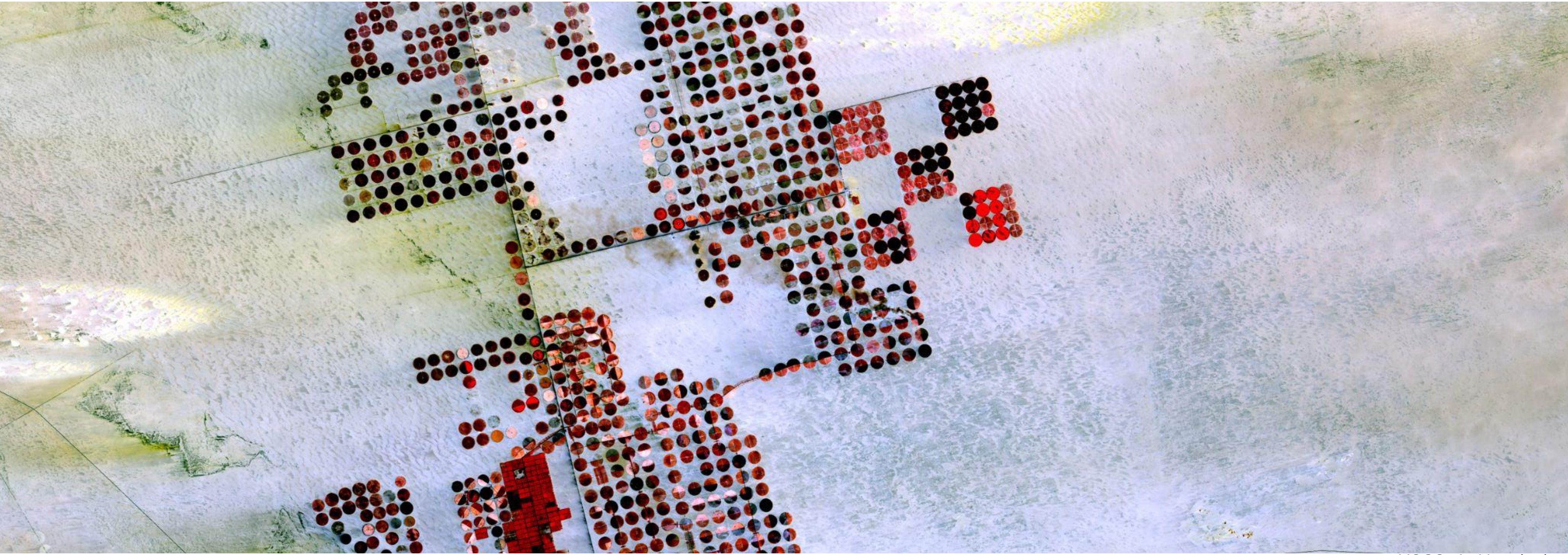
EDS 223: Geospatial Analysis & Remote Sensing
Week 6



USGS via Unsplash

Welcome!

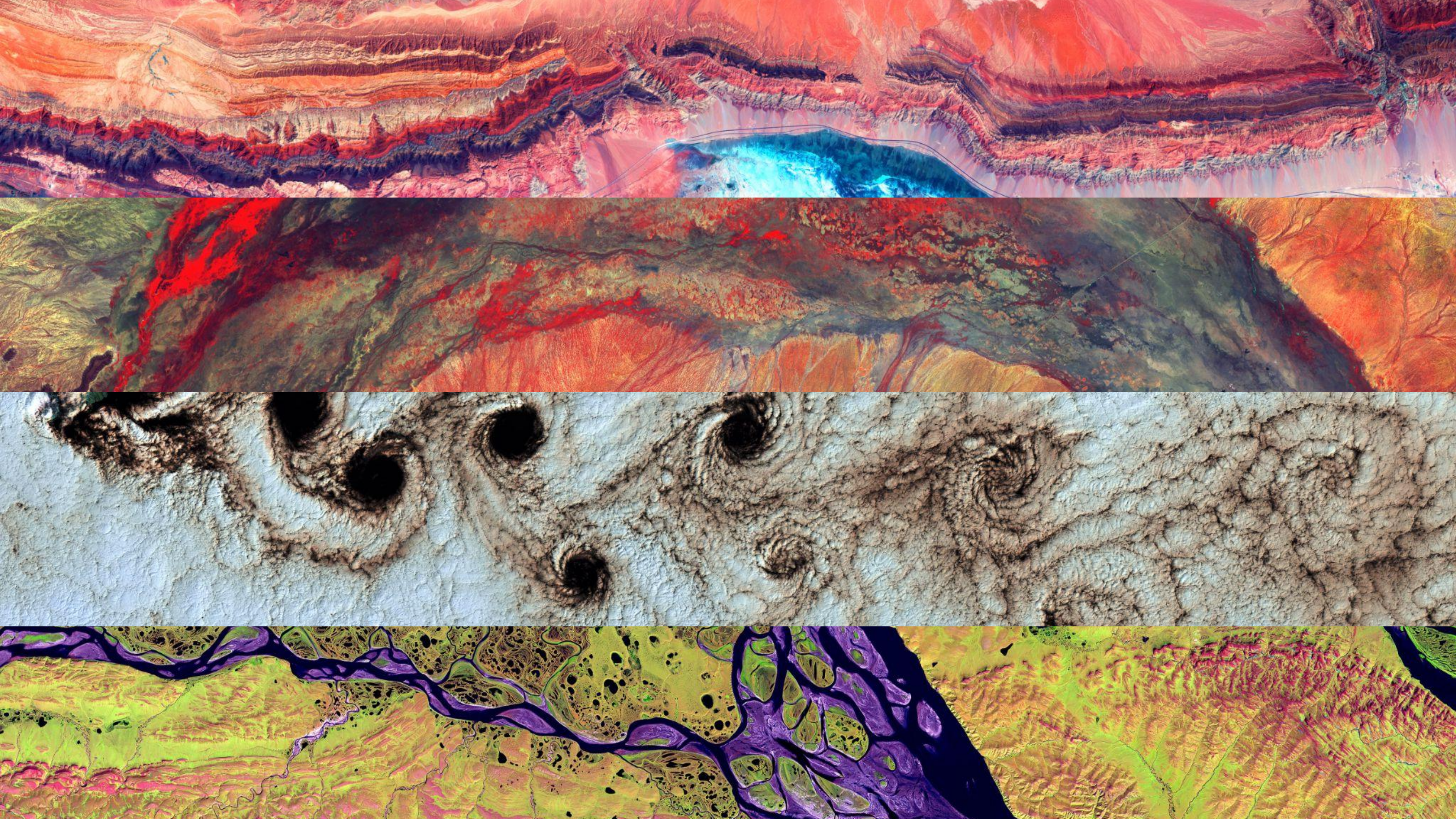
- **Course logistics**
  - Hybrid instruction on November 21
  - non-MEDS students – portofolio proposal

Welcome!

- **Remote sensing basics**
  - Energy transfer
  - Electromagnetic radiation
  - Radiation budget
- **“Self-checks” (aka the opposite of debugging)**
- **Raster geometry operations**

Learning objectives

- **Basic understanding of the physical processes that create remote sensing images**



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."
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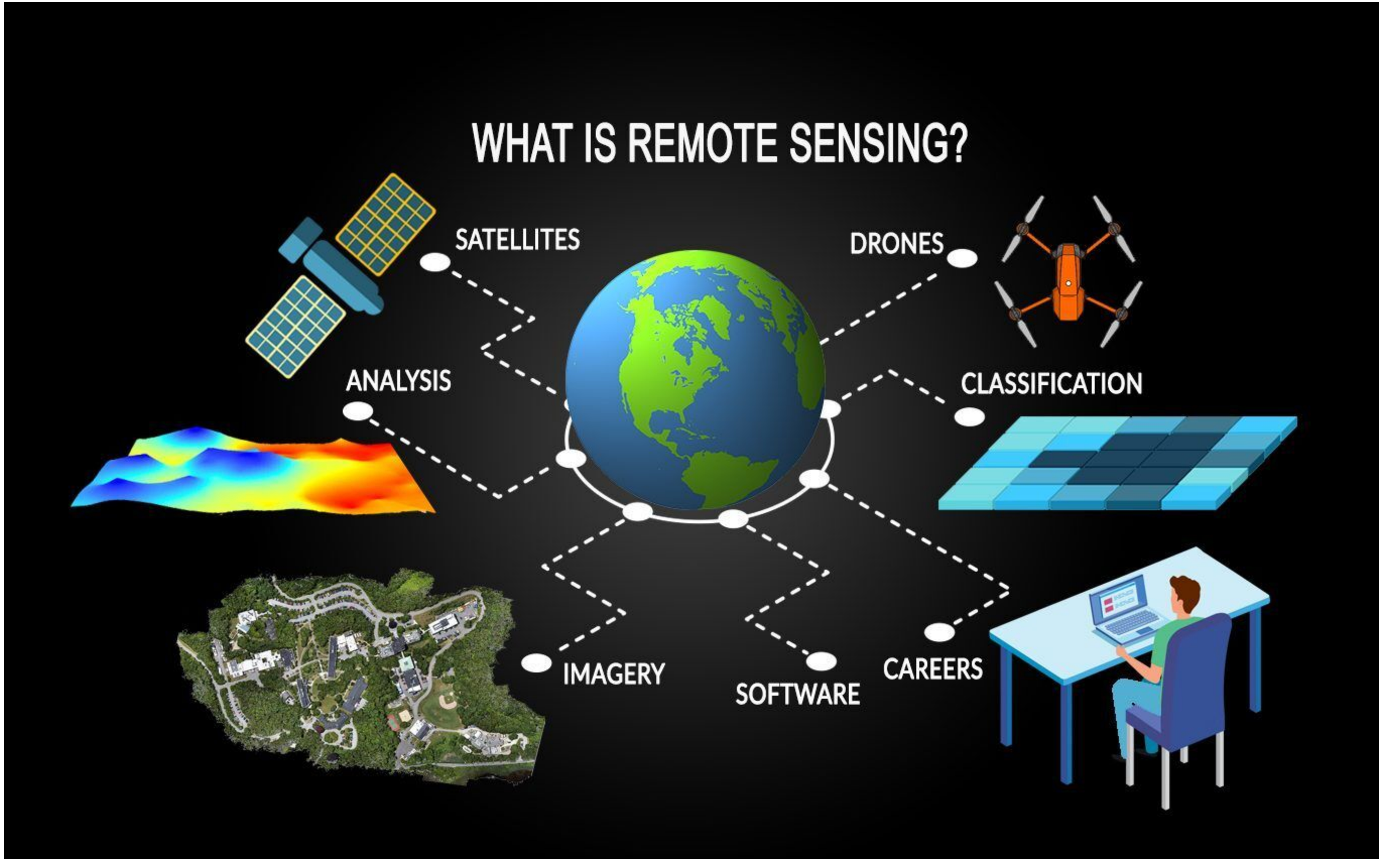

Source: GIS Geography

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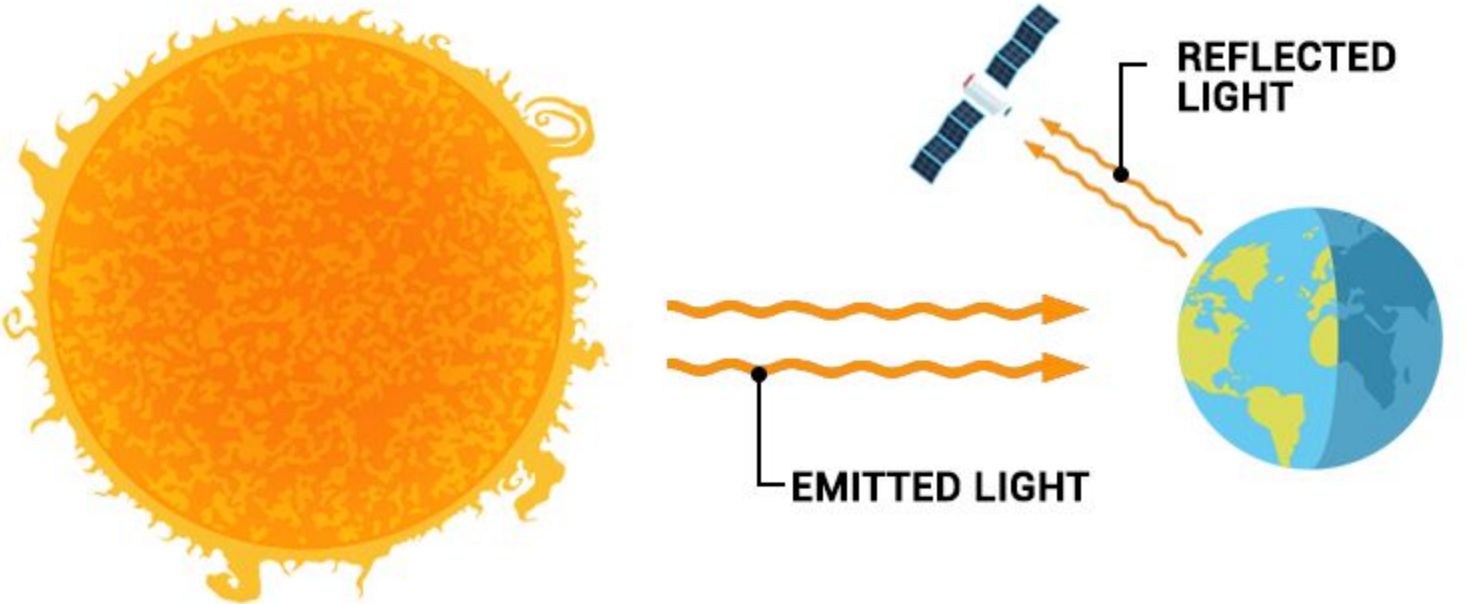
Lots of ways to be a remote senser, but you are already a remote sensor!

Energy: passive



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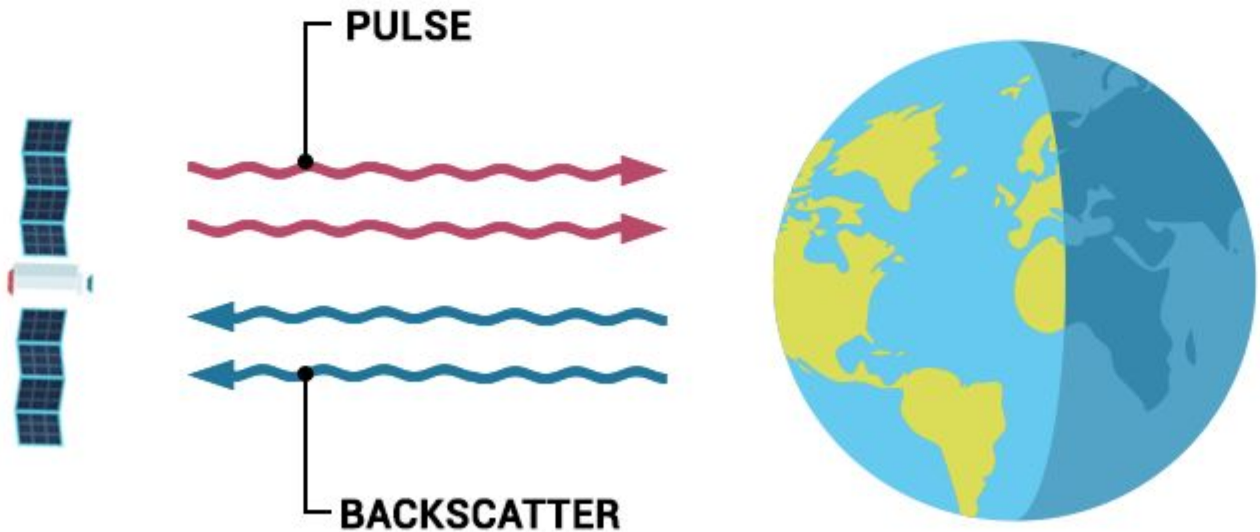
Energy: active



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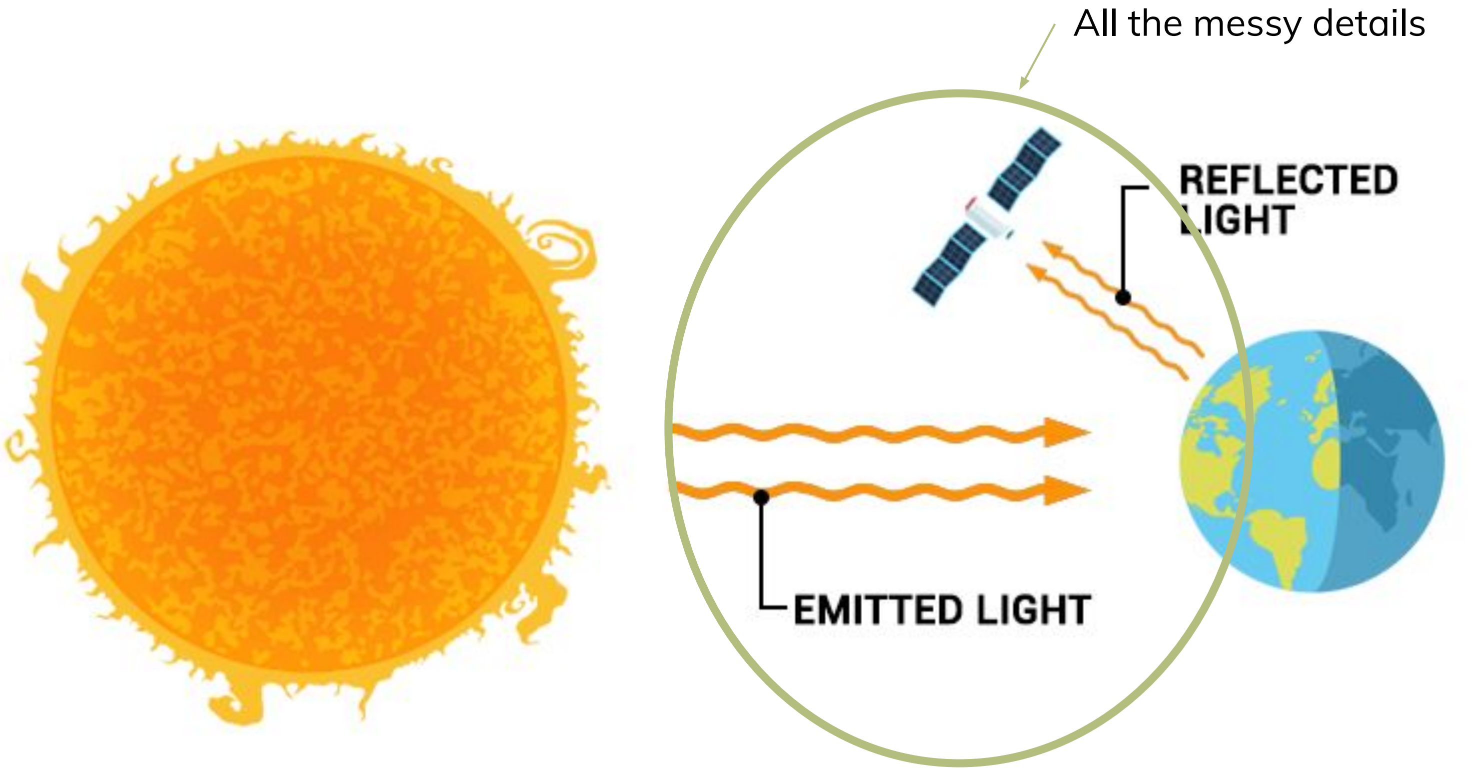

