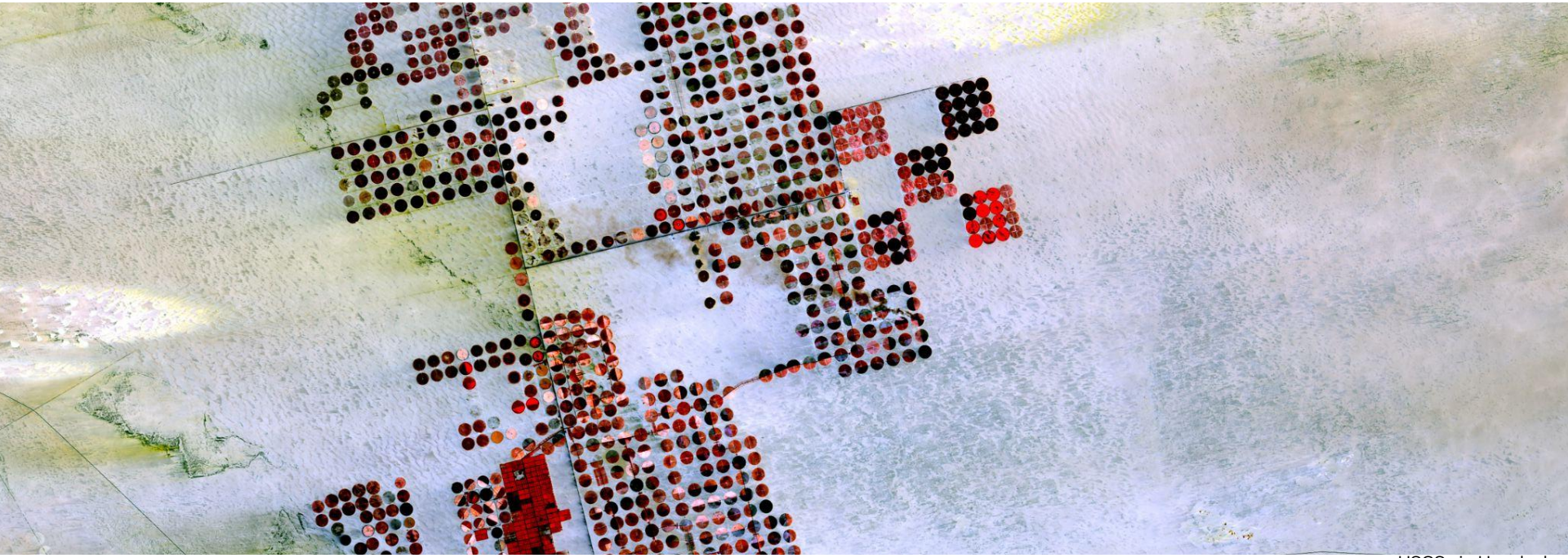
EDS 223: Geospatial Analysis & Remote Sensing
Week 6



USGS via Unsplash

Welcome!

- **Course logistics**
  - Absence policies
  - In-class etiquette
  - Efficient studying

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  - Absence policies
  - In-class etiquette
  - Efficient studying
- **Remote sensing basics**
- **Energy transfer**
- **Electromagnetic radiation**
- **Radiation budget**

What is remote sensing?

“the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring, and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems.”
(Colwell, 1997)

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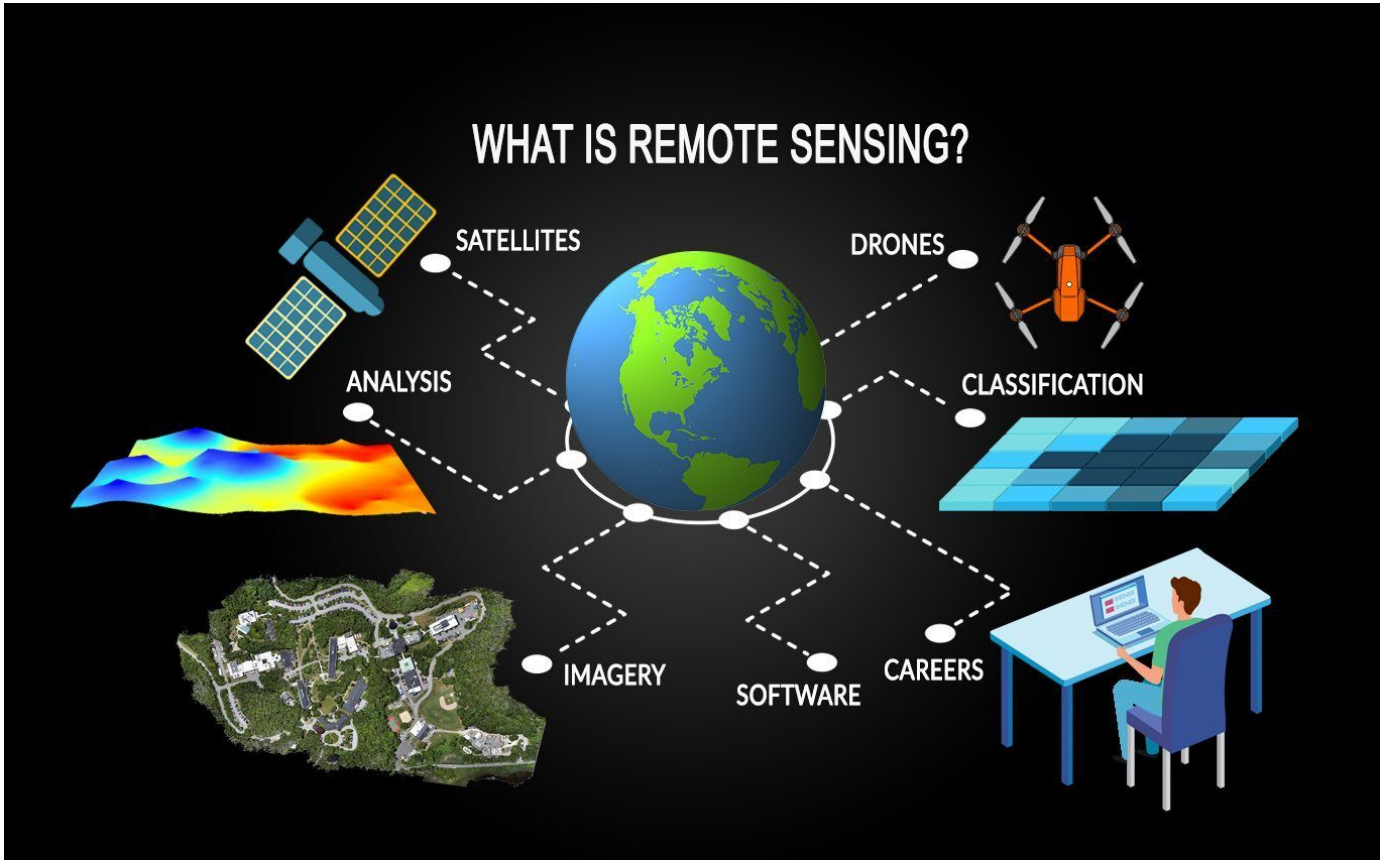

Source: GIS Geography

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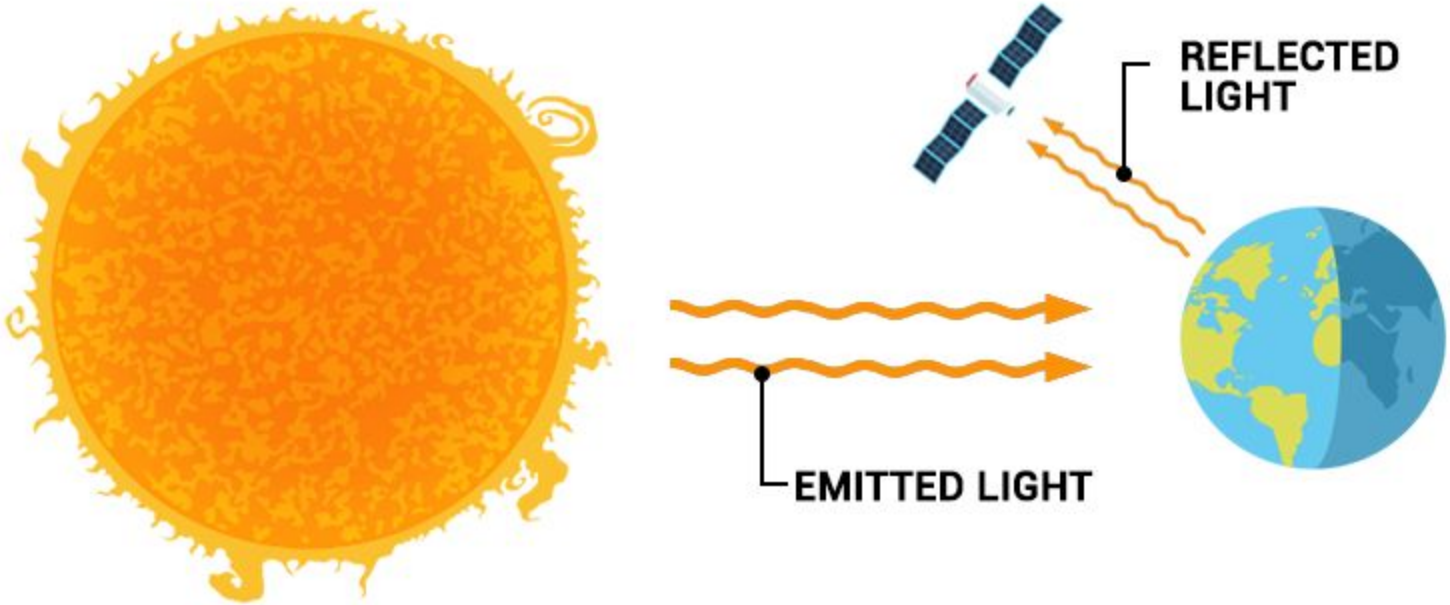
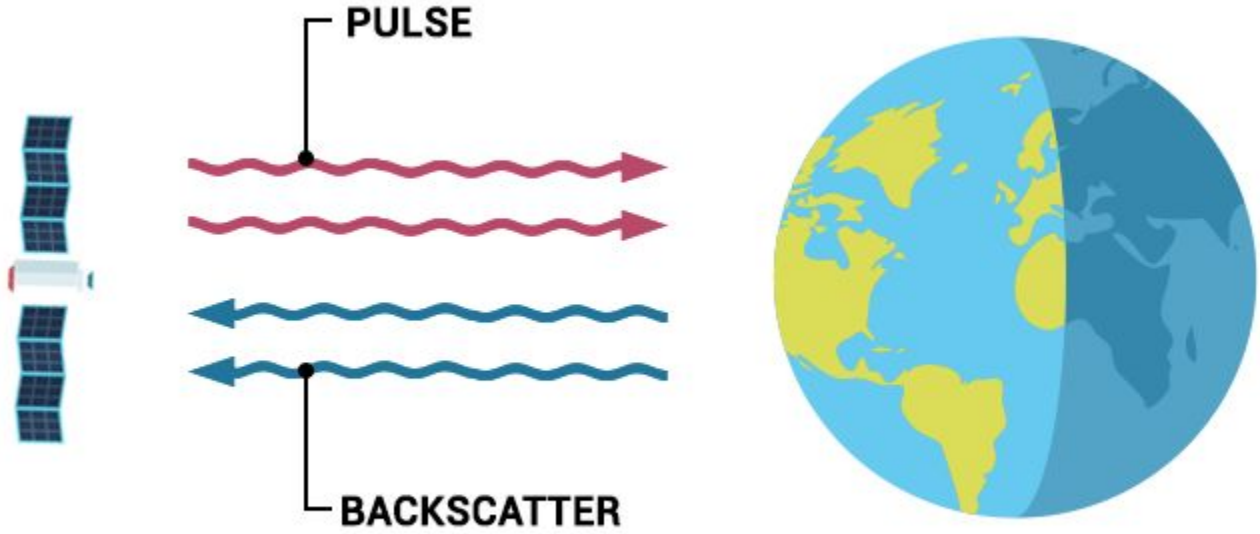
Lots of ways to be a remote senser, but you are already a remote sensor!

Energy: passive



Source: GIS Geography

Energy: active



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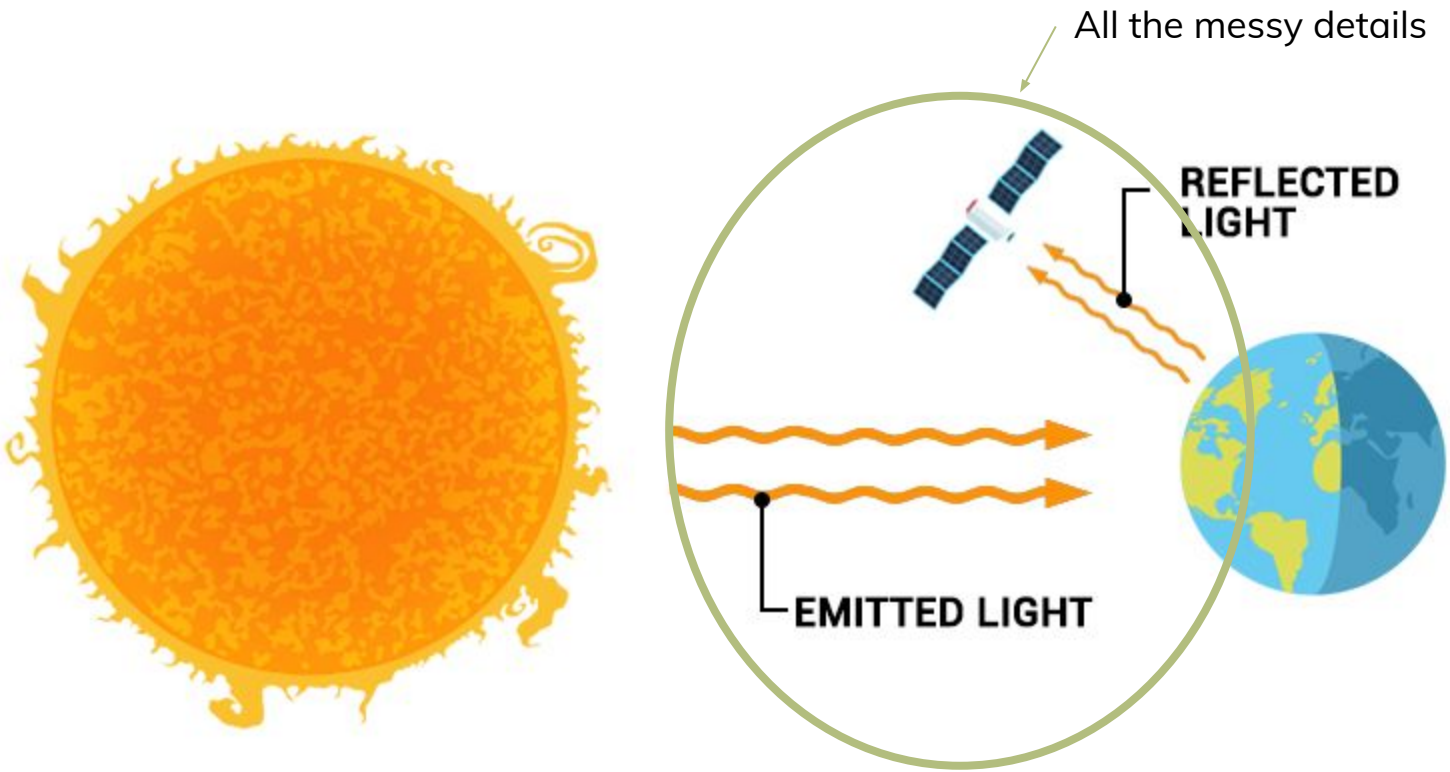

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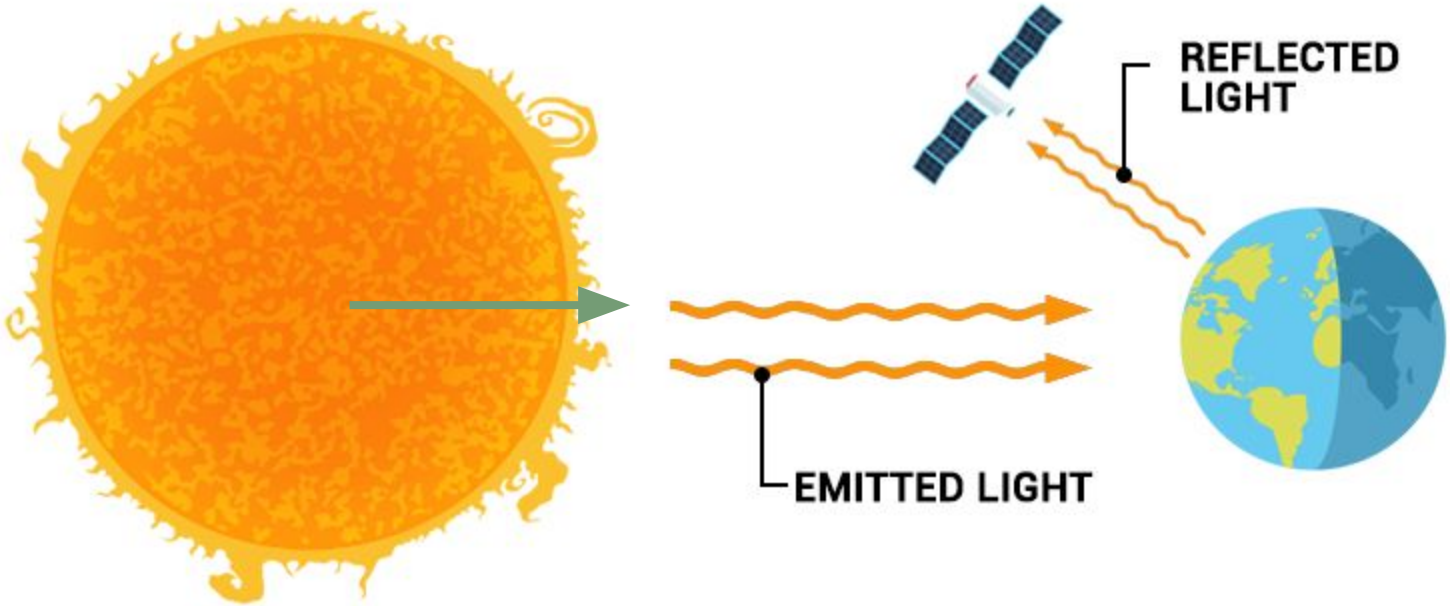

Source: GIS Geography

What is energy?

