Observing the Earth using the Electromagnetic Spectrum

Learning Objectives

- In this lecture you will learn…
  - Understand the basis of the electromagnetic spectrum
  - Understand what major wavelengths we observe the Earth with
  - Be able to describe the different types of radiation from the Sun

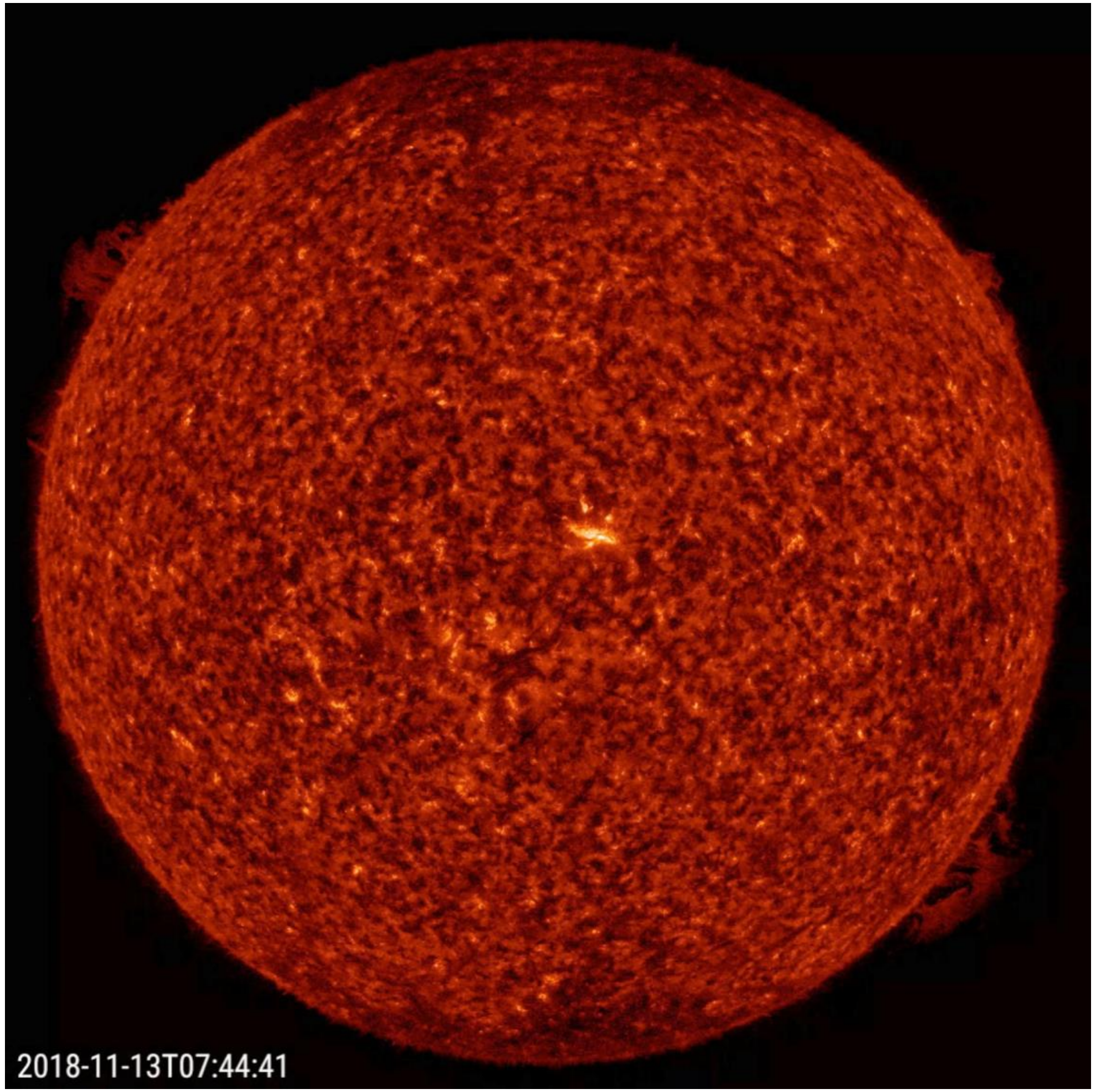
Radiation Fundamentals

- The fundamental unit of radiation is the photon

- Photons are released from objects when matter:
- is excited thermally
- is engaged in nuclear processes (fusion, fission)

- Photons are also absorbed and reflected by matter

- The speed of photons in a vacuum (c) is 3.0 x 10^8 m/s but have different energies related to their wavelength



Opposing Solar Prominences (Source: NASA)

- 109 times bigger than the Earth (diameter).
- 99.86% of the total mass of the Solar System.
- Surface temperature: 5,800 K
- Energy comes from nuclear fusion of hydrogen into helium
- Emits light in virtually every part of the EMS

