Blackbody emission

HOMEWORK DUE TODAY

Put in alphabetical boxes at the back of the room

Reminder from last class

- Defined terms: wavelength and frequency
- Light was a type of radiation
- Different wavelength for different “colors”
- Defined flux and albedo,
  as important for incoming energy from the sun

Today: two important laws

- Wien’s displacement law
- Stefan-Boltzman law
- This explaines outgoing energy, and ***energy balance***

Which of the following is NOT true

a) Wavelength of light is related to temperature
b) Amount of energy emitted is related to temperature
c) Solar constant depends on the speed of light
d) Energy leaving Earth is always about equal to solar radiation coming in because of a negative feedback
e) If the distance from the earth to the Sun changes, so would the equilibrium temperature

Blackbody radiation

Consider the thought experiment…

Why do we see colors?
Light of a particular wave length is reflected into our eyes

What happens for a white object?
Light of ALL wavelengths are reflected into our eyes
(white is not a color, as such)

What is happening when we see black?
NO light of any wavelength is reflected!

So ***black bodies perfectly absorb*** all radiation.
That is, radiation with a spectrum of wave lengths

If they absorb all the radiation, they must also emit it all (i.e., a balance).

A backbody is an object with both perfectly absorbs and emits radiation

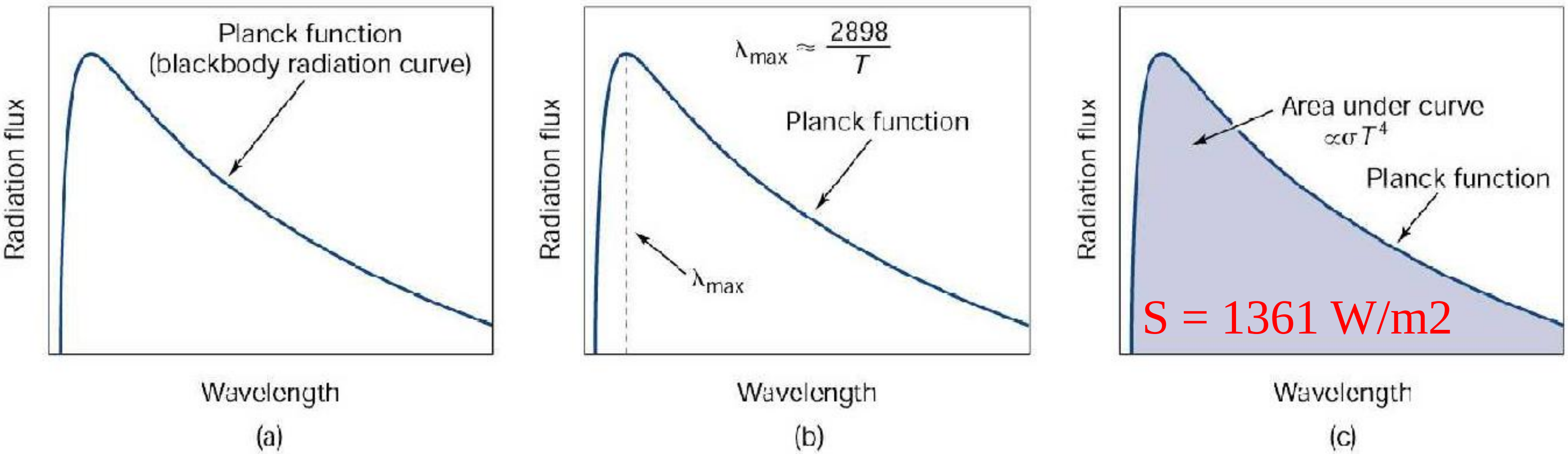
Black body spectrum

What color is black body emission?

Mixture of colors, i.e., a spectrum

As described by the "*Plank function*"

(Remember Plank from the last class? E = hυ)



