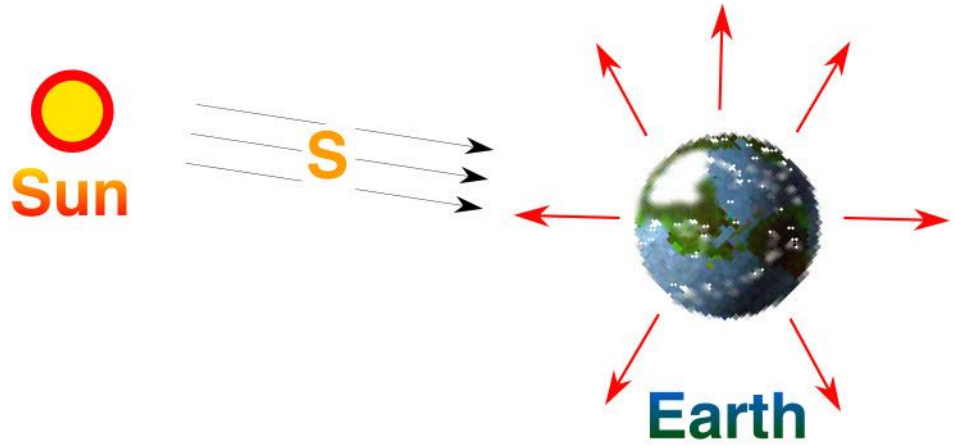
Energy and Radiation

Module 2

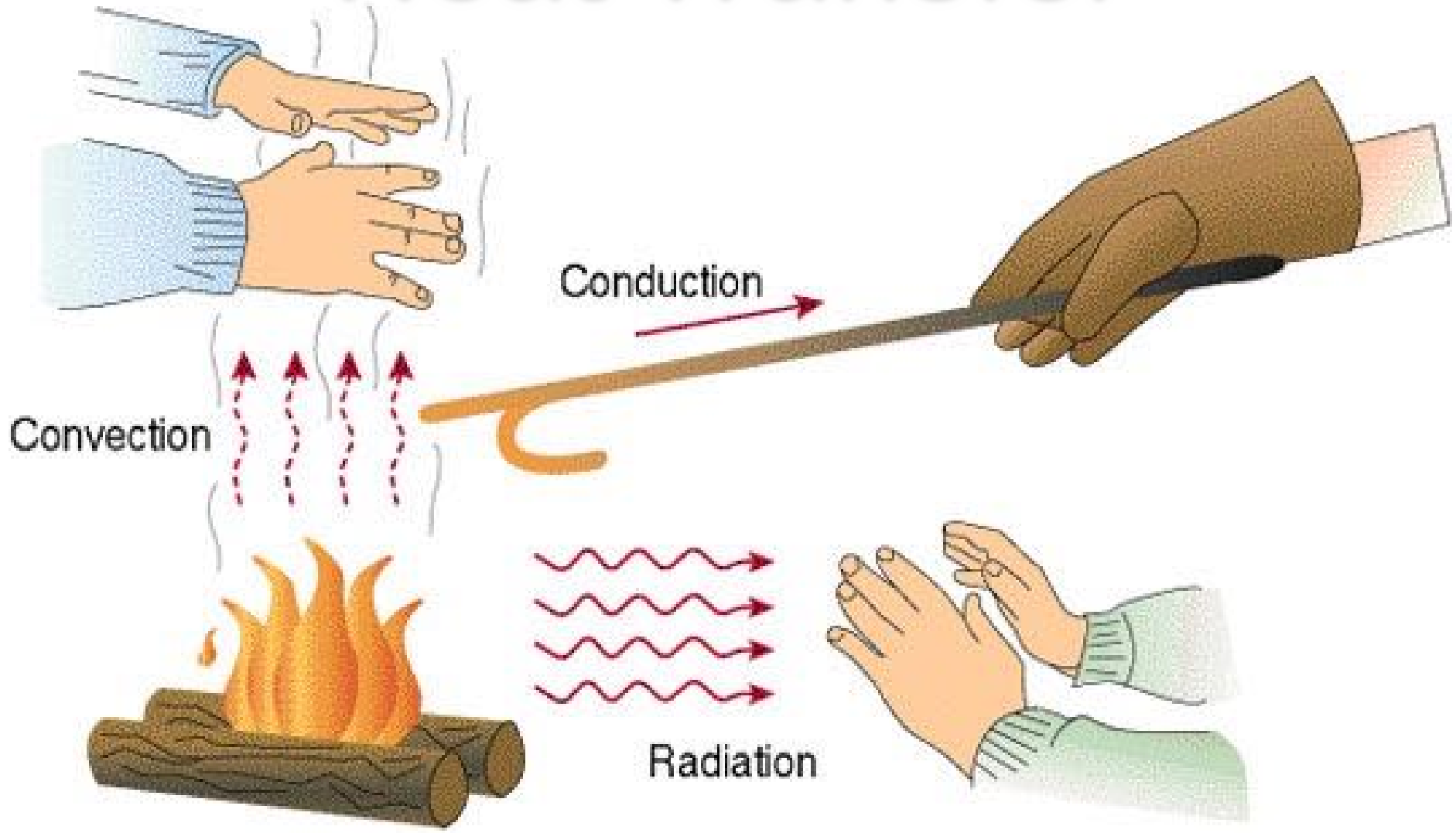
Heating and Cooling the Earth

Heating and Cooling Earth's Climate



- All the heat comes from the Sun
- It all has to get back out!
- How?

Heat Transfer