Radiation Fundamentals

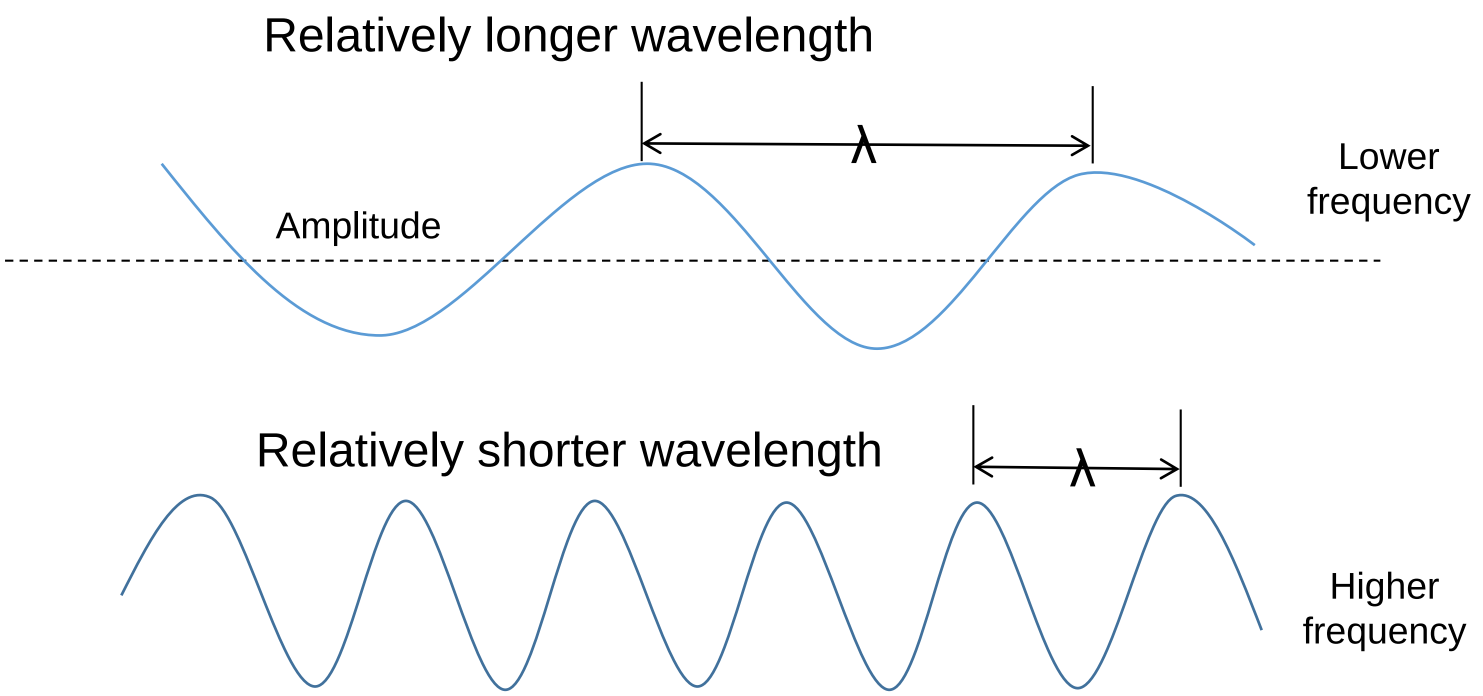
We relate frequency and wavelength by:

$$c = \lambda v$$

where c = speed of light (a constant), lambda = wavelength and v = frequency.