- Energy is a scalar physical quantity
  - the ability to do work
  - Several different forms of energy exist to explain all known natural phenomena.
    - kinetic, potential, thermal, gravitational, sound, light, elastic, and electromagnetic energy, etc.
- Any form of energy can be transformed into another form, but the total energy always remains the same (conservation of energy).
  - *Energy cannot be destroyed.*

What is energy?

A newton is a measure of force...
(F = ma)
the force needed to accelerate 1 kg of mass as the rate of 1 m/s^2

$$1\ \mathrm{N} = 1\ \frac{\mathrm{kg\ m}}{\mathrm{s}^2}$$

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A joule is a measure of energy...
the energy transferred to (or work done on) an object when a force of 1 N acts on an object through a distance of 1 m

$$1\ \mathrm{N} = 1\ \frac{\mathrm{kg\ m}}{\mathrm{s}^2}$$

$$1\ \mathrm{J} = 1\ \mathrm{N\ m} = 1\ \frac{\mathrm{kg\ m}^2}{\mathrm{s}^2}$$

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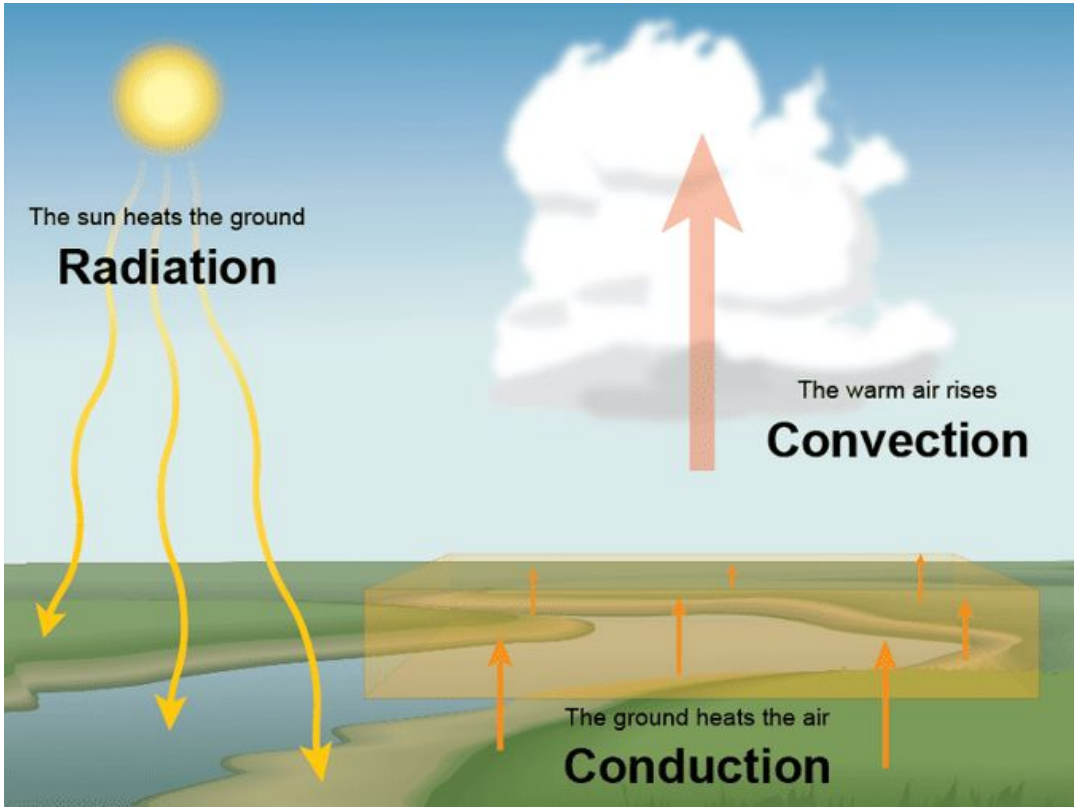
A watt is a measure of power...
the rate of energy transfer

$$1\ W = 1\ J/s$$
$$= 1\ \frac{kg\ m^2}{s^3}$$

Energy transfer



Source: UCAR

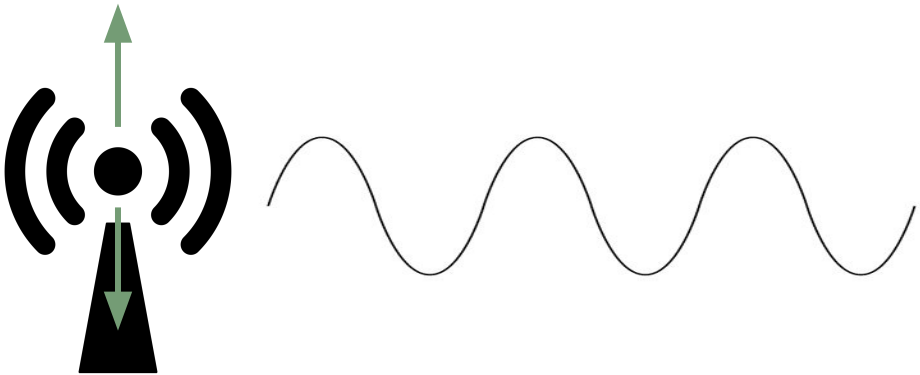
Conduction: A body/object transfers its kinetic energy to another by colliding with it.

Convection: Kinetic energy transferred by physically moving objects.

Radiation: Electromagnetic energy in the form of electromagnetic waves may be transmitted through the vacuum of space from the Sun to the Earth (the only form of energy that can take place in a vacuum).

Electromagnetic radiation

- Generated when a charged particle changes velocity



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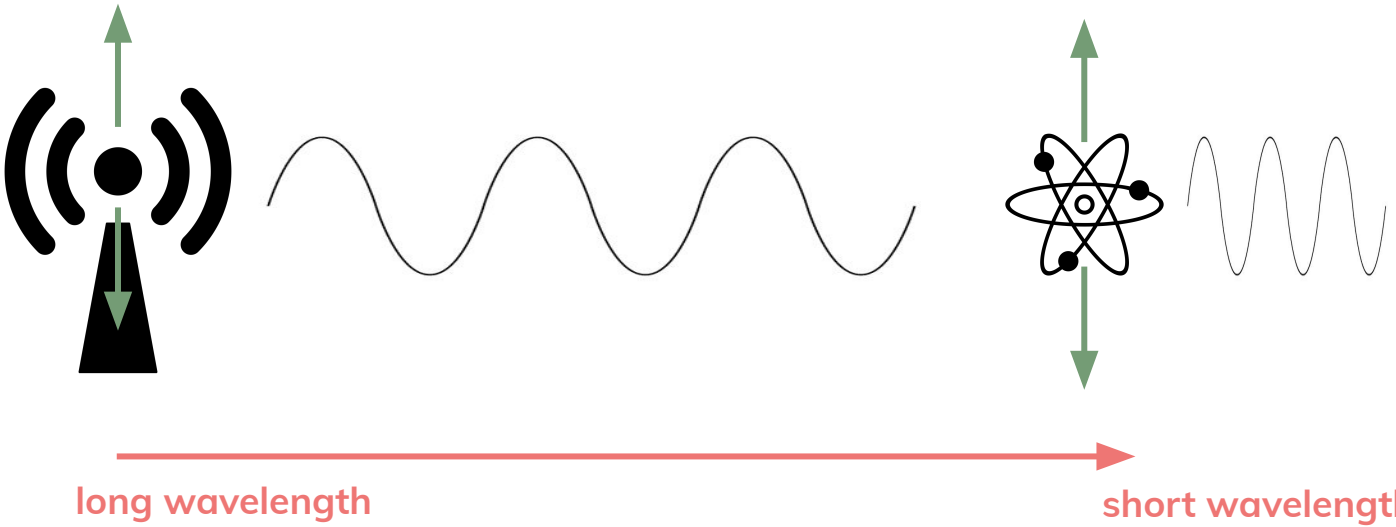

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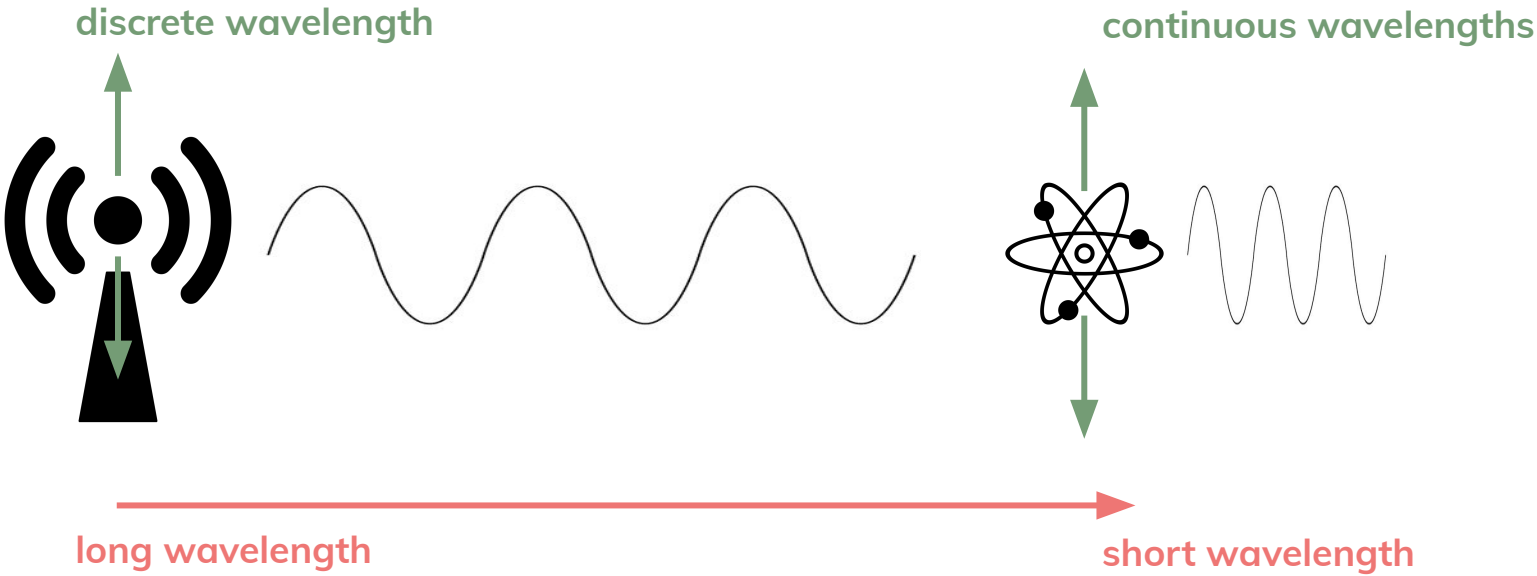

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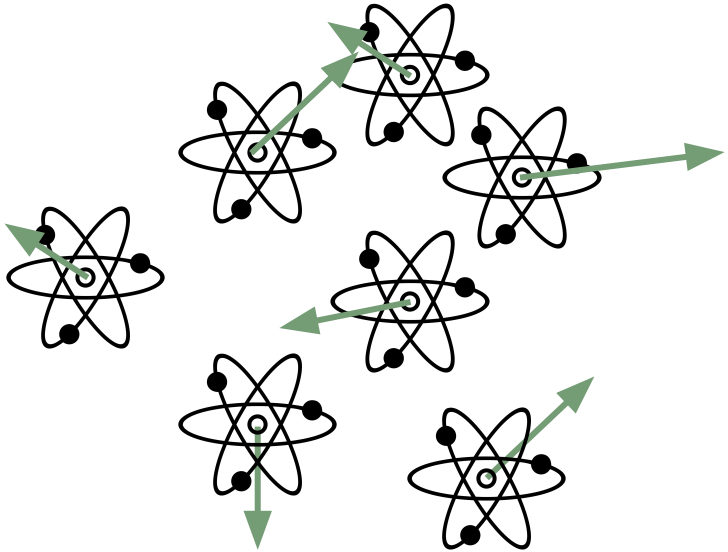

continuous wavelength

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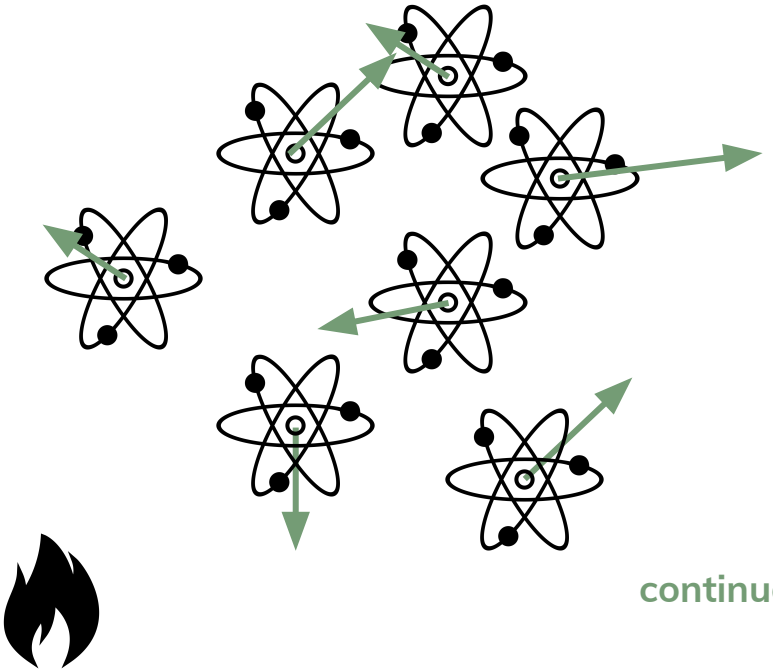

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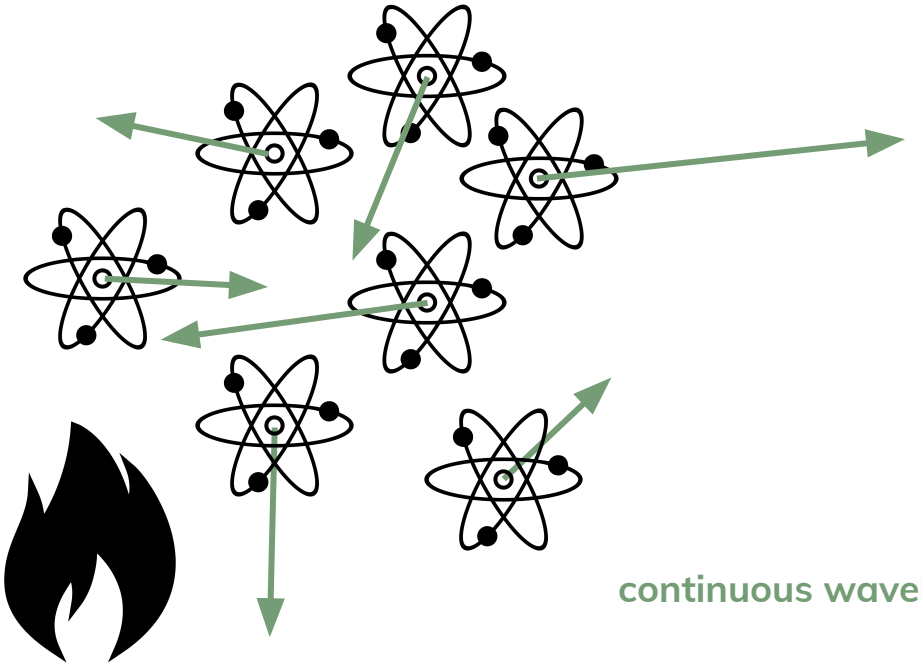