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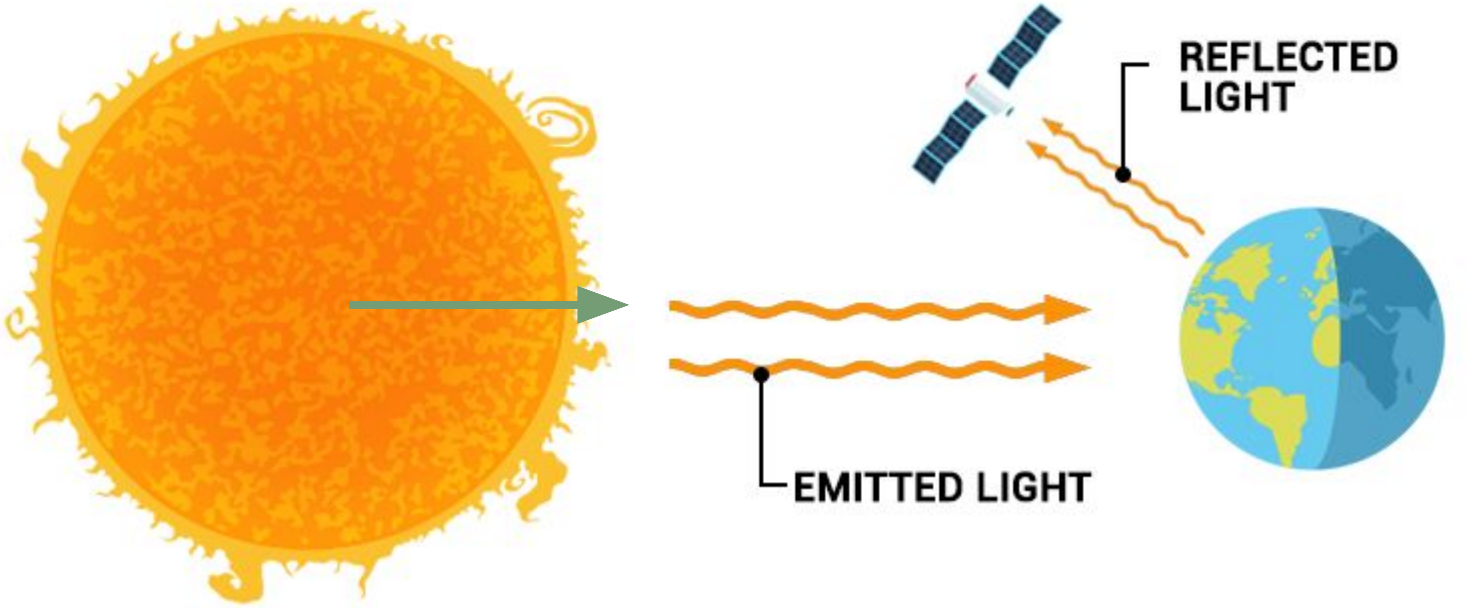

Source: GIS Geography

What is energy?

- The ability to do work (force applied over a distance)
- Lots of different types!
  - 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 on transferred.

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

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

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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

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

$$1\ \text{J} = 1\ \text{N m}$$

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

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

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

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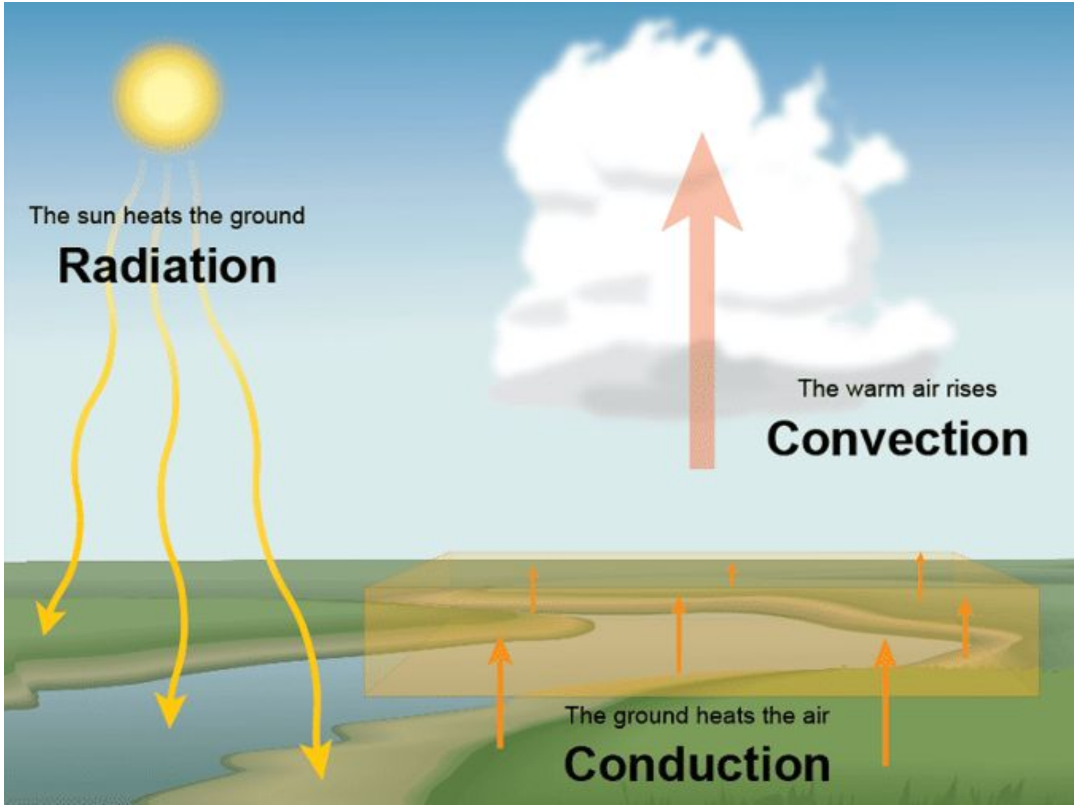

Source: UCAR

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

Convection: Kinetic energy transferred by physically moving objects.

Radiation: emission of energy as electromagnetic waves or as moving subatomic particles

What is radiation?

Fact: All materials with temperature above absolute zero emit radiation.

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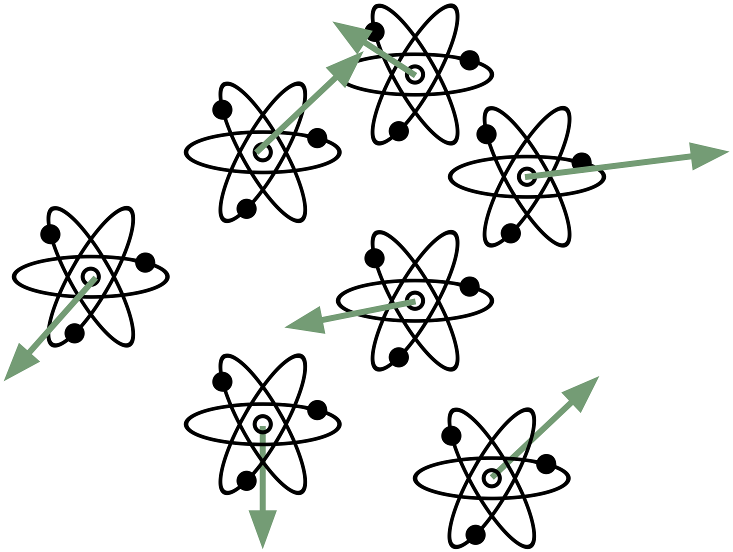
What is **kinetic energy**?
Movement!

What is radiation?



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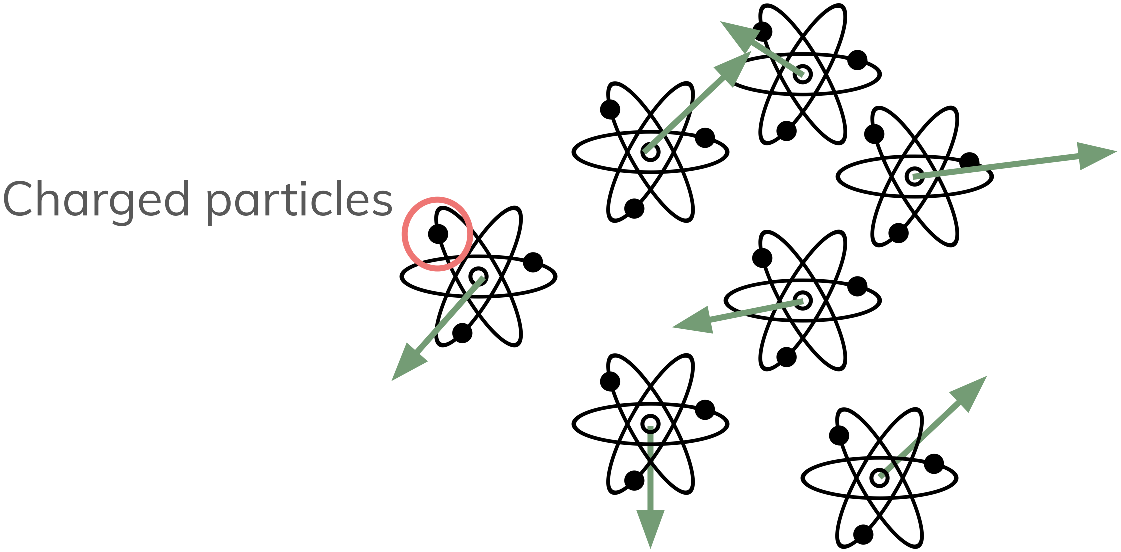
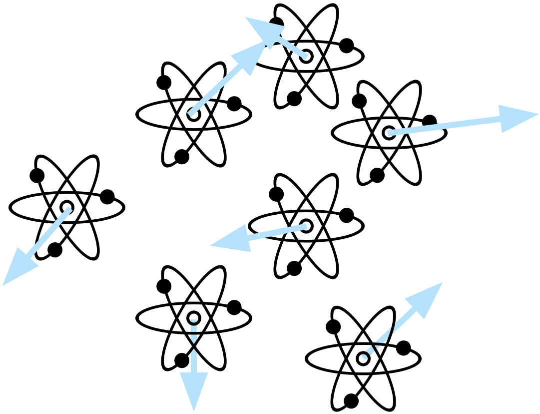
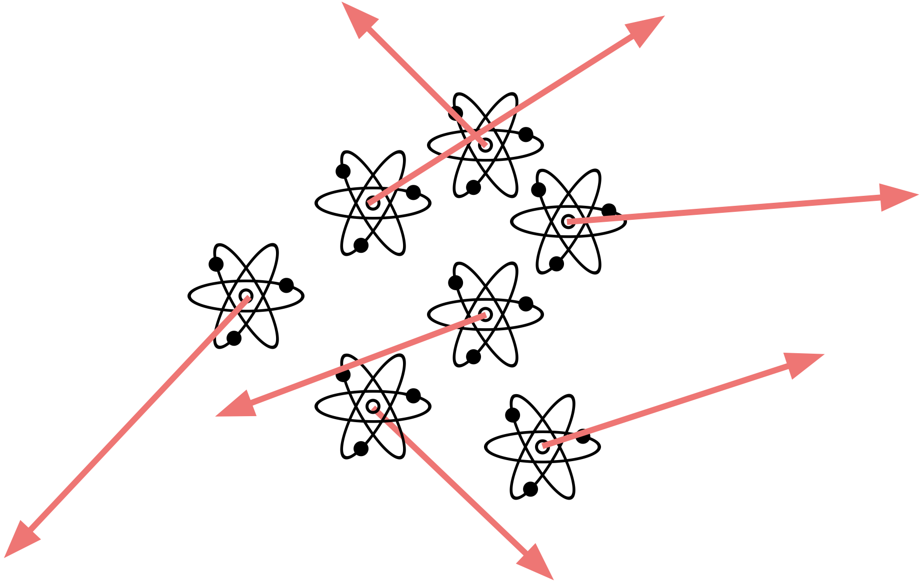


How is radiation related to temperature?



Low temperature
Less movement
Less kinetic energy



High temperature
More movement
More kinetic energy

How is radiation related to temperature?

As temperature increases, emitted radiation....

(a) Stays the same
(b) Increases
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But, by how much?

How is radiation related to temperature?

- **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 x 10^{-8}W $m^{-2}K^{-4}$)

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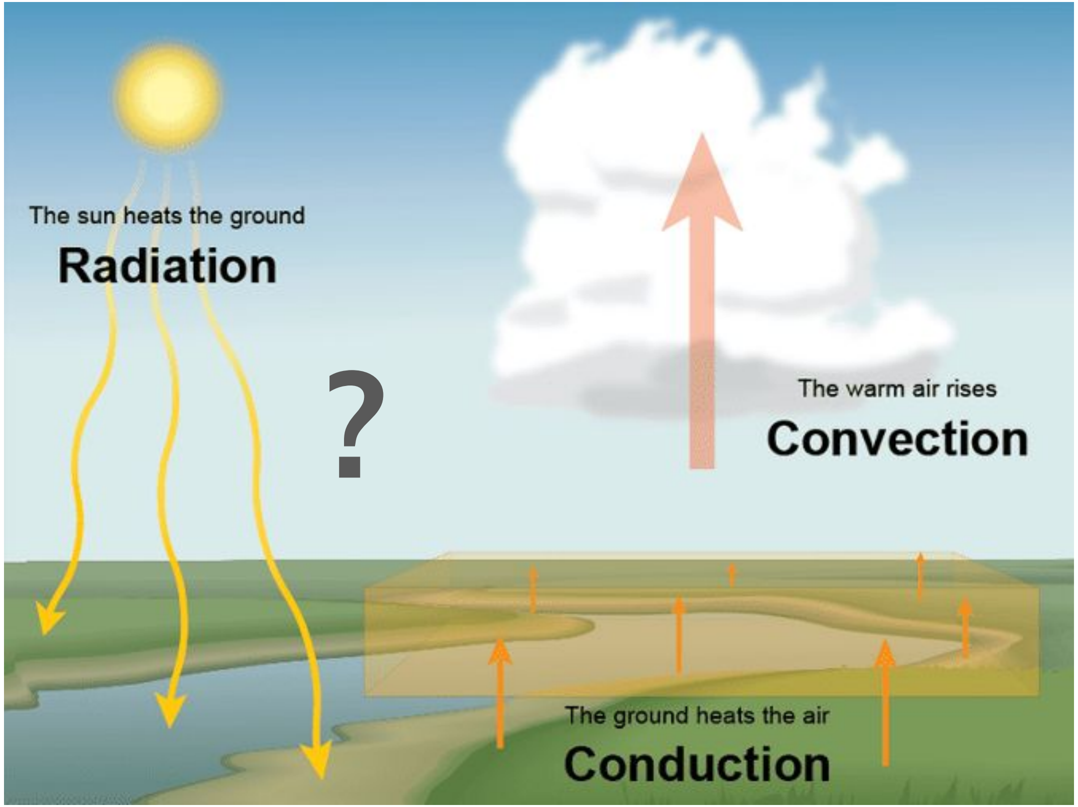

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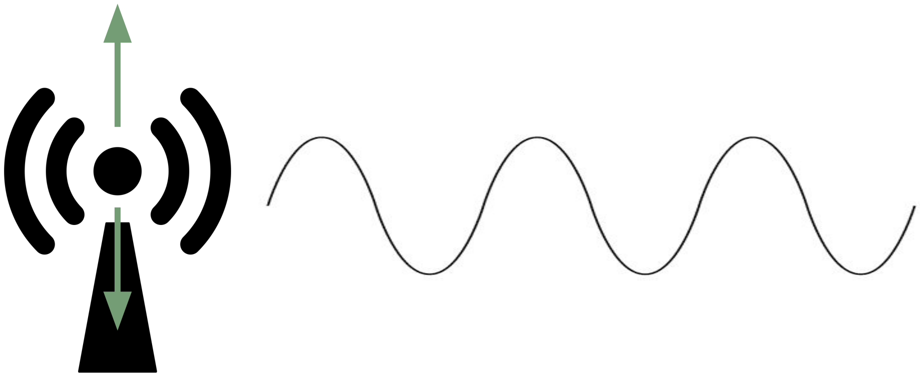
- **We know that radiation is produced by the movement of charged particles, but how is transferred??**
- **We don't *really* know!**
  - But we've come up with 2 analogies that help us make sense of this:
    - Wave vs. particle model
    - Like all models, neither is perfect but both are useful!