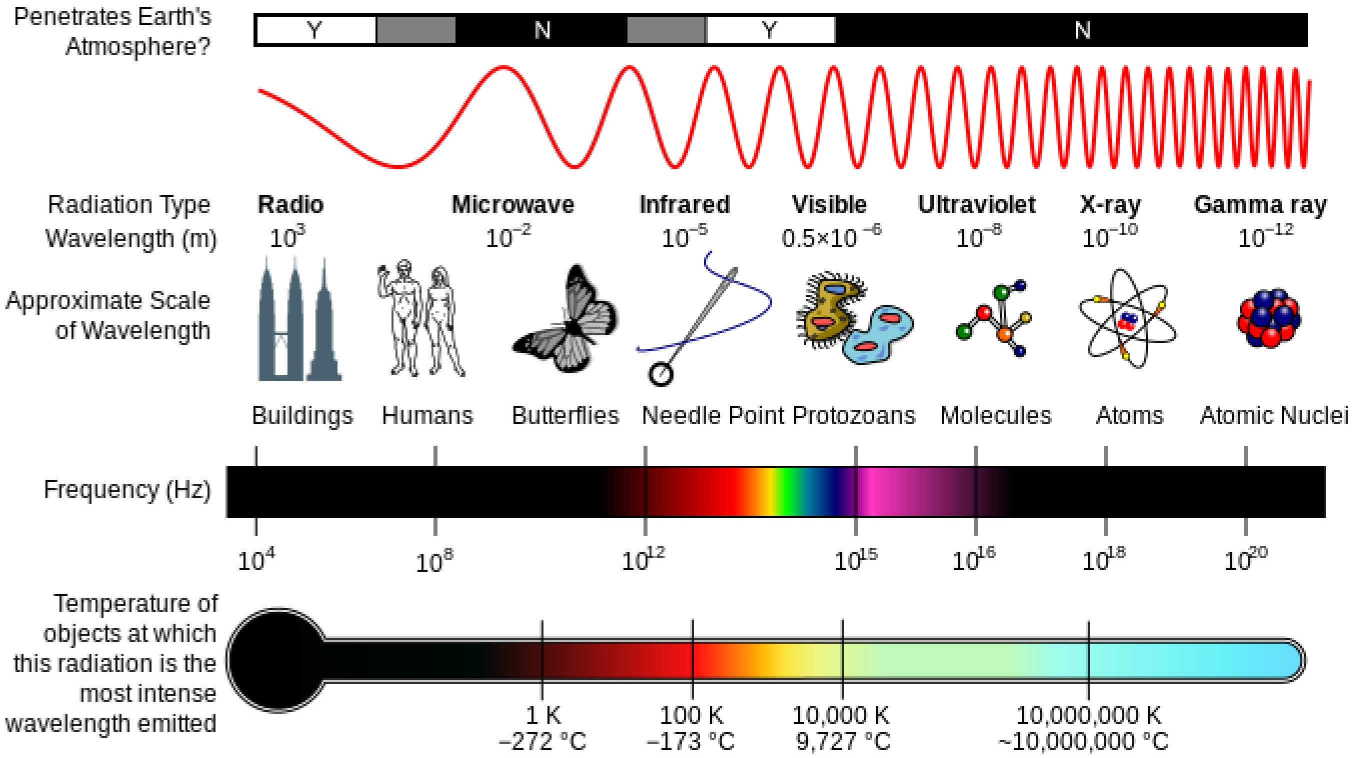
So, we see that as wavelength increases (gets longer), the lower the frequency (and energy).

Radiation Fundamentals



EMR Spectrum

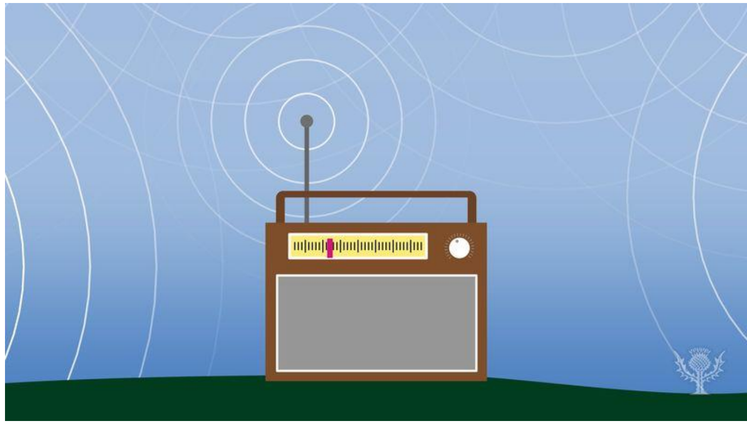
- Wavelengths range in size from radio waves which are several meters long, to visible light which is measured in microns or millionths of a meter (10^{-6} m)



EM Spectrum Properties edit (Source: Wikimedia Commons)

Radio Waves

- Radio waves have the longest wavelengths in the spectrum
- They range from the length of a football field to larger than our planet
- You can tune a radio to a specific radio amplitude (AM) or frequency (FM)
  - And listen to your favorite music
- The radio "receives" these electromagnetic radio waves and converts them to mechanical vibrations in the speaker to create sound



Radio Waves

- Astronomical objects often produce radio waves
    - Thus radio telescopes can view planets, stars, and galaxies
- Since radio waves are longer than optical waves, radio telescopes must be physically very large
- In order to make a clearer, or higher resolution, radio image, radio astronomers often combine several smaller telescopes, or receiving dishes, into an array

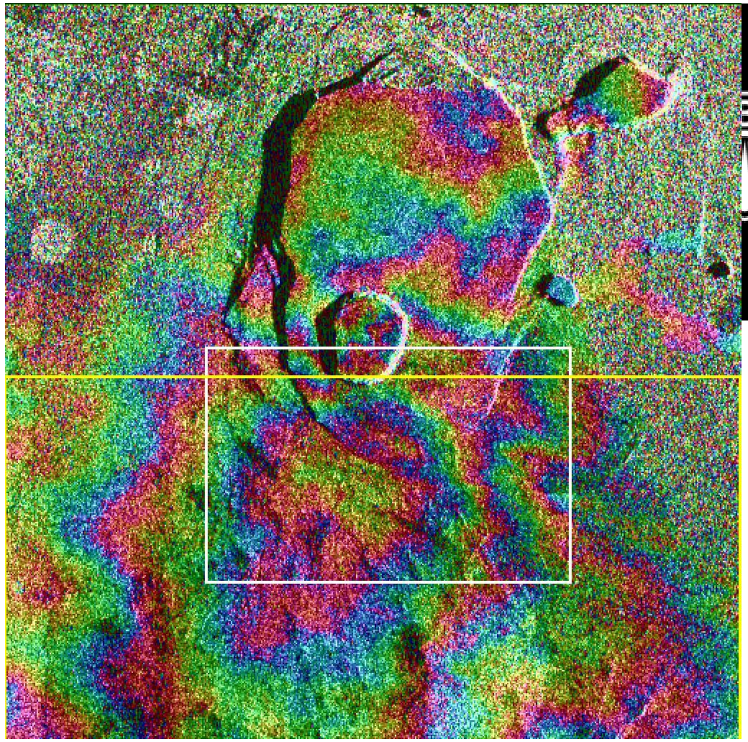
CSIRO ScienceImage 3881 Five Antennas at Narrabri - restoration1 (Source: Wikimedia Commons)

