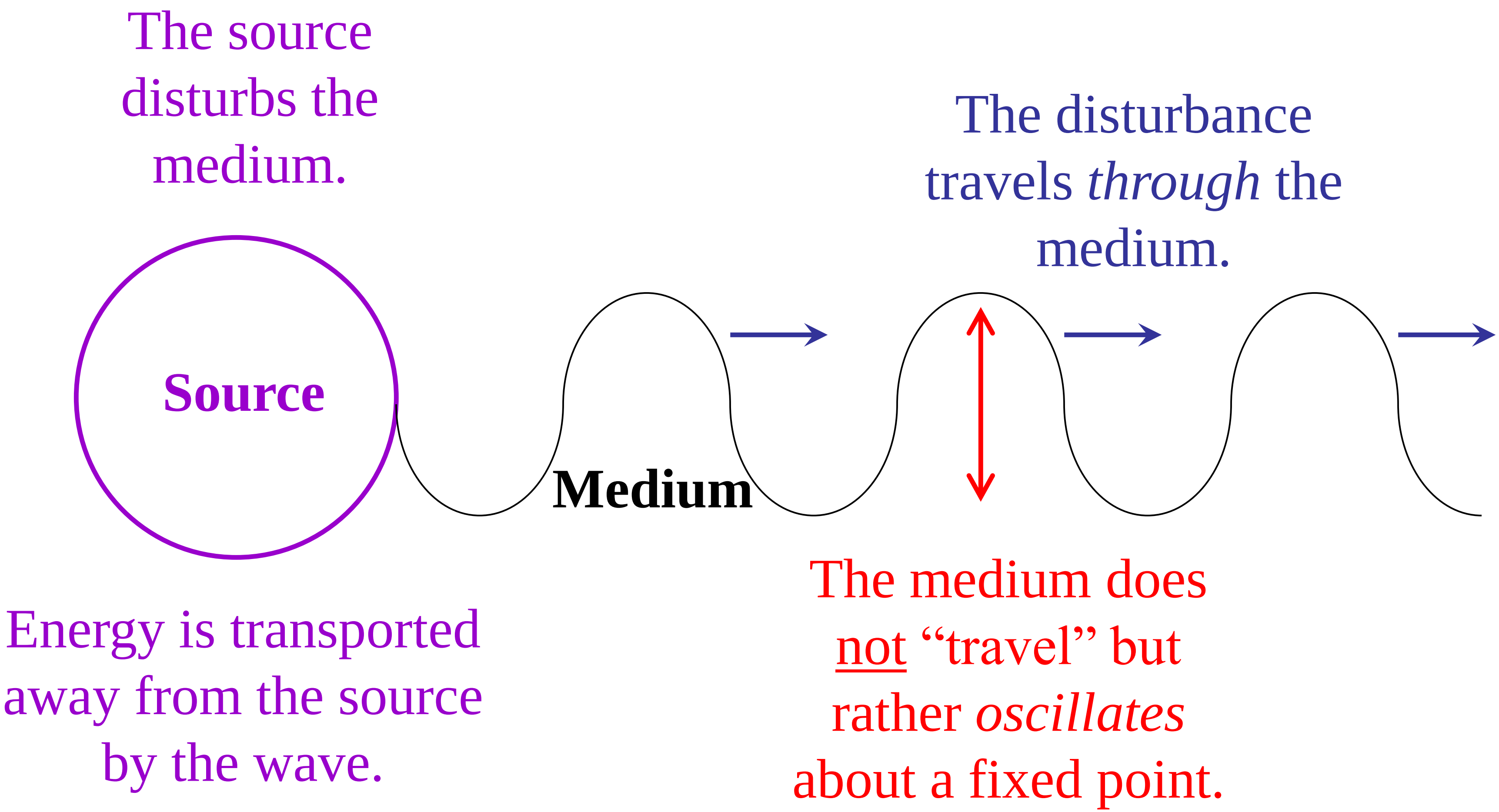

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Wave Types

- There are many different types of waves, characterized by the way in which the medium is disturbed from its equilibrium state.
- Two common types are: transverse waves and longitudinal waves.

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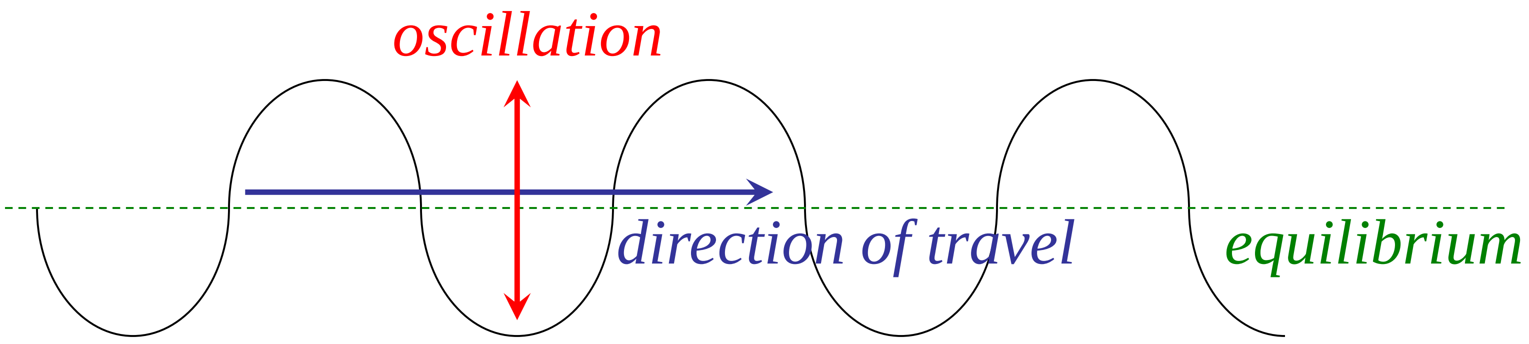
Transverse Waves

In a **transverse wave** the oscillation of the medium is perpendicular to the direction the wave travels.



Crest = upward or positive displacement or change of the medium

Trough = downward or negative displacement or change of medium

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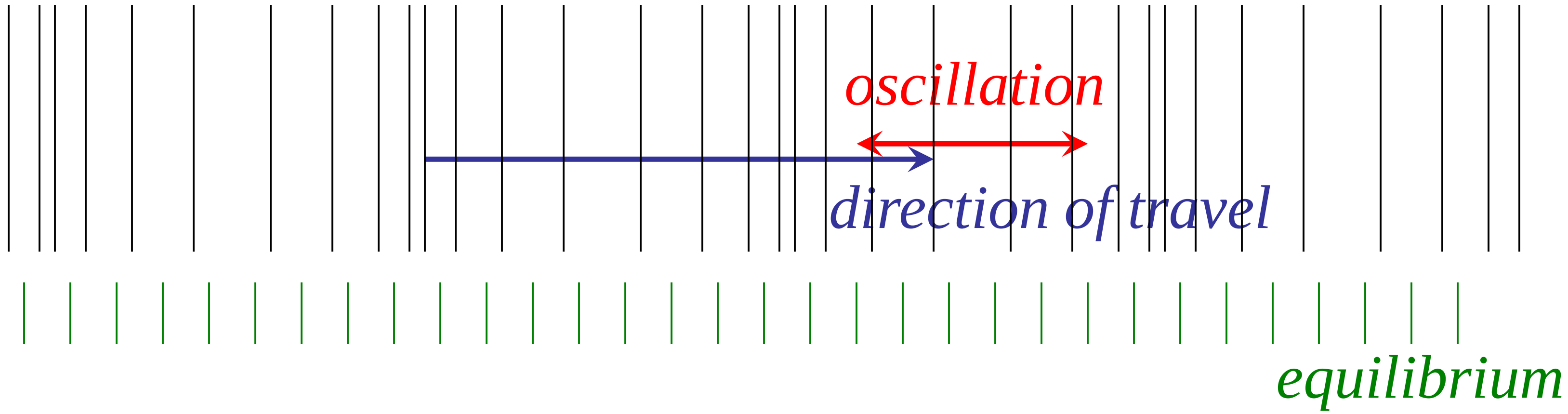
Longitudinal Waves

In a **longitudinal wave** the oscillation of the medium is parallel to the direction the wave travels.



Compression = medium is more tightly spaced than normal

Rarefaction = medium is less tightly spaced than normal

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Ready everybody? Let’s do “the Wave”!!!!!

In groups of 3 or 4 discuss and answer:

1. What is the medium? What is the source? Is there a disturbance from an equilibrium?
2. Are there crests, troughs, compressions, and/or rarefactions? What type of wave is it? Would other types be possible?
3. Does the wave propagate? Is there a transfer of energy?
4. Is “the Wave” really a wave?

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Wave Parameters

- The **speed** of a wave is the rate at which the disturbance travels through the medium.
- The **amplitude** is the maximum level of disturbance, measured from equilibrium.
- **Period** is the time for one complete cycle.
- **Frequency** is the number of cycles per unit time.
- **Wavelength** is the length of one complete cycle (measured along a line parallel to the direction of wave travel)

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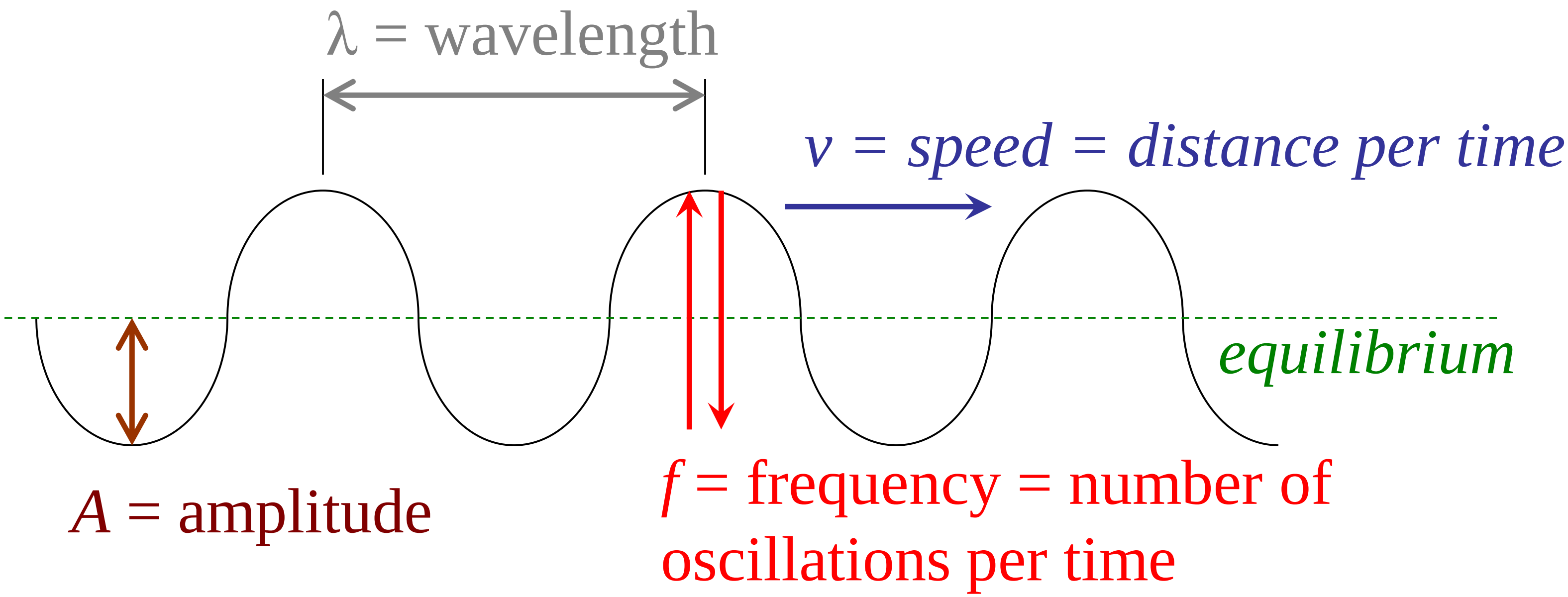