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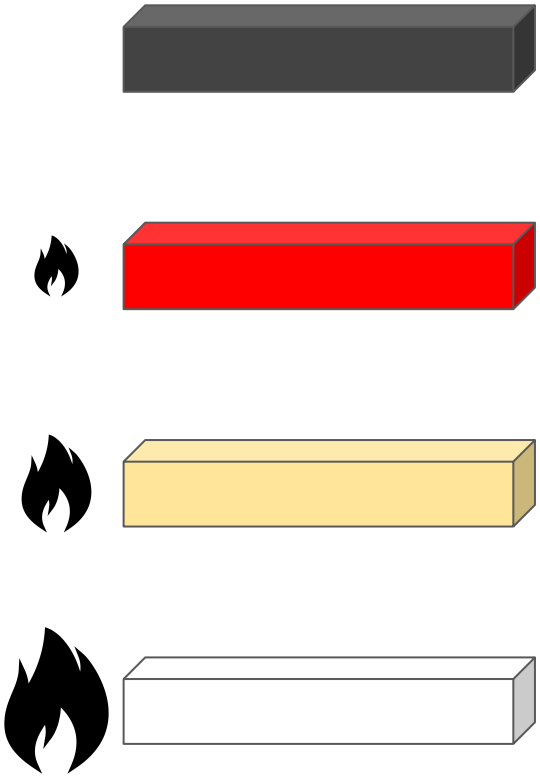
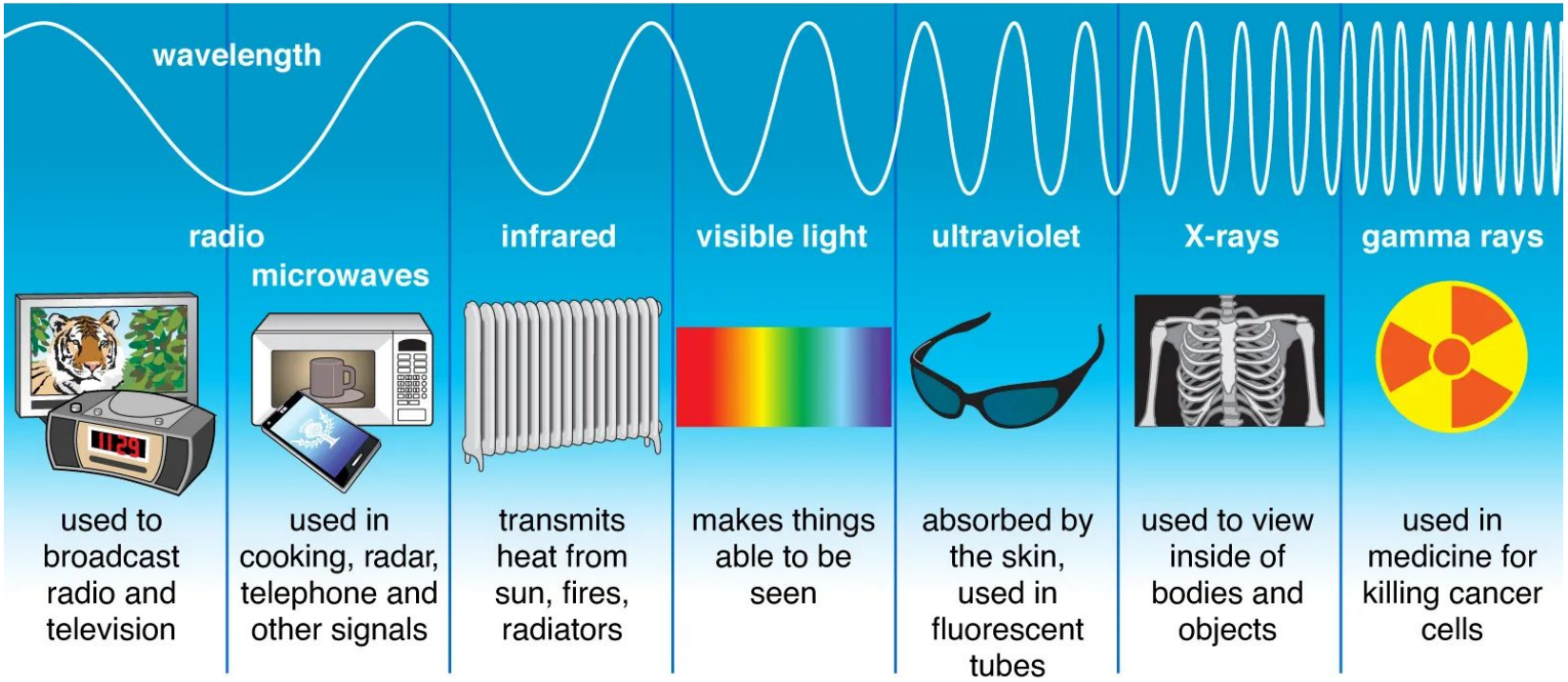


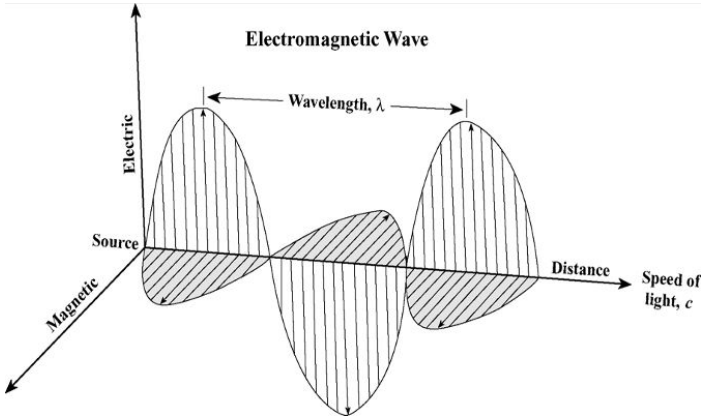
Wave theory



Wave theory

- James Maxwell conceptualized electromagnetic radiation (EMR) as an electromagnetic wave that travels through space at the speed of light
  - **c** (3×10^8 m/s)
- ***Wavelength*** (**λ**) - distance between maximums (or minimums) of a roughly periodic pattern
  - measured in micrometers (μm) or nanometers (nm).
- ***Frequency*** (**ν**) - # of wavelengths that pass a point per unit time
  - measured in cycles per second or Hertz (Hz).

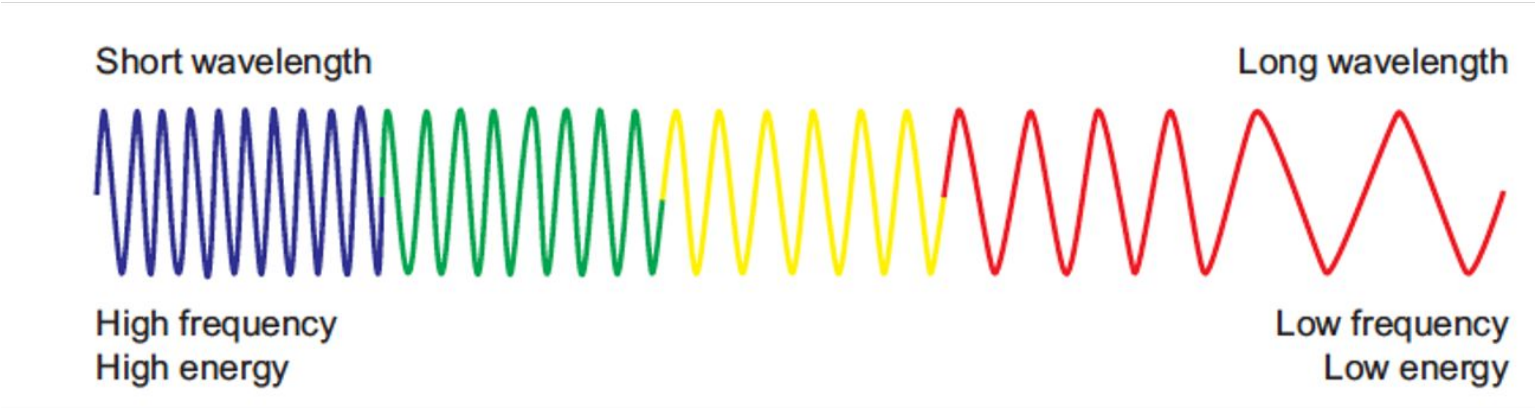
$$c = \lambda\nu$$



Wave theory

$$c = \lambda v$$

- Frequency and wavelength are inversely related
- Passive remote sensing:
  - describes energy in terms of wavelengths
- Active remote sensing:
  - describes energy in terms of frequency



Source: Tempfli et al. 2009

Energy transfer

Fact: All materials with temperature above absolute zero emit radiation

How much radiation?

(Stefan-Boltzmann Law)

What is the dominant wavelength of the radiation?

(Wien's Displacement Law)

Wave theory: blackbody

- **Blackbody**
  - a theoretical object which radiates energy with perfect efficiency
  - No radiation passes through it and none is reflected
  - Emits all energy
- **Total emitted radiation from a blackbody**

$$M_\lambda = \sigma T^4$$

(σ is the Stefan-Boltzmann constant: $5.6697 \times 10^{-8} W\ m^{-2} K^{-4}$)

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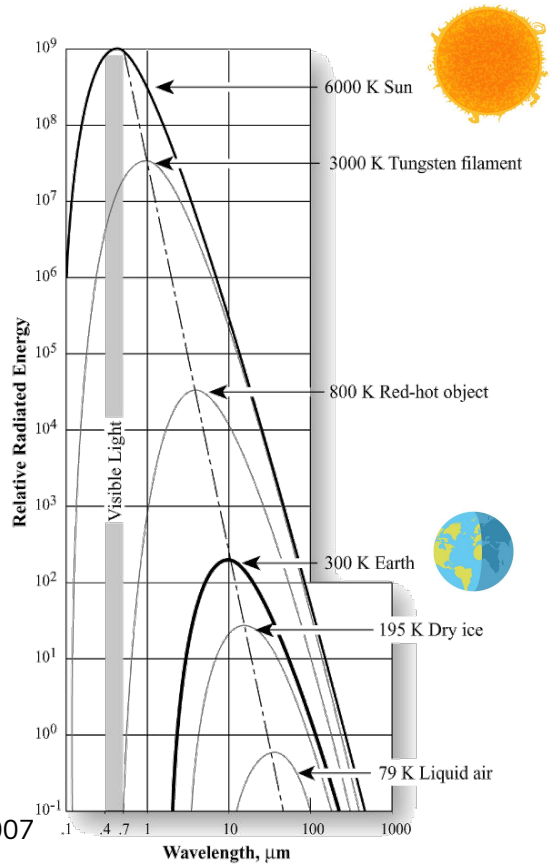
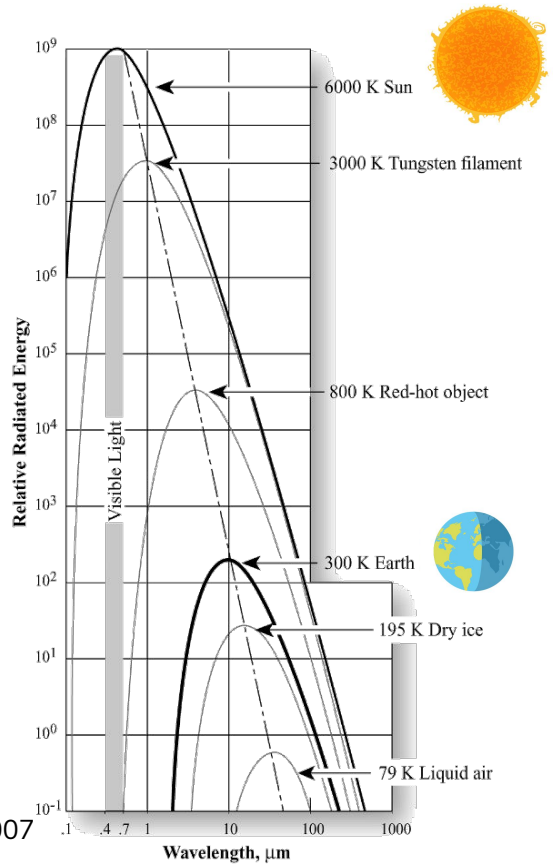
POINT: the total amount of radiation energy emitted by an object is proportional to its temperature

Wave theory: blackbody radiation



Source: Jensen 2007

Wave theory: blackbody radiation



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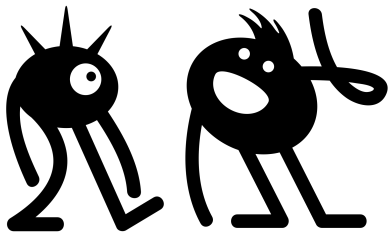

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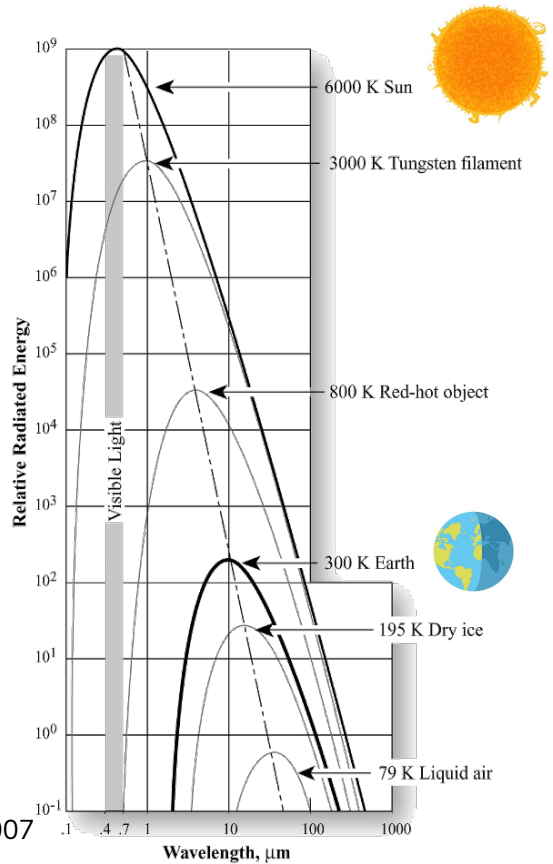


radiated energy

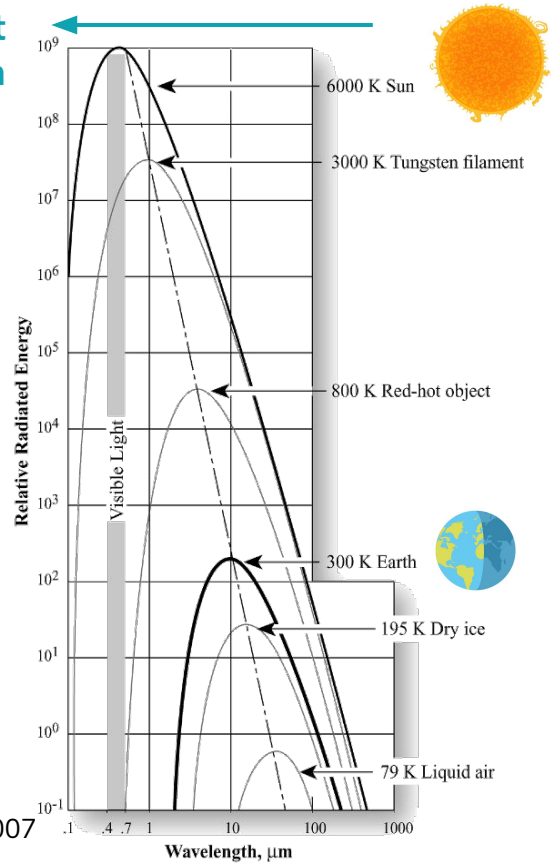
temperature

- As temperature increases, radiated energy increases
  - Total energy emitted is equal to the area under the curve

Source: Jensen 2007

Wave theory: blackbody radiation

dominant wavelength



temperature

- As **temperature** increases, **radiated energy** increases
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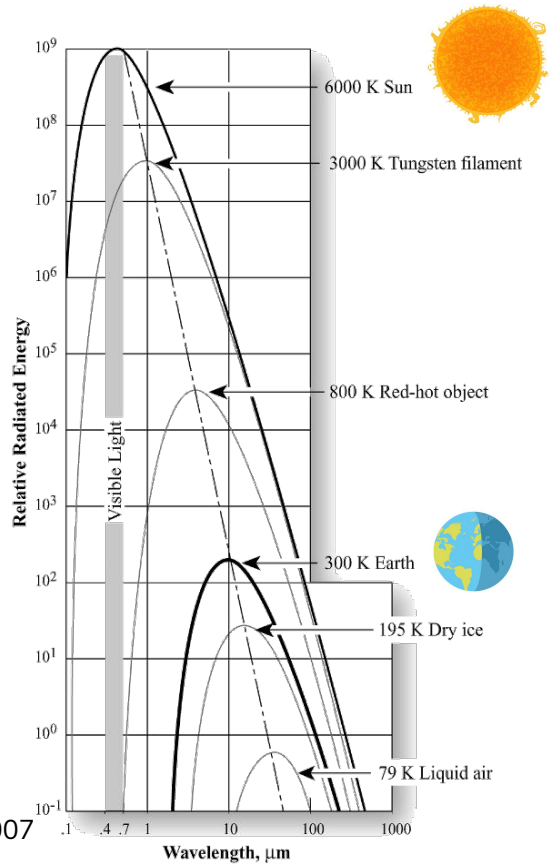
Wave theory: blackbody radiation