Microwaves

- Microwaves are the portion of waves in the spectrum at the end of the radio spectrum
- Most communication satellites use C-, X-and Ku-bands to send signals to a ground station

- Remote sensing using X, C, L and P

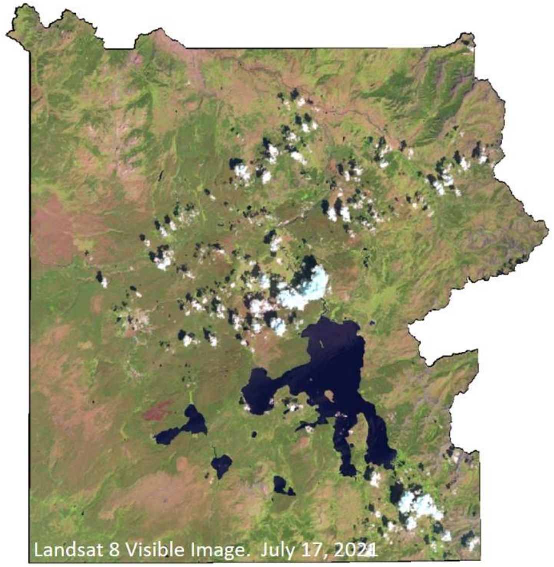
- Microwaves that can see through haze, light rain and snow, clouds, and smoke are beneficial for satellite communication and studying the Earth from space

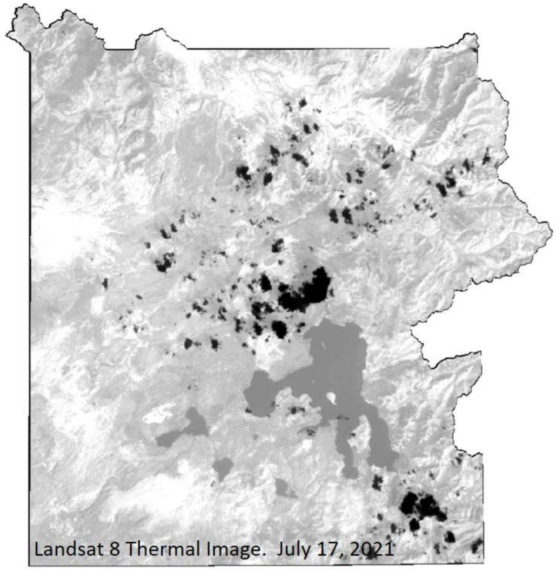


Space Radar Image of Kilauea, Hawaii (Using C & X Band; Source: NASA)

Infra-Red Waves

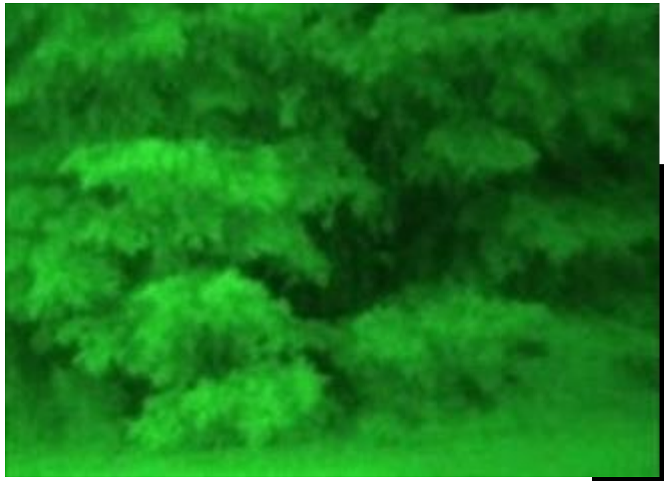
- The infrared region is divided into:
  - Near-
  - Mid- (or Short wave)
    - Near and mid infrared wavelengths are classified as reflective infrared
  - and Far-infrared
    - Far-infrared is classified as longwave emitted infrared
    - These wavelengths are best for studying the longwave thermal energy radiating from our planet





Infra-Red Waves

- Objects emit radiation as they heat up
- The thermal (or far/longwave) infrared radiation that is emitted as an object warms is what we sense as heat
  - Some objects are so hot they also emit visible light—such as a fire
  - Other objects, such as humans, are not as hot and only emit infrared waves
  - Our eyes cannot see these infrared waves but instruments that can sense infrared energy—such as night-vision goggles or infrared cameras–allow us to "see" the infrared waves emitting from warm objects such as humans and animals