Conduction is by hot molecules colliding with neighbors
Convection is by hot stuff moving in bulk from place to place

Electromagnetic Radiation

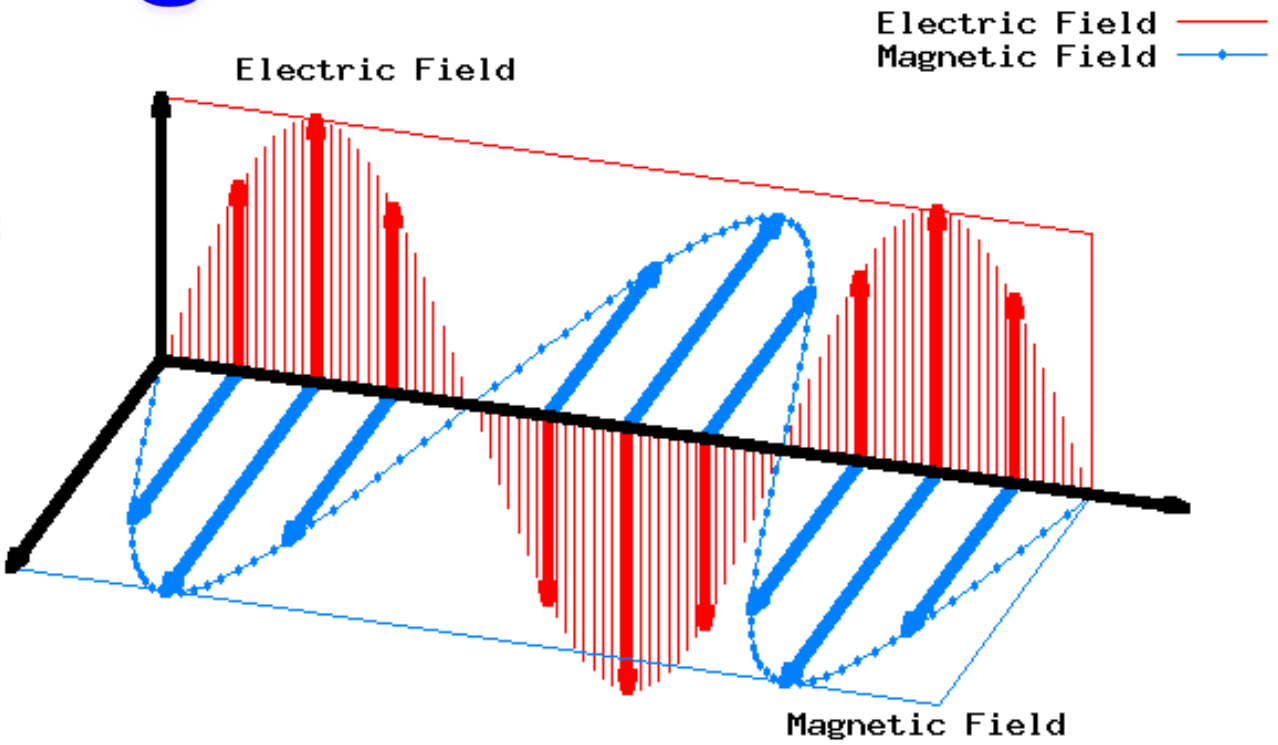
Changing electric fields create changing magnetic fields …

and vice versa!