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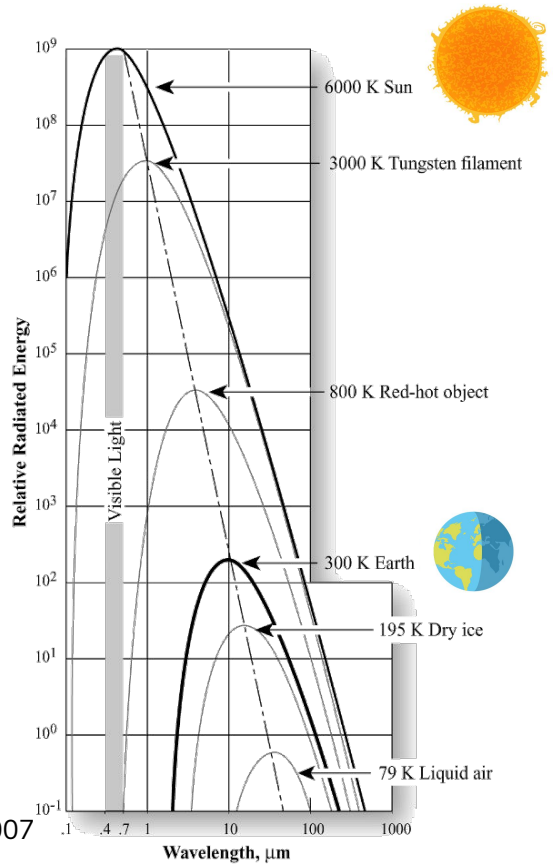

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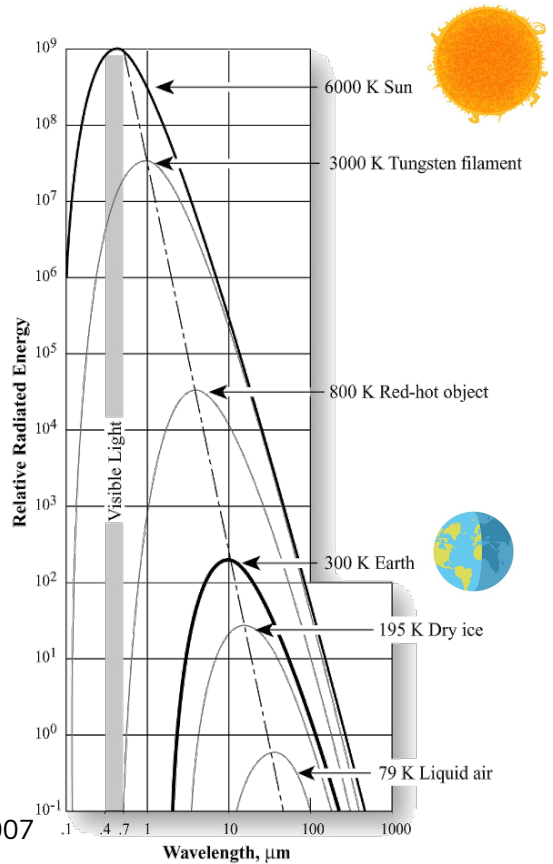
$$\lambda_{max} = \frac{k}{T} \qquad k = 2898\ \mu m\ K$$

Wave theory: blackbody radiation



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Sou[illegible]2007

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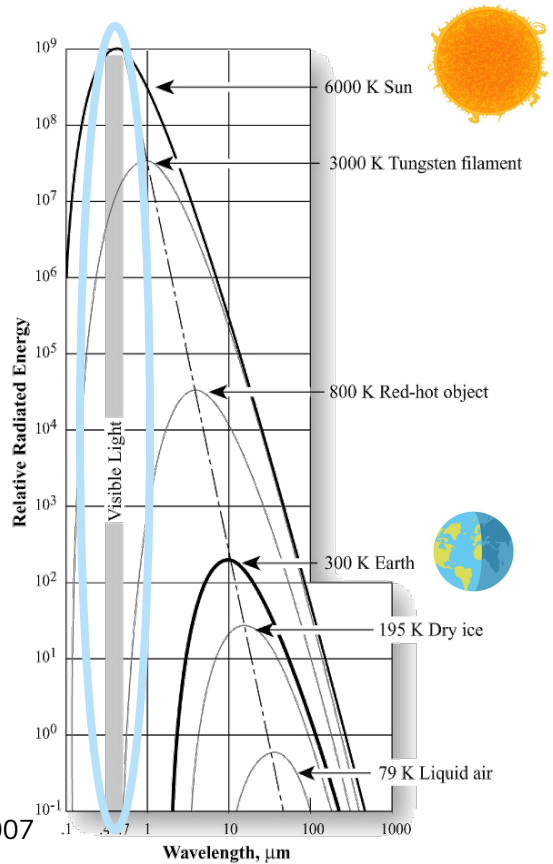
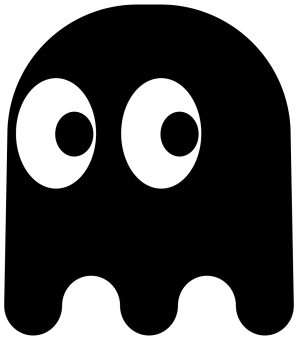


Source: Jensen 2007

- The Sun produces 41% of its energy between 0.4 and 0.7 **μ**m (blue to red light)
- Human eyes are only sensitive to light between 0.4 and 0.7 **μ**m



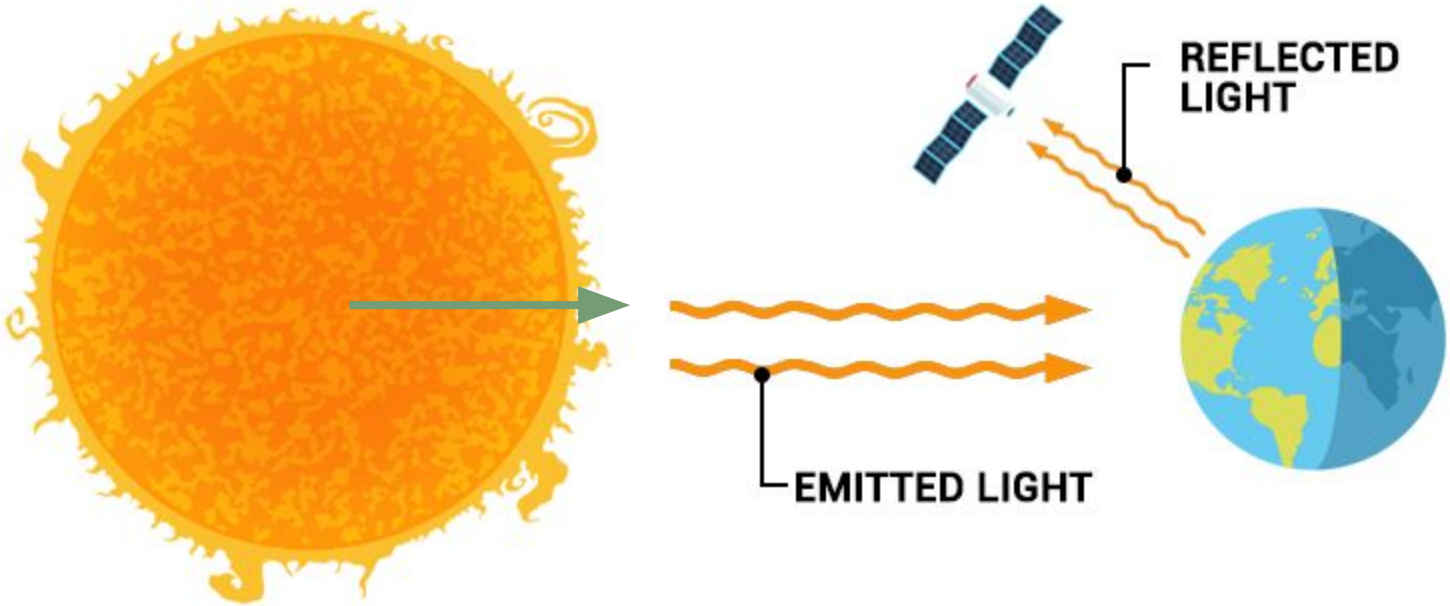
Wave theory: Stefan-Boltzmann

- **Very few objects on Earth are blackbodies**
  - Instead, we need to know an object's ability to radiate energy
  - emissivity (**ε**): scale of 0 to 1, where a blackbody's emissivity is 1

$$M_\lambda = \sigma T^4 \varepsilon$$

(σ is the Stefan-Boltzmann constant: $5.6697 \times 10^{-8} W\ m^{-2} K^{-4}$)

POINT: the total amount of radiation energy emitted by an object is proportional to its temperature, and modified by it's emissivity



Source: GIS Geography

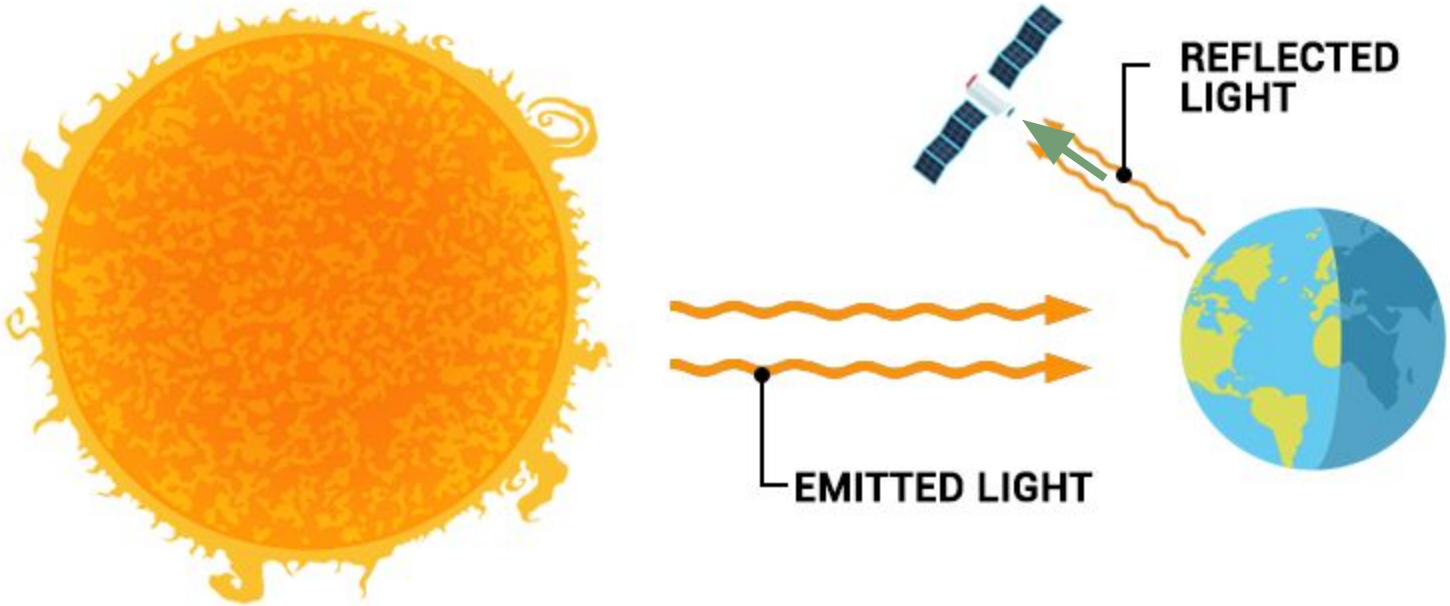
Particle model

- **Niels Bohr and Max Planck proposed the quantum theory of electromagnetic radiation:**
  - Energy is transferred in discrete packets called quanta or photos
- **We can relate the wave and particle models**
  - The energy of a quantum (Q, measured in joules) is related to the frequency of the radiation (**v**)

$$Q = h\mathbf{v}$$

(*h* is the Planck constant: $6.63 \times 10^{-34} J\ s^{-1}$)

All remote sensing instruments, including cameras, measure the energy of photons, not of waves



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Measuring energy

	Term	Symbol	Units
	Radiant energy	Q	J (Joules)
	Radiant flux	ϕ	W (Watts, J/s)
Radiant flux density	Irradiance	E	W/m^2
	Radiant exitance	M	W/m^2
	Radiance	L	W/m^2sr

Capacity for radiation within a specified spectral band to do work

Measuring energy

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Time rate of energy onto, off of, or through a surface

Measuring energy

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Radiant flux upon a surface per unit area

Radiant flux leaving a surface per unit area

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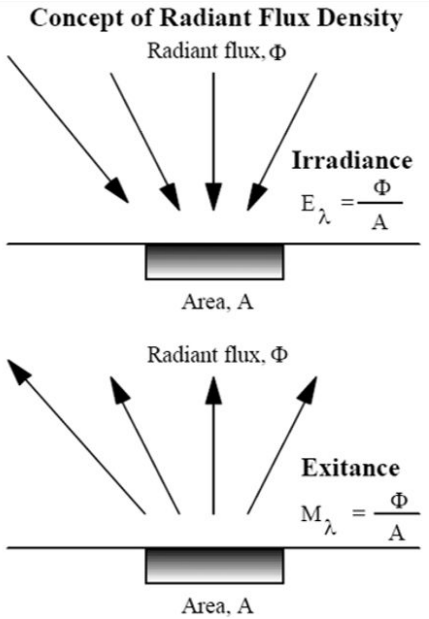

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Remote sensing is the quantification and study of radiance.

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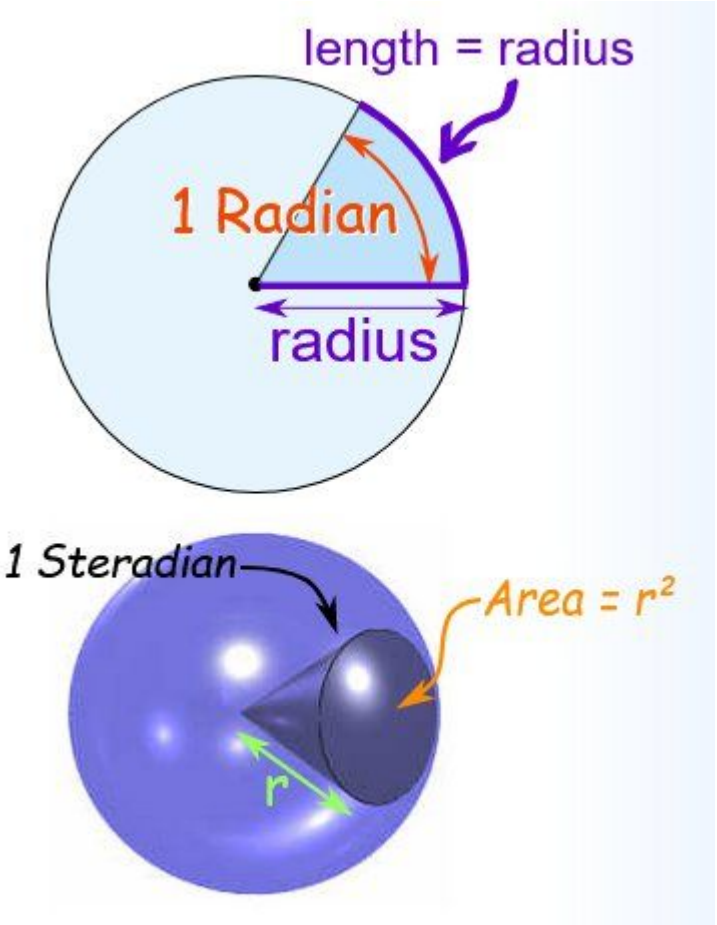
Remote sensing is the quantification and study of radiance.