Wave model of radiation

- Generated when a charged particle changes velocity



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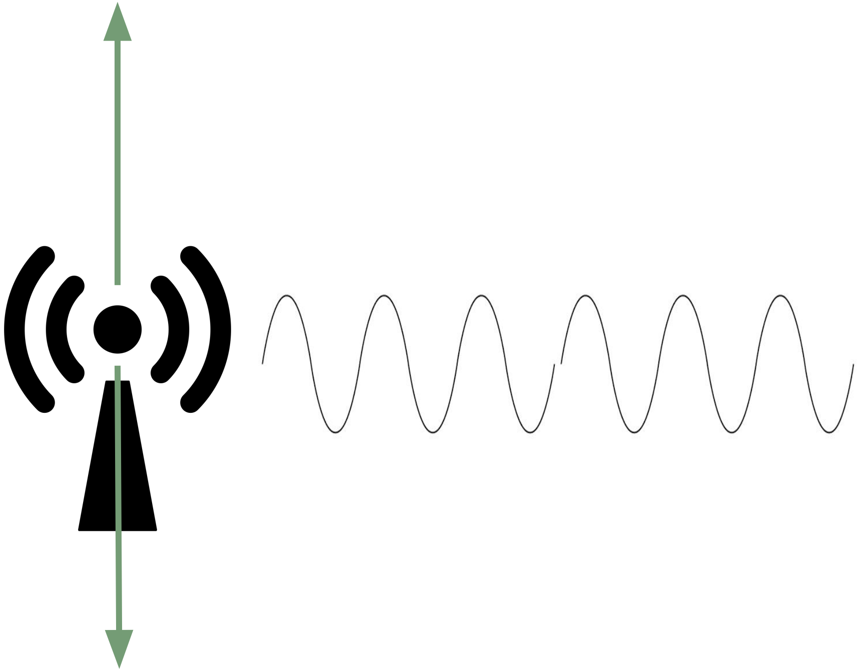
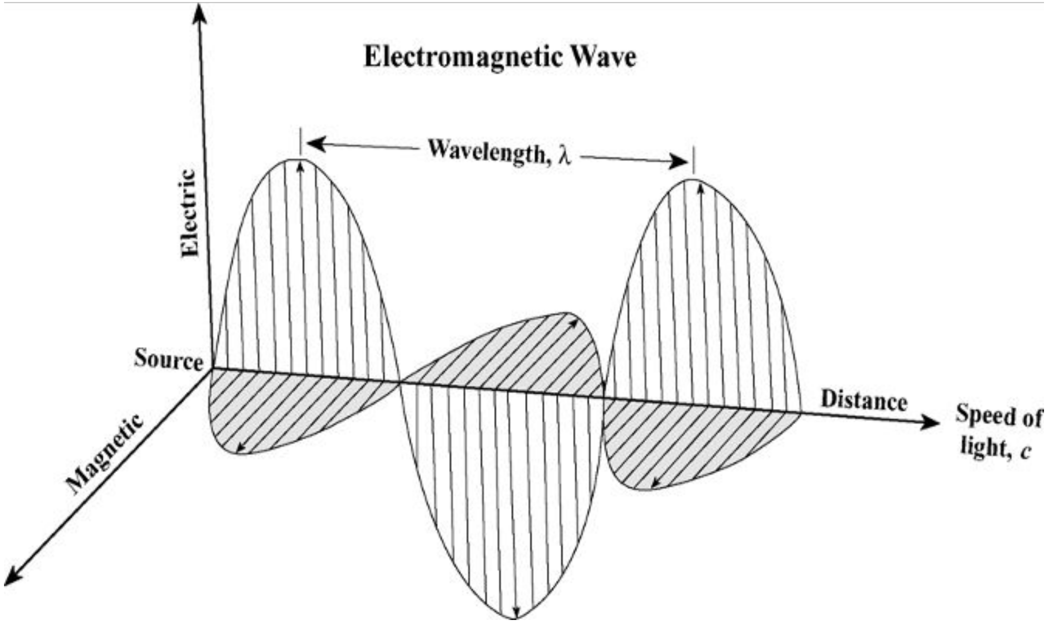


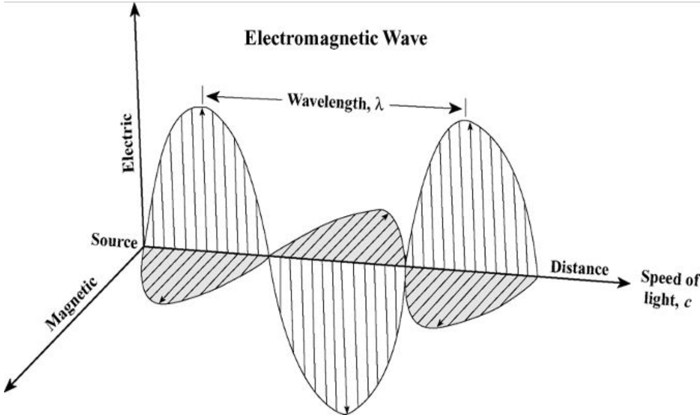
Wave model of electromagnetic radiation



Wave model of electromagnetic radiation

- 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* (**v**) - # of wavelengths that pass a point per unit time
  - measured in cycles per second or Hertz (Hz).

$$c = \lambda v$$



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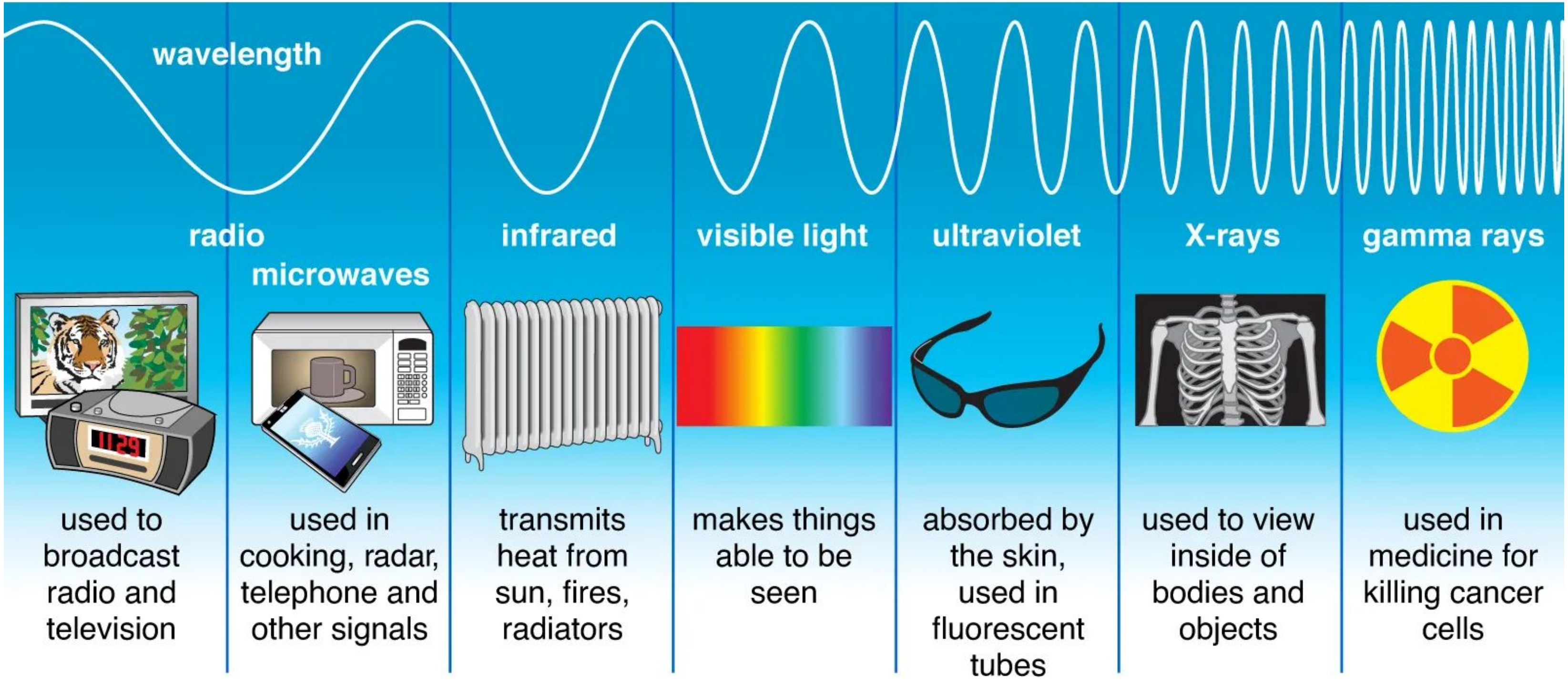

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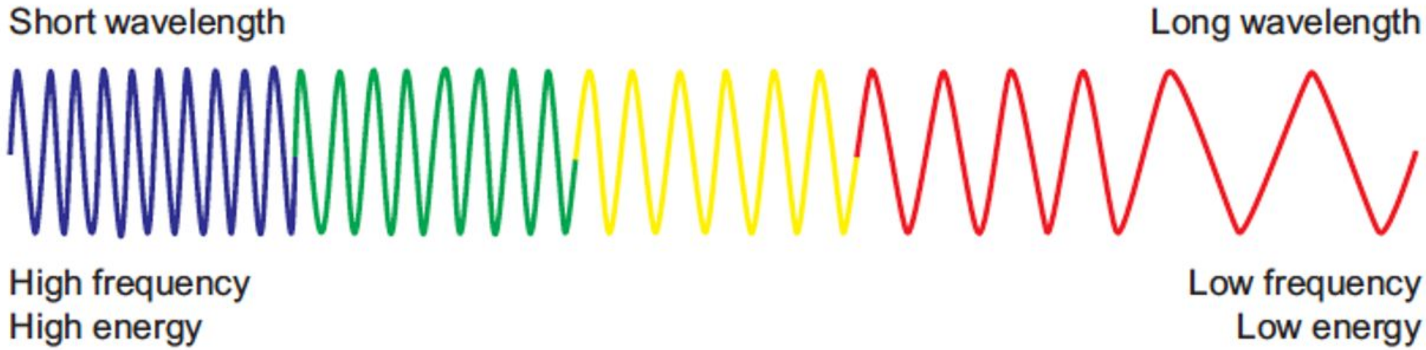
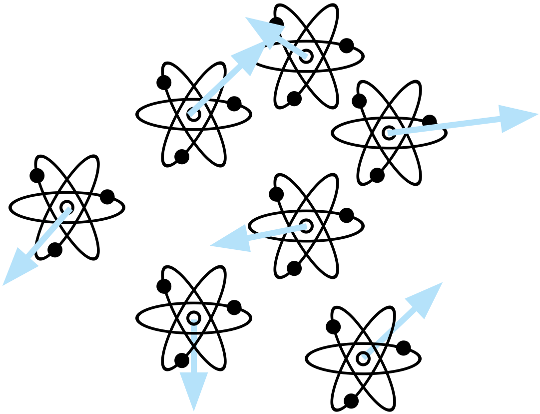


Source: Tempfli et al. 2009

How is radiation related to temperature?

How does temperature relate to the wavelength of emitted radiation?



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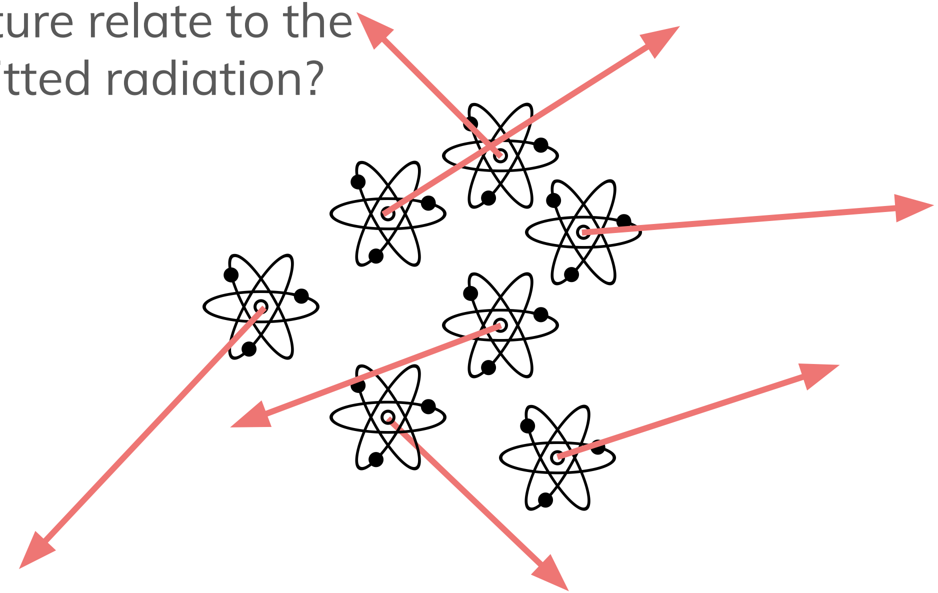

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Wien's displacement law:

$$\lambda_{max} = \frac{k}{T}$$

k = 2898 µm K

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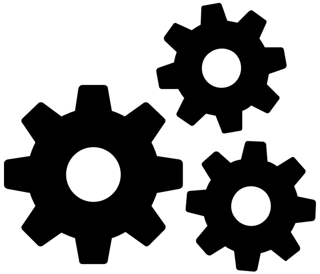

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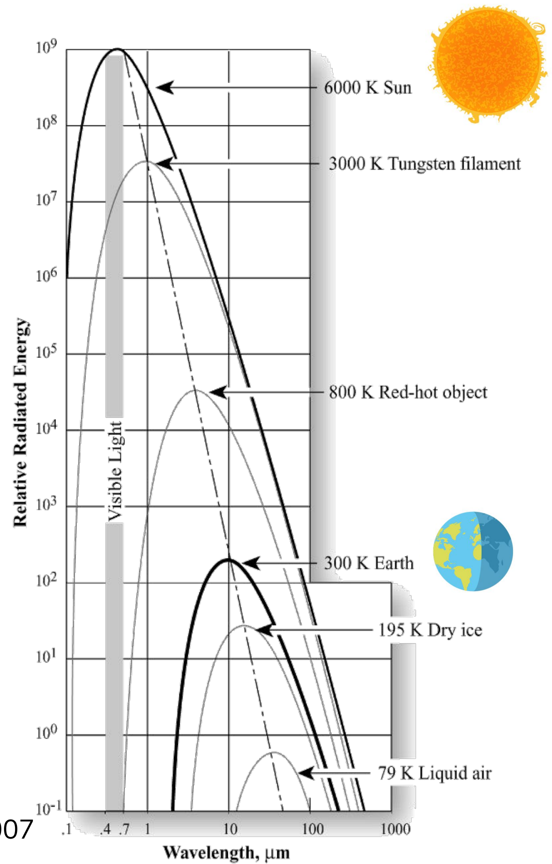

Source: Jensen 2007

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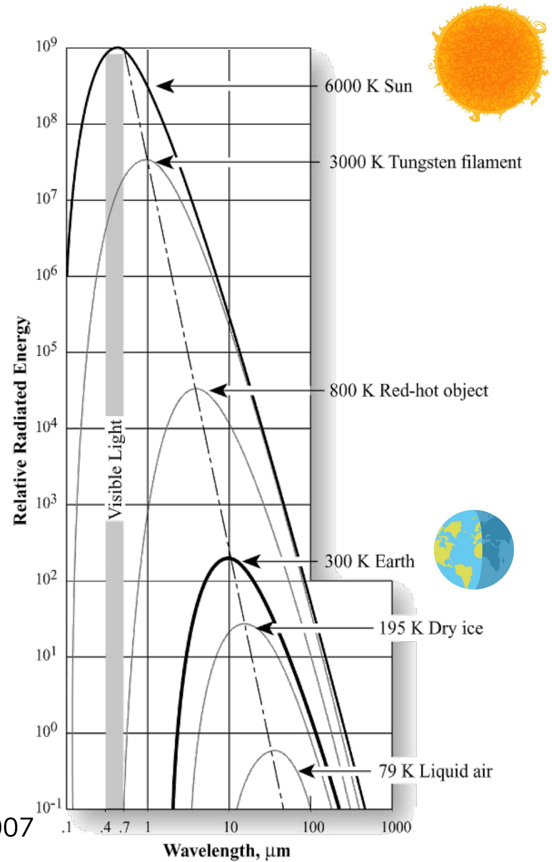

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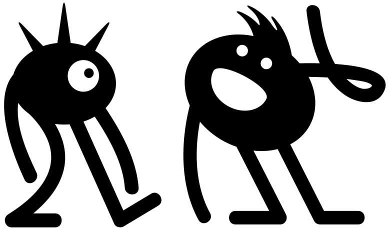

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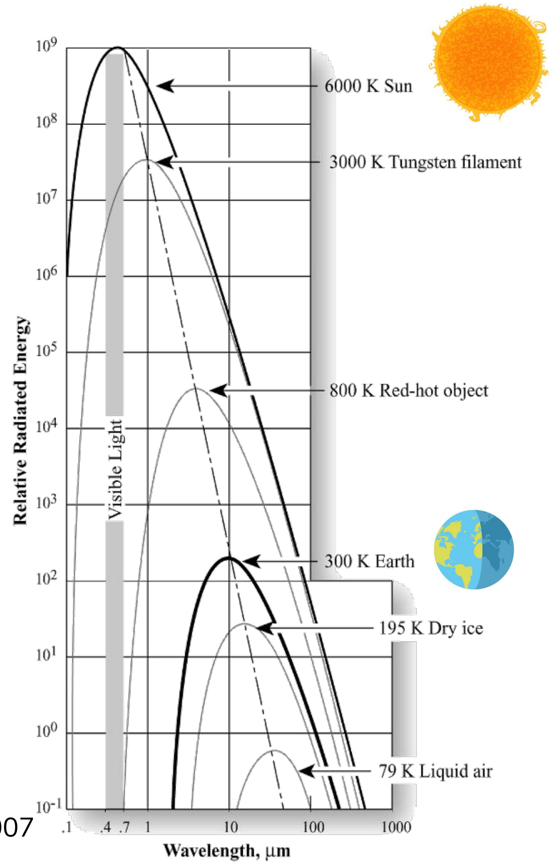


radiated energy

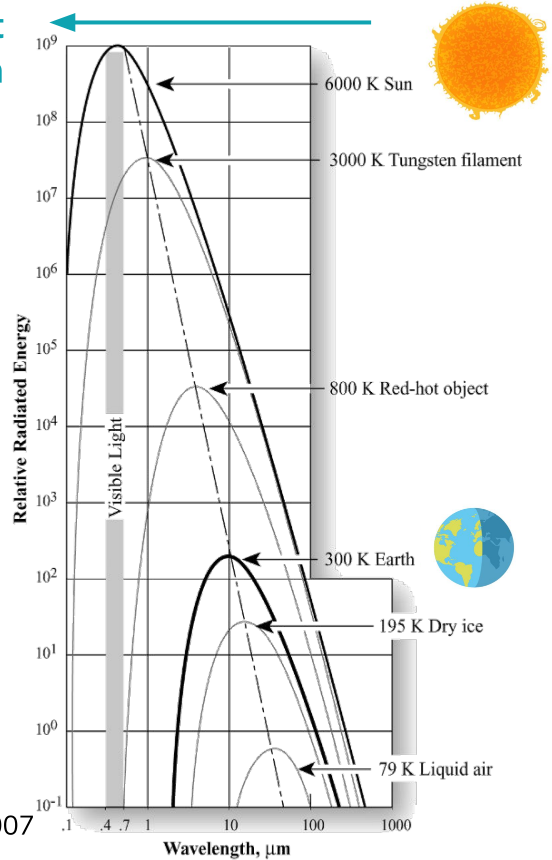
temperature

- 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



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Source: Jensen 2007

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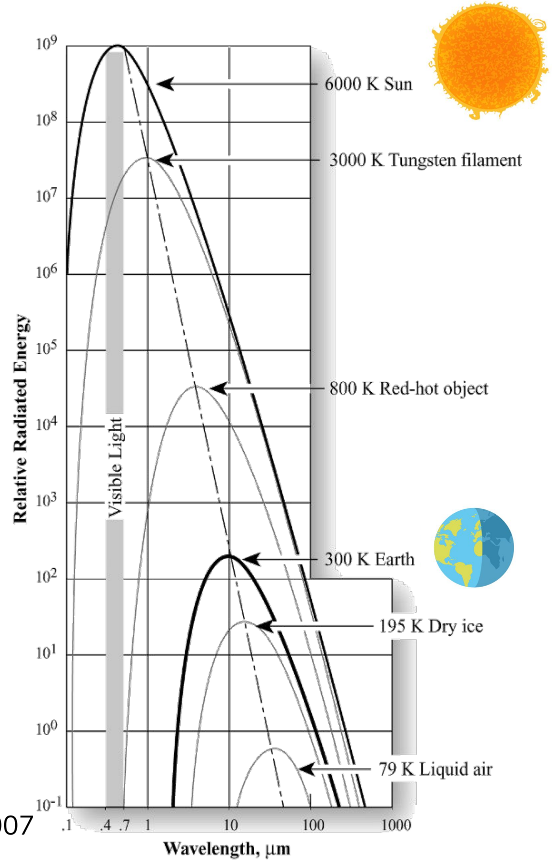