$$v = f \cdot \lambda$$

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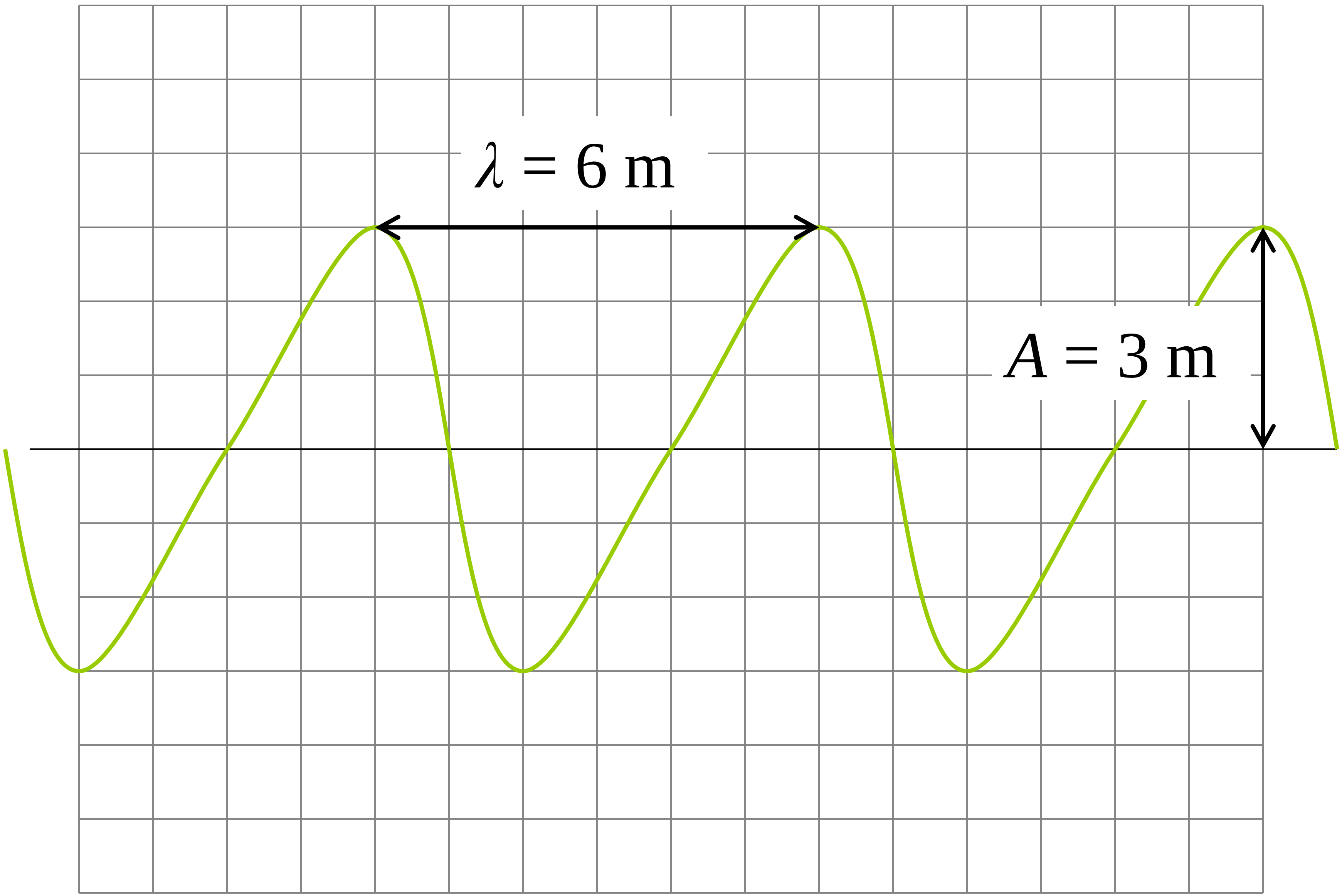
Find wavelength and amplitude.



Scale: each square is 1 meter wide.

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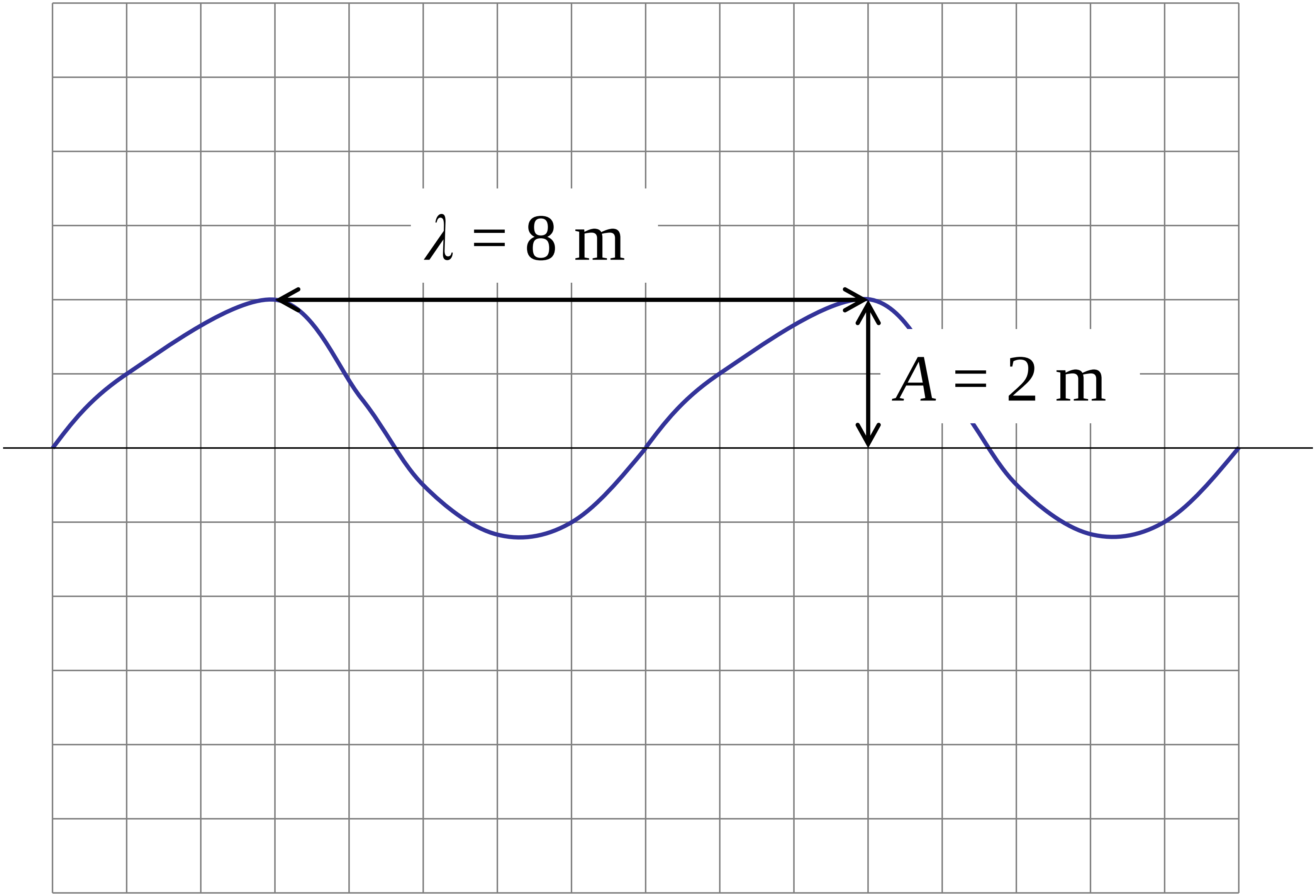
Find wavelength and amplitude.



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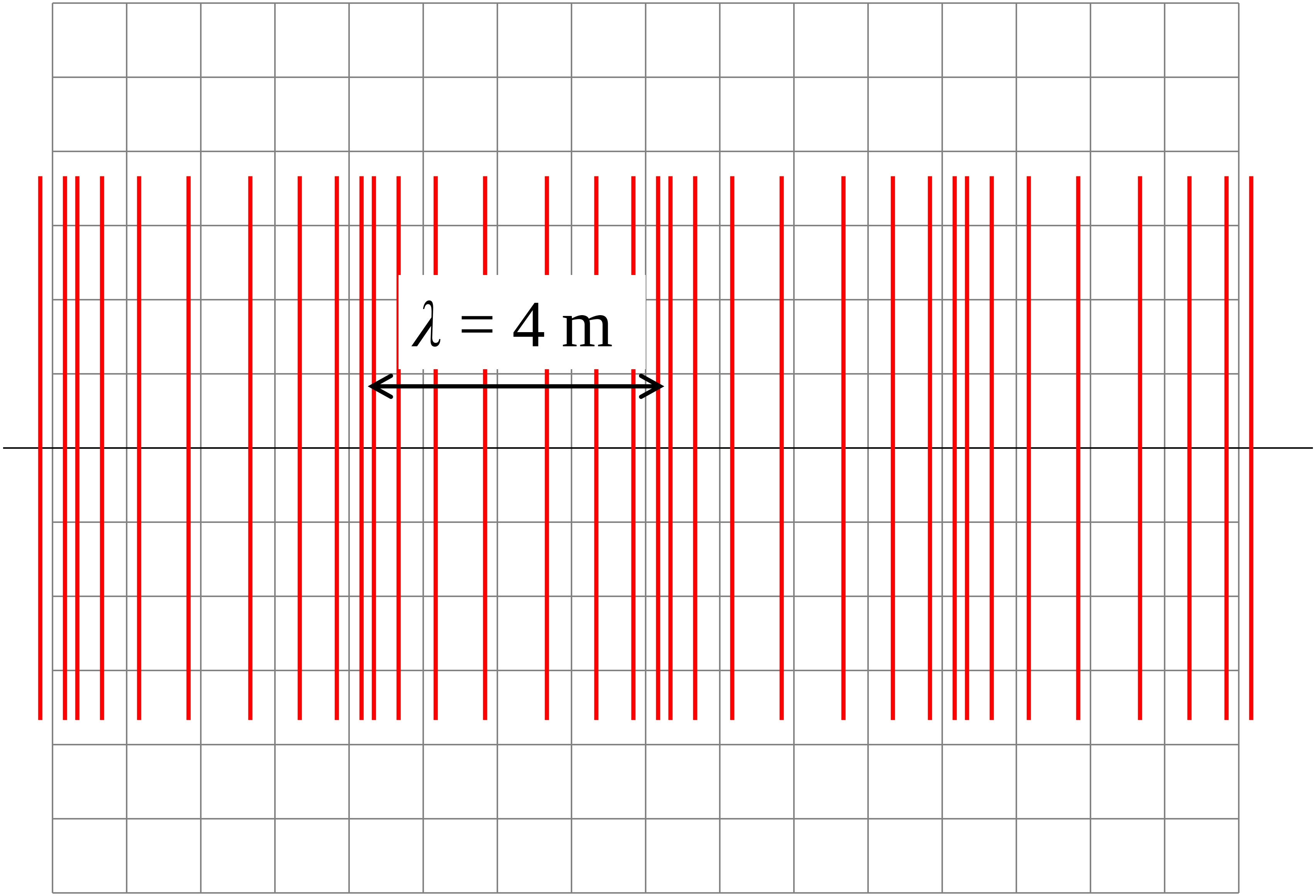
Find wavelength.