This makes energy move even through empty space

We can see it, feel it

Plants harvest it directly, and we harvest them!

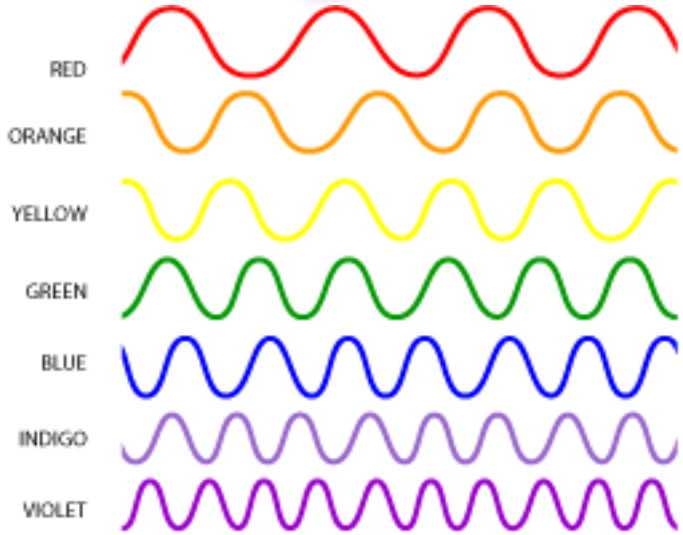


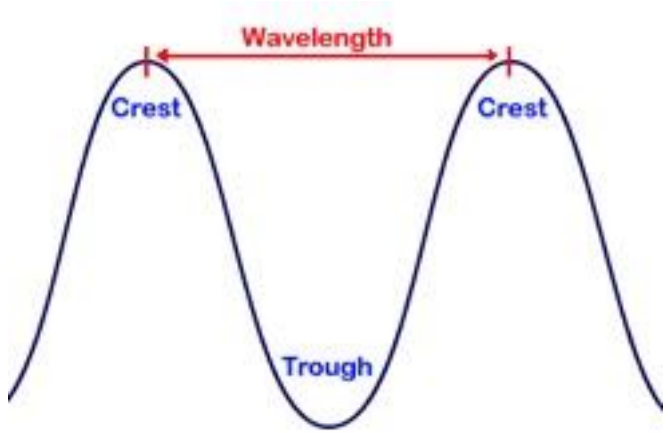
Travels at 186,000 miles / sec !