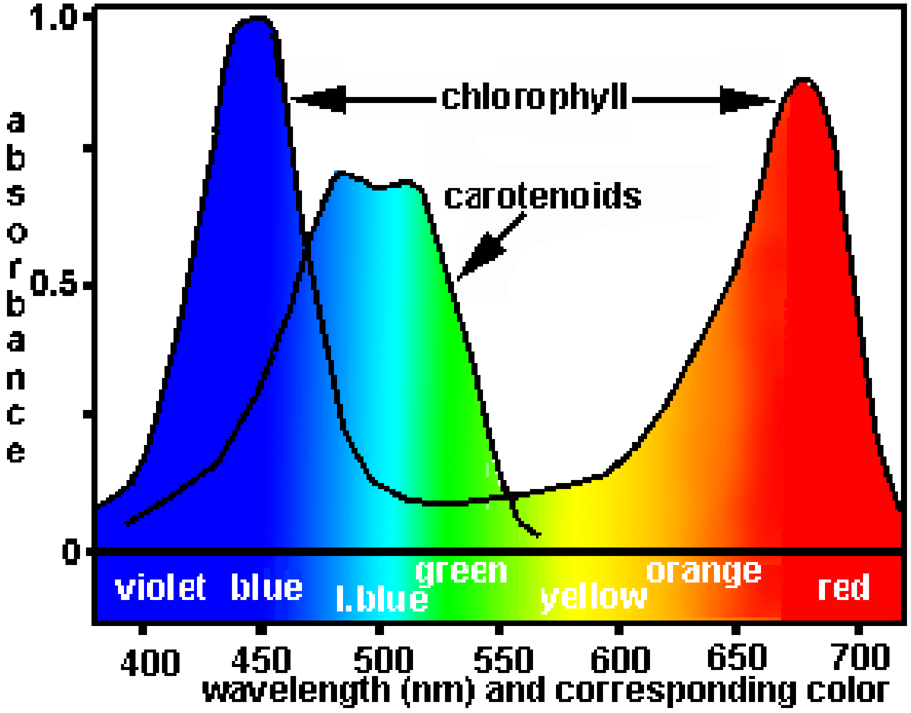
Total energy is the area under the curve

(i.e., add up radiation of all wave lengths)

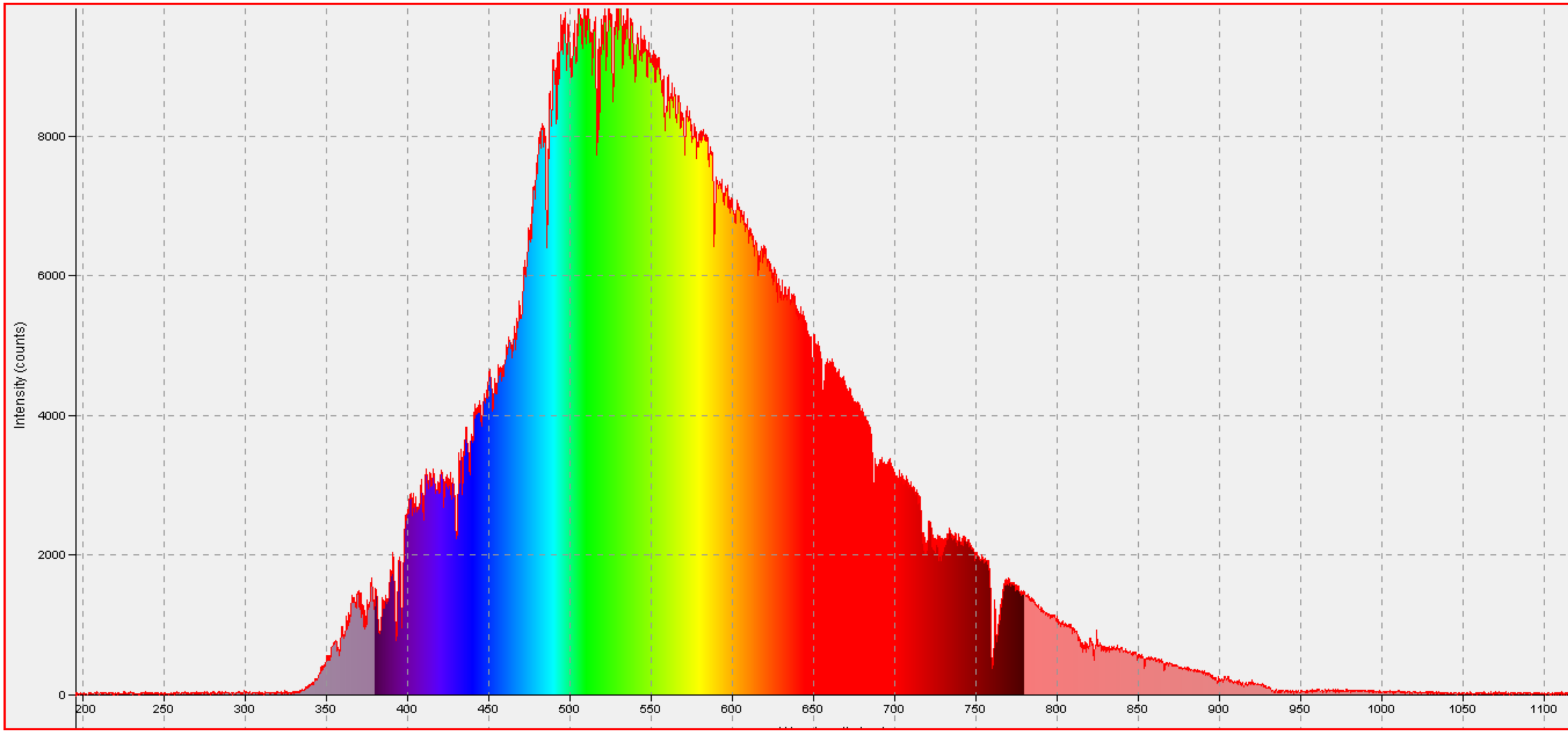
Monday's class, see this is related to temperature