Visible vs. thermal image of a person standing in a bush

Near Infra-Red Waves

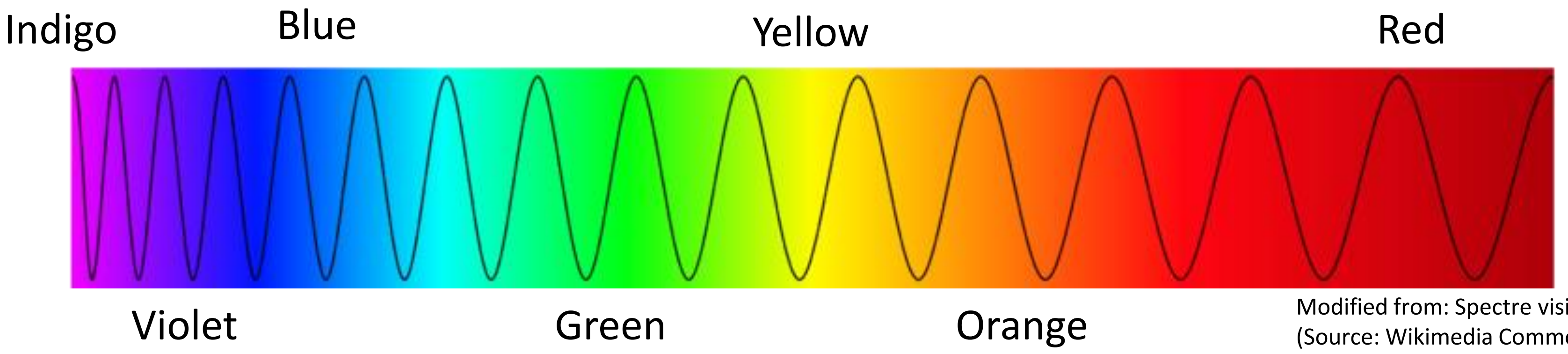
- A portion of radiation just beyond the visible spectrum is referred to as near-infrared
- This is not heat
  - It is reflected, transmitted, and absorbed light and it is very useful for observing health of vegetation and soil composition
- Reflected near-infrared radiation can be sensed by satellites, allowing scientists to study vegetation from space

Suzhou, Jingsu, China (Source: NASA)

High resolution NIR satellite image (where more red areas represent greater reflection of NIR light)

Visible Waves

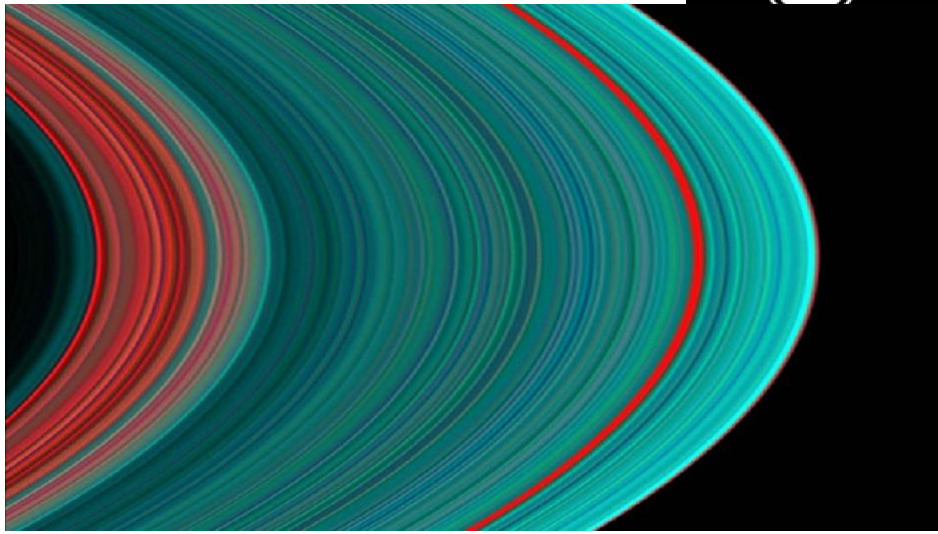
- All electromagnetic radiation is light, but the portion of this radiation our eyes can see is called visible light
- The wavelengths of visible light fall out like a rainbow
- Violet has the shortest wavelength, at around 380 nanometers, and red has the longest wavelength, at around 700 nanometers
  - Green is in the middle
- Each color in a rainbow corresponds to a different wavelength of electromagnetic spectrum



Modified from: Spectre visible light el
(Source: Wikimedia Commons)

UltraViolet Waves

- Ultraviolet (UV) light has shorter wavelengths than visible light
- Although UV waves are invisible to the human eye, some insects, such as bumblebees, can see them
- The Sun is a source of all UV light
  - UV-C rays are the most harmful and are almost completely absorbed by our atmosphere
  - UV-B rays are the harmful rays that cause sunburn
- Only a small amount of UV-A waves hit the Earths surface and those are the ones we use in Earth observation