Scale: each square is 1 meter wide.

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1. A wave in a lake has speed 3.0 m/s and wavelength 4.0 m. What is the frequency of this wave?

2. Suppose a wave in the same lake has a frequency of 1.5 Hz – what is its wavelength? (Speed is the same!)

3. A wave is created in a long spring by shaking it back and forth at 4.0 Hz. The crests created in the spring are 0.20 m apart. What is the speed of this wave?

4. A wave traveling through the ocean at 4.0 m/s causes a boat to move up and down at frequency 1.2 Hz. Find the wavelength of the wave.

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5. A certain sound wave has frequency 256 Hz and wavelength 1.34 m. Find the speed of this sound.

6. Using the same speed, find the frequency of a sound with wavelength 5.00 m. Repeat for a wavelength of 10.0 m.

7. Assuming the speed of sound is same as found above determine the wavelength for a sound with frequency 20.0 Hz. Repeat for 20.0 kHz.

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10	State and apply Kirchoff’s Laws of continuous, emission, and absorption spectra and describe the components and operation of a spectroscope.	18 – 21
11	Explain how spectral lines and the width and intensity of those lines are related to properties of atoms and or molecules.	22 – 25
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17	Solve mathematical problems involving light gathering capacities.	39 – 42

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.

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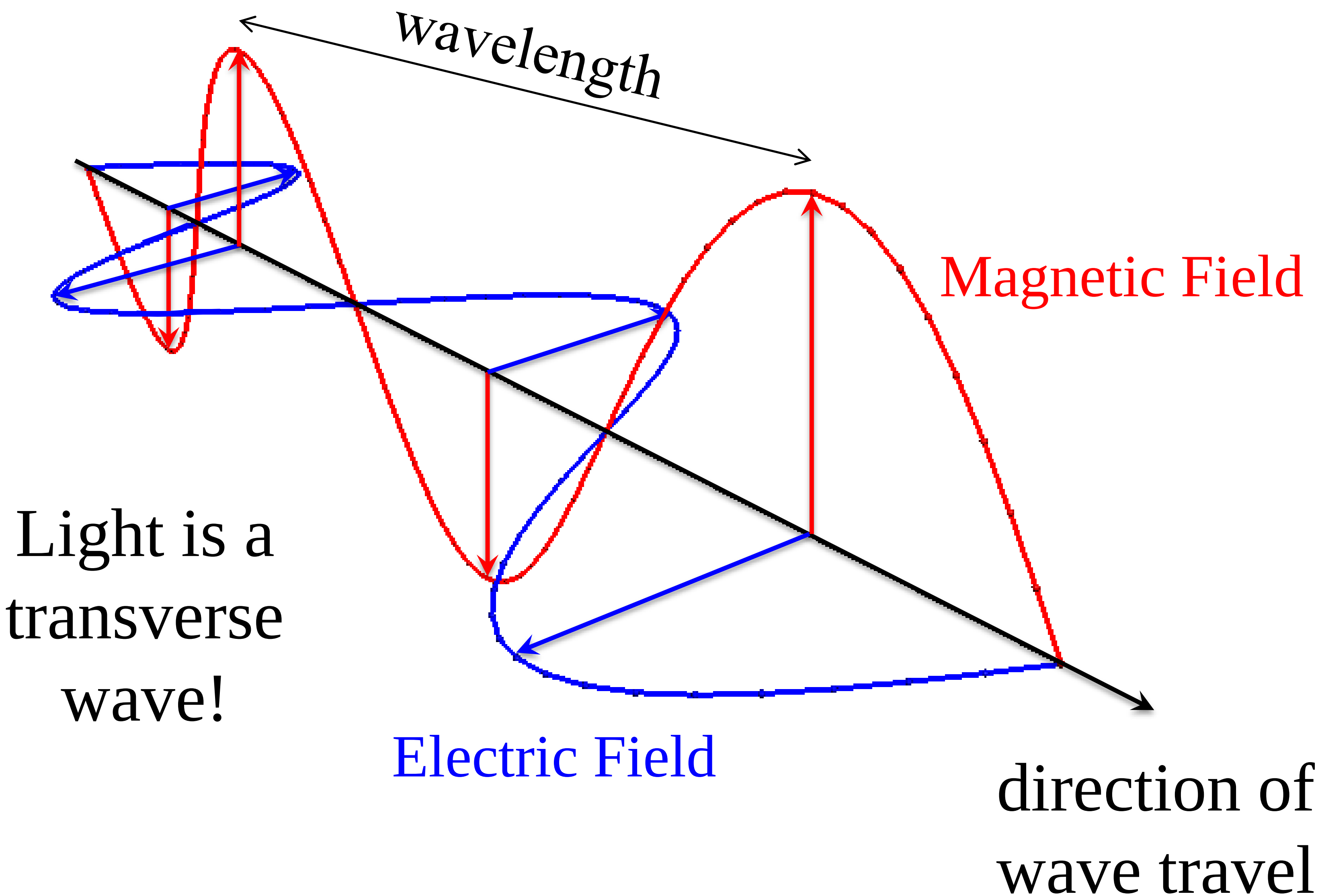

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Speed of Light

- 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 299792458 m/s, or about 3.00×10^8 m/s.
- The speed through air is about the same but light is significantly slower through denser materials such as water or glass.

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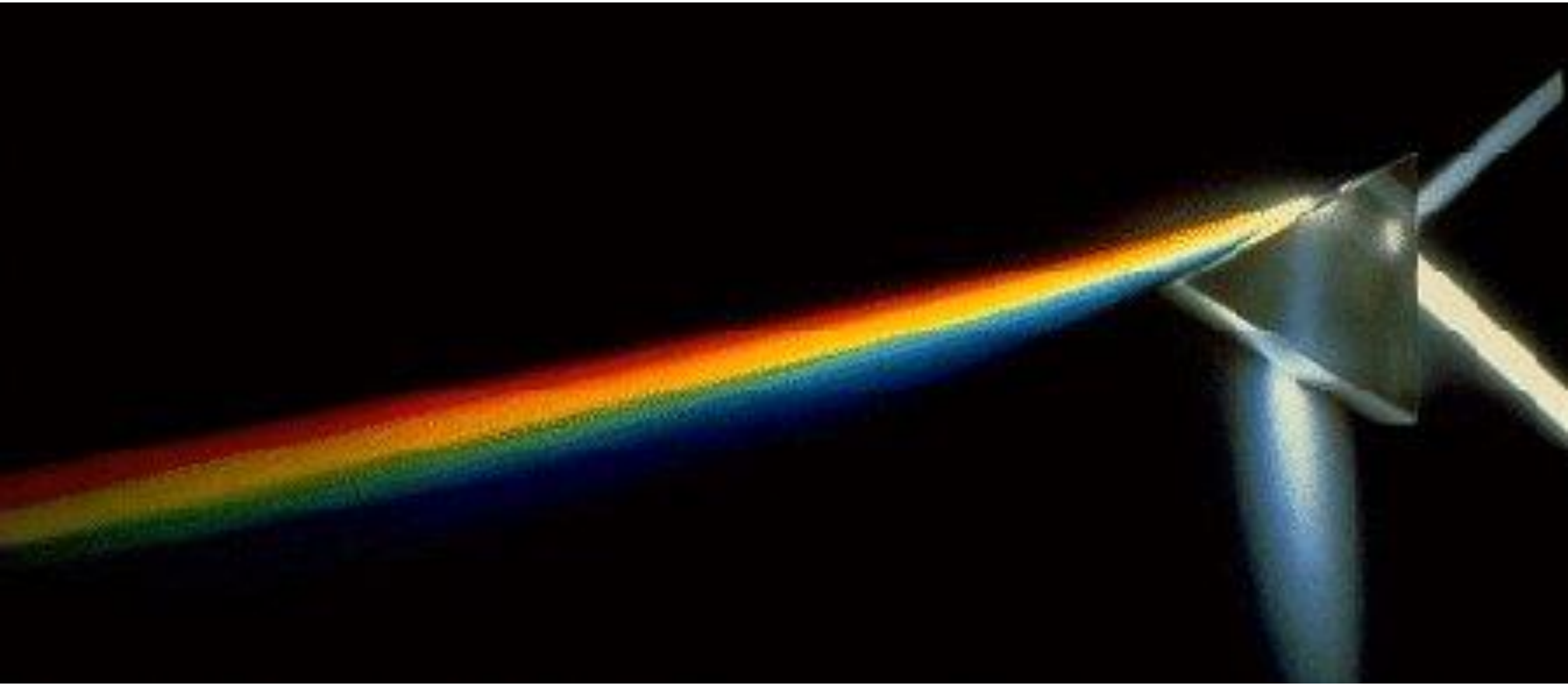
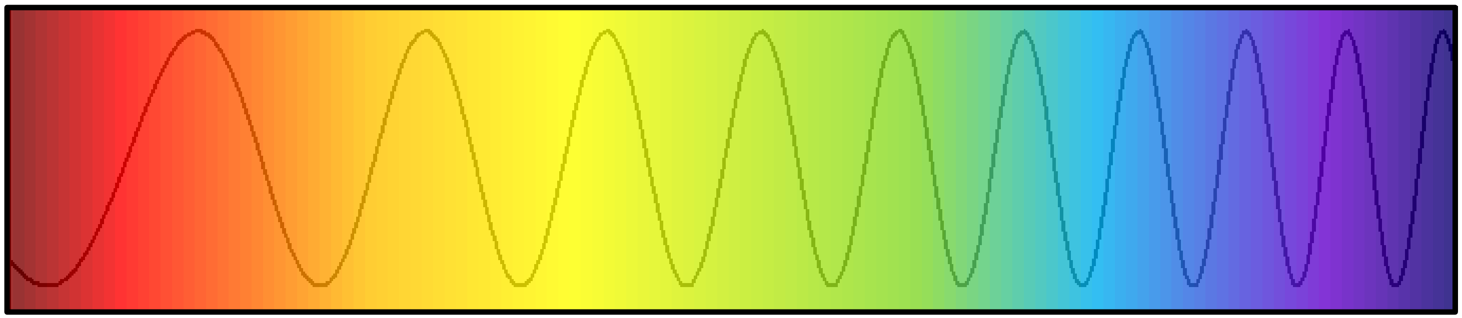