How to see a spectrum?

Cucumbers are red!
(oops… lets try a leaf)

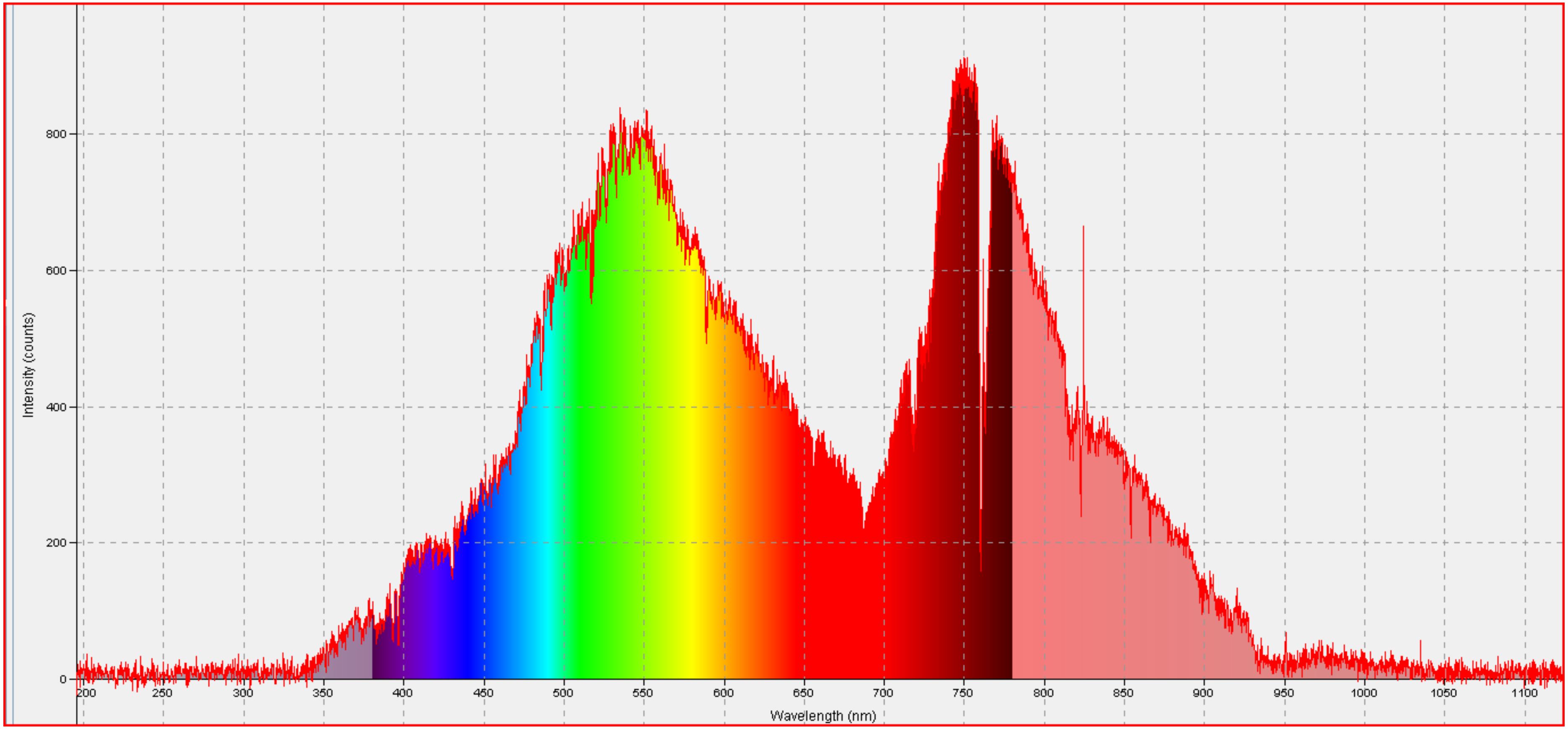


Sky from David’s office window



Scattered solar radiation from clouds.
Notice today’s sky is hazy white with cloud

Tree outside David's office window



Reflected solar from leaves

Notice leaves absorb a bunch of radiation, which makes them grow. Which wavelengths related to photosynthesis

Wien's displacement law

$$\lambda = \frac{2897}{T}$$

Higher temperature, smaller wave length (λ).