Measuring energy: steradians

- An angle in radians, projected onto a circle, gives a length
- A solid angle in steradians, projected onto a sphere, gives an area on the surface



Measuring energy: exitance, irradiance, and radiance

	Term	Symbol	Units
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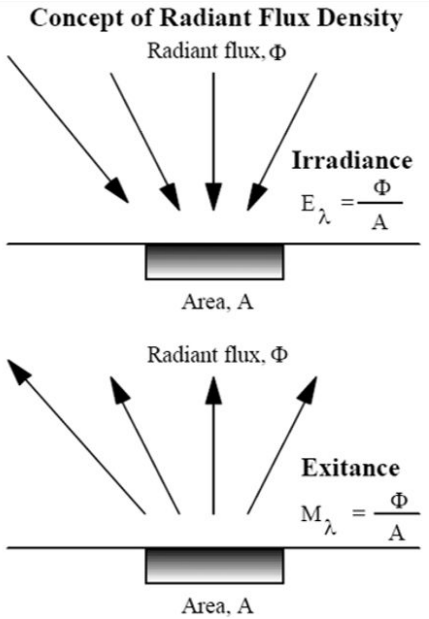
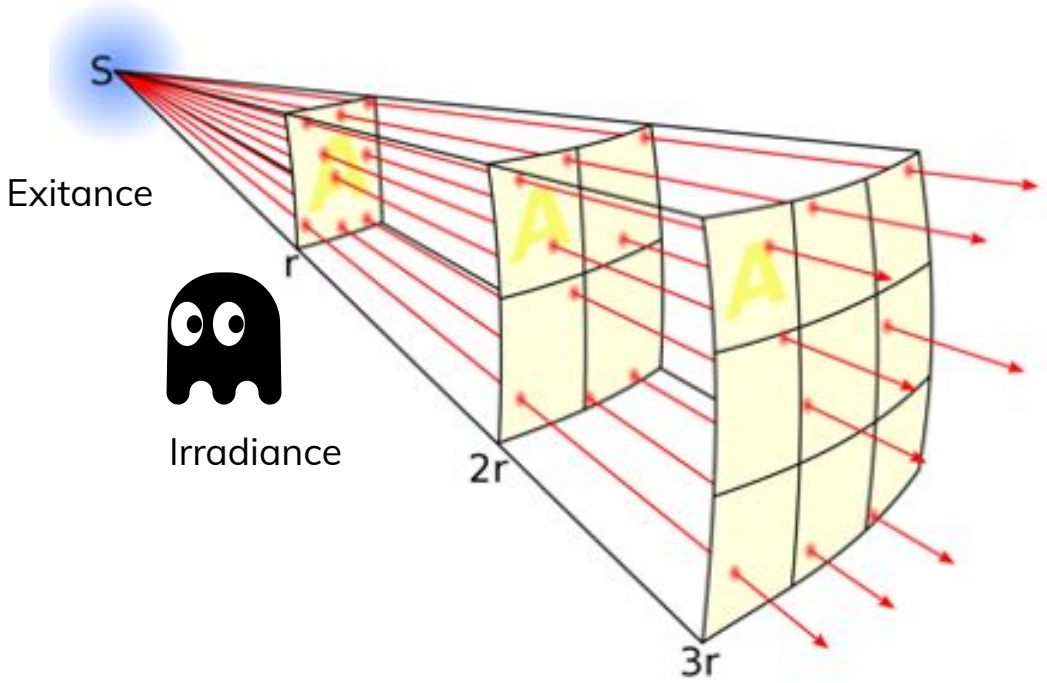


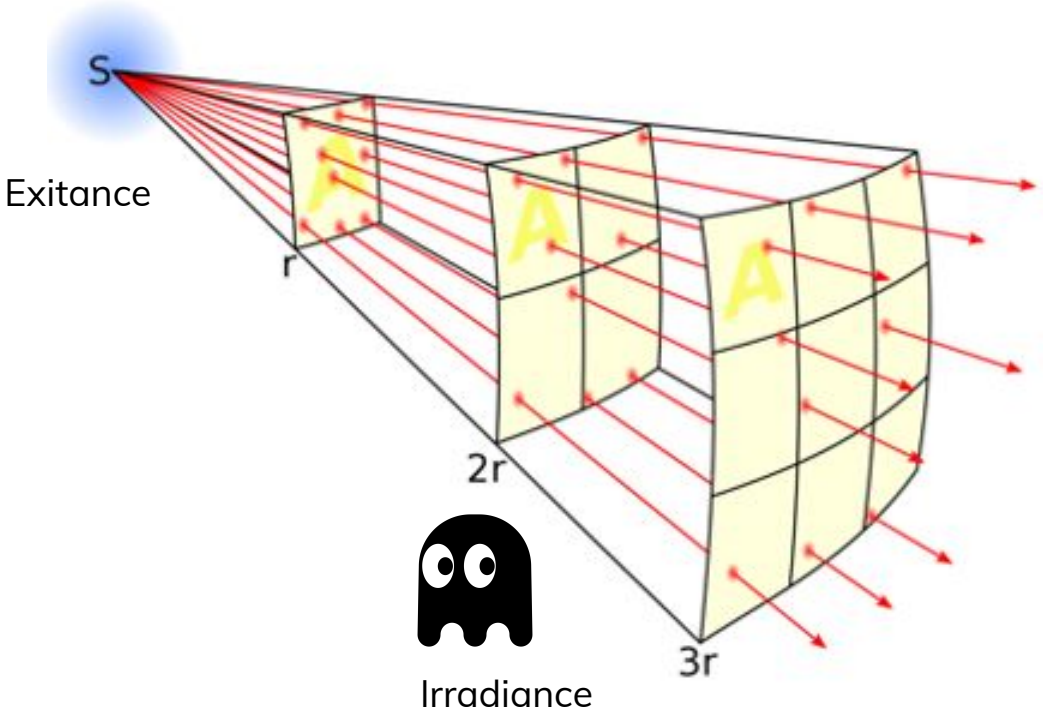
Source: Jensen 2007

Measuring energy: irradiance vs. radiance



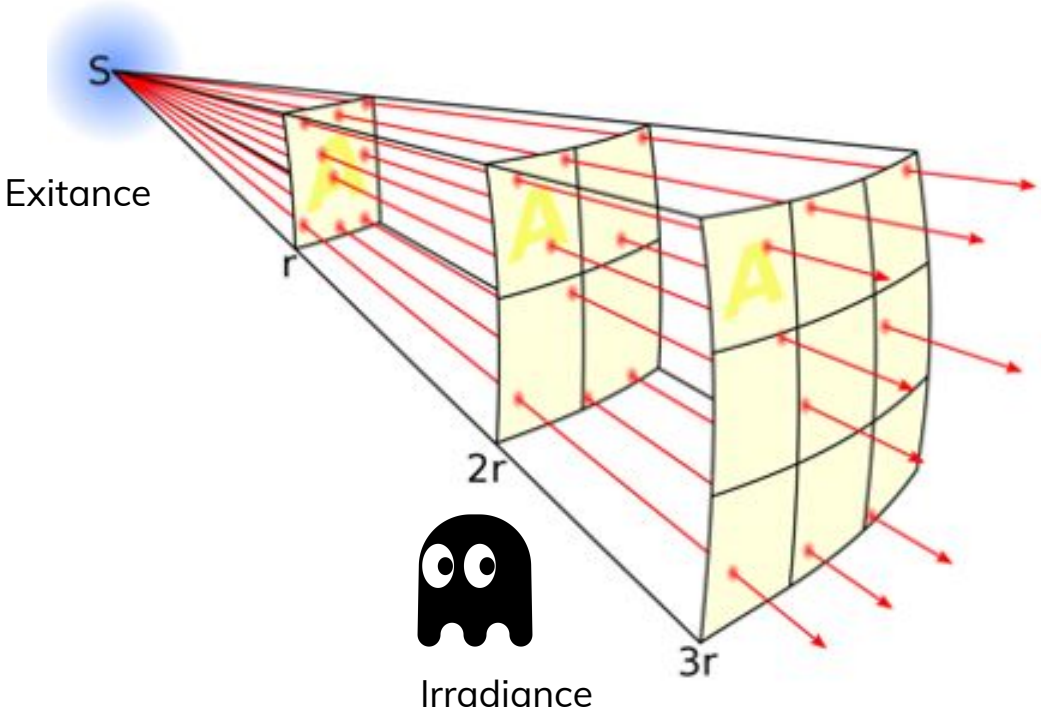
Source: Wikipedia

Measuring energy: irradiance vs. radiance



Source: Wikipedia

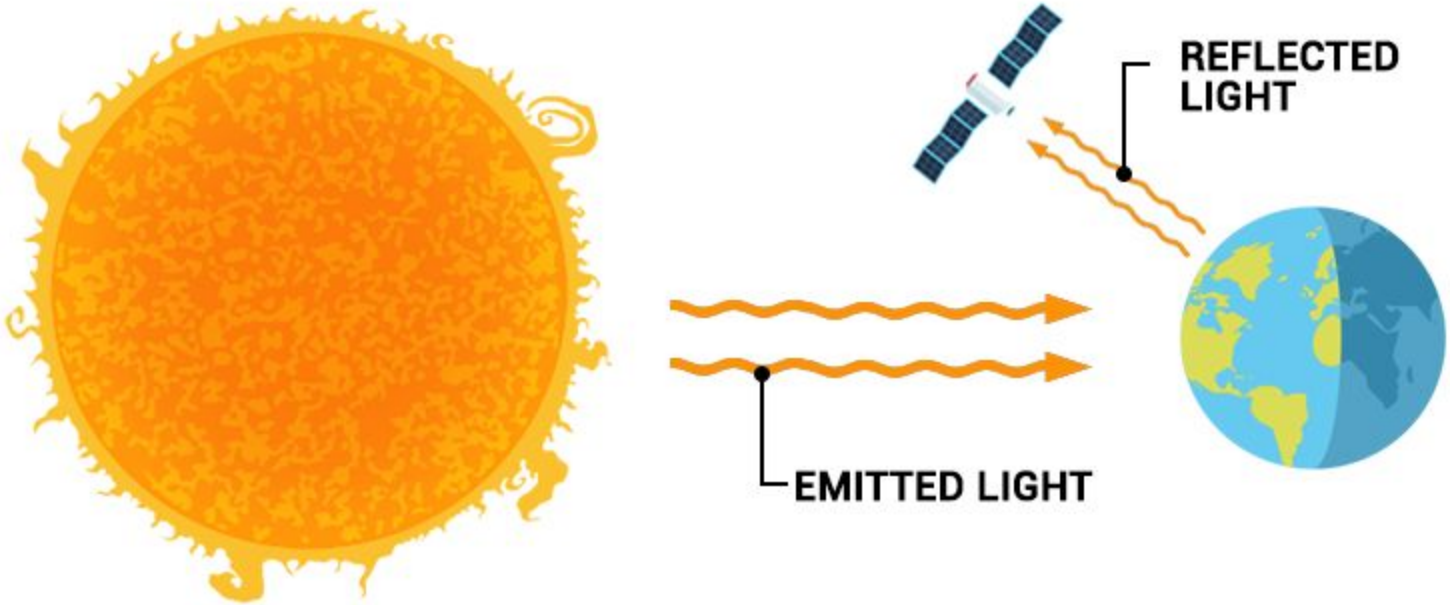
Measuring energy: irradiance vs. radiance



- Even when exitance stays constant, irradiance falls off with distance
- Normalizing by steradian means that radiance stays constant
  - Radiance does not change with distance
  - Makes remote sensing possible!

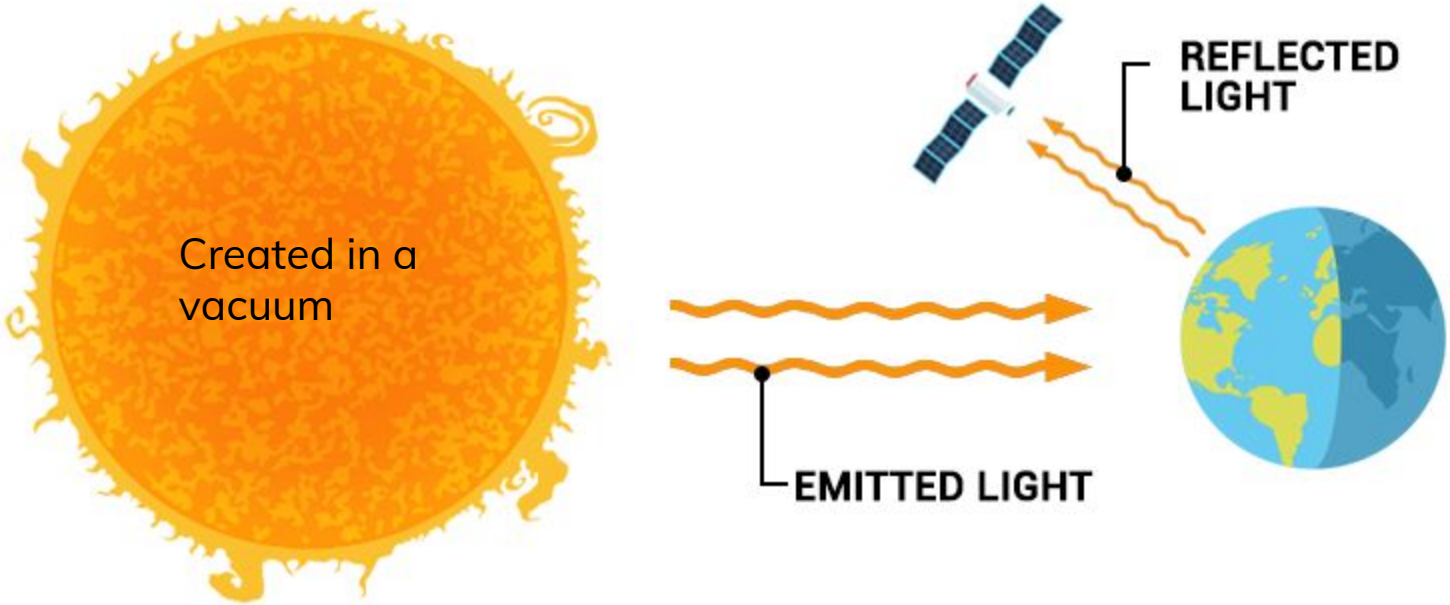
Source: Wikipedia

Radiation budget



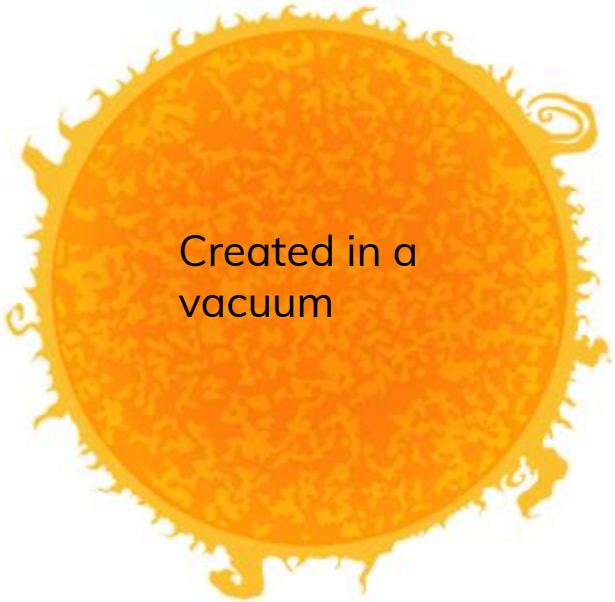
Source: GIS Geography

Radiation budget

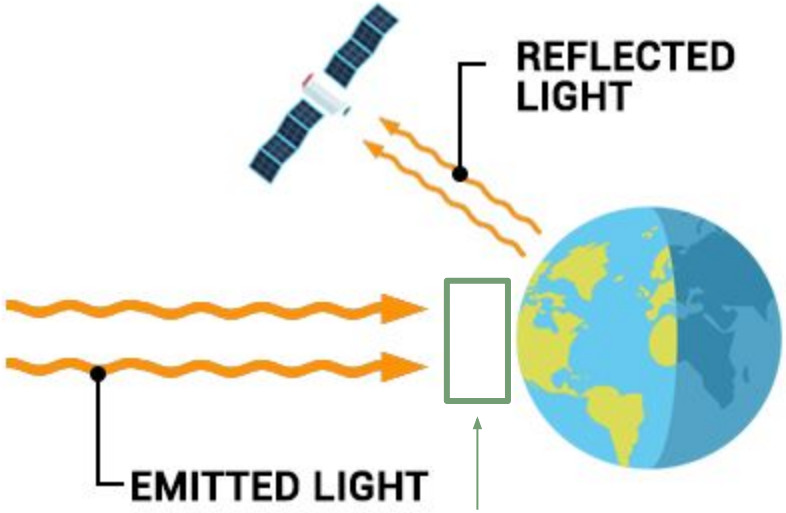


Source: GIS Geography

Radiation budget



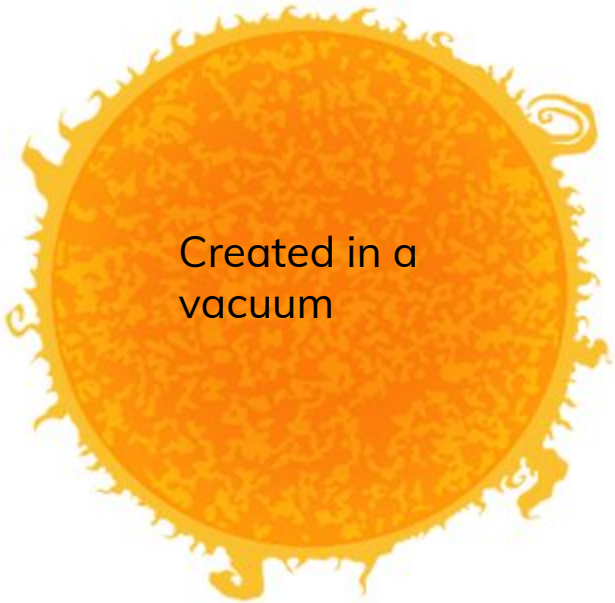
Created in a vacuum



In the atmosphere, can be absorbed and/or scattered

Source: GIS Geography

Radiation budget



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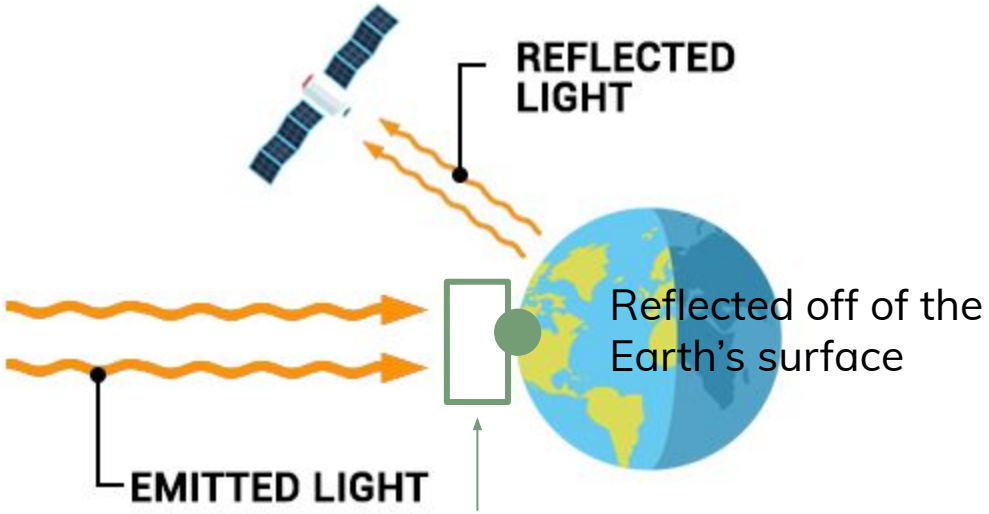