The colors of the rainbow are the only part of the electromagnetic spectrum to which the human eye reacts – this is visible light!



decreasing wavelength

increasing frequency

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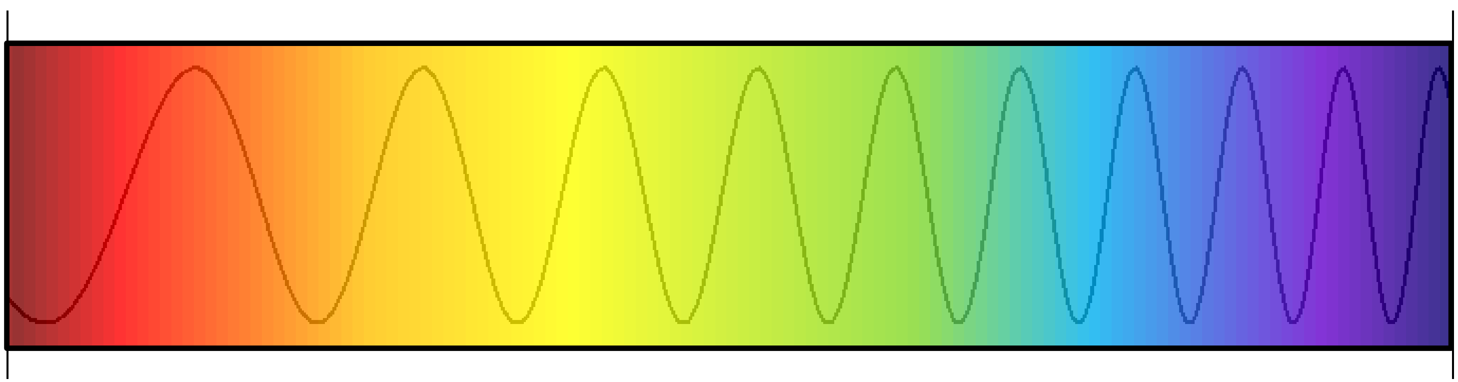
The range of visible wavelengths of light is from 400 nm to 750 nm (approximately). Determine the range of visible *frequencies*.

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



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

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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*.
- The speed of other types of radiation is the <u>same</u> as the speed of light!

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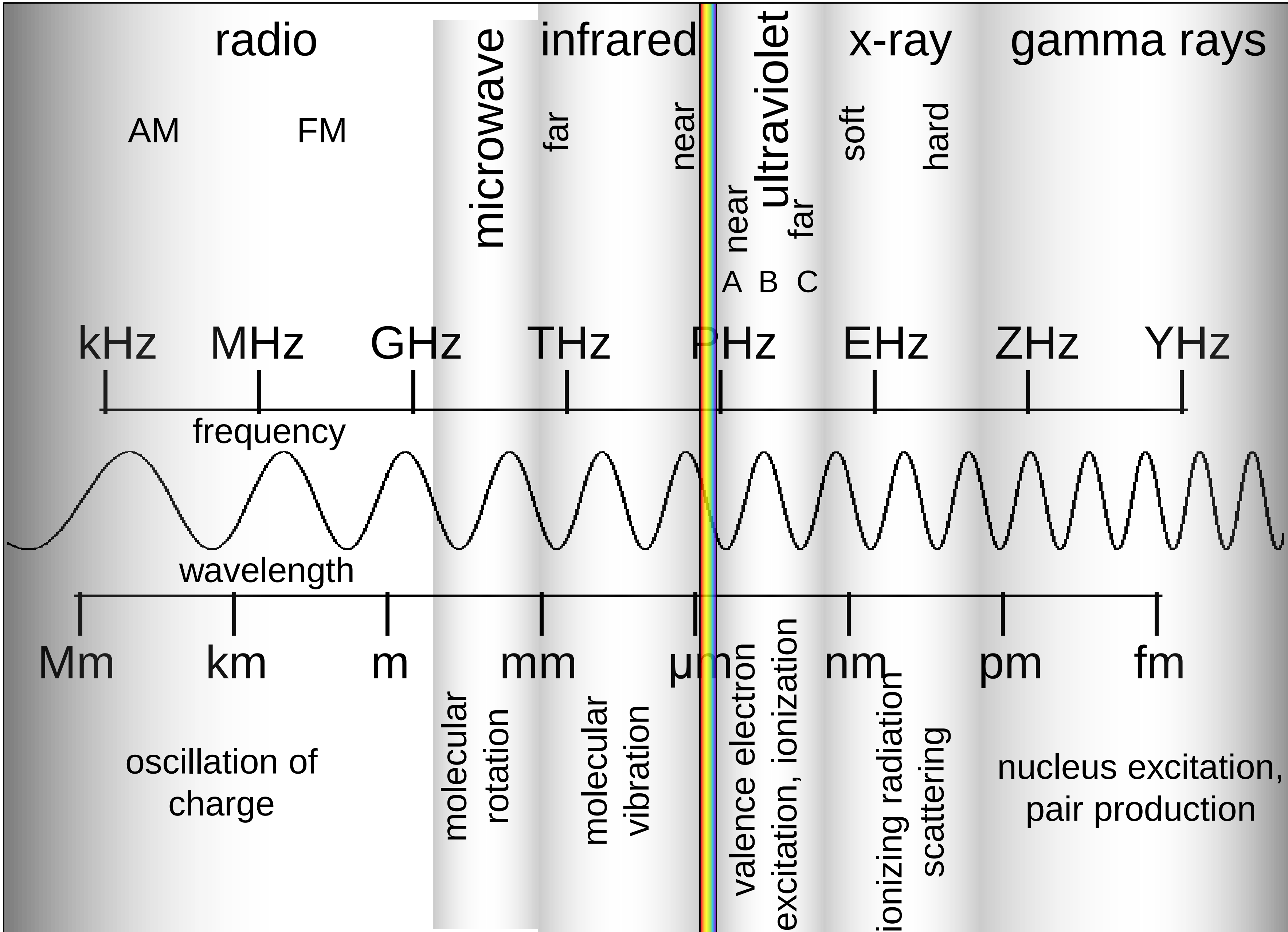
the Electromagnetic Spectrum



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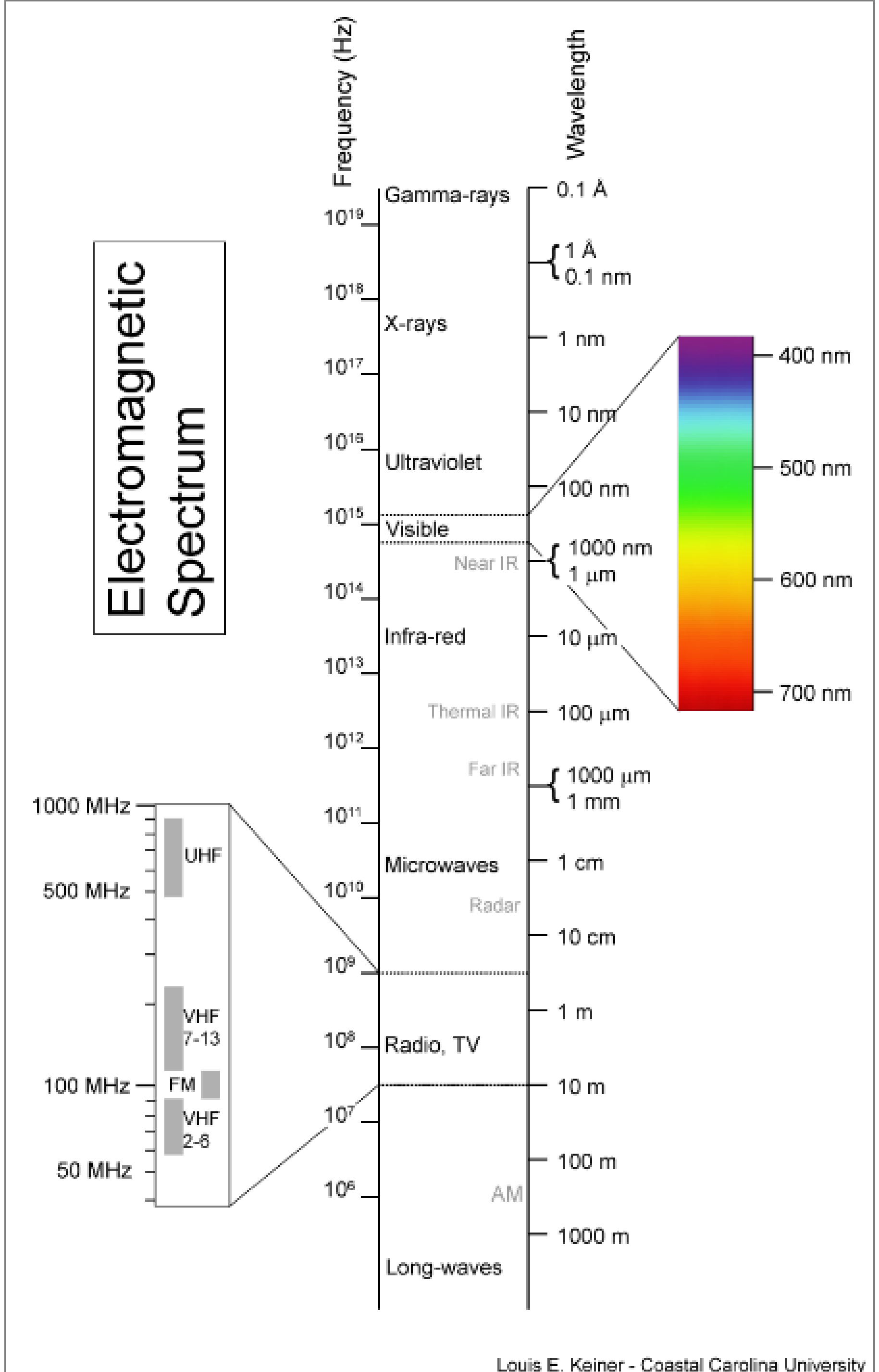
Electromagnetic Spectrum
Frequency (Hz)
Wavelength
Gamma-rays
X-rays
Ultraviolet
Visible
Near IR
Infra-red
Thermal IR
Far IR
Microwaves
Radar
Radio, TV
AM
Long-waves
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
0.1 Å
1 Å
0.1 nm
1 nm
10 nm
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	
	FM (WIMZ)	103.5 MHz	
	TV (VHF ch 10)	195 MHz	
	TV (UHF ch 43)	647 MHz	
Microwave	microwave oven	2450 MHz	
	classroom generator	10.525 GHz	
Infrared	human (98.6 °F)		9.35 μm
	hot oven (300 °F)		6.87 μm
	remote control		940 nm