Ultraviolet Imaging Spectrograph (UVIS) used to capture imagery of Saturn's rings (Source: NASA)

X-Ray Waves

- X-rays have much higher energy and much shorter wavelengths than ultraviolet light
- As a result we often refer to X-rays in energy rather than their wavelength

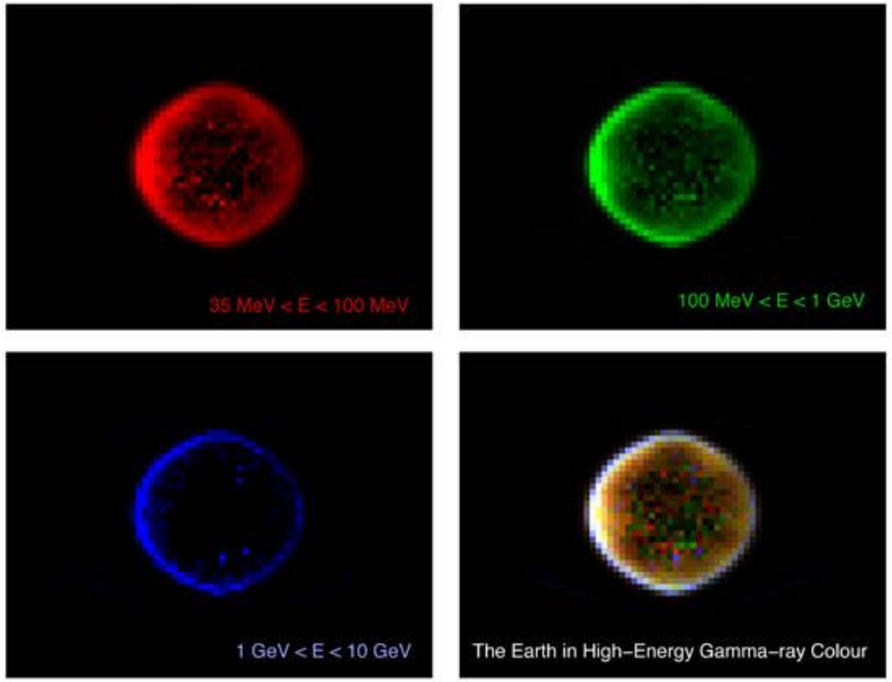
- Different objects absorb different amounts of x-rays
- Different hot bodies like the Sun and stars all emit x-rays

- We don’t use X-rays to observe changes on the Earth

X-ray of all 32 human teeth (Source: Wikimedia Commons)

Gamma Waves

- Gamma rays have the smallest wavelengths and the most energy
- They are produced by the hottest and most energetic objects in the universe, such as neutron stars and pulsars, supernova explosions, and regions around black holes
- On Earth, gamma waves are generated by nuclear explosions, lightning, and radioactive decay
- Unlike optical light and x-rays, gamma rays cannot be captured and reflected by mirrors
  - Gamma-ray wavelengths are so short that they can pass through the space within the atoms of a detector
- Gamma-ray detectors are usually densely packed crystal blocks
  - As gamma rays pass through, they collide with electrons in the crystal
  - These collisions create charged particles that can be detected by the sensor



New Image of Earth, Seen Through Gamma-Ray Eyes (Source: NASA)

EMR Spectrum

- **Gamma rays and x-rays** (normally measured in Å) < 10 Å; Earth's atmosphere blocks this radiation almost completely.

- **Ultraviolet** 1-400 nm; Most blocked by Earth's atmosphere (O_3 absorption) except from 300-400 nm.

- **Visible** 400-700 nm; peak solar wavelengths; Earth's atmosphere almost completely transparent (relatively speaking to other EMR).

- **Reflective (near/mid) infrared** 700-3000 nm (0.7 – 3.0 μm); high absorption by water vapor in the atmosphere; commonly used by earth observation satellites to monitor vegetation cover/health.

- **Thermal (far) infrared** 3.0 – 10,000 μm; terrestrially derived; absorption by water vapor and CO_2 in atmosphere.

- **Microwave** – 0.1 – 30 cm; wavelengths used in RADAR; atmosphere mostly transparent.