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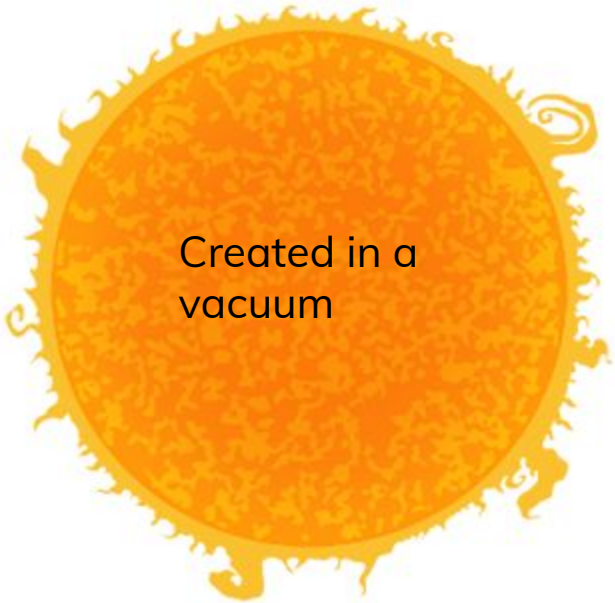

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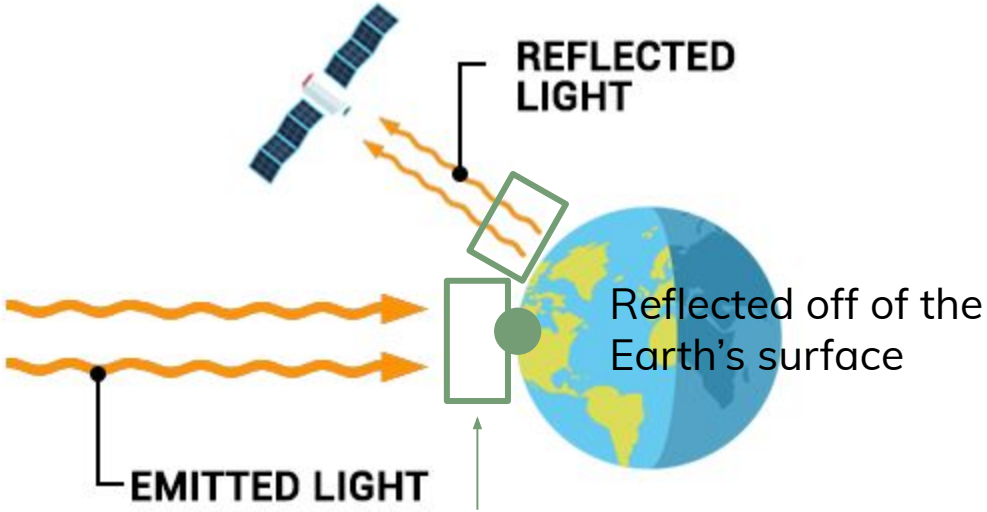
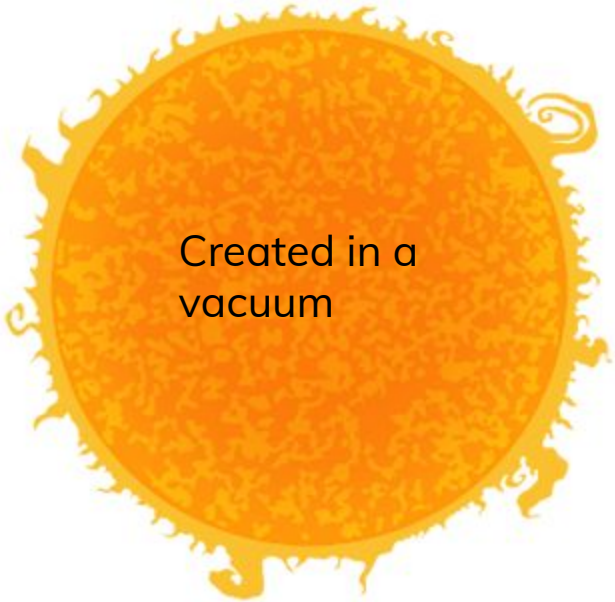


Reflected off of the Earth's surface

In the atmosphere, can be absorbed and/or scattered

Source: GIS Geography

Radiation budget



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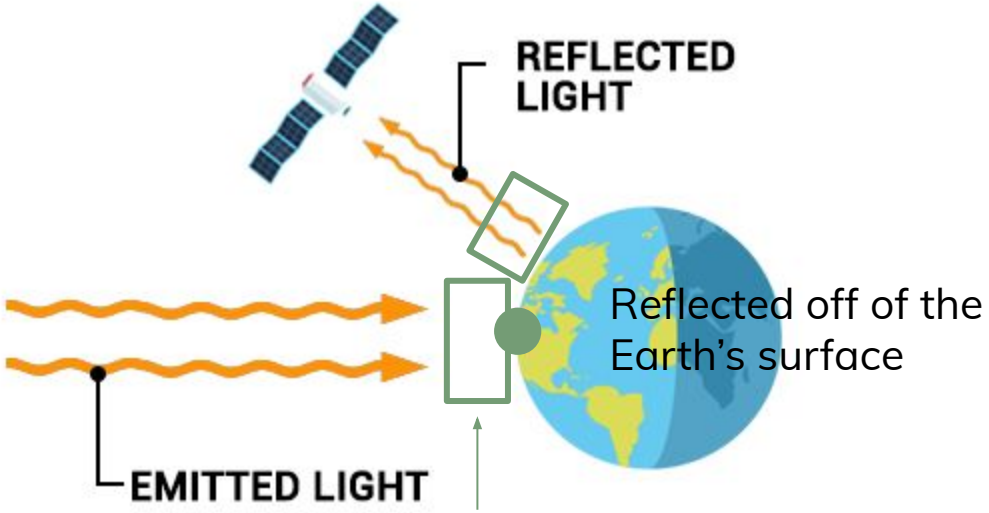


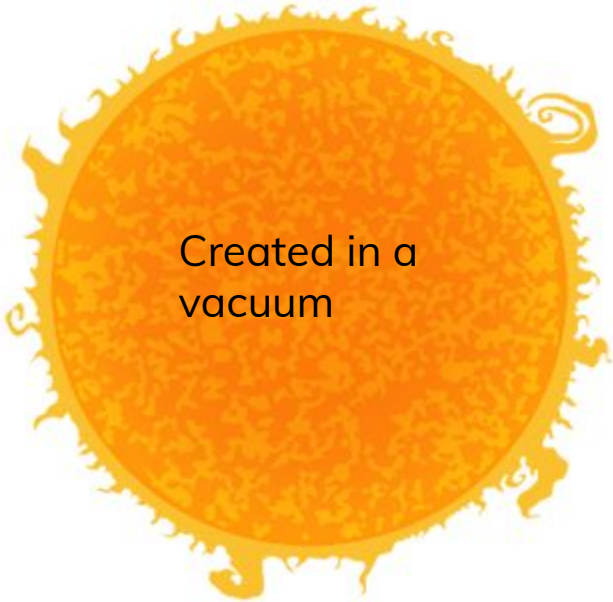
Reflected off of the Earth's surface

In the atmosphere, can be absorbed and/or scattered

By passing through media of different densities, can be refracted

Source: GIS Geography

Radiation budget



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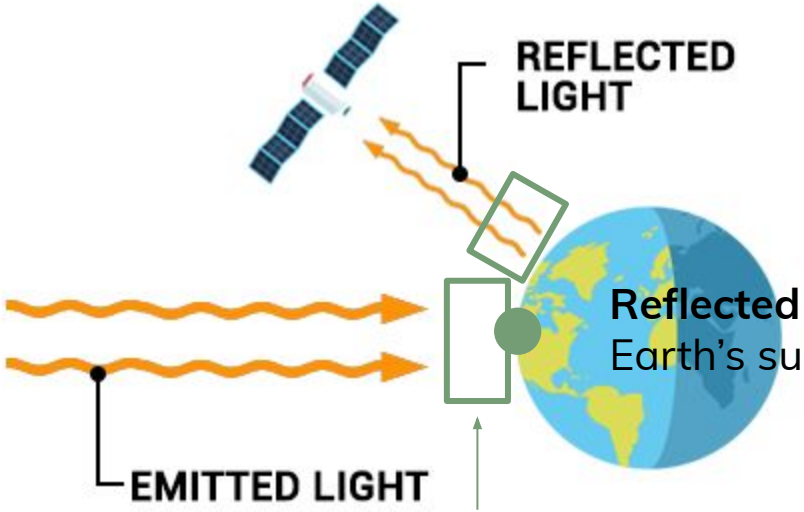

Reflected off of the Earth's surface

In the atmosphere, can be **absorbed** and/or **scattered**

By passing through media of different densities, can be **refracted**

Source: GIS Geography

Absorption

- The process by which radiant energy is absorbed and converted into other forms of energy

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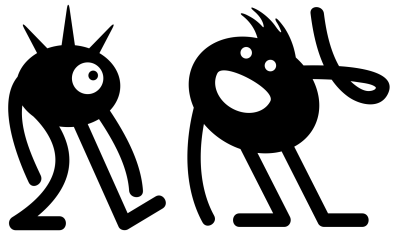
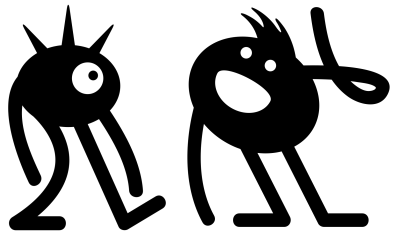
- Name the top 3 atmospheric constituents which absorb radiation:

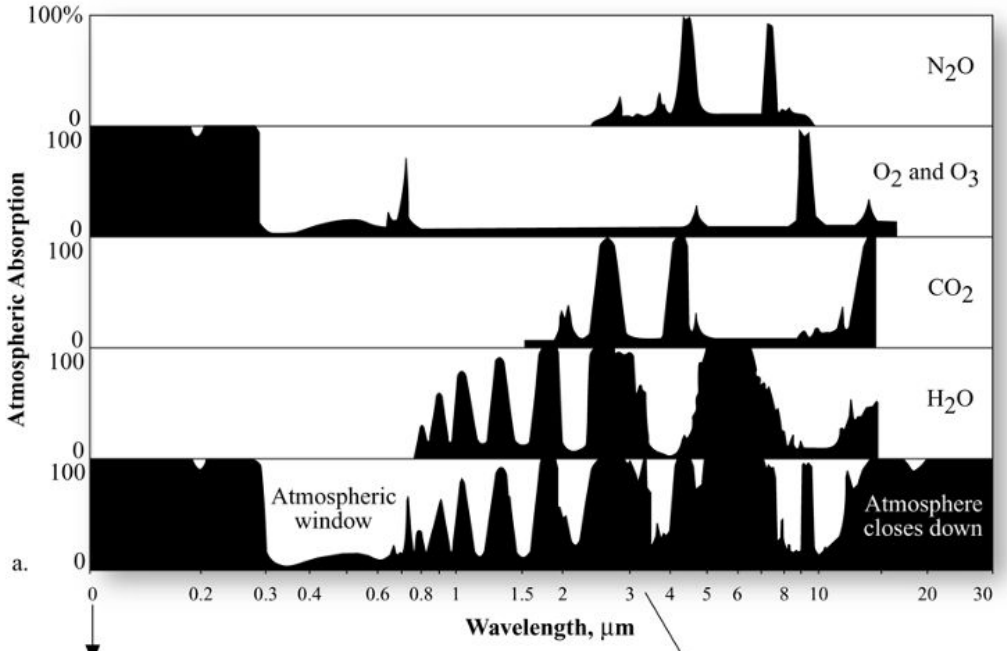


Absorption

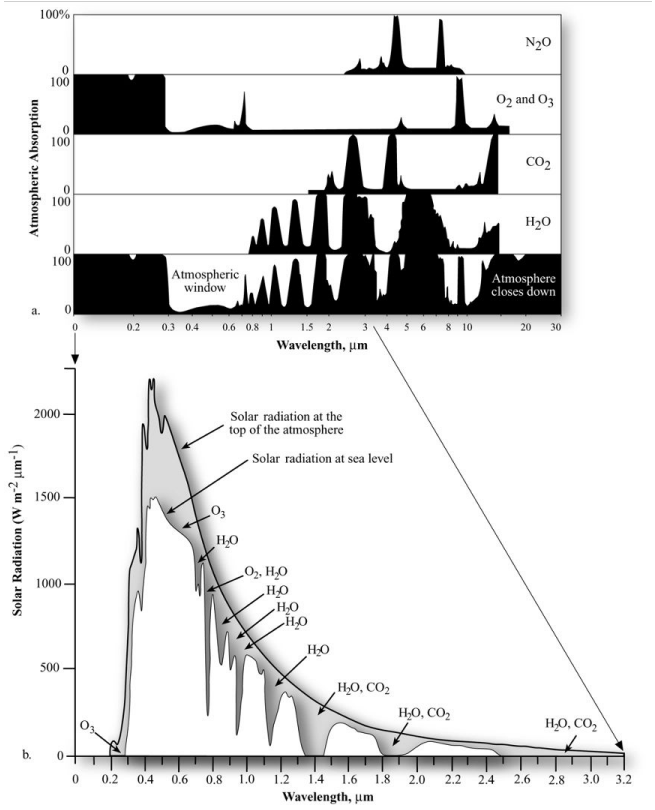
- **The process by which radiant energy is absorbed and converted into other forms of energy**
- **Name the top 3 atmospheric constituents which absorb radiation:**
  - Ozone
  - Carbon dioxide
  - Water vapor



Absorption


100%
0
N_2O
100
0
O_2 and O_3
100
0
CO_2
100
0
H_2O
100
0
Atmospheric Absorption
Atmospheric window
Atmosphere closes down
a.
0
0.2
0.3
0.4
0.6
0.8
1
1.5
2
3
4
5
6
8
10
20
30
Wavelength, μm

Absorption


100%
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Atmospheric Absorption
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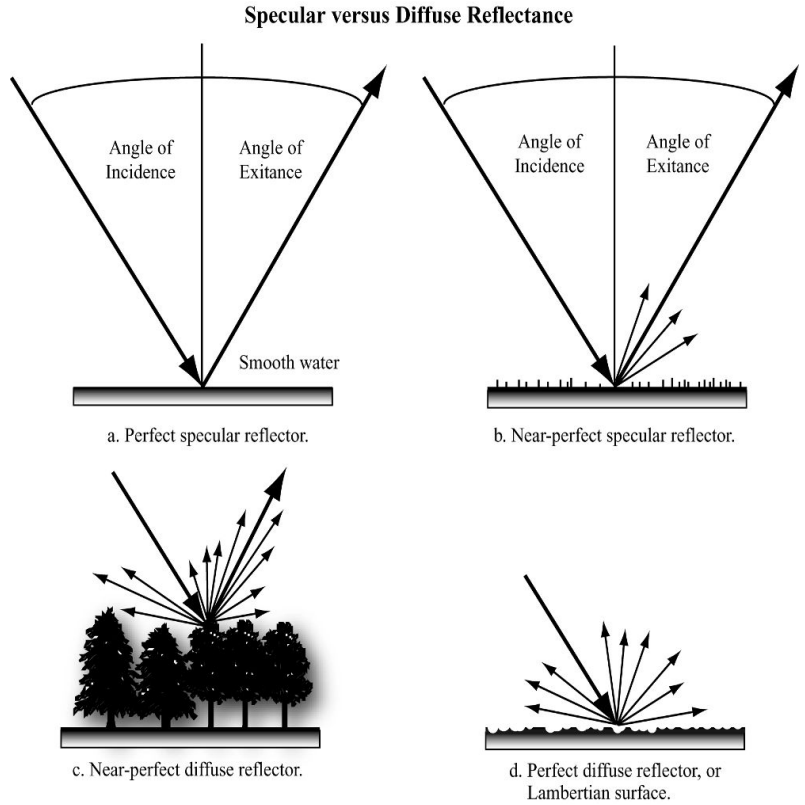
Atmospheric window
Atmosphere closes down
a.
0 0.2 0.3 0.4 0.6 0.8 1 1.5 2 3 4 5 6 8 10 20 30
Wavelength, μm
Solar Radiation (W m^{-2} μm^{-1})
2000
1500
1000
500
0
Solar radiation at the top of the atmosphere
Solar radiation at sea level
O_3
H_2O
O_2, H_2O
H_2O
H_2O
H_2O
H_2O
H_2O, CO_2
H_2O, CO_2
H_2O, CO_2
O_3
b.
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2
Wavelength, μm