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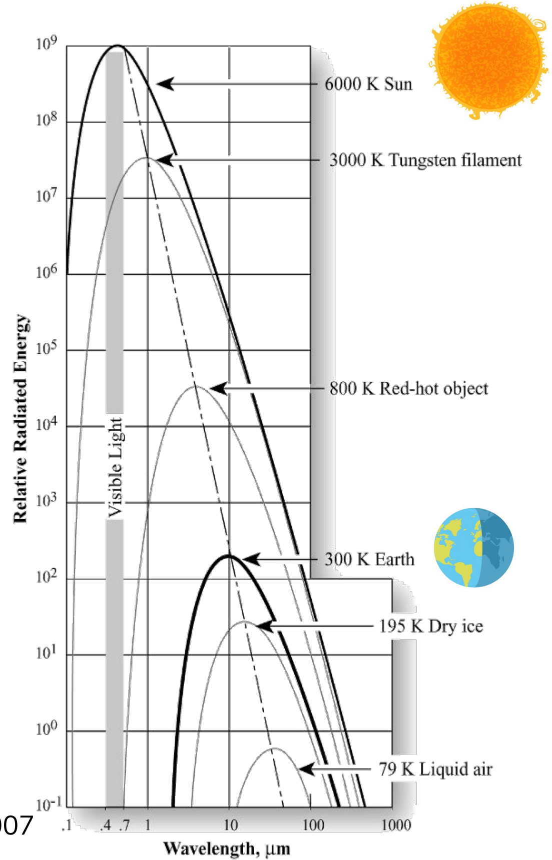
  - Stefan-Boltzmann's Law

- As temperature increases, the dominant wavelength of the radiation decreases
  - Wien's Displacement Law

Wave theory: blackbody radiation



Sou[illegible]en[illegible]2007

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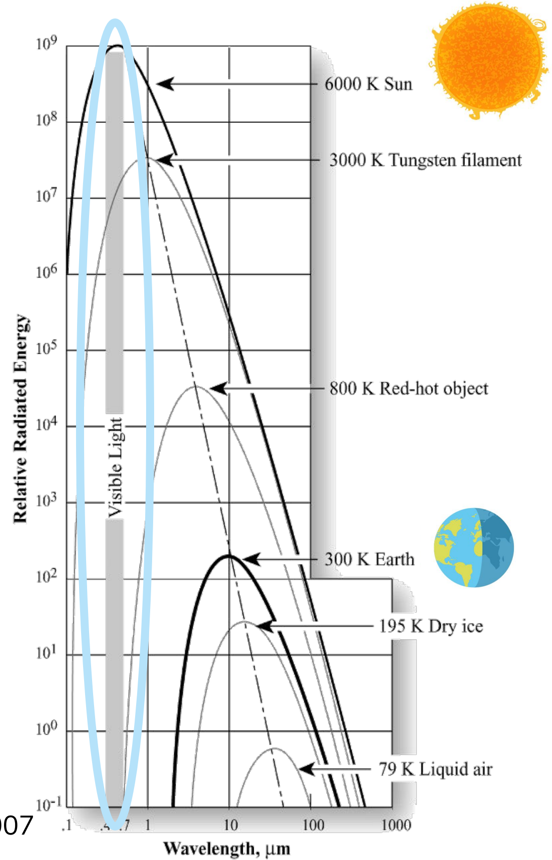
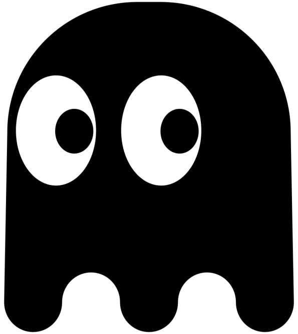


Source: Jensen 2007

- 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 x 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

BREAK

The issues...

- **Many possible solutions to one problem**
  - Why use one approach over another?
- **Some solutions will get you to the right answer but need more work**
  - Take the case of “st_join” from assignment 2
- **Unsatisfying answers from the instructor and TA**
  - “Can I use X for this question?” “Sure!” “But the answers wrong....”

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What’s our goal with all of this again?

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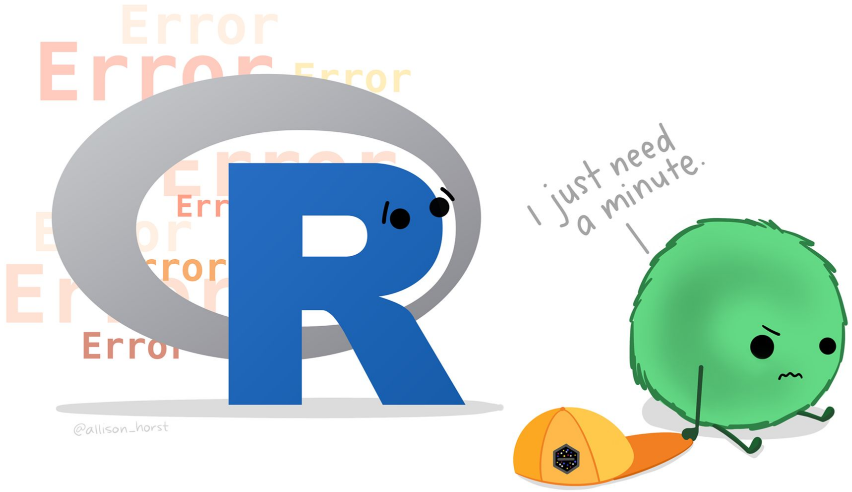
What’s our goal with all of this again?
Building code heroes!
Which means thinking critically about problems.
It’s about the process, not the end point!

What's our solution?

- **Adding critical thinking directly into the rubric for assignments!**
- **Aiming to help with…**
  - Building a better understanding of what your code does and why
  - Reducing frustrating situations with the instructional team :)

Building self-checks into your code



Bugs are scary,
but code that runs but doesn't do what you think it does is even SCARIER….

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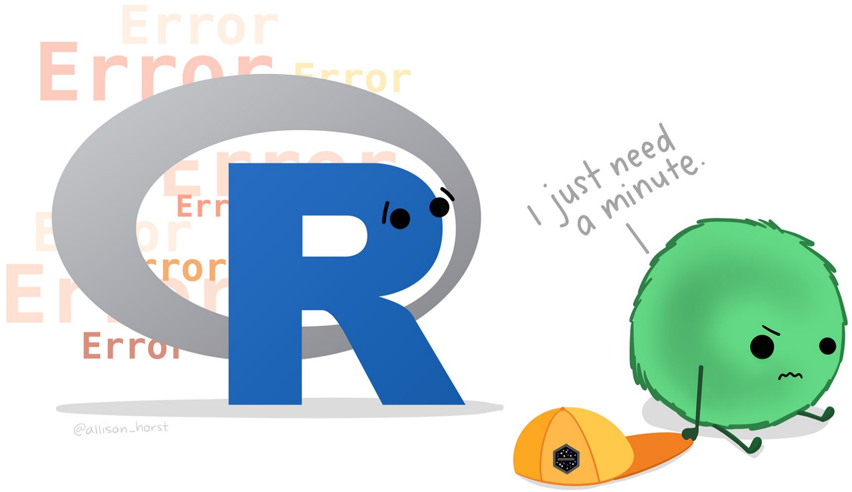

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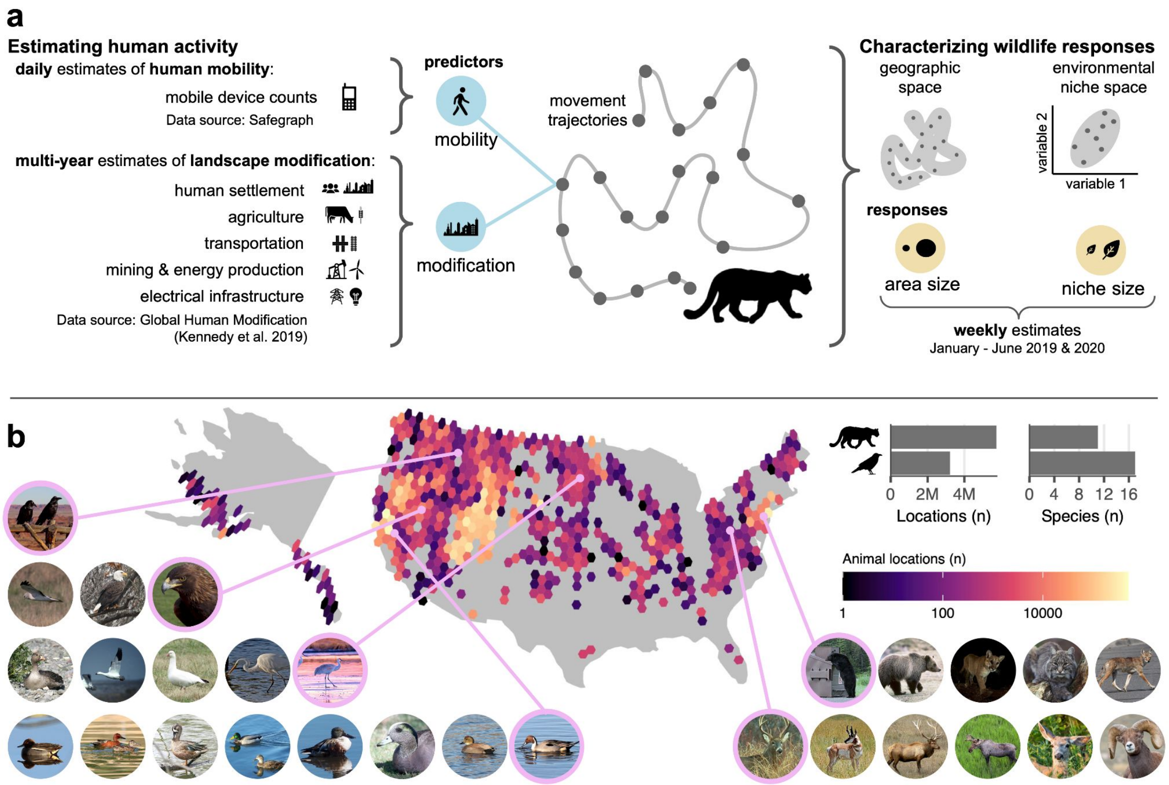
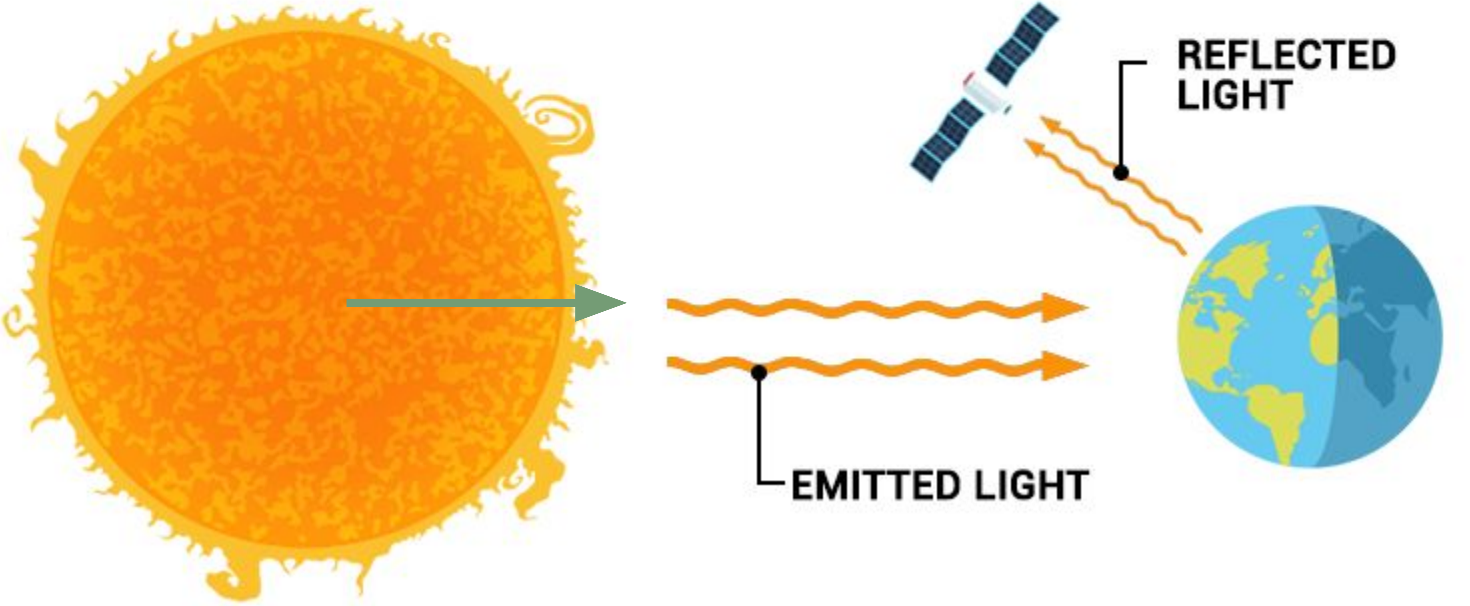
Because... figuring it out takes a lot of dissecting!

Self-check tutorial

Human mobility drives animals' interactions with space and environment



Oliver, Yanco et al. in prep



Source: GIS Geography

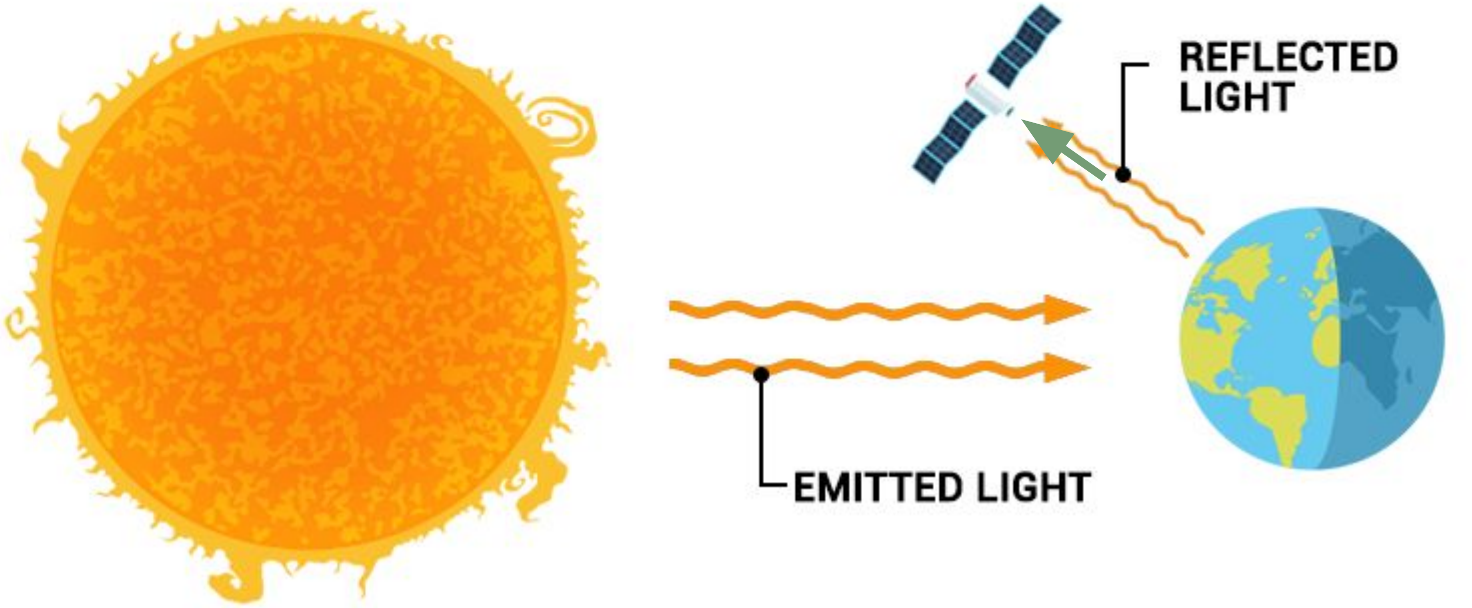
Particle model

- **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**)

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

(h is the Planck constant: 6.63×10^{-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 flux density	Radiant exitance	M	W/m^2
	Radiance	L	$W/m^2 sr$

Capacity for radiation within a specified spectral band to do work

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

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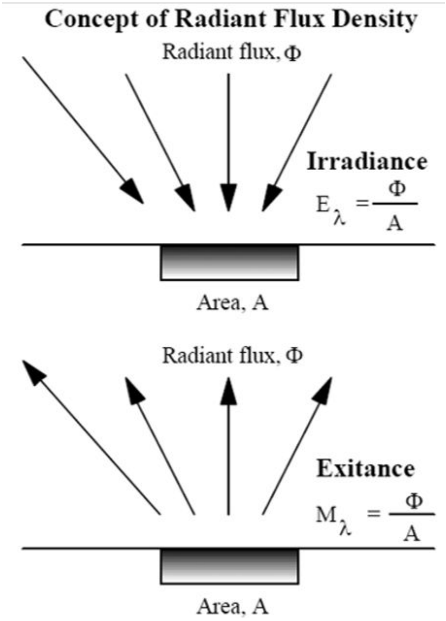
Radiant flux density	Irradiance	E	W/m^2	Radiant flux upon a surface per unit area
	Radiant exitance	M	W/m^2	Radiant flux leaving a surface per unit area
	Radiance	L	W/m^2sr	

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 flux density	Radiant exitance	M	W/m^2
	Radiance	L	W/m^2sr



Source: Jensen 2007

Measuring energy

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Remote sensing is the quantification and study of radiance.