Distance it goes in one cycle is called the wavelength

Electromagnetic Radiation

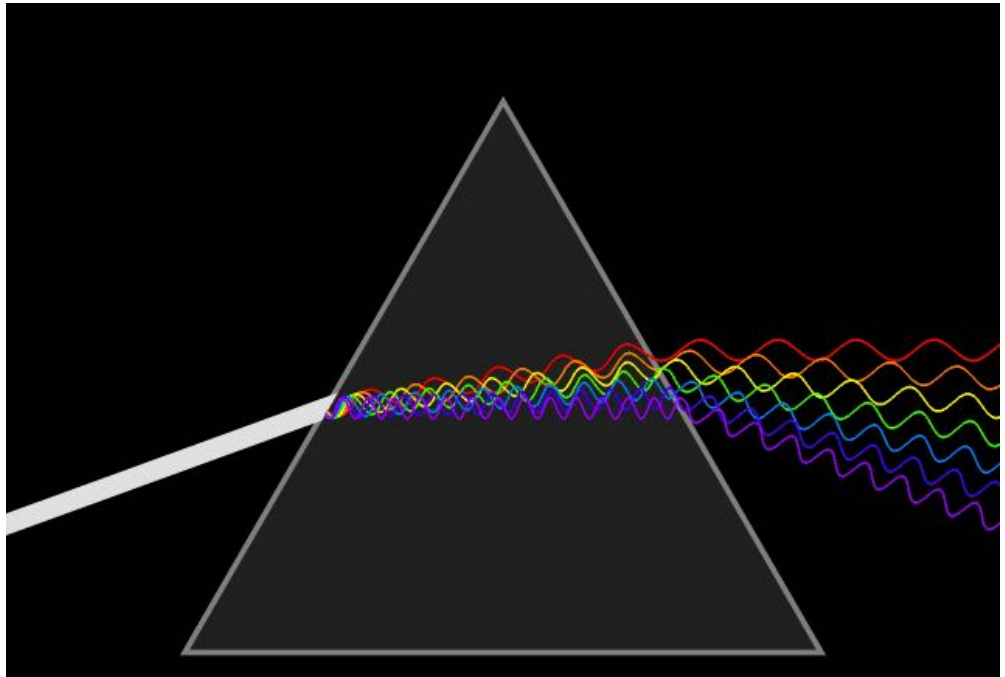
Radiation travels as waves or photons





Waves do not require molecules to propagate

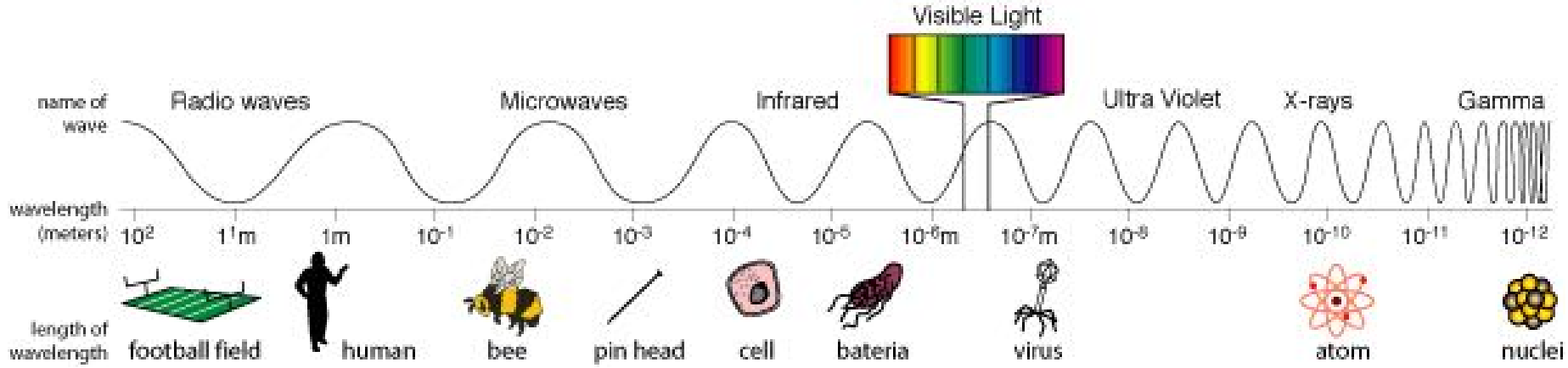
Shorter waves carry more energy than longer ones



Remember

- All incoming heat comes from the Sun, & must get back out to space or we'd burn up
- Only radiation can carry heat to and from the Earth
- Radiant energy is carried by waves oscillating electric and magnetic fields
- Short waves are bluer & carry more energy; long waves are redder & carry less energy
- The hot Sun emits mostly short visible waves; the cooler Earth emits longer thermal waves (infrared)

Electromagnetic Radiation Spectrum



Shorter waves carry more energy than longer waves

Electromagnetic waves interact with matter at similar scales (sizes) as the waves

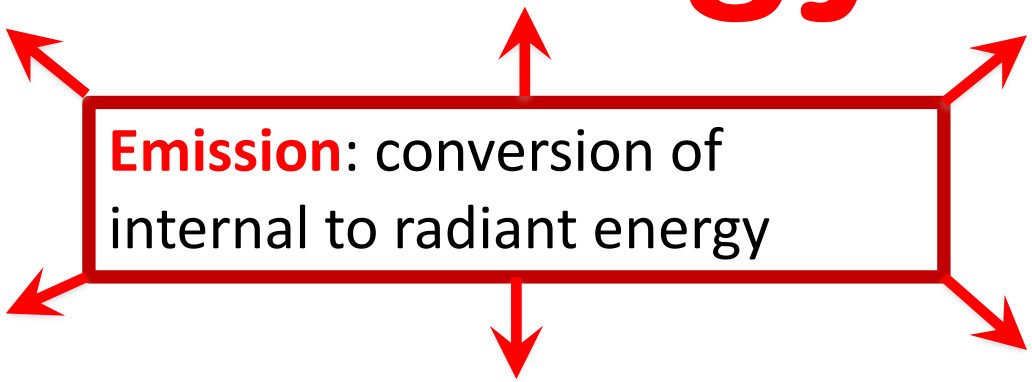
Thermal Radiation

"Everything emits thermal radiation"