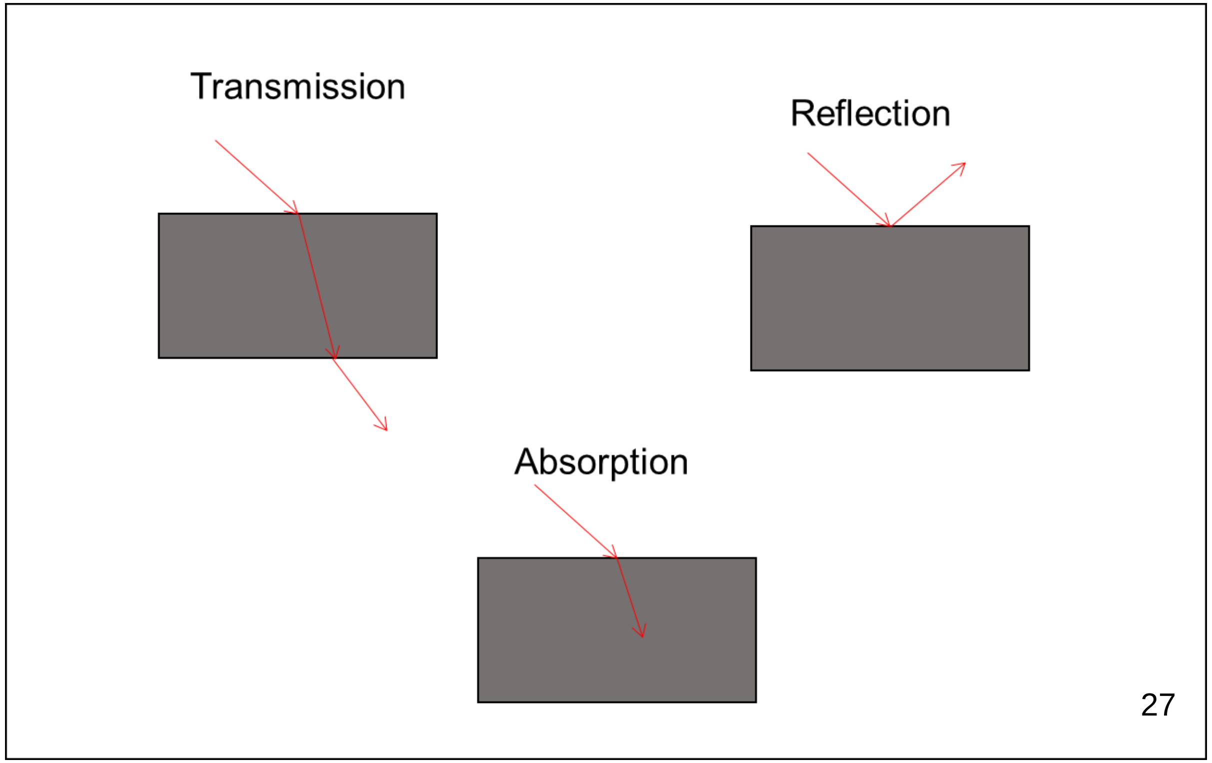
- **Radio** - > 30 cm; atmosphere almost completely transparent.

Surface Interactions

Electromagnetic radiation interacts with features on the Earth's surface

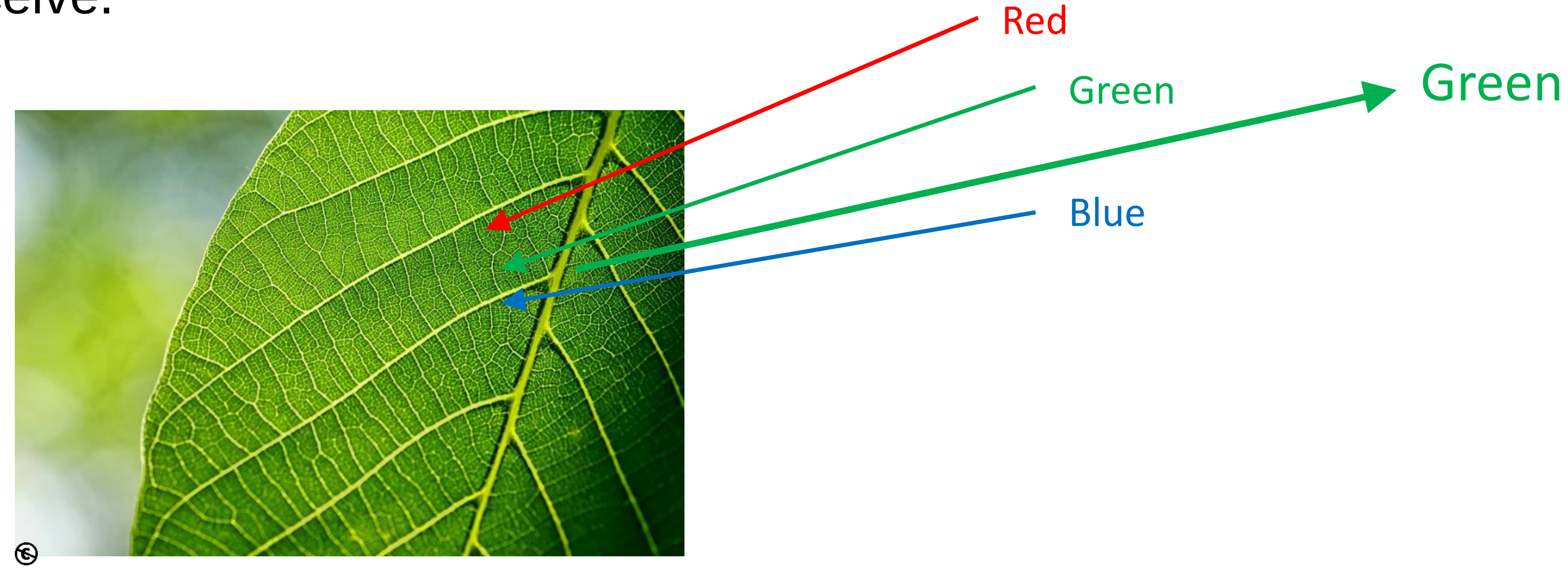
It can be

- absorbed,
- reflected,
- and transmitted.