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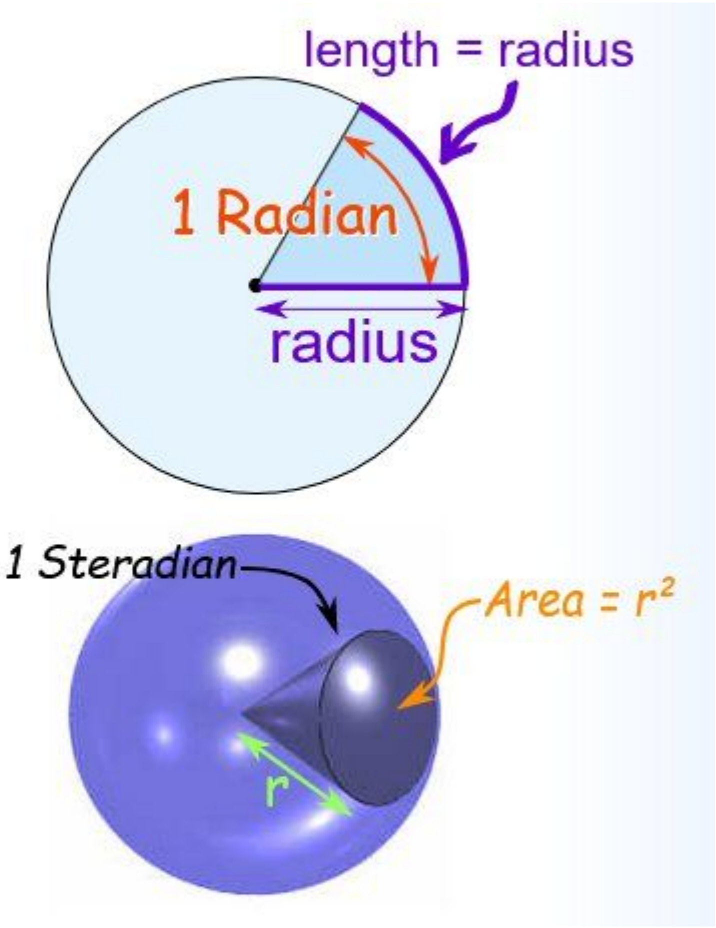
Remote sensing is the quantification and study of radiance.

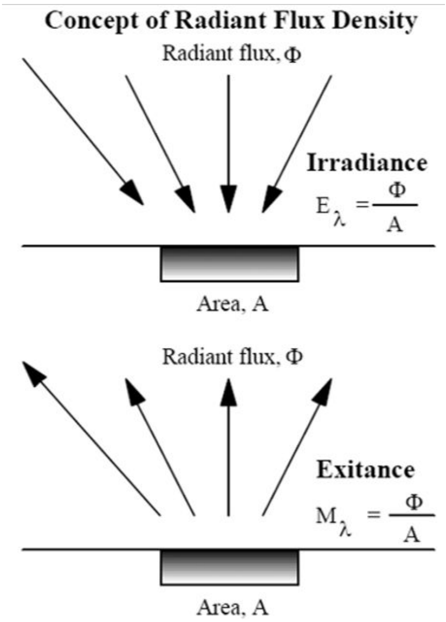
Measuring energy: steradians

- 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



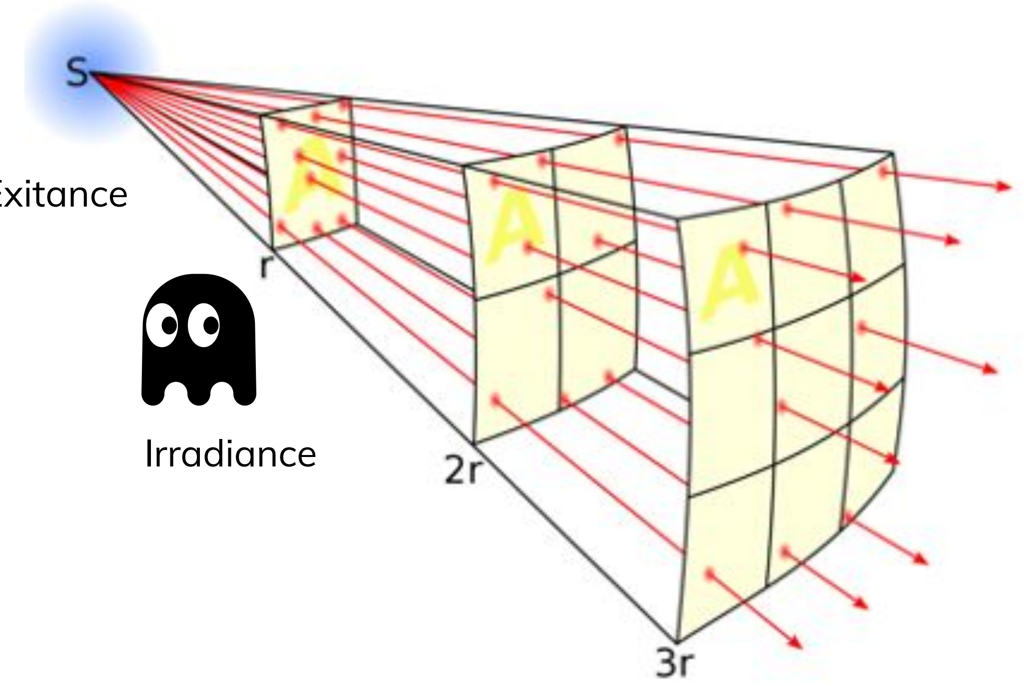
Measuring energy: exitance, irradiance, and radiance