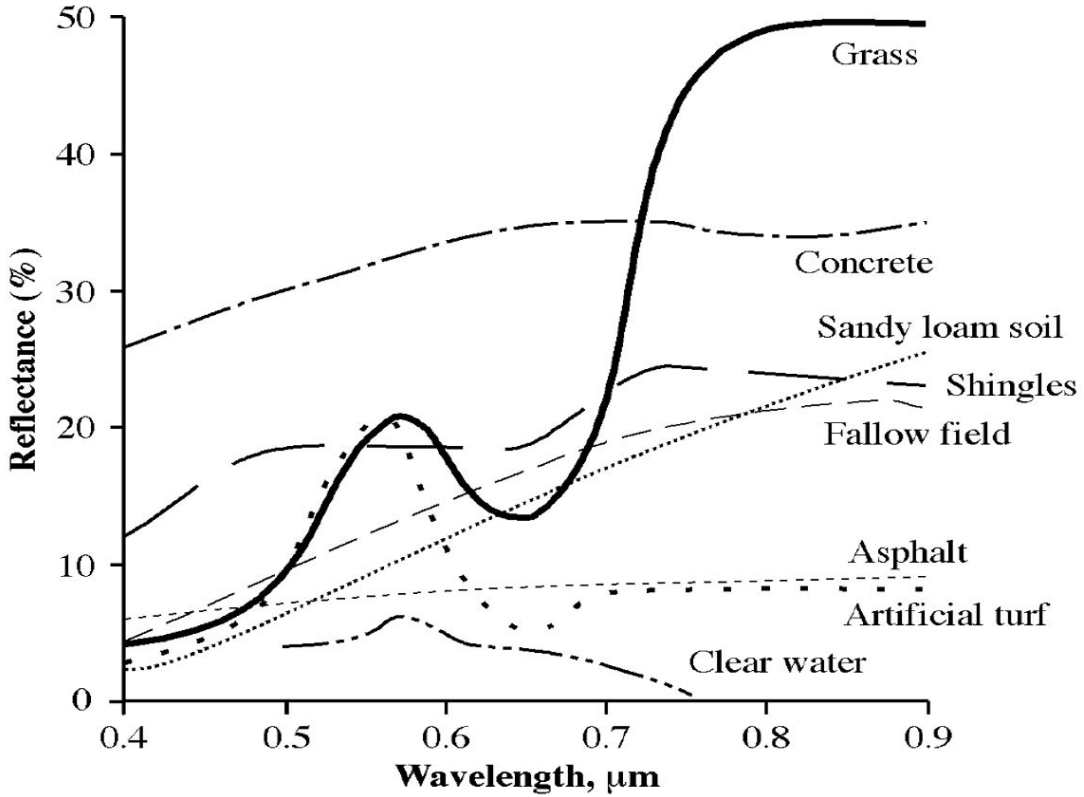
Reflectance

- The process whereby radiation “bounces off” an object and experiences no change in wavelength or frequency

Reflectance



Reflectance



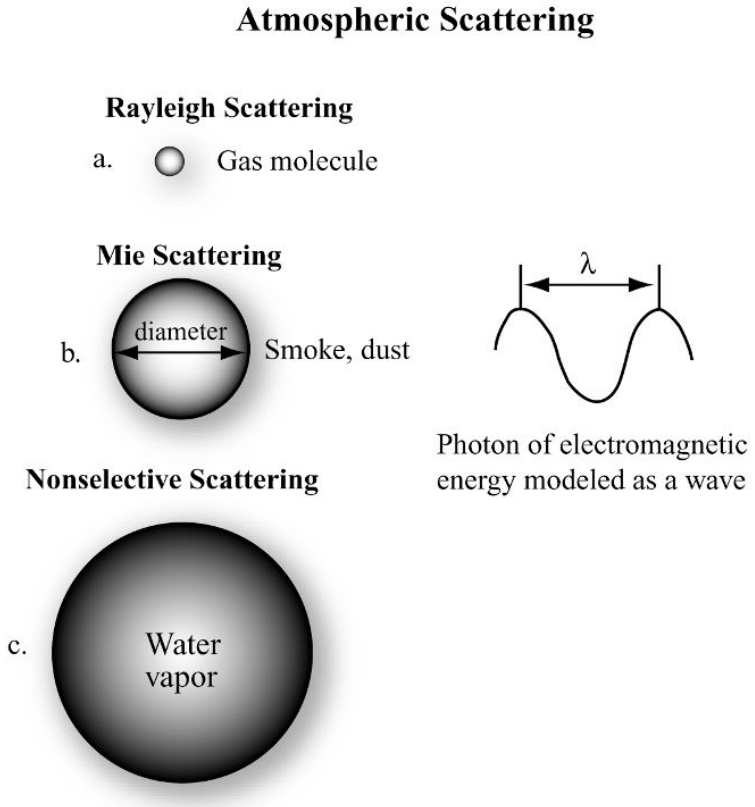
Scattering

- **Reflectance in an *unpredictable* manner**
- **Amount of scattering depends on:**
  - Amount and size of particles or gases radiation is interacting with
  - Wavelength of radiation
  - Distance that radiant energy travels through atmosphere

Scattering

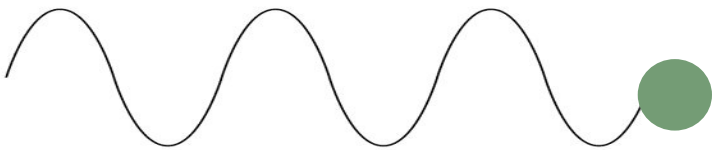
Three types of scattering:

- **Rayleigh scattering**
  - Particle size <<< λ_{light}
  - Highly dependent on wavelength
- **Mie scattering**
  - Particle size ~ λ_{light}
  - Not strongly dependent on wavelength
- **Non-selective scattering**
  - Particle size >>> λ_{light}



Rayleigh scattering

$$I = \frac{1}{\lambda^4}$$



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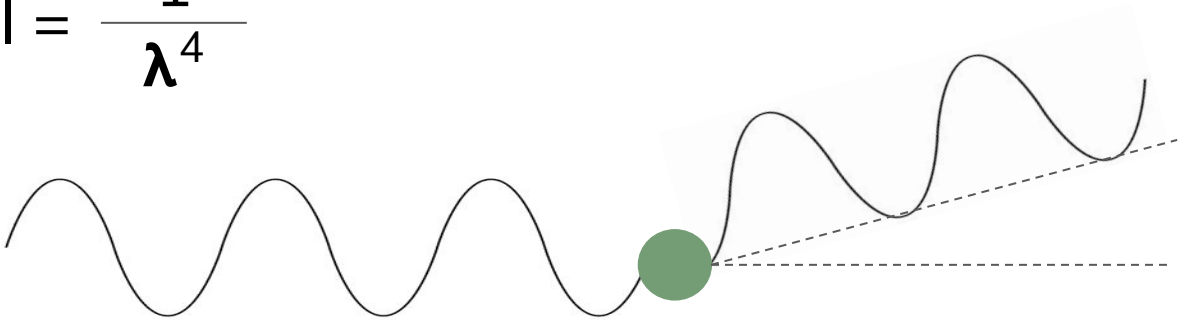

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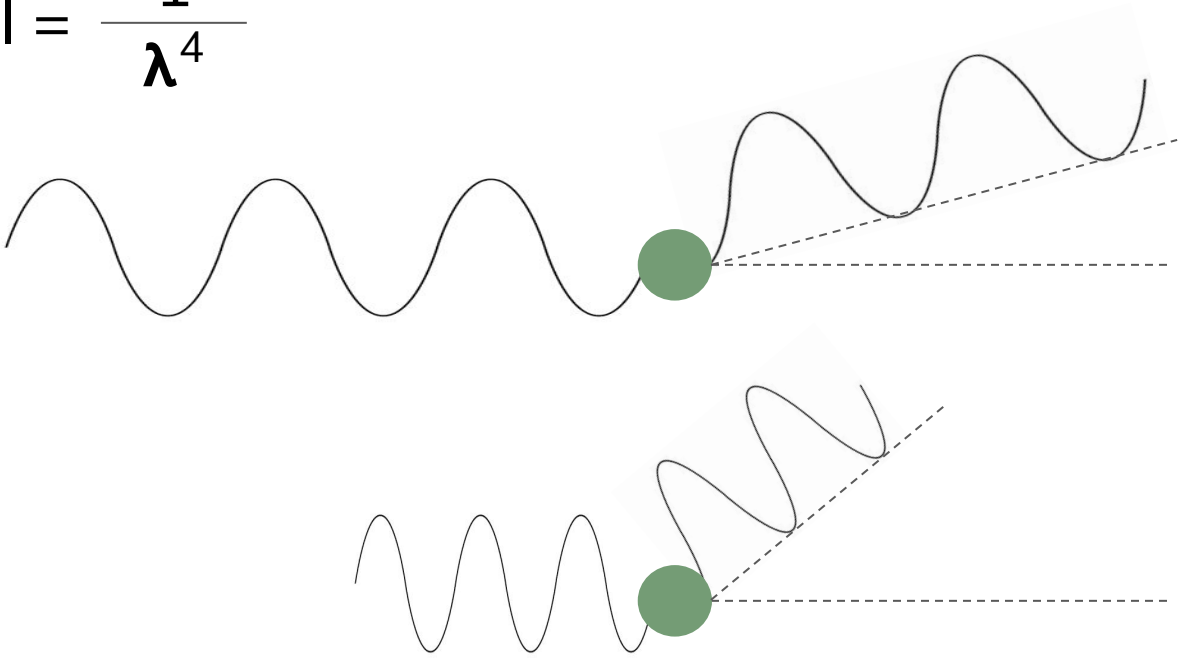

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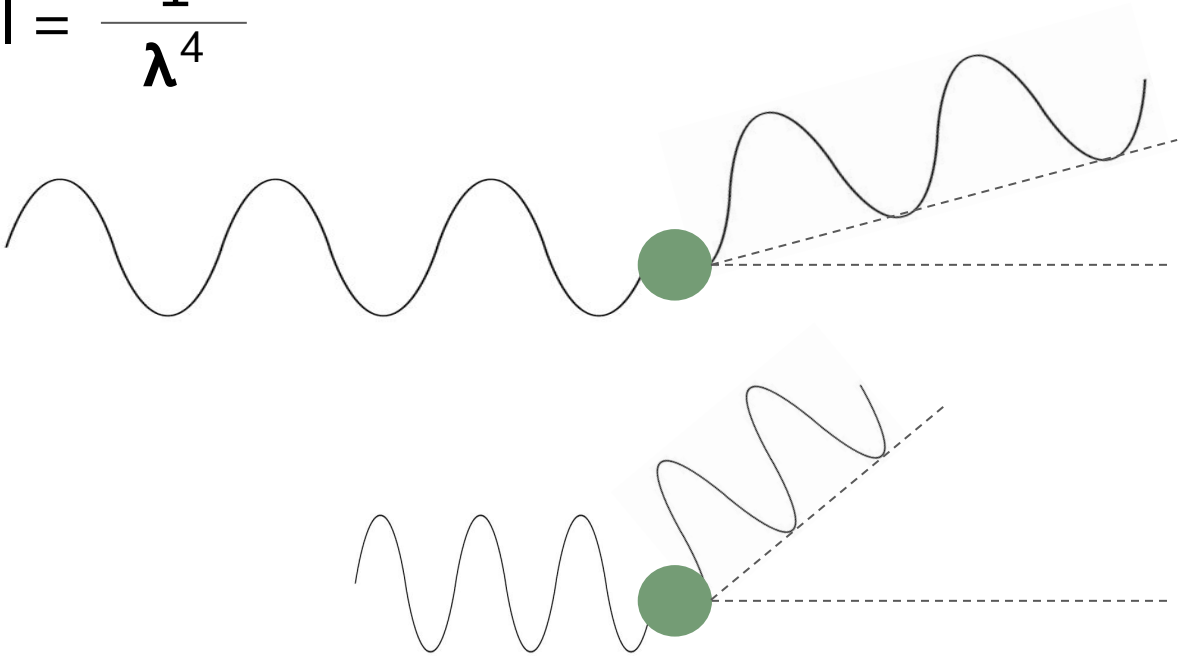
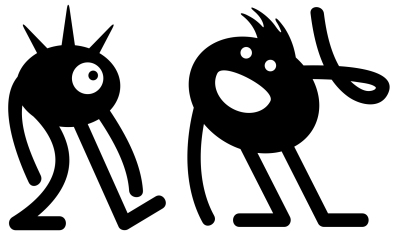


As wavelength increases, intensity of scattering decreases

Rayleigh scattering

- Why is the sky blue?
- Why are sunsets red?



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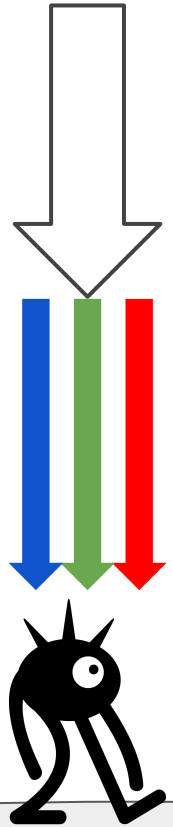

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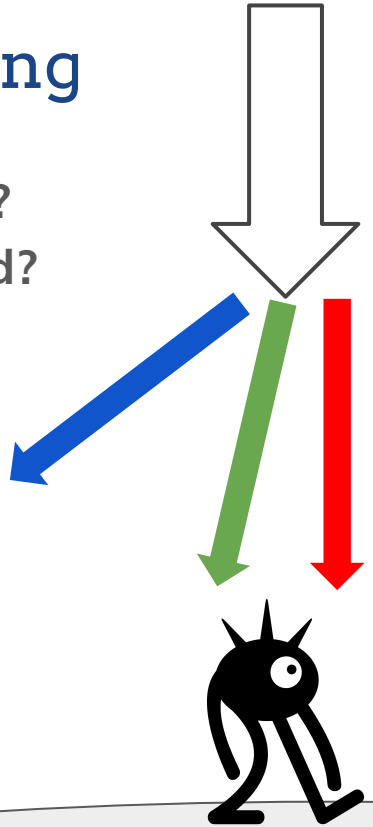