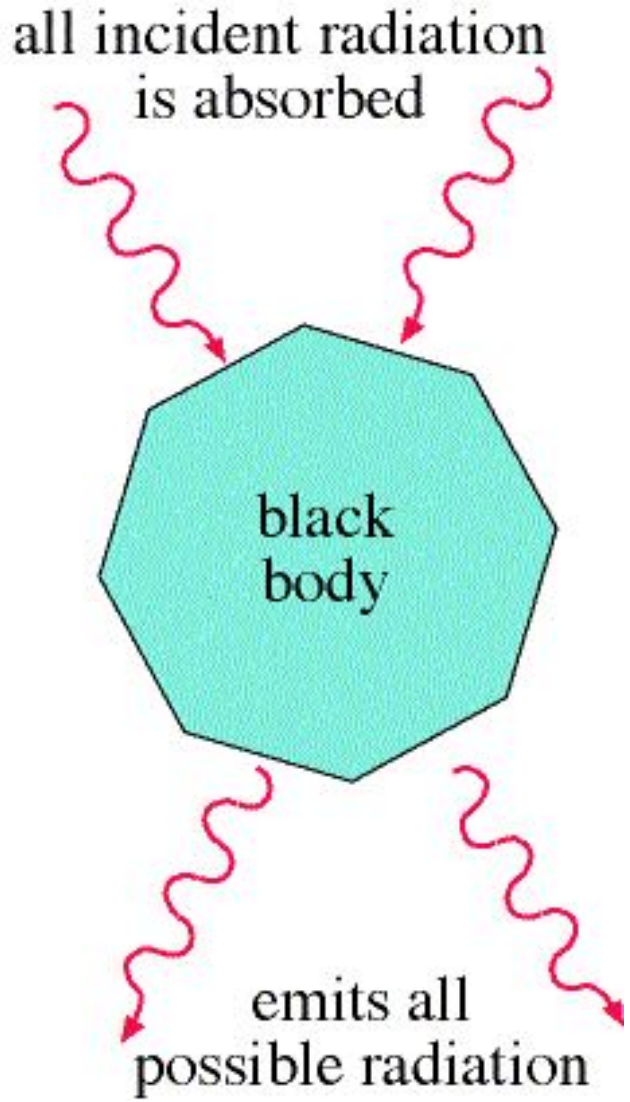
Conservation of Energy

Radiant (EM) energy is

- **Emitted**
- **Absorbed**
- **Reflected**
- **Transmitted**



“Black Body”