Surface Interactions

- When visible light strikes a leaf, certain light is reflected
  - Creating the image of the leaf we see.
- The portion not reflected is absorbed or transmitted (which is why some light can be seen through it).
- Absorbed energy raises the temperature of the leaf and is reemitted as heat.
- The leaf's reflectance and absorption characteristics are what give it the color we perceive.



Surface Interactions

Upon striking the land or ocean surface the incoming radiation partitions into three responses:

- Transmittance - some fraction (up to 100%) of the radiation penetrates into certain surface materials such as water and if the material is transparent and thin, it normally passes through, generally with some diminution

- Absorption - some radiation is absorbed through electron or molecular reactions within the medium; a portion of this energy is then re-emitted, usually at longer wavelengths (thermal)

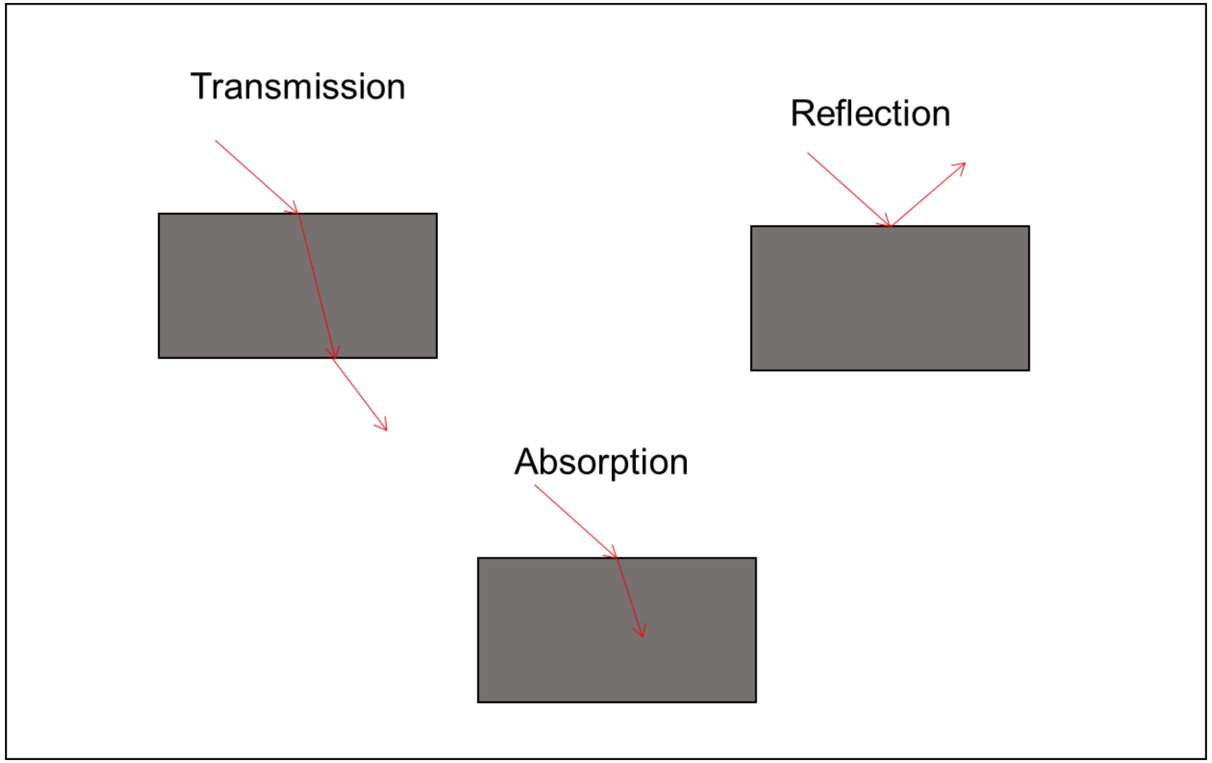
- Reflectance - some radiation reflects (moves away from the target) and scatters away from the target at various angles, depending on the surface roughness and the angle of incidence of the rays

- These three parameters are dimensionless numbers (between 0 and 1), but are commonly expressed as percentages.

Surface Interactions

- Example:
  - 60% transmission
  - 30% reflection
  - How much absorption?
    - 10% absorption

- Total must equal 100%



Important Topics

- What happens to photons (i.e. light) that are not reflected?
- How do you calculate the frequency of a wave?
- What is the longest wavelength type?
- What is NIR (near infra-red) light frequently used to measure/monitor, from earth observing satellites?
- What are the shortest and longest wavelengths sizes of visible light (in nm)?
  - What colours do they represent?