	Term	Symbol	Units
	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



Source: Jensen 2007

Measuring energy: irradiance vs. radiance

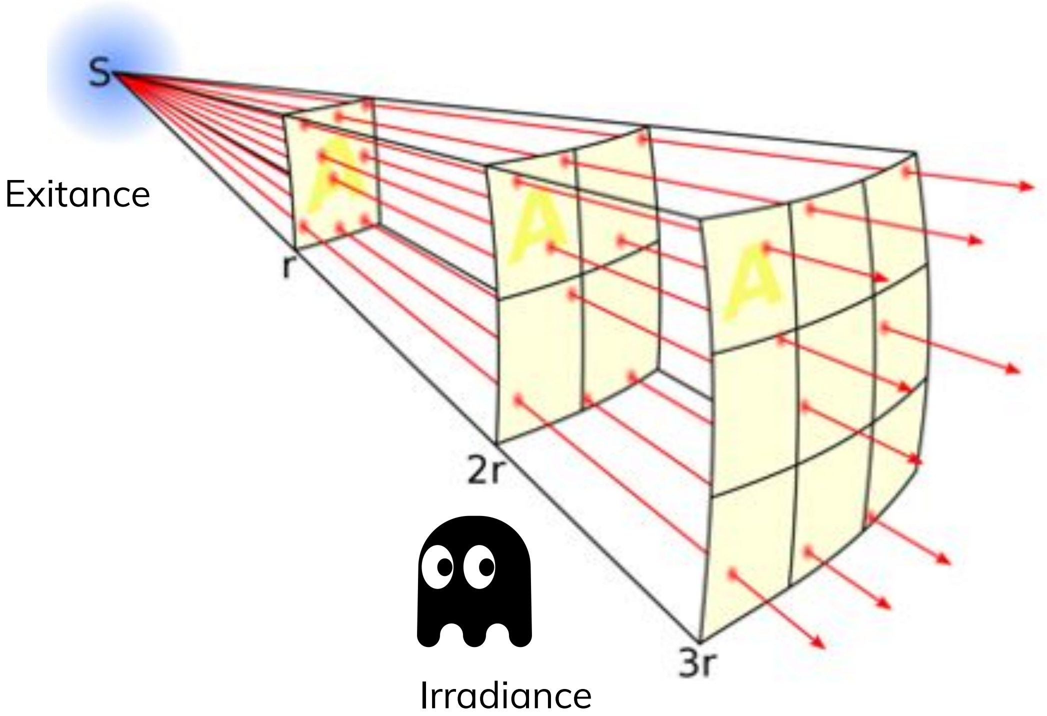


Exitance

Irradiance

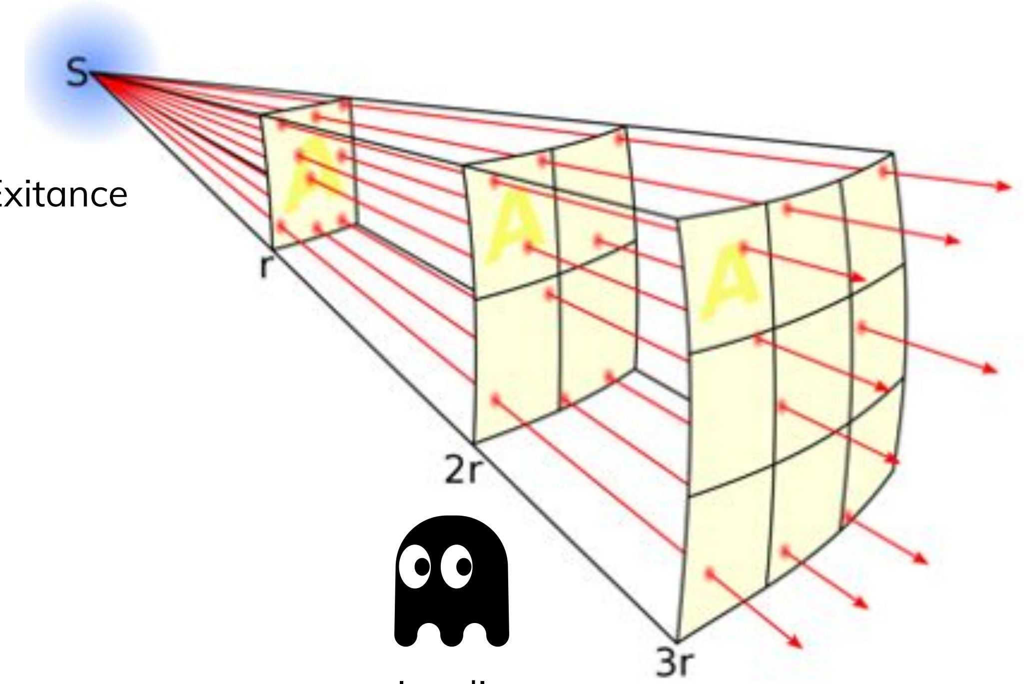
Source: Wikipedia

Measuring energy: irradiance vs. radiance



Source: Wikipedia

Measuring energy: irradiance vs. radiance



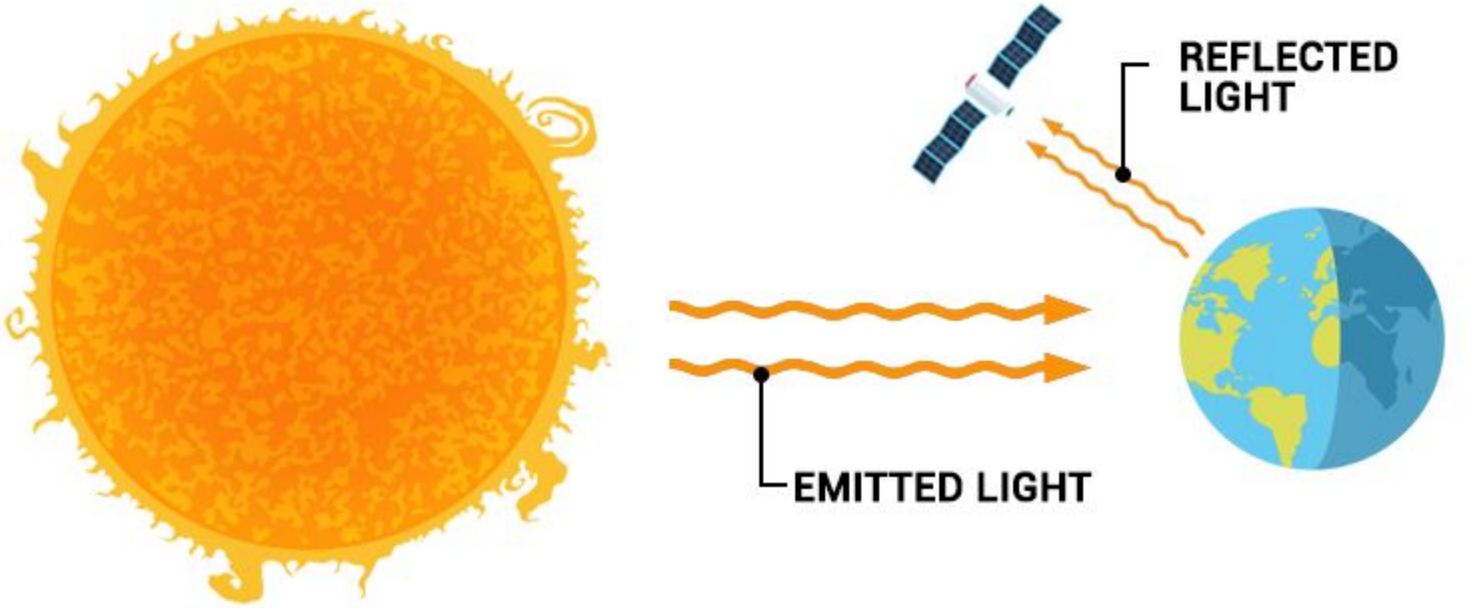
Exitance

Irradiance

- 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

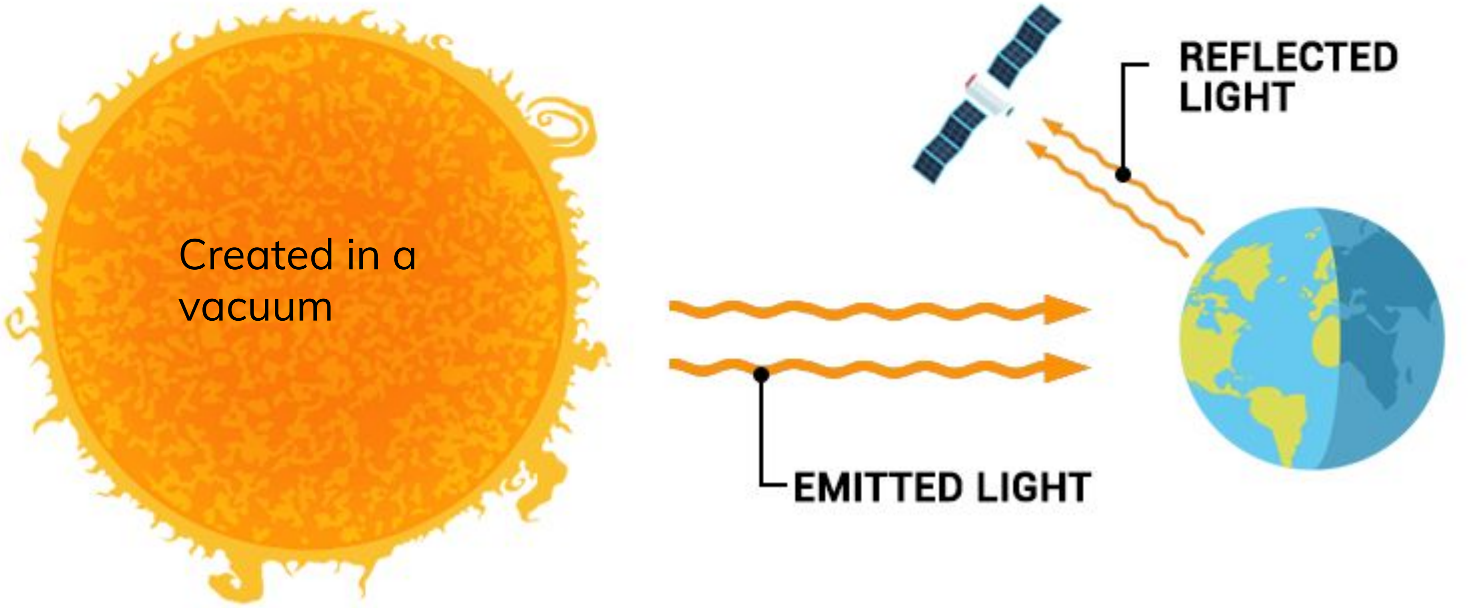
Radiation budget



Source: GIS Geography

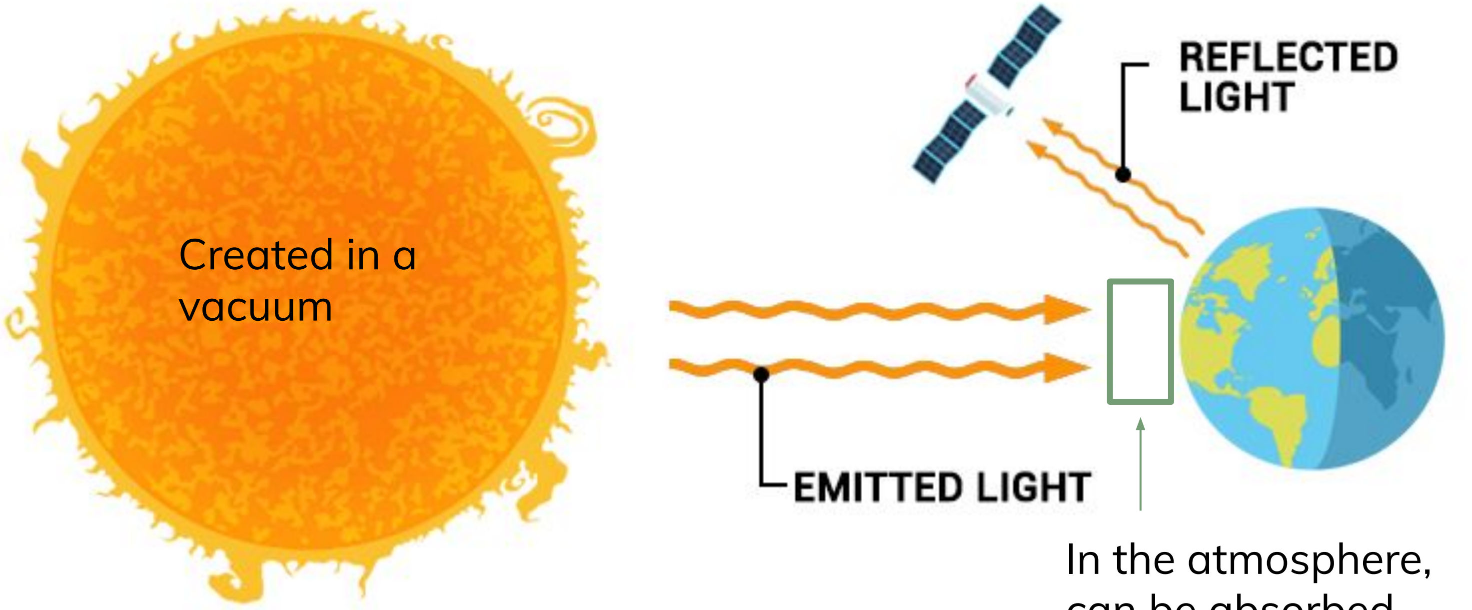
Radiation budget

Created in a vacuum



Source: GIS Geography

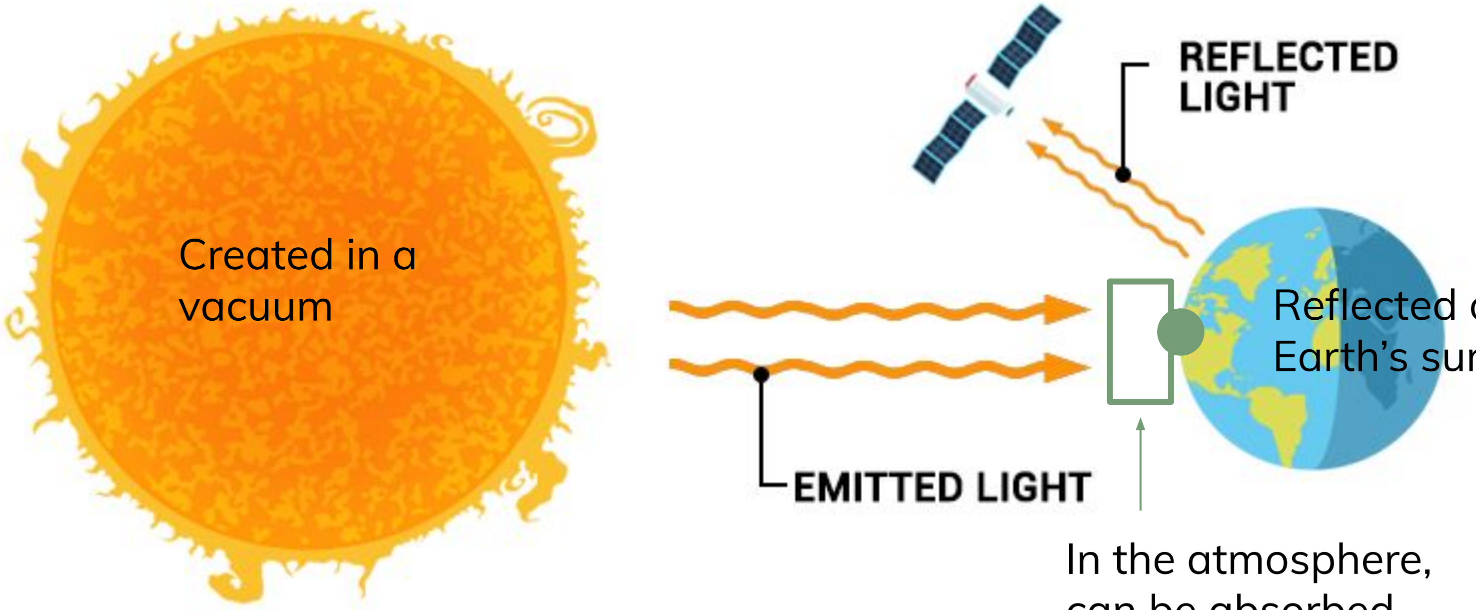
Radiation budget



In the atmosphere, can be absorbed and/or scattered

Source: GIS Geography

Radiation budget



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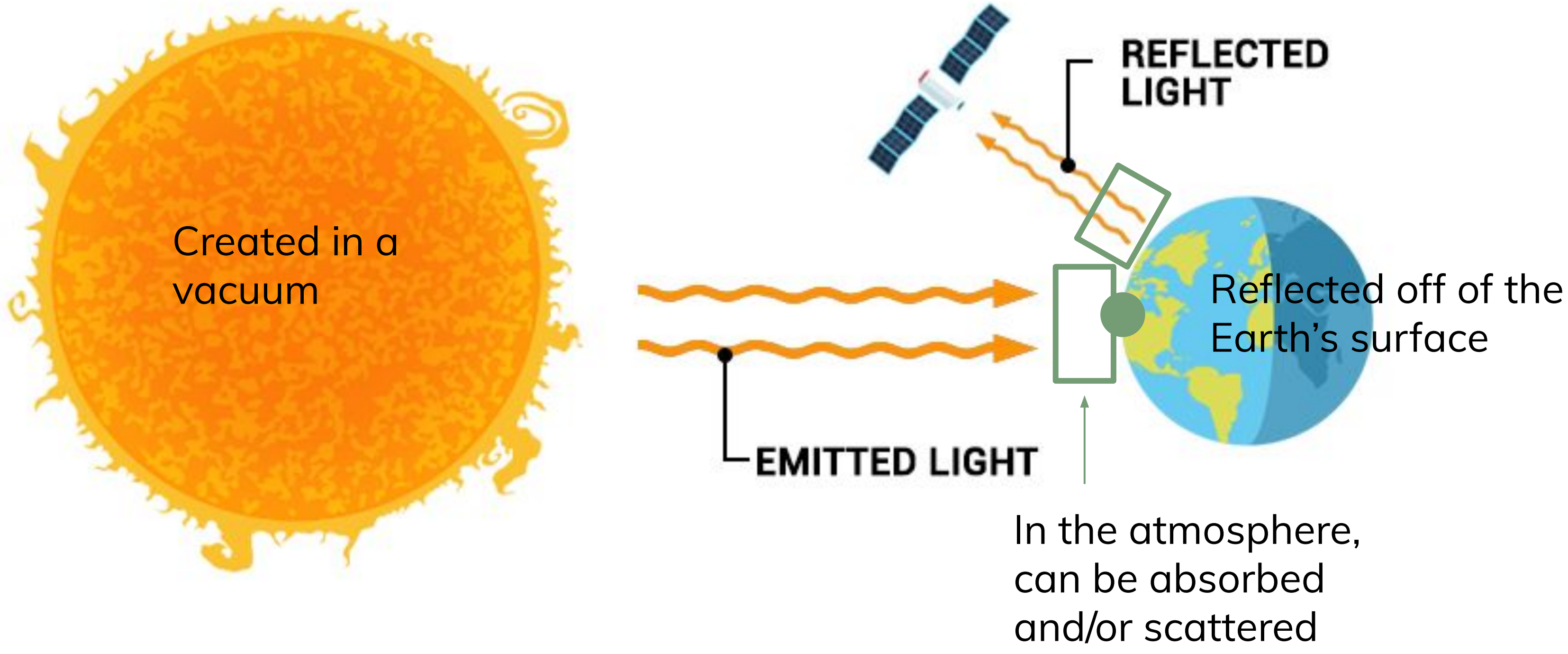
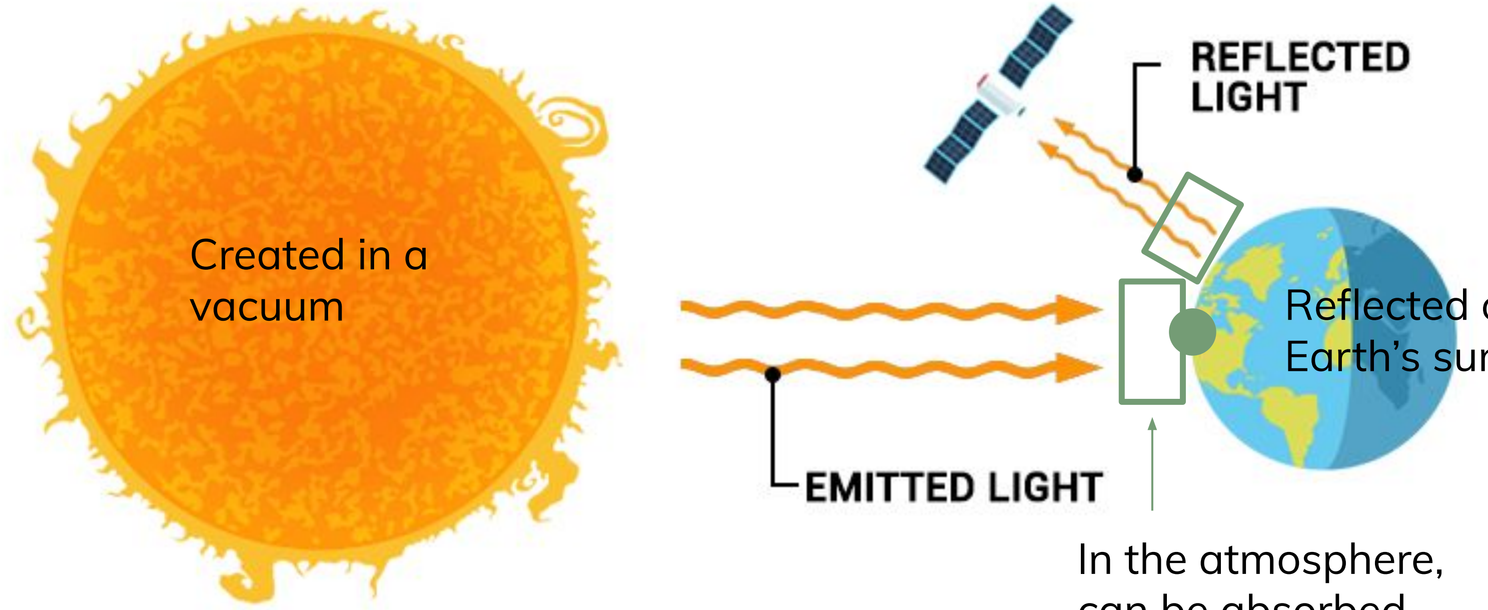


Source: GIS Geography

Radiation budget



Created in a vacuum

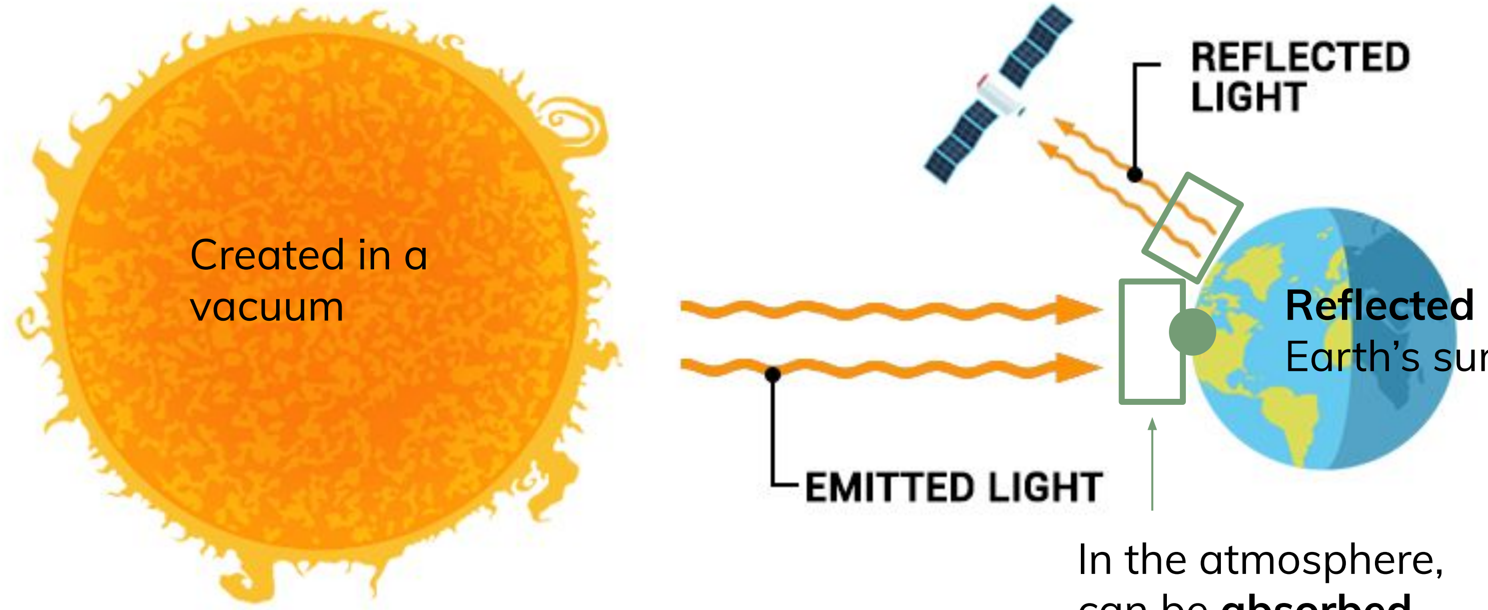
Reflected off of the Earth's surface

In the atmosphere, can be absorbed and/or scattered

By passing through media of different densities, can be refracted

Source: GIS Geography

Radiation budget



Created in a vacuum

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**

Absorption

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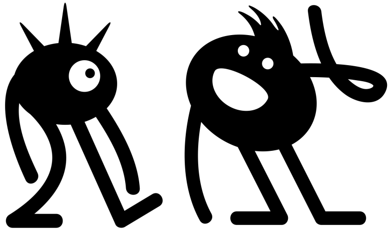
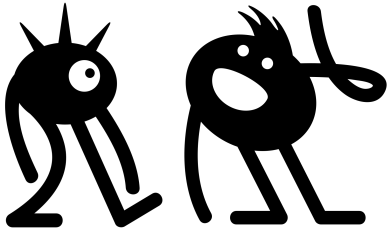
- Name the top 3 atmospheric constituents which absorb radiation:

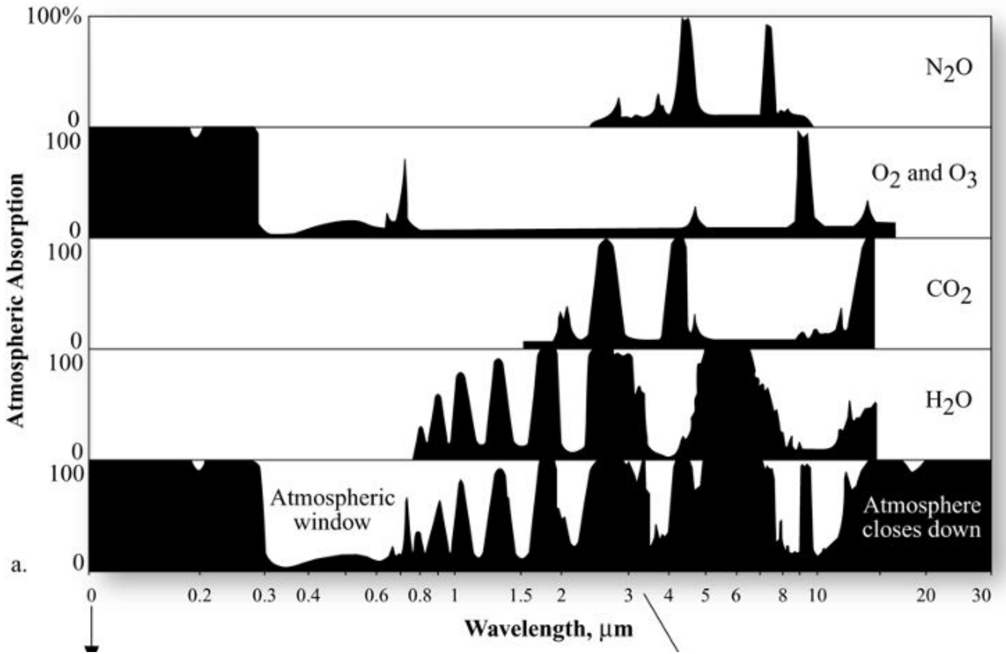


Absorption

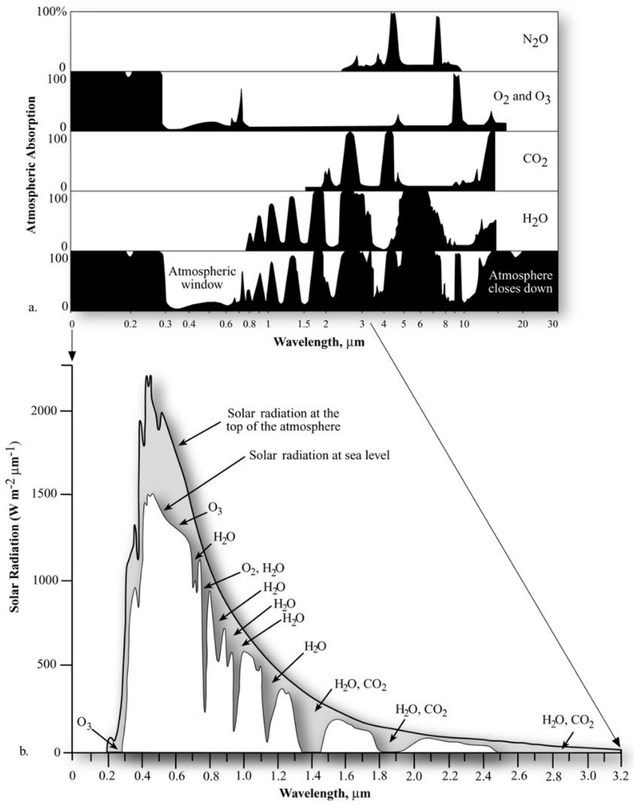
- **The process by which radiant energy is absorbed and converted into other forms of energy**
- **Name the top 3 atmospheric constituents which absorb radiation:**
    - Ozone
    - Carbon dioxide
    - Water vapor