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Visible Light	far red		750 nm
	red laser pointer		650 nm
	green laser pointer		532 nm
	deep violet		400 nm
Ultraviolet	UVA		365 nm
	UVC		100 nm
X-ray	“soft”		1 nm
	“hard” (medical)		2.48×10^{-11} m
Gamma	radioactive cobalt-60		9.31×10^{-13} m

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	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

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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

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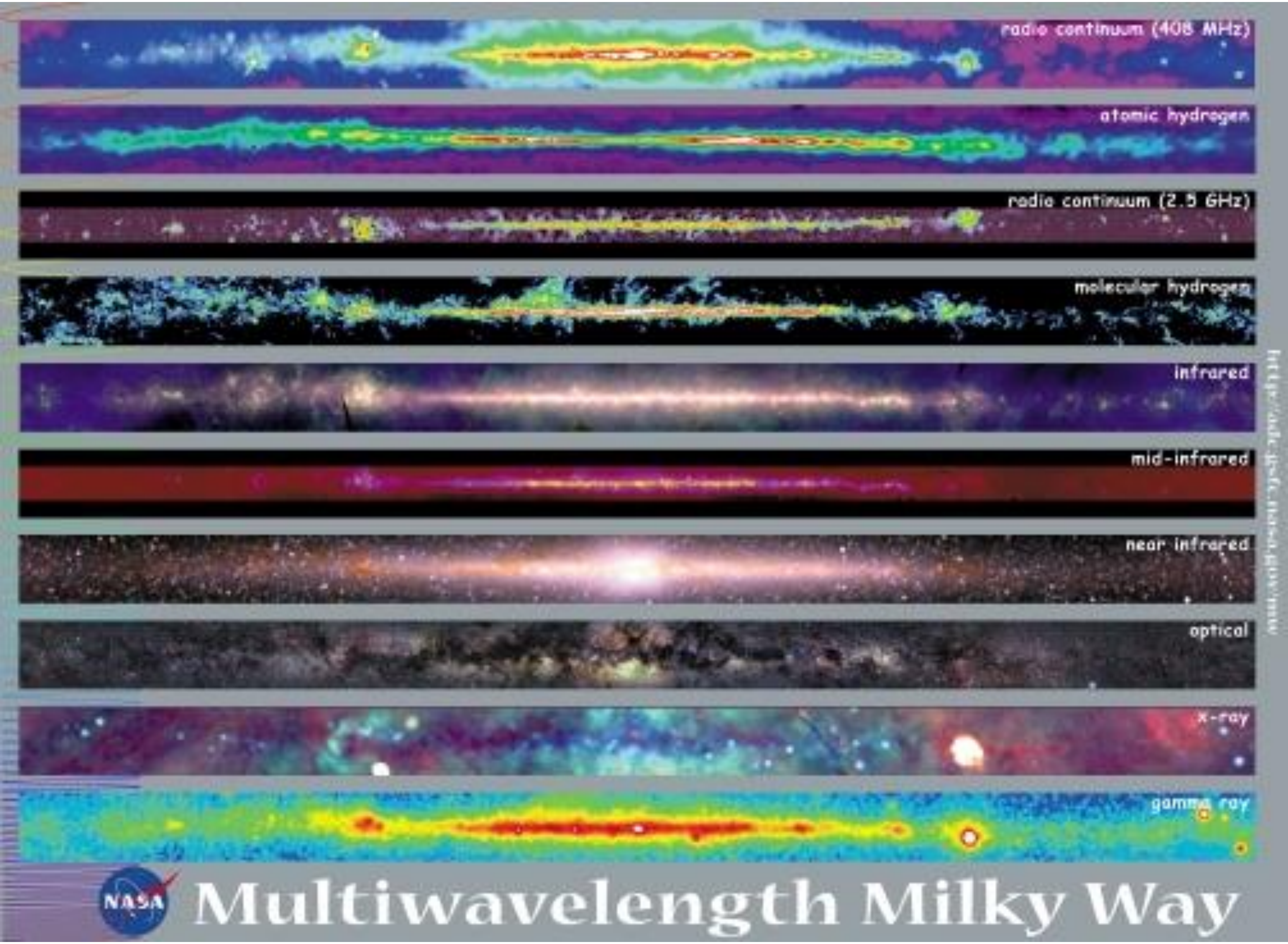
radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
NASA
Multiwavelength Milky Way

False Color Images

- Using special cameras and detectors astronomers can produce pictures using EMR that is not visible.
- The colors in such an image will correspond to particular nonvisible wavelengths (usually in order ROYGBV).

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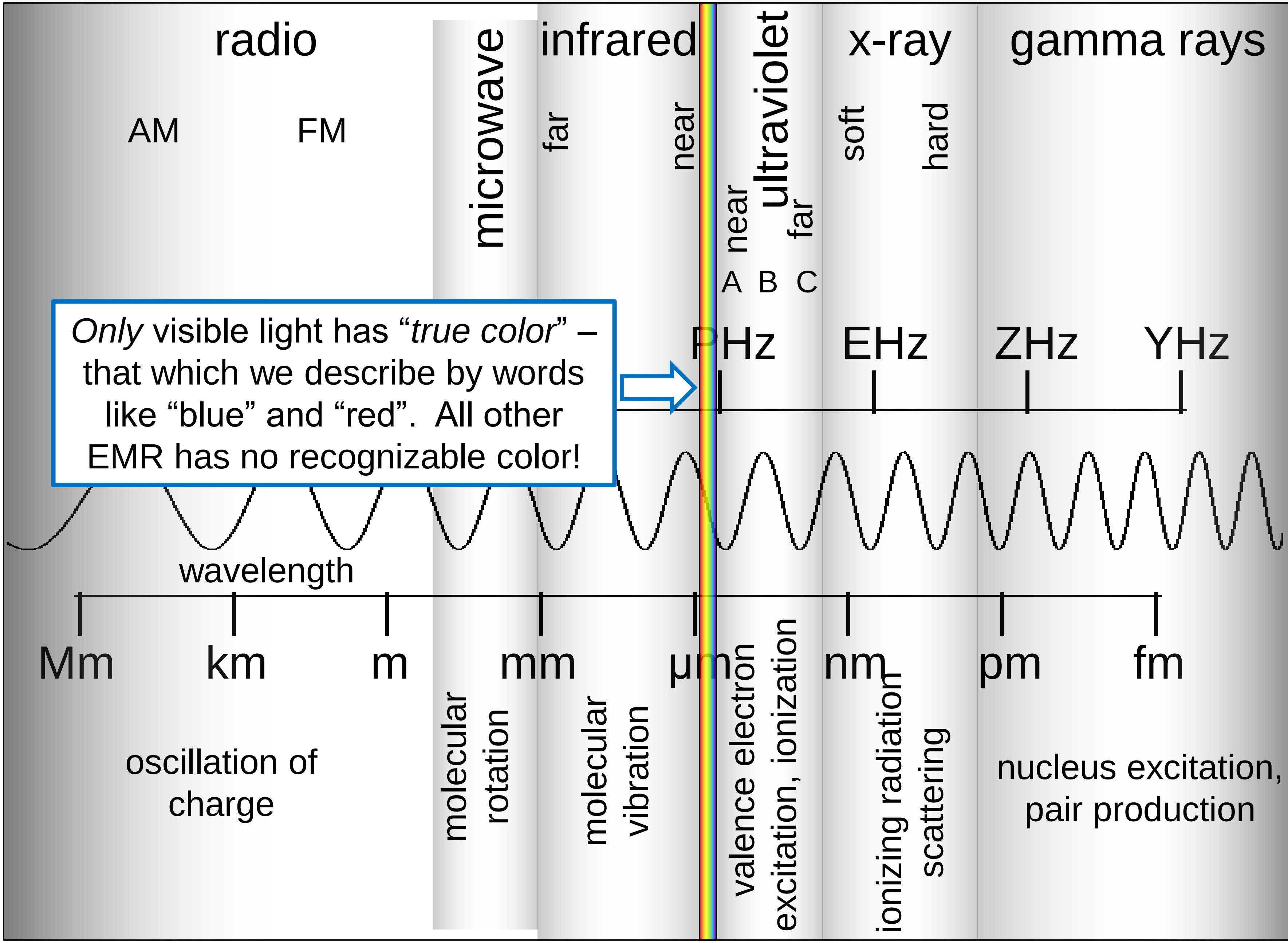
the Electromagnetic Spectrum