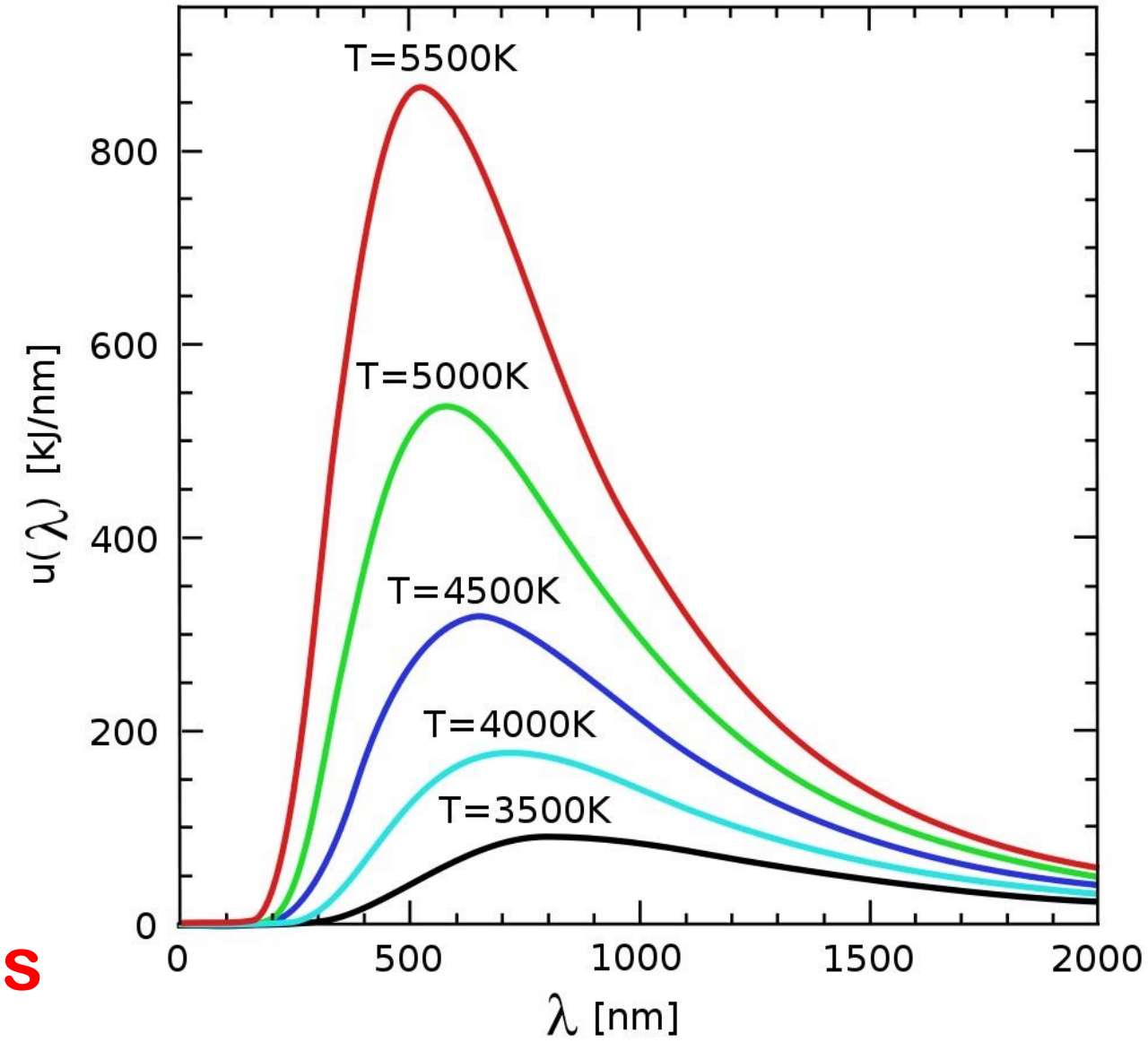


Just an idea, really …

- **Idealized object that absorbs all radiation that falls on it**
- **No transmission, no reflection, just absorption and emission**
- **Emits energy according to temperature**

Blackbody Emission

- Hot objects emit *much* more than cold objects at every wavelength
- Peak emission at shorter waves at higher temperatures



Units: Energy vs Power

- Energy is an intrinsic property of an object, measured in Joules

- Power is a rate of transfer of energy, or a flow of energy, measured in Joules per second

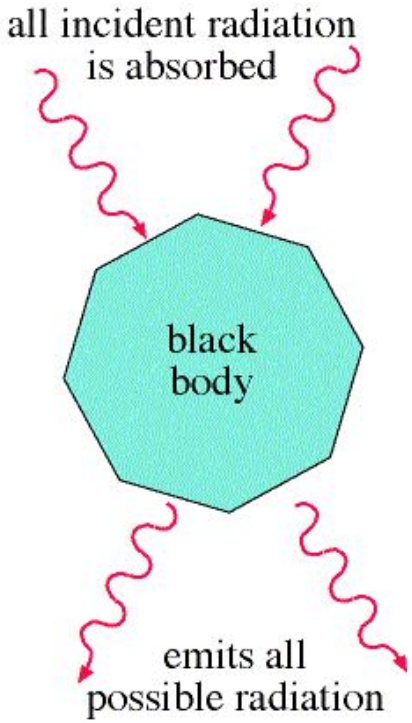
- We define:

  1 Joule per second = 1 Watt

Blackbody Power

$$F_{BB} = \sigma T^4$$

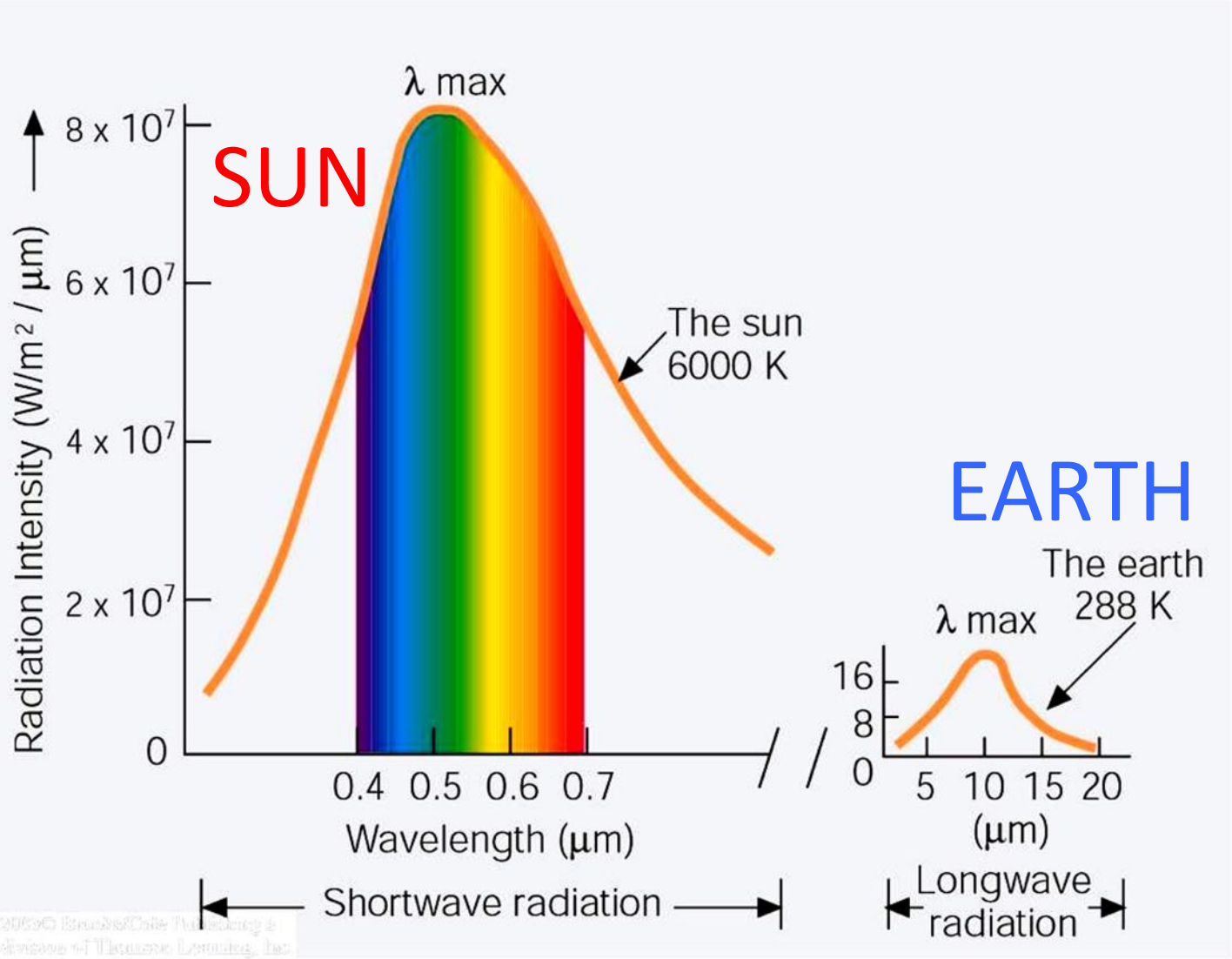
Stefan-Boltzmann Law



- Total **rate of energy emission** by a blackbody is proportional to its $T \times T \times T \times T = T^4$
- Proportionality constant σ is measured to be the same for all blackbodies

$\sigma = 5.67 \times 10^{-8}$ is the *Stefan-Boltzmann constant*

Thermal Emission



Both are almost perfect blackbodies!

The hot sun radiates at shorter (visible) wavelengths that carry more energy

Energy absorbed by the cooler earth is then re-radiated at longer (thermal infrared) wavelengths