Absorption


100%
0
100
0
100
0
100
0
100
0
N_2O
O_2 and O_3
CO_2
H_2O
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%
0
100
0
100
0
100
0
100
0
Atmospheric Absorption
N_2O
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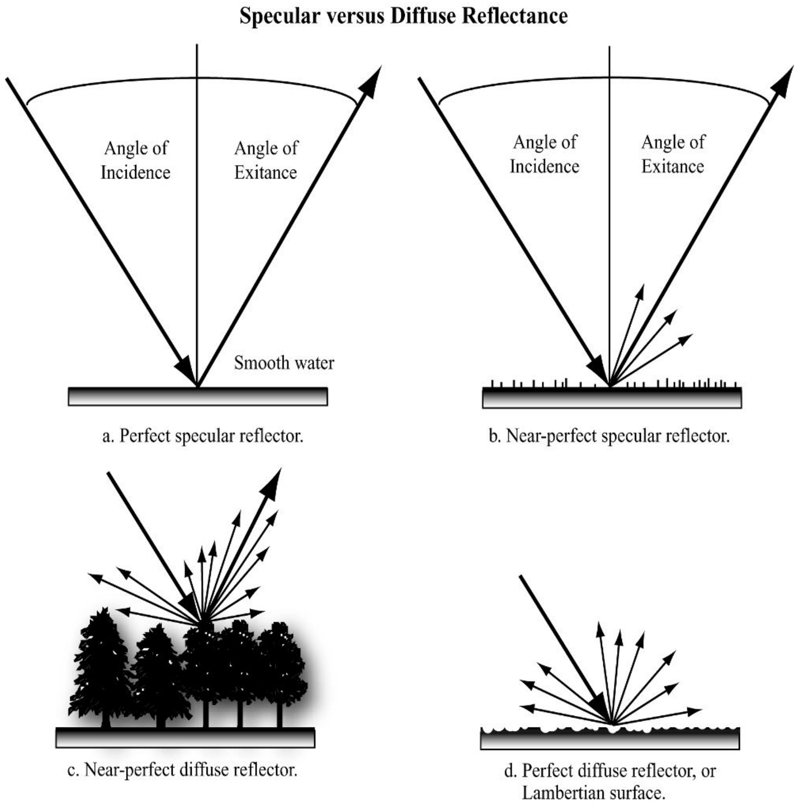
H_2O
Atmospheric window
Atmosphere closes down
a.
0 0.2 0.3 0.4 0.6 0.8 1 1.5 2 3 4 5 6 8 10 20 30
Wavelength, µm
Solar radiation at the top of the atmosphere
Solar radiation at sea level
O_3
H_2O
O_2, H_2O
H_2O
H_2O
H_2O
H_2O
H_2O, CO_2
H_2O, CO_2
H_2O, CO_2
O_3
Solar Radiation (W m^{-2} μm^{-1})
2000
1500
1000
500
0
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

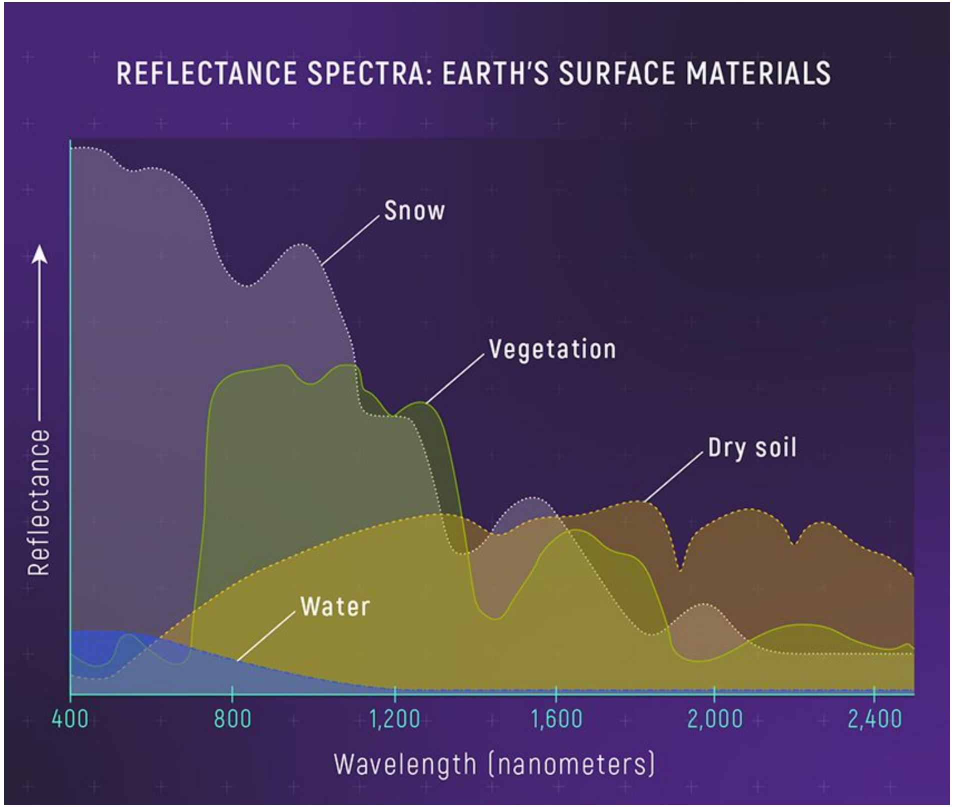
Reflectance

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

Reflectance



Reflectance



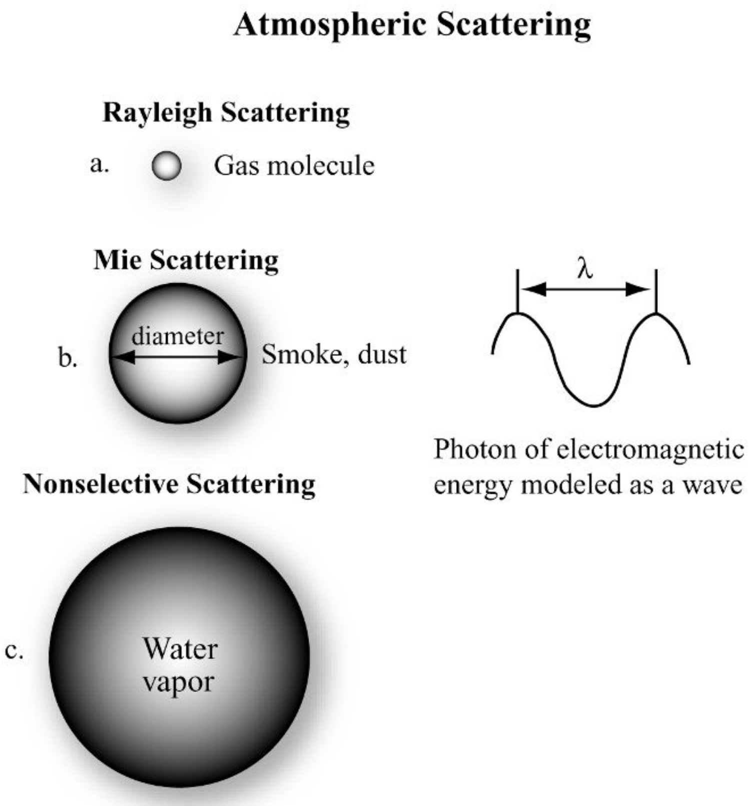
Scattering

- **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

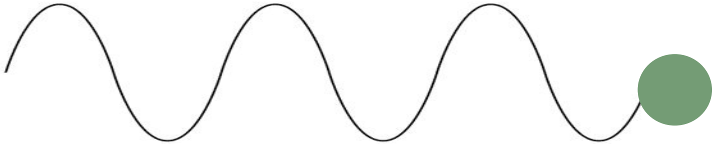
Three types of scattering:

- **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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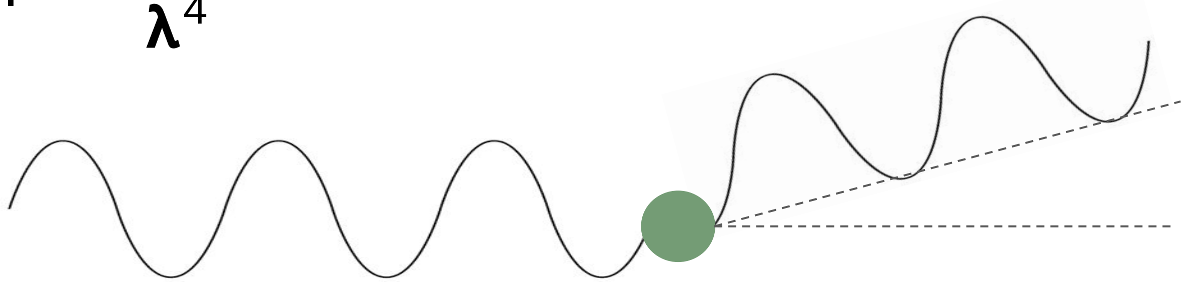

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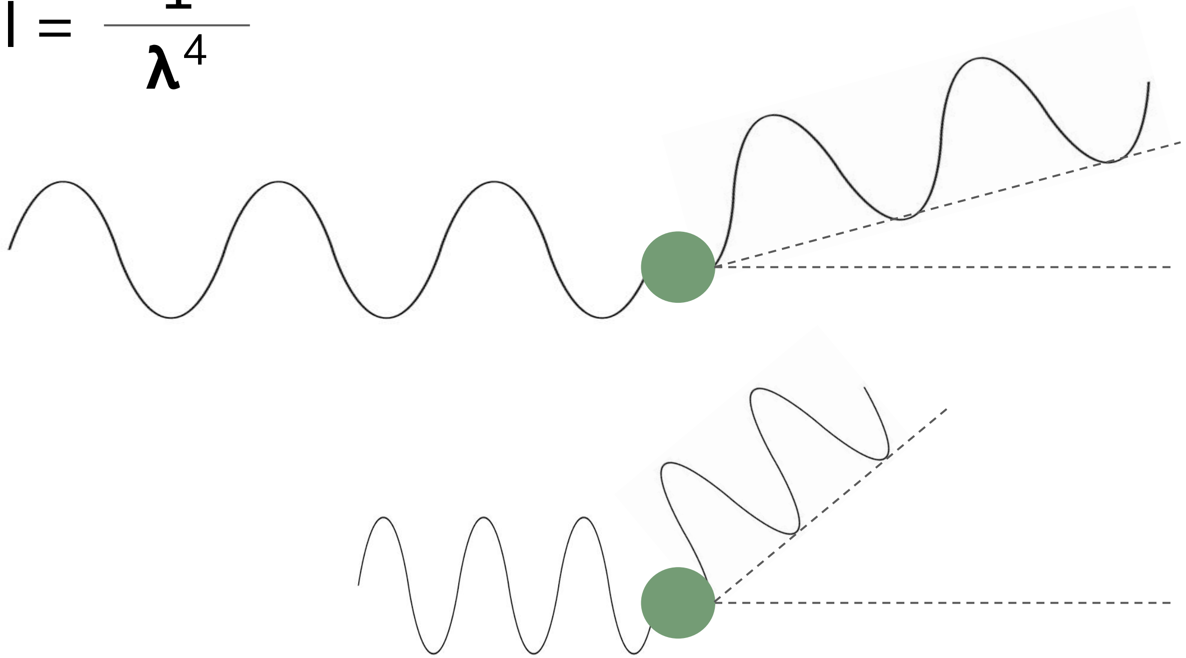

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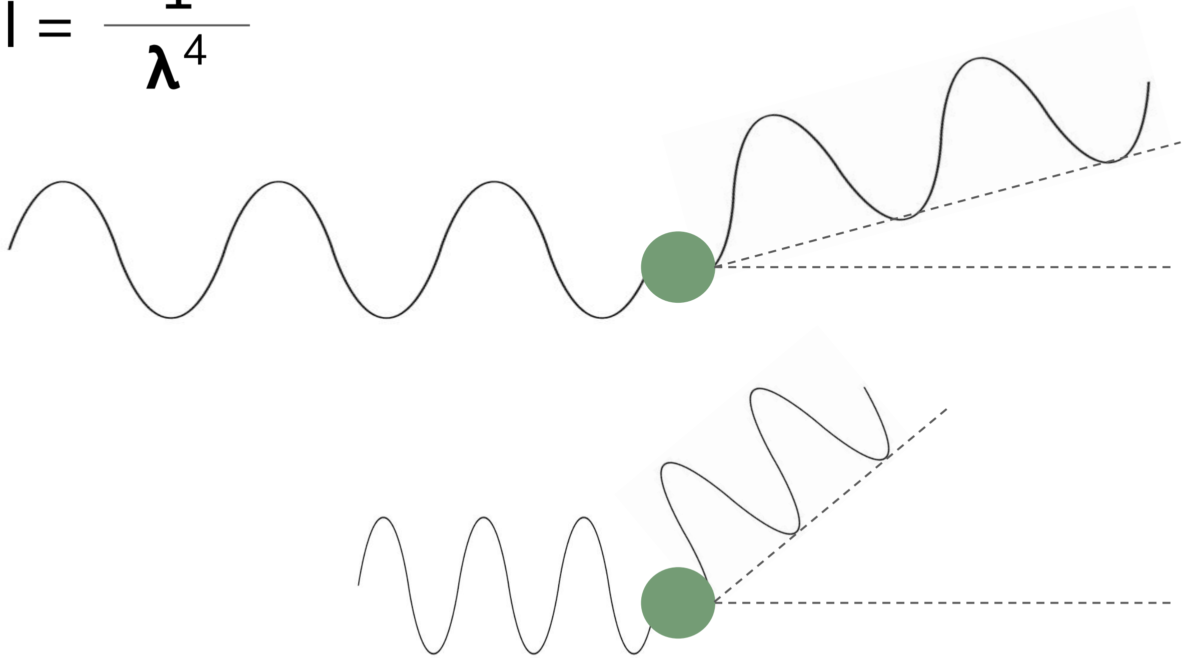
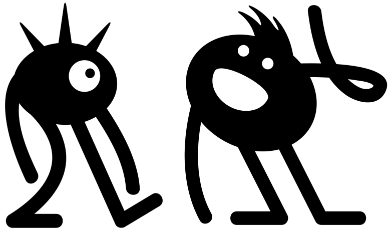


As wavelength increases, intensity of scattering decreases

Rayleigh scattering

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



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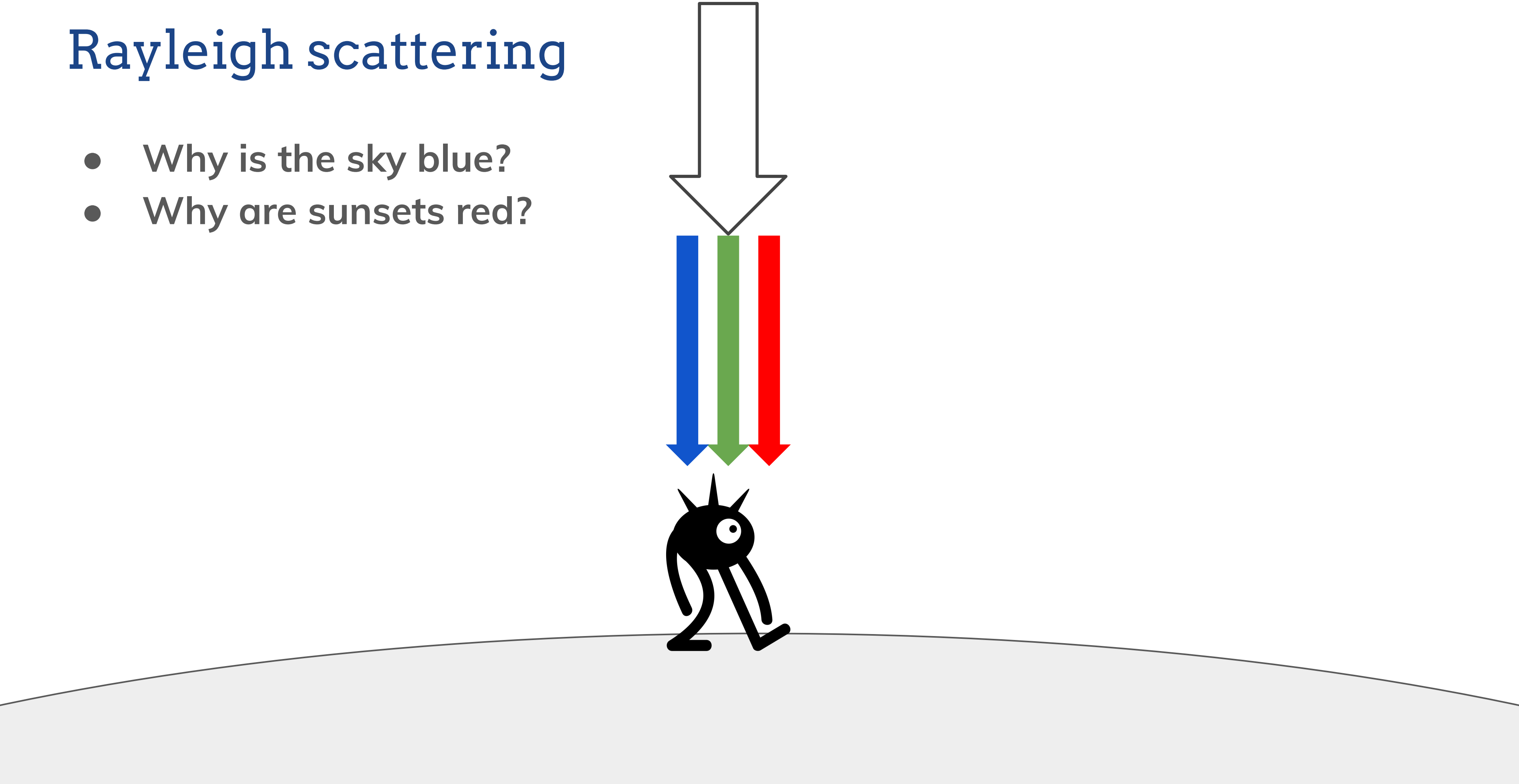