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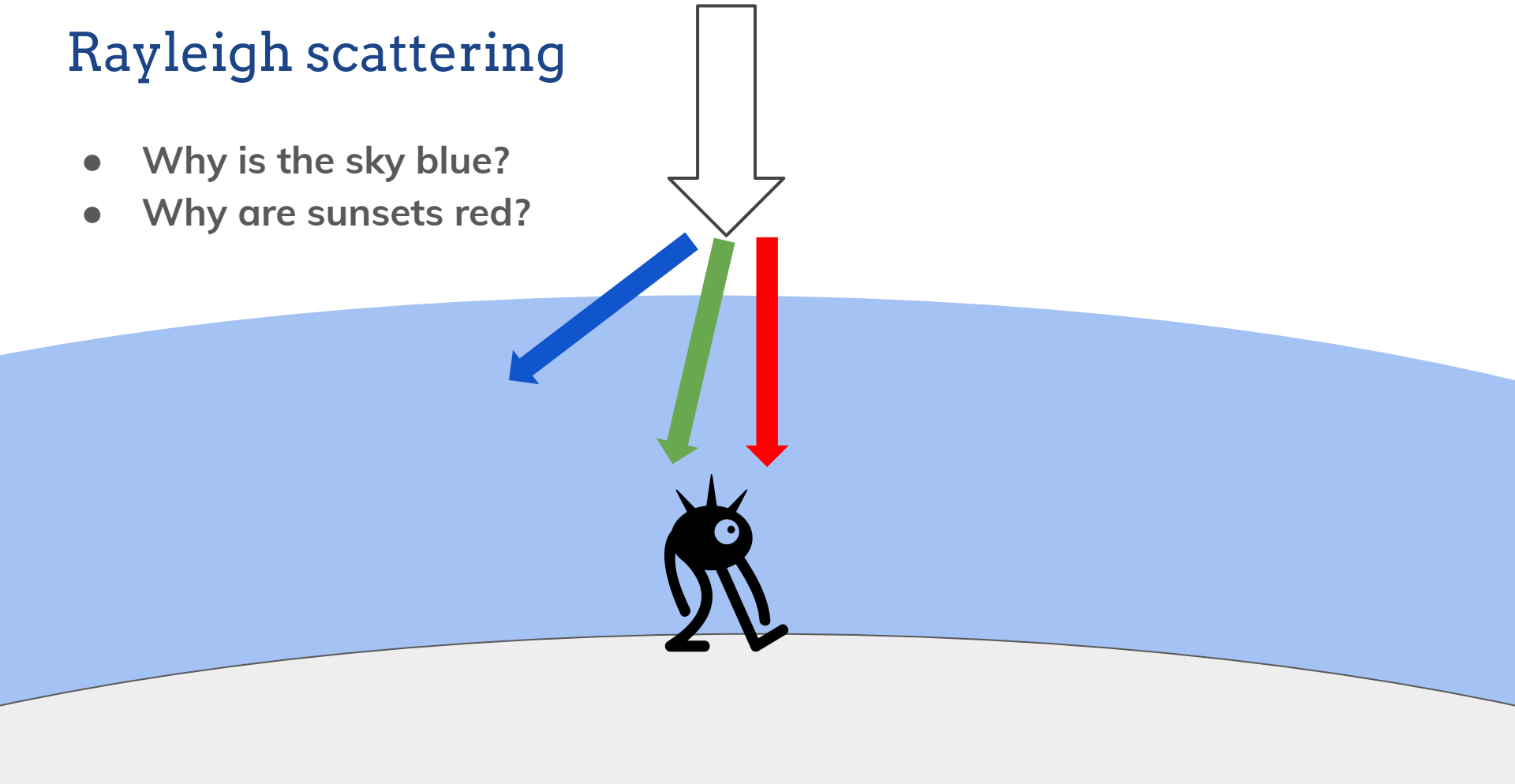

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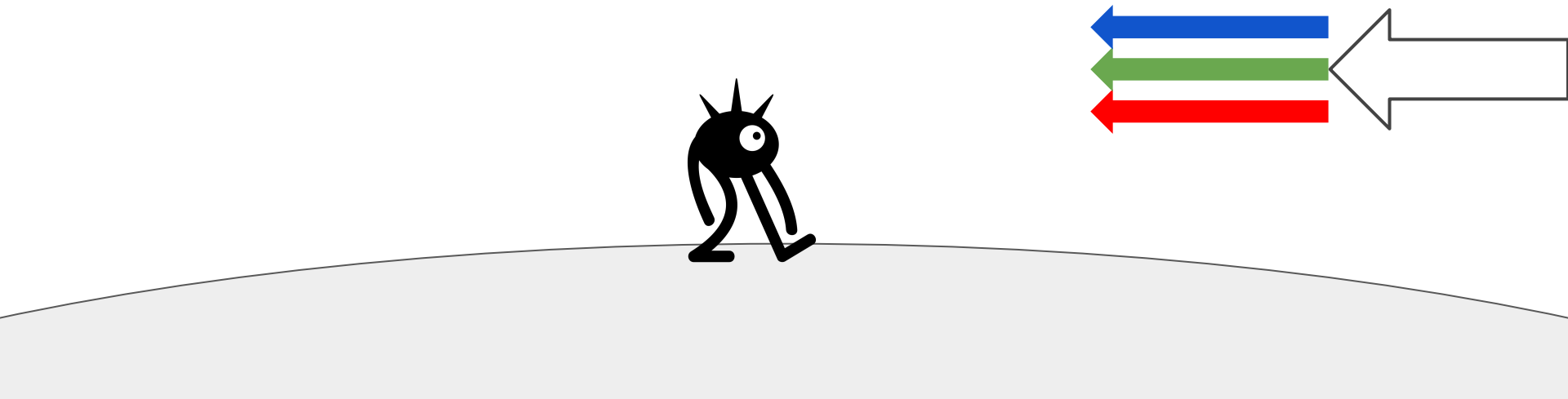

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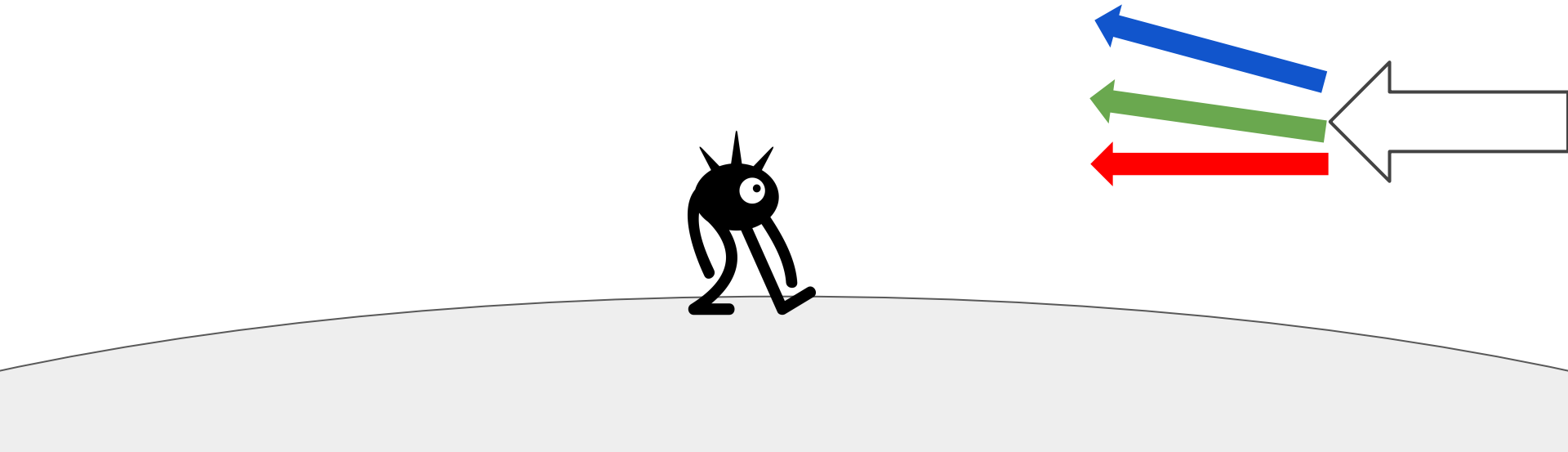

Rayleigh scattering

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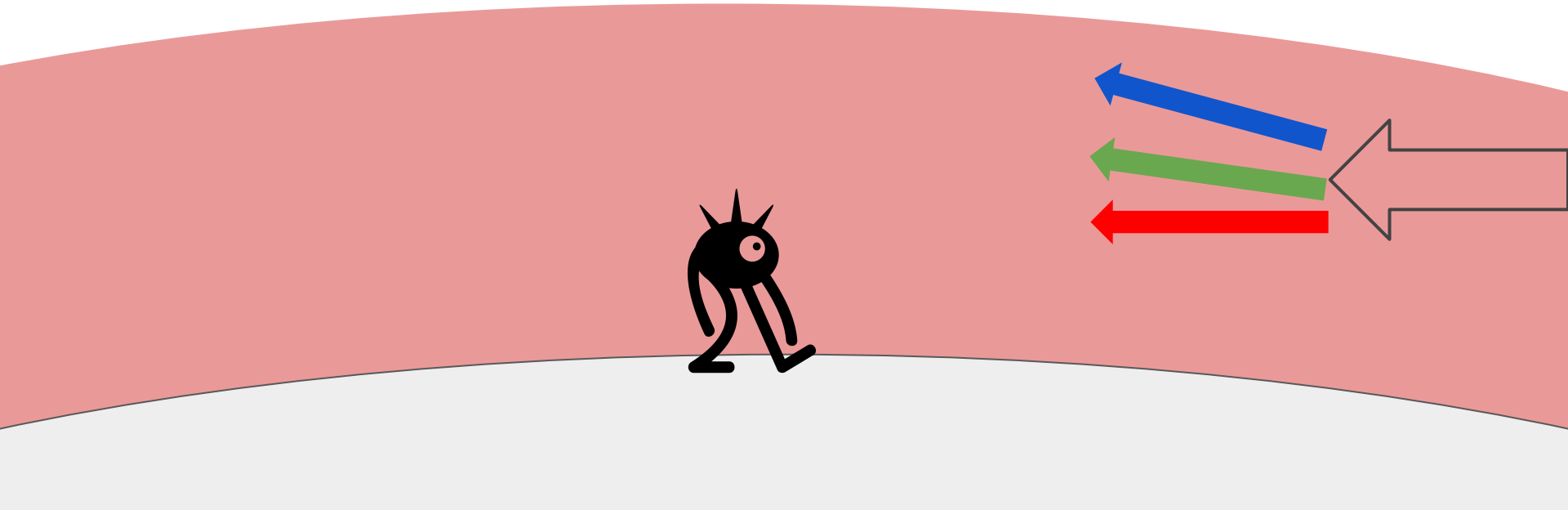


Mie and non-selective scattering

- **Mie scattering**
  - Amplifies wavelengths of similar size to particle
  - Pollution and aerosols scatter blue and green light away, contributing to red sunsets
- **Non-selective scattering**
  - Particles in the atmosphere several times the diameter of the wavelength
  - All wavelengths are scattered
  - Water droplets scatter all wavelengths of visible light equally well
    - Why clouds are white!

Refraction

- Refraction is ‘bending’ of light when it passes from one medium to another of different density.
  - The speed of EMR changes
  - In a vacuum $c \approx 3x10^8$ m/s
- *Frequency of a light wave in a medium is determined by its source and is unaffected by the medium!*

Energy-matter interactions with terrain

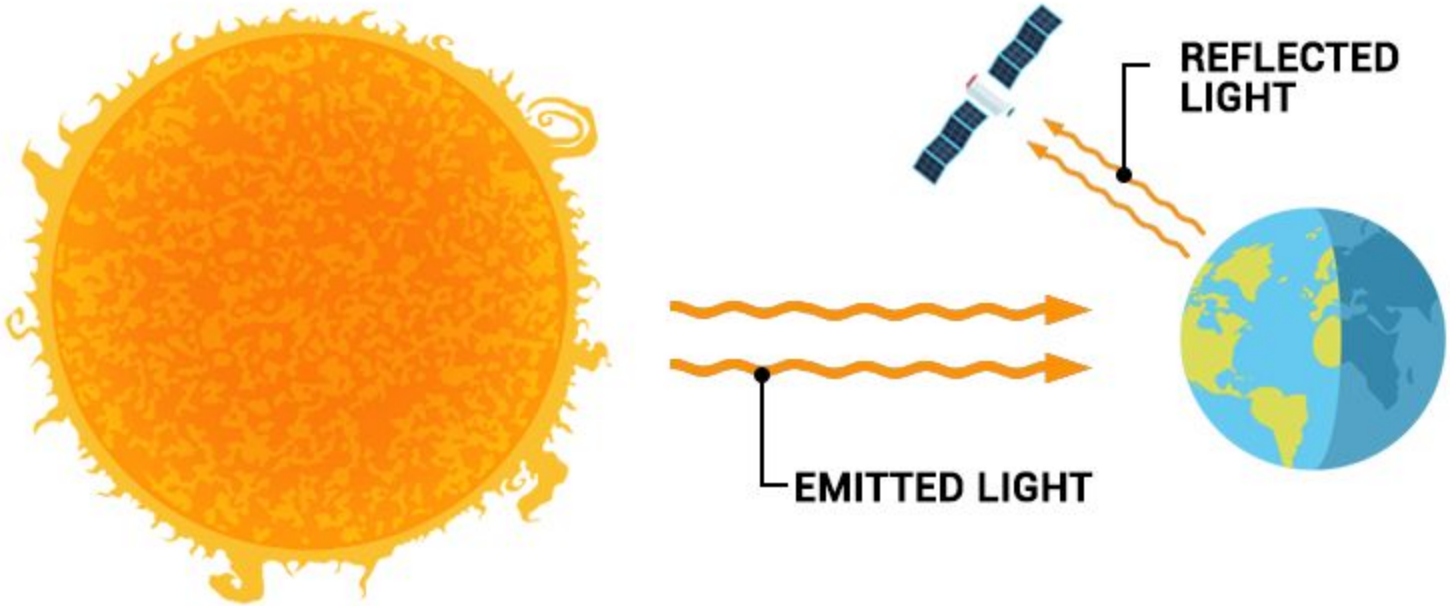
Absorption: process by which radiation is absorbed and converted to other forms of energy.

Reflectance: process whereby radiation “bounces off” an object.

Scattering: reflectance in an unpredictable manner.

Refraction: bending of light through mediums of different density.

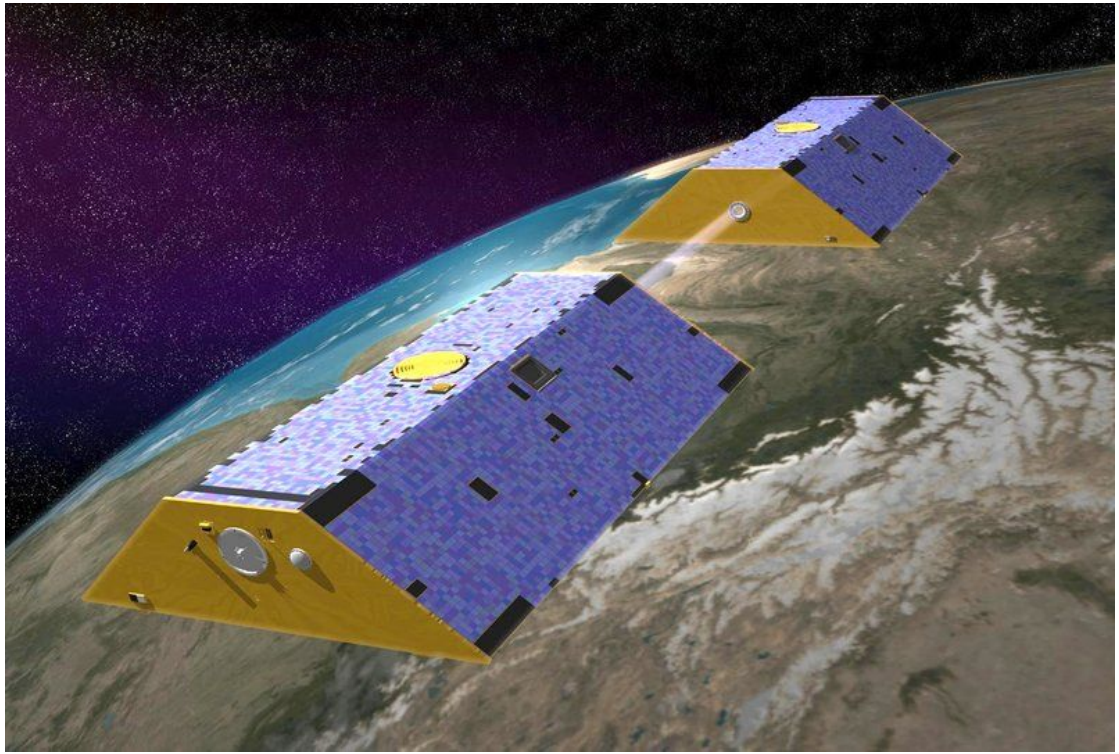
Transmittance: process by which radiation passes through a material.



Source: GIS Geography

A random aside….

GRACE: Gravity Recovery and Climate Experiment



Source: NASA JPL

A random aside….

NASA Finds New Way to Monitor Underground Water Loss

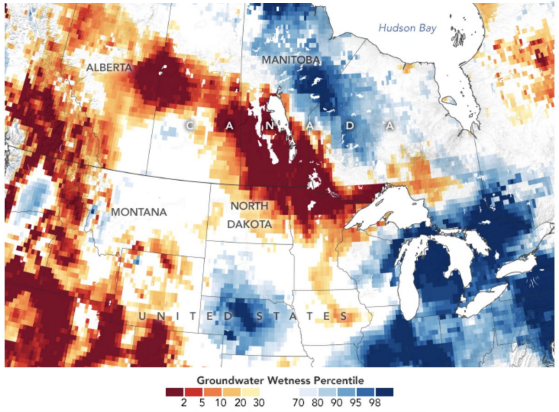
Researchers have untangled puzzling patterns of sinking and rising land to pin down the underground locations where water is being pumped for irrigation.

NASA-led Study Reveals the Causes of Sea Level Rise Since 1900

Scientists have gained new insights into the processes that have driven ocean level variations for over a century, helping us prepare for the rising seas of the future.

Drought in the Northern Great Plains

Decades of drought across the U.S. Southwest has led some scientists to classify the intense, prolonged dryness as a “megadrought.” But drought in North America took a different shape in 2021, affecting areas that do not face long-term or intense drought as often. The northern Great Plains has been coping with drought for months.



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A random aside…

INTERNET of ANIMALS