Reflection

- **Albedo**: the fraction of incoming radiation that gets reflected

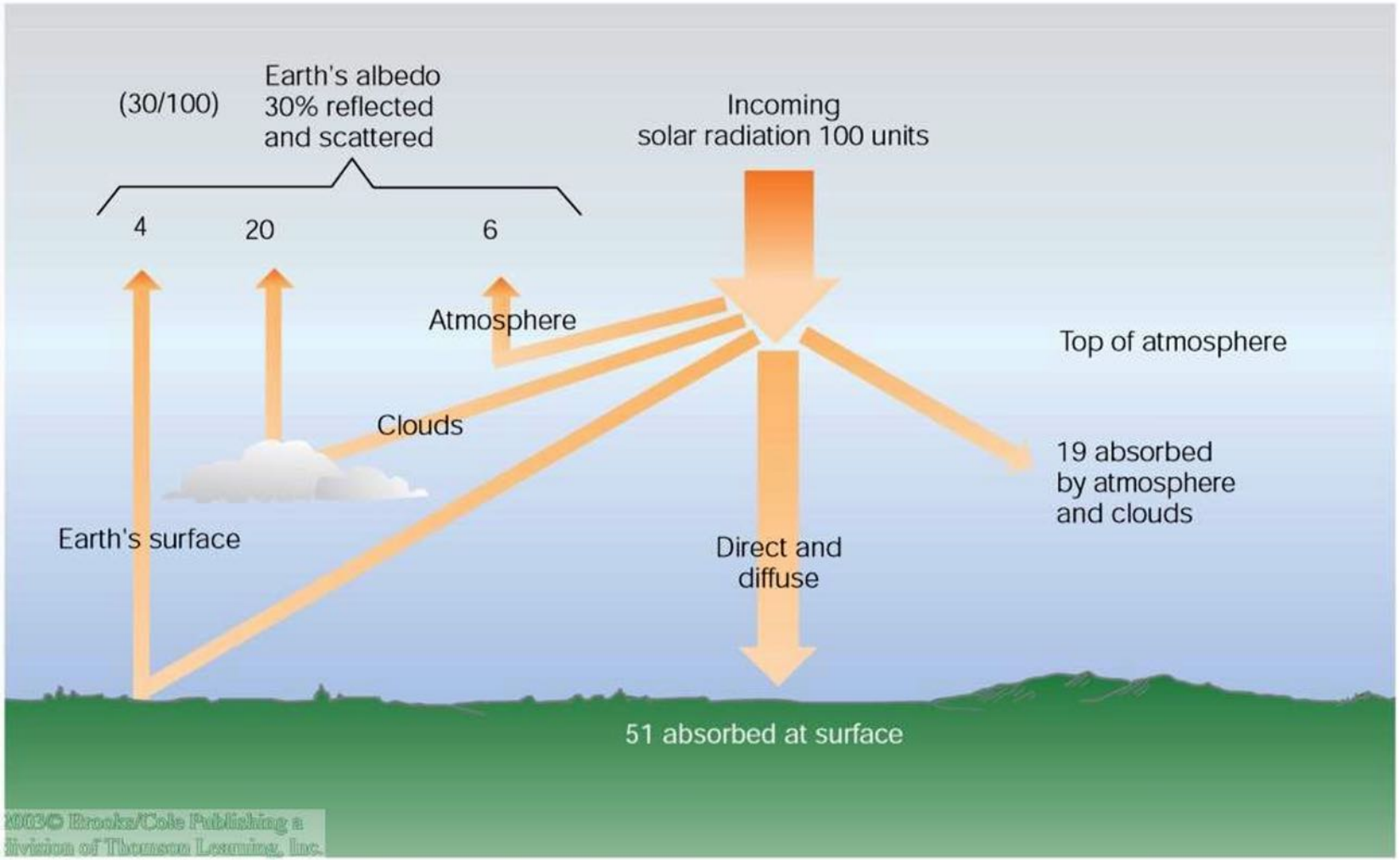
- Surface albedo varies according to the material
  - Spatially
  - Temporally

TABLE 2.3 Typical Albedo of Various Surfaces

SURFACE	ALBEDO (PERCENT)
Fresh snow	75 to 95
Clouds (thick)	60 to 90
Clouds (thin)	30 to 50
Venus	78
Ice	30 to 40
Sand	15 to 45
Earth and atmosphere	30
Mars	17
Grassy field	10 to 30
Dry, plowed field	5 to 20
Water	10*
Forest	3 to 10
Moon	7

*Daily average.

Solar Radiation



- 30% reflected by clouds, air, dust, and surface
- 19% absorbed by the atmosphere (mostly clouds)
- 51% absorbed at the surface

Remember

- Radiation can be emitted, absorbed, reflected, or transmitted
- Thermal radiation is just light that's redder than red (infrared) so we can't see it
- Solid objects are pretty much "blackbodies"
- Blackbodies **emit** thermal radiation at a rate proportional to the 4^{th} power of their temperature