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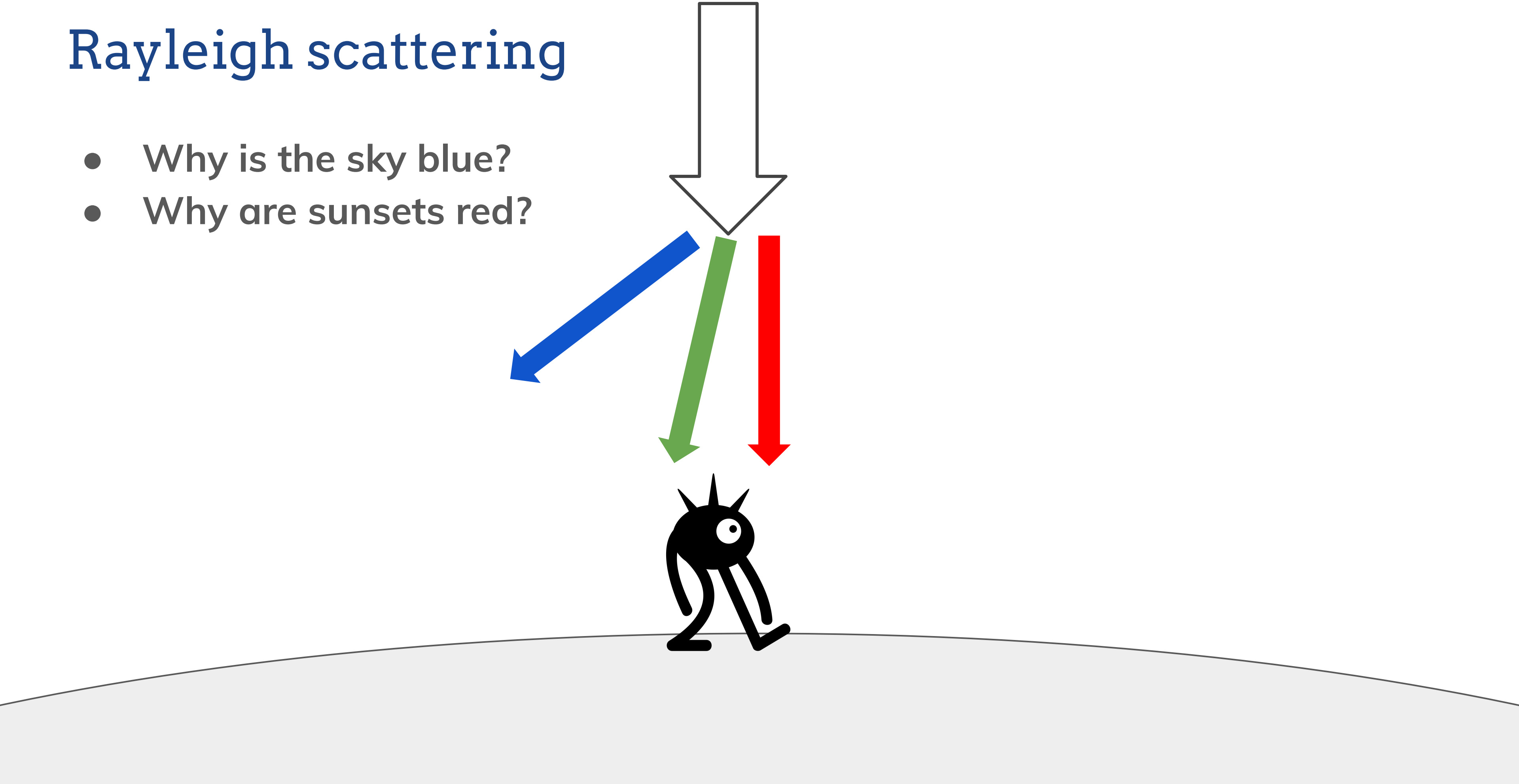

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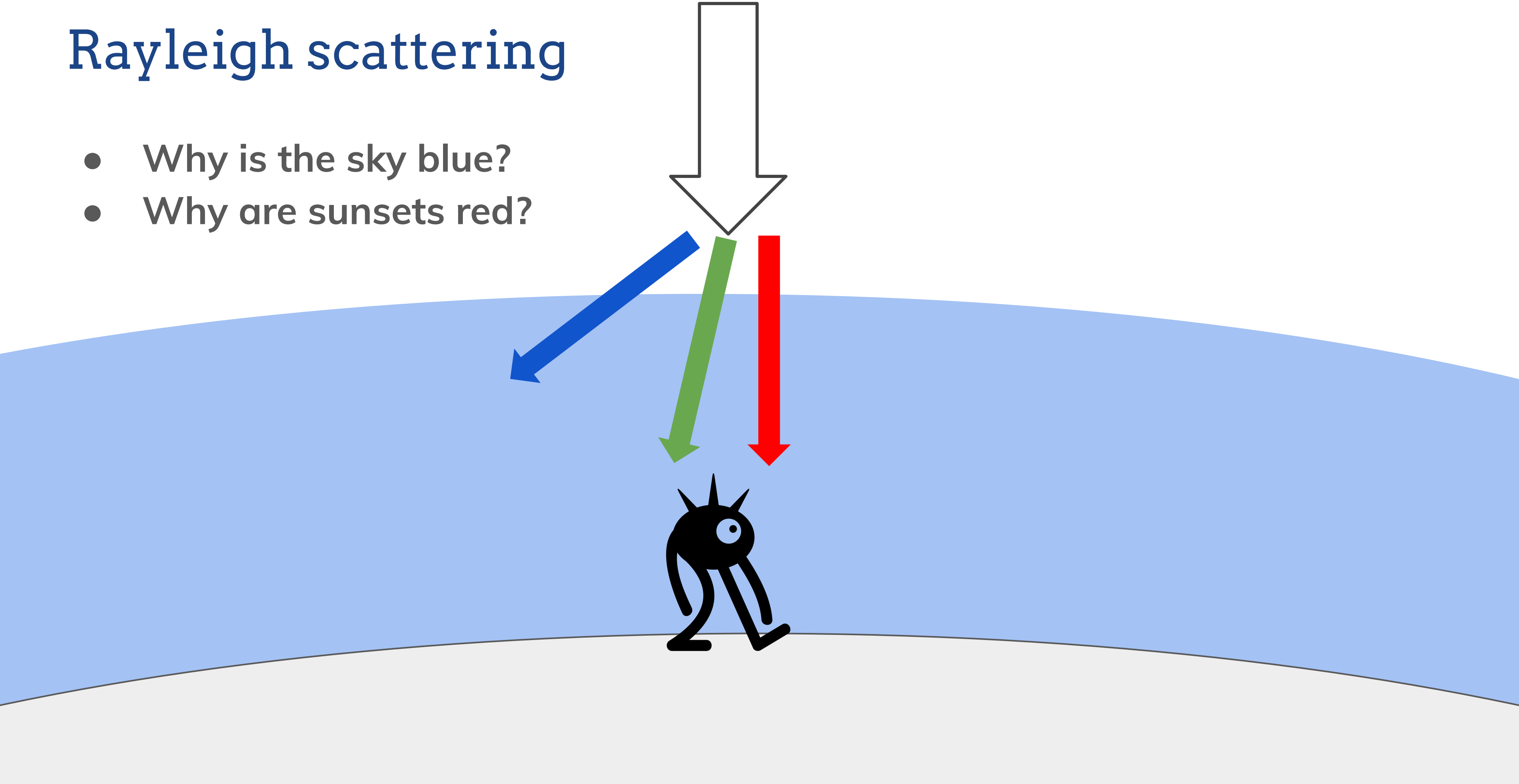

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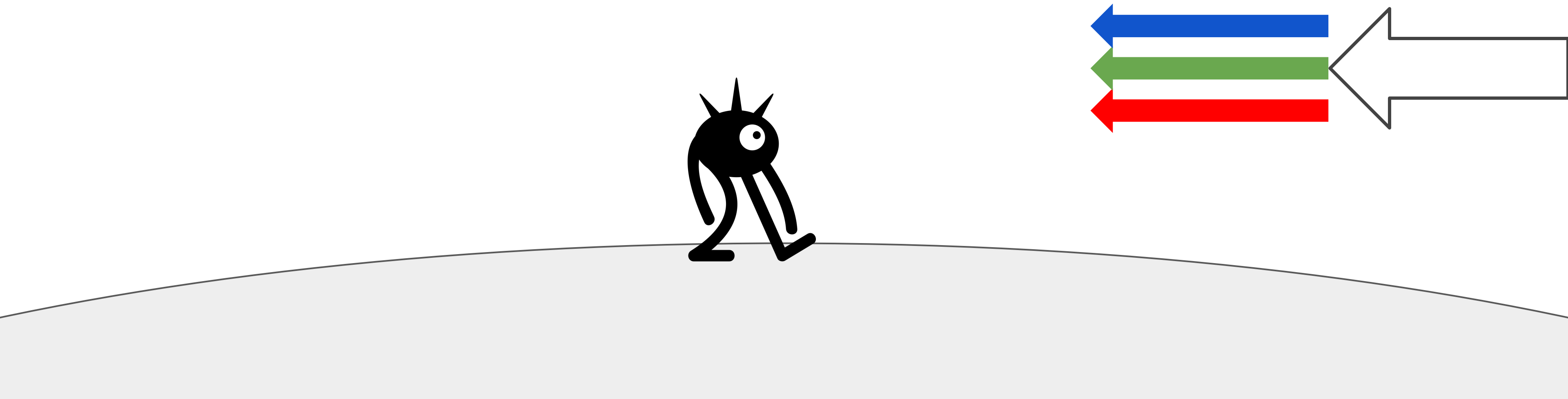

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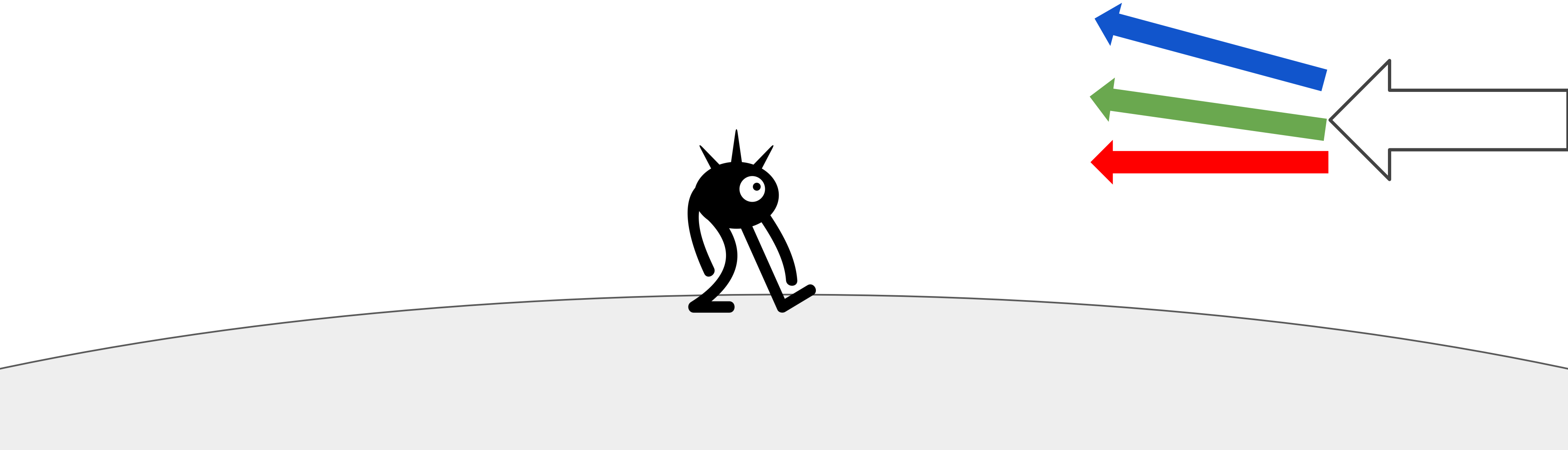

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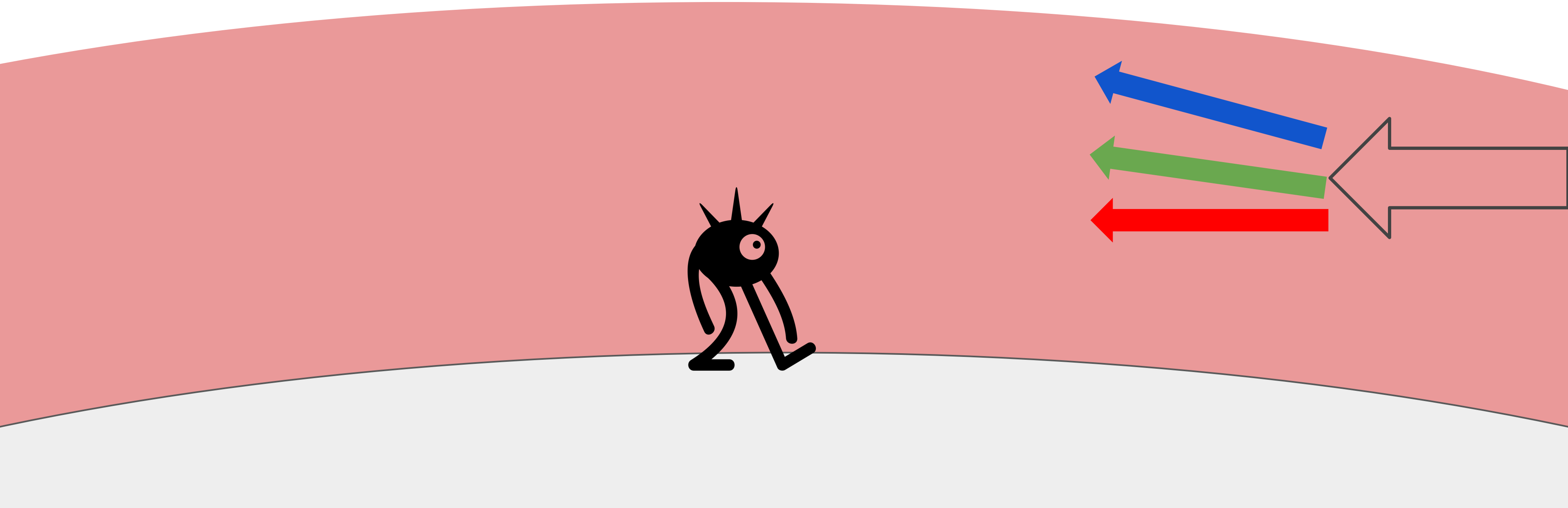


Mie and non-selective scattering

- **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.

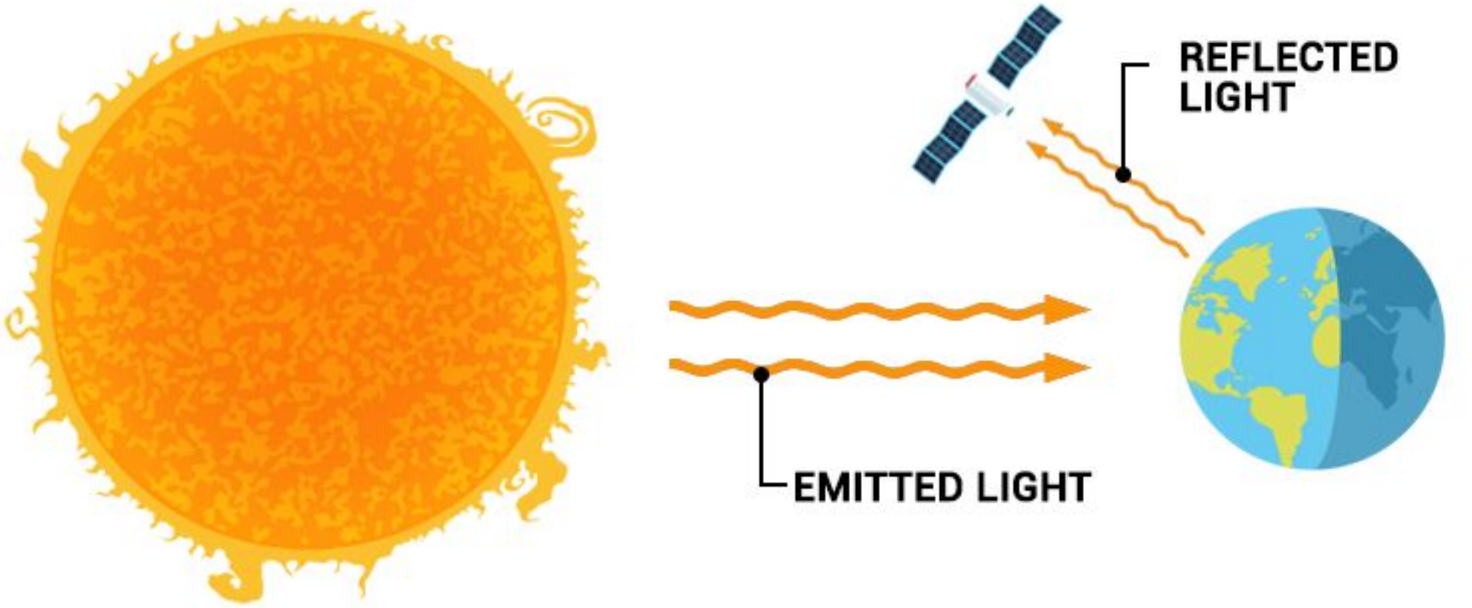
Reflectance: process whereby radiation "bounces off" an object.

Scattering: reflectance in an unpredictable manner.

Refraction: bending of light through mediums of different density.

Transmittance: process by which radiation passes through a material.

Create your own path diagram



Source: GIS Geography

Half way done!