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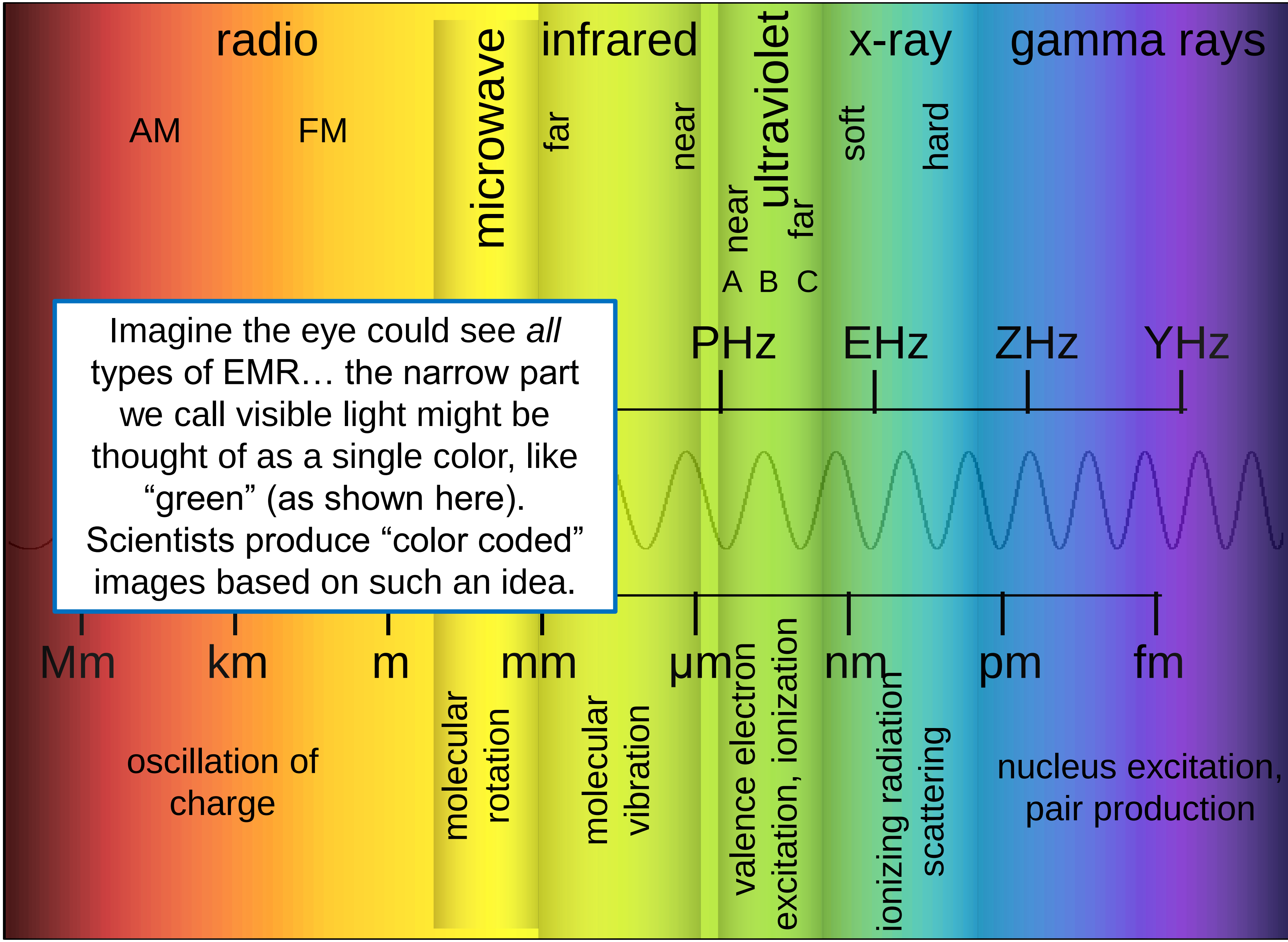
the Electromagnetic Spectrum



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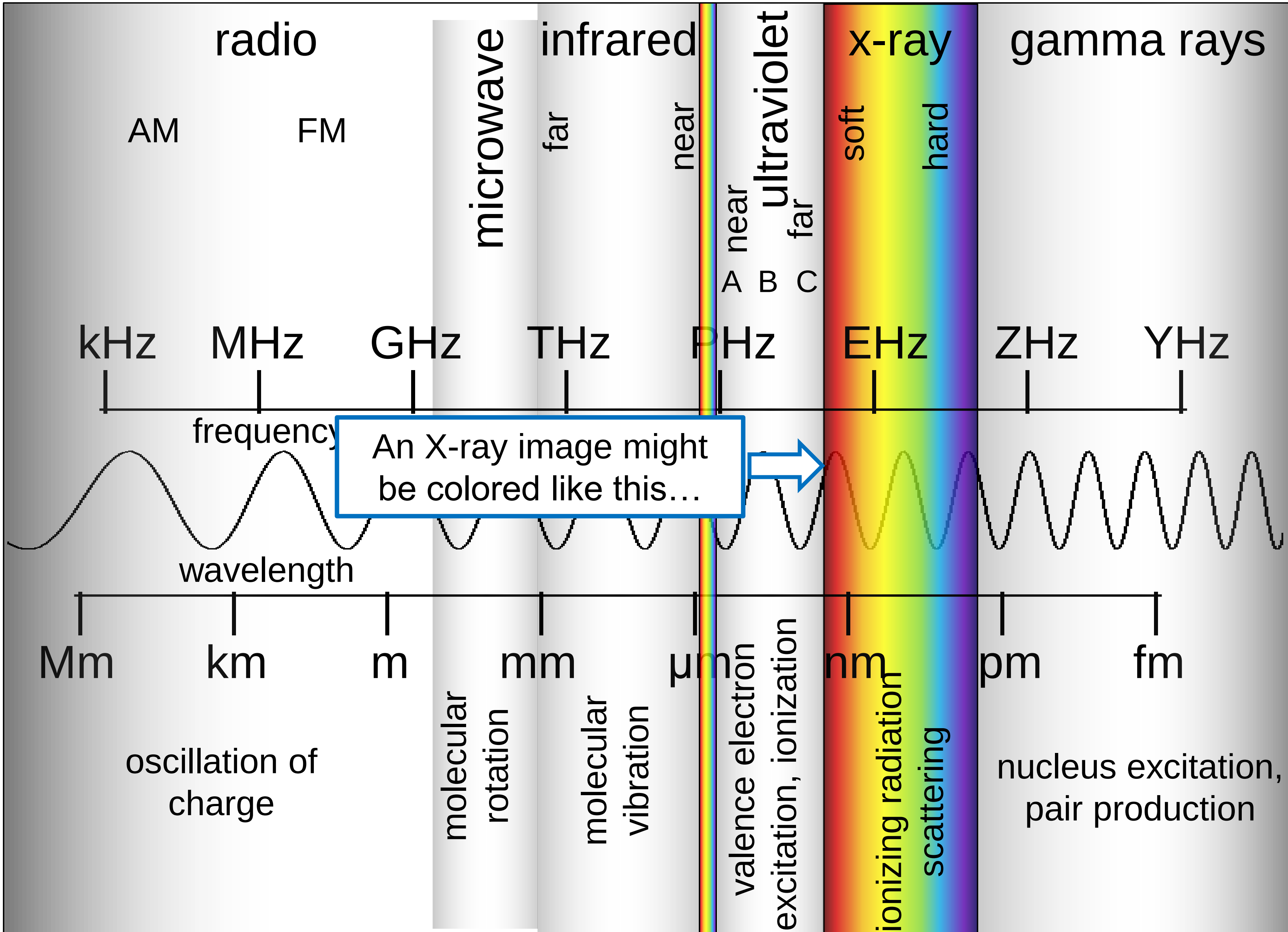

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the Electromagnetic Spectrum

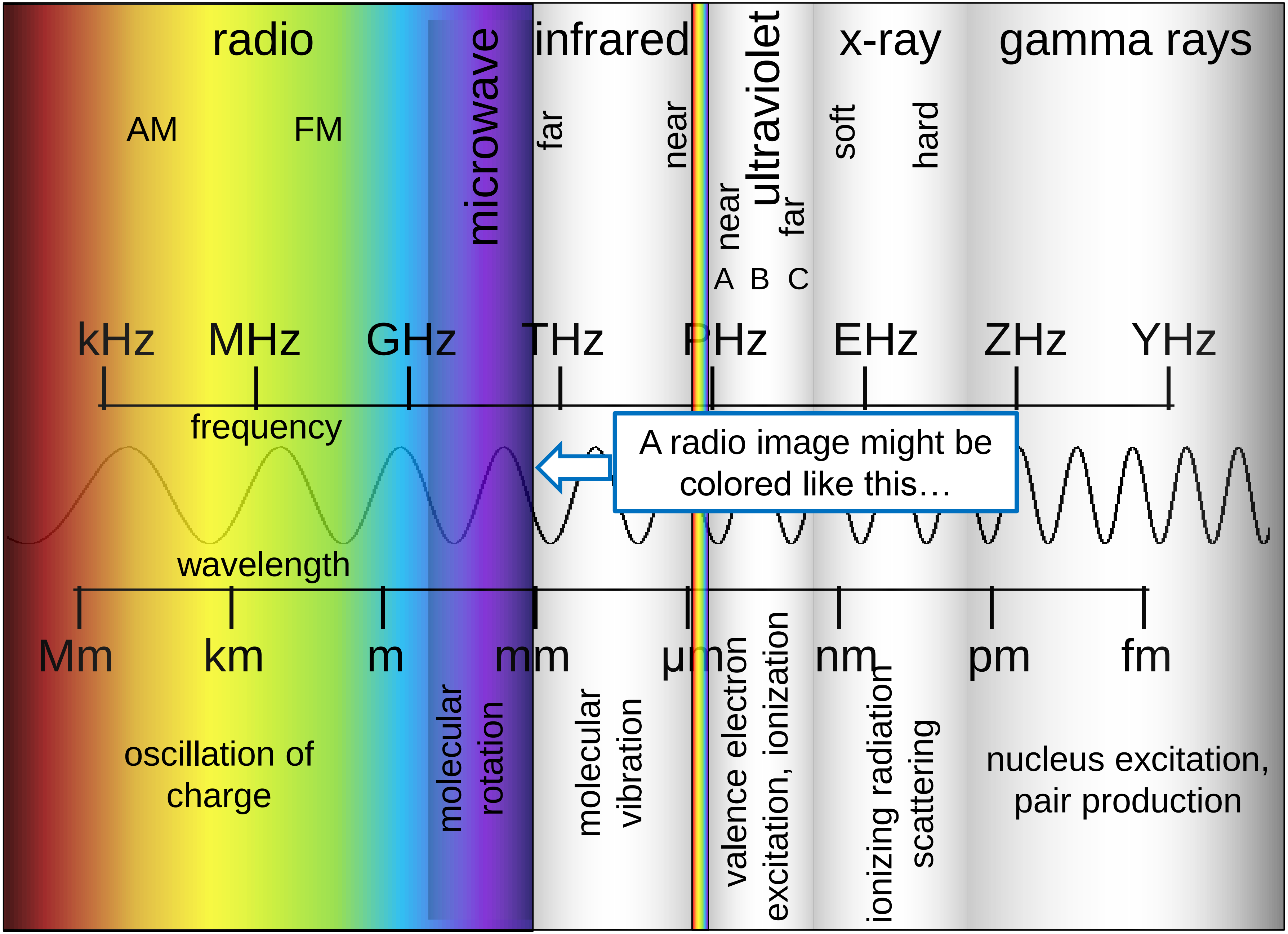

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image: Matthew Spinelli
Orion – Visible Light

APOD – 2005 April 19 IRAS 3 IR wavelengths

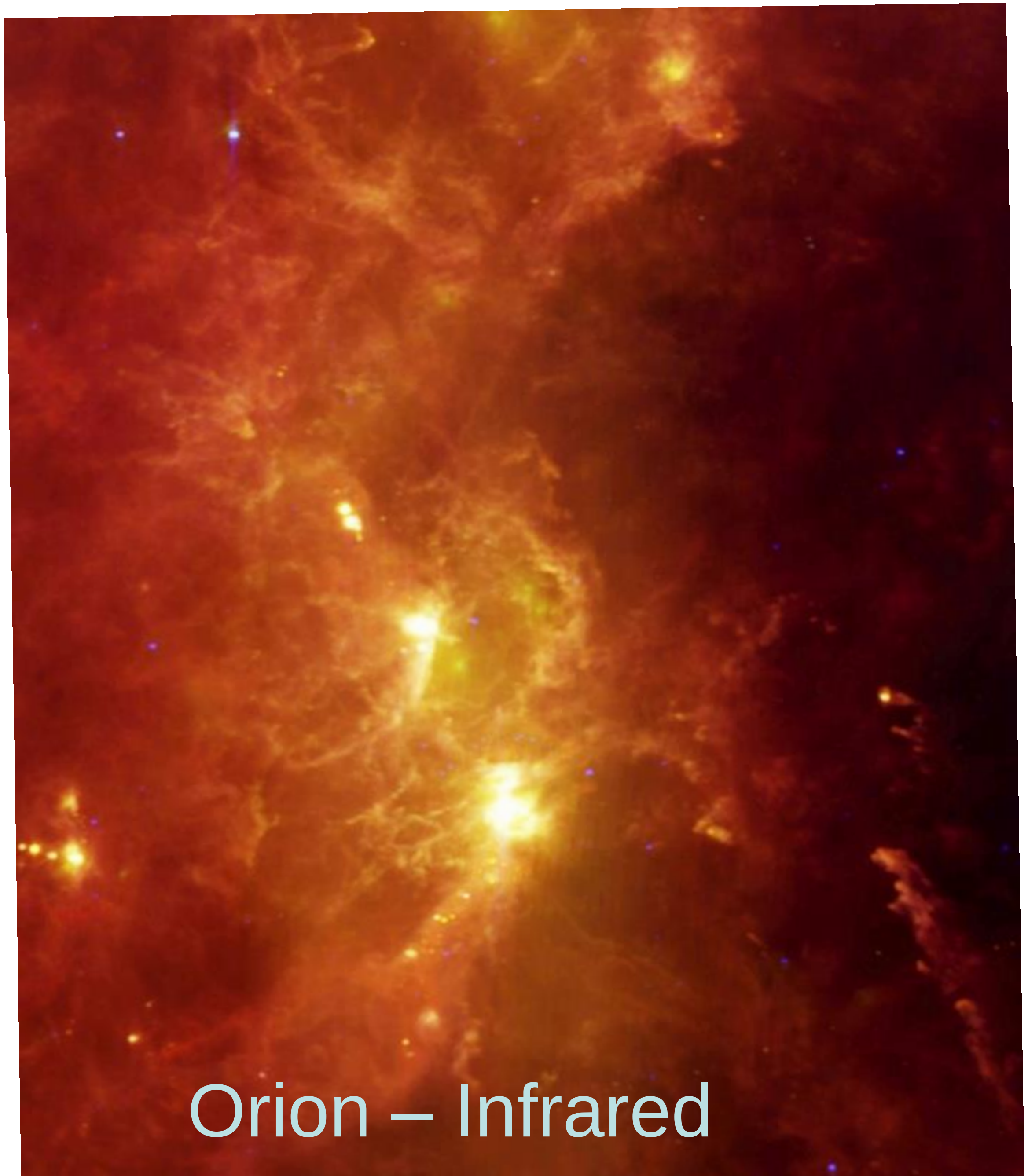



image: Matthew Spinelli
Orion – Visible Light

Max Planck Institute

Orion – X-ray

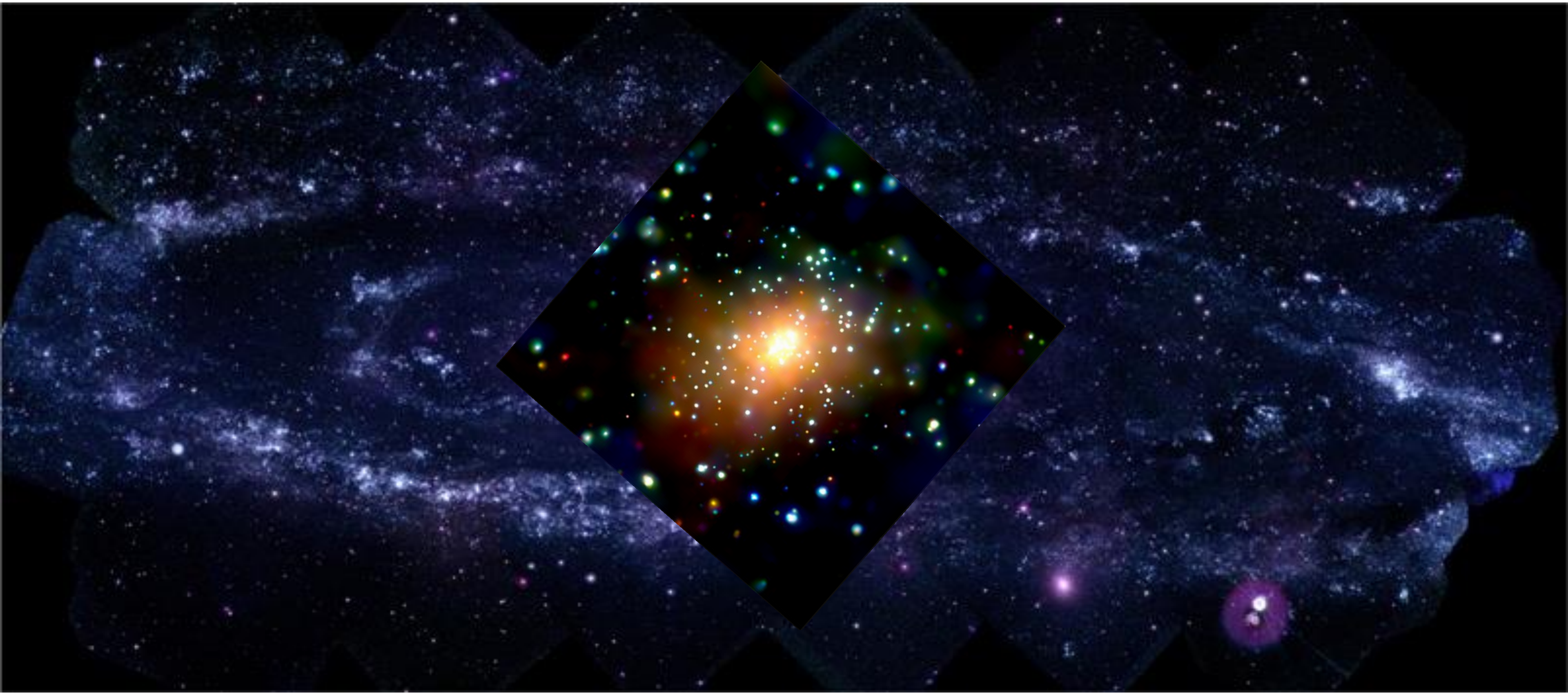
The Andromeda Galaxy – Visible Light

Credit: UV - NASA/Swift/Stefan Immler (GSFC) and Erin Grand (UMCP)
Optical - Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF

The Andromeda Galaxy – Ultraviolet

Credit: UV - NASA/Swift/Stefan Immler (GSFC) and Erin Grand (UMCP)
Optical - Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF

The Andromeda Galaxy – X-ray

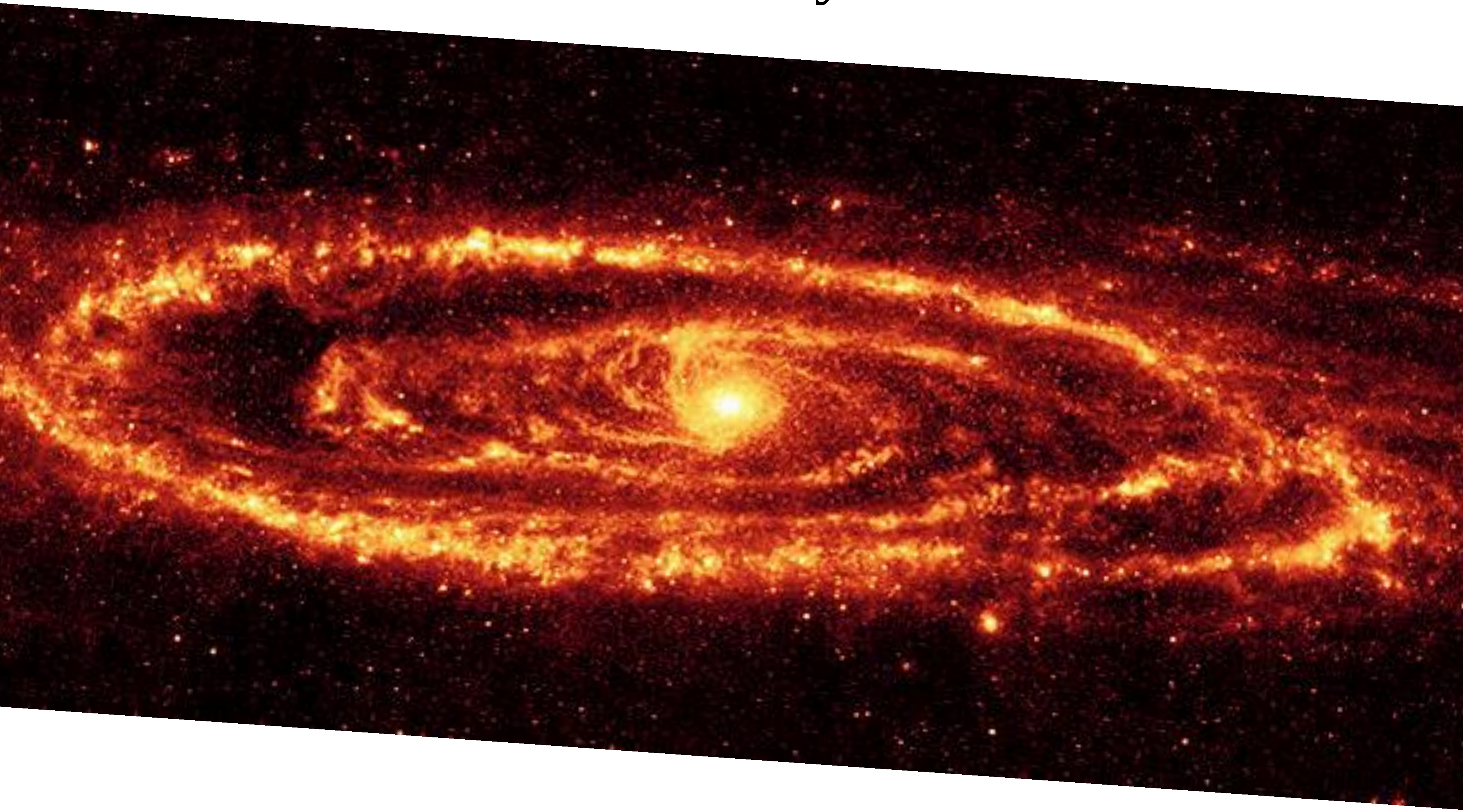


Credit: UV 190 – 260 nm - NASA/Swift/Stefan Immler (GSFC) and Erin Grand (UMCP)
X-ray 0.5 – 1 keV, 1 – 2 keV, 2 – 4 keV - NASA/Chandra/UMass/Z.Li & Q.D.Wang

The Andromeda Galaxy – Visible Light

Credit: UV - NASA/Swift/Stefan Immler (GSFC) and Erin Grand (UMCP)
Optical - Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF

The Andromeda Galaxy – Infrared



24 μm NASA/JPL-Caltech/Univ. of Ariz.

Particles of Light?

- Although light can be clearly demonstrated to behave as a wave there are certain situations in which it appears to behave 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.

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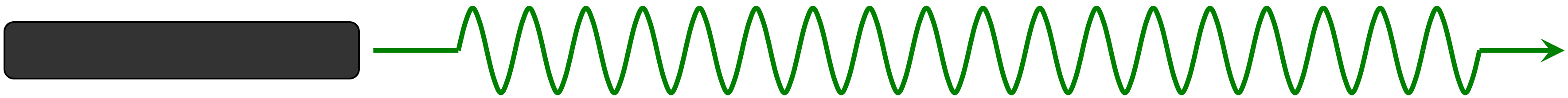
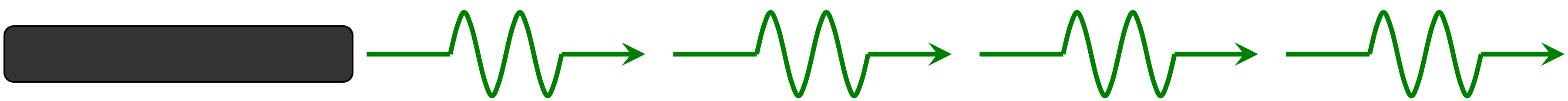
Visualizing Photons…



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.

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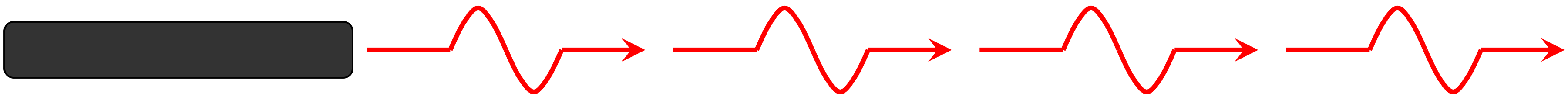
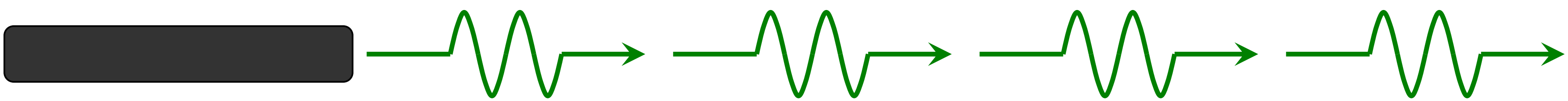
Visualizing Photons…



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.

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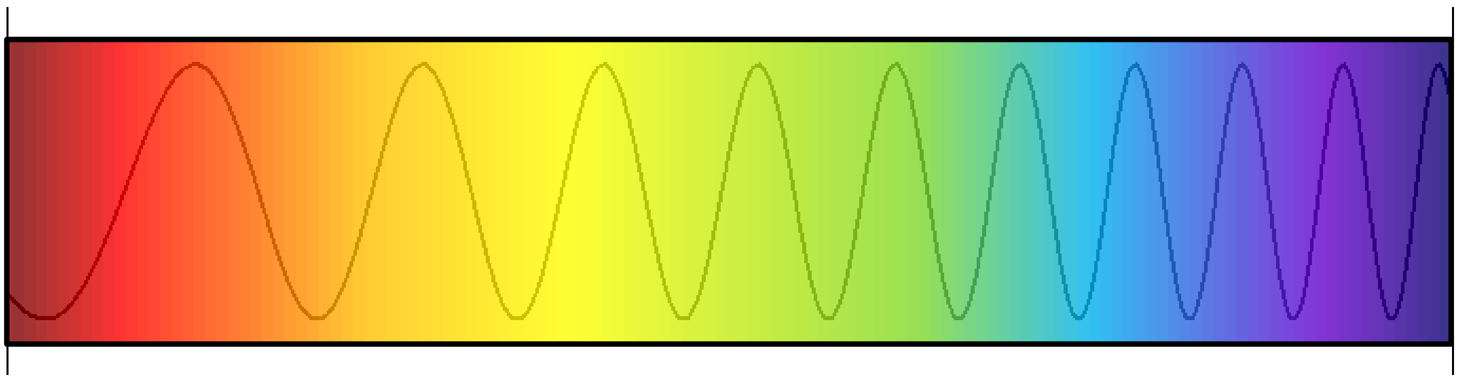
Visible Light Parameters



increasing frequency

increasing energy per photon

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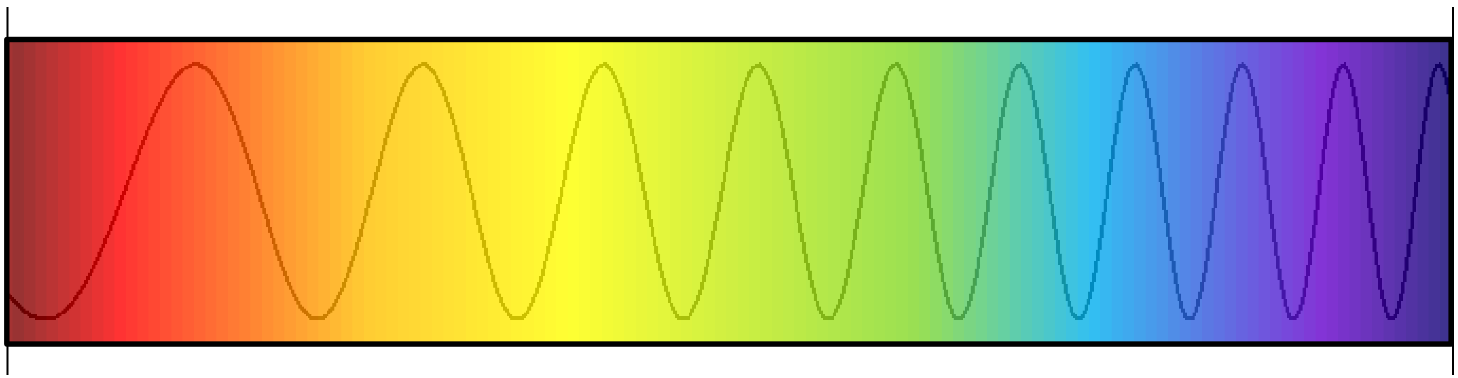
Visible Light Parameters



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

400 THz - - - - - frequency - - - - - 750 THz

1.7 eV - - - energy per photon - - - 3.1 eV

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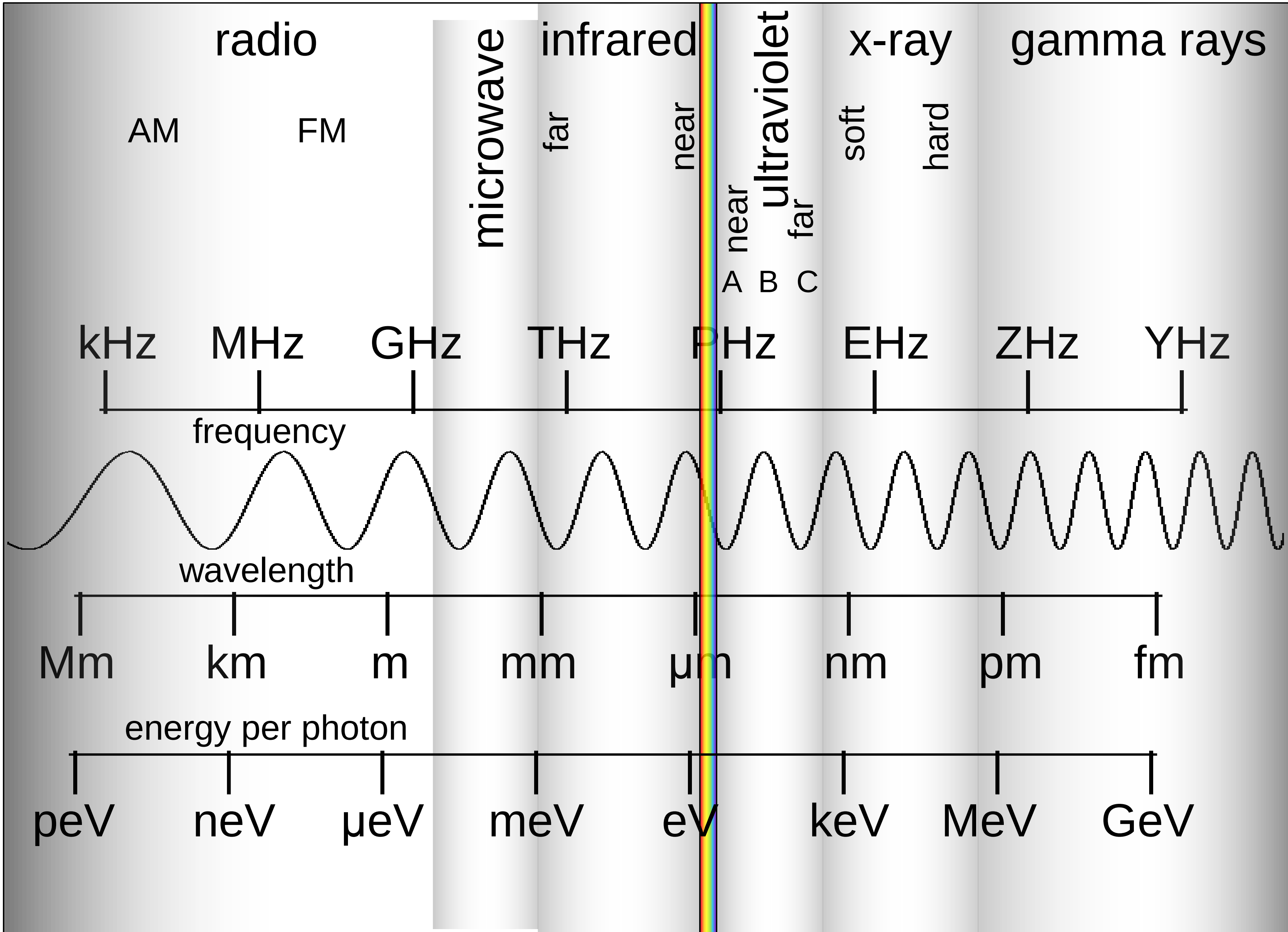
the Electromagnetic Spectrum



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