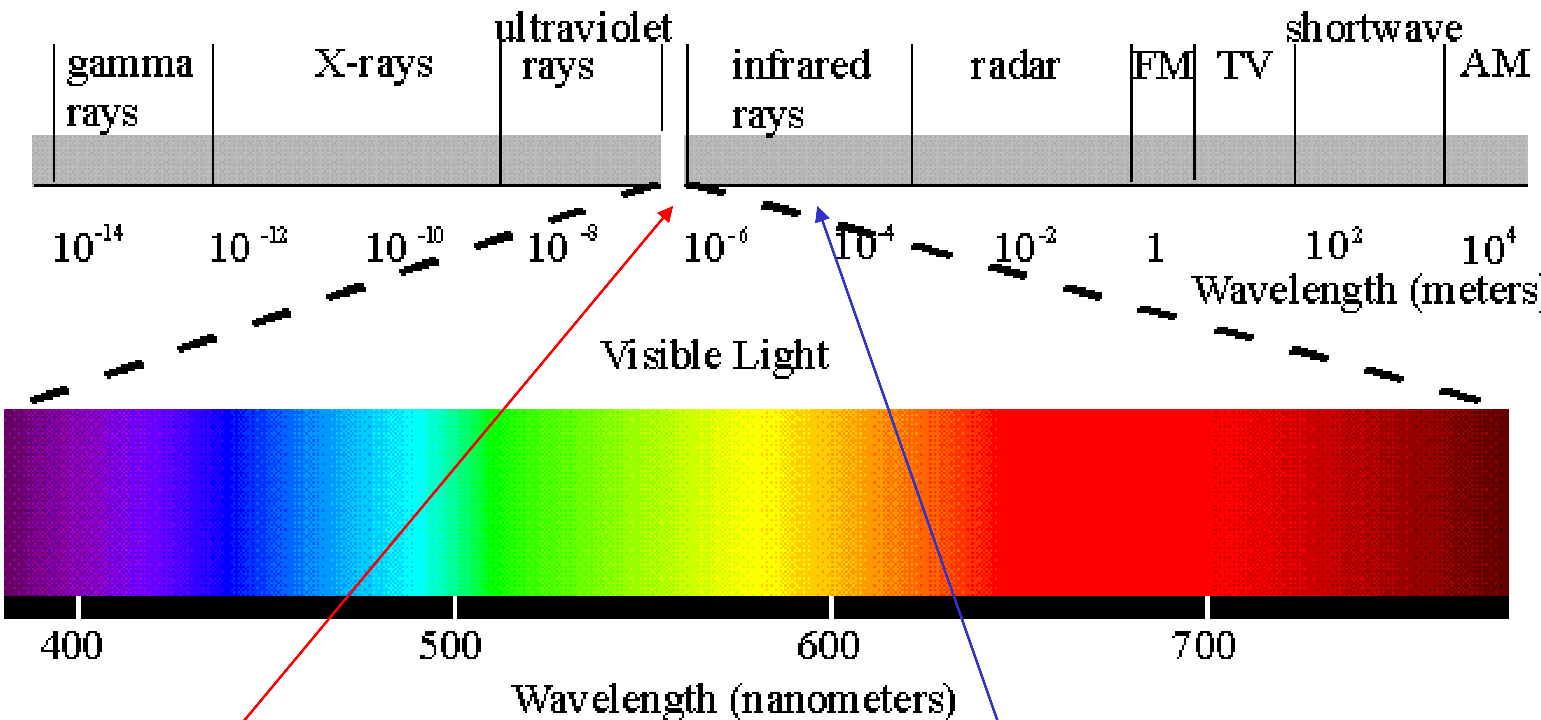
e.g. (1): Sun T~6000K, so λ = 2897/6000 = 0.48 μm (visible, short)

e.g. (2): Earth: T ~ 300K, so λ = 2897/300 = 9.7 μm (infrared, long)

1 million micrometers (μm) = 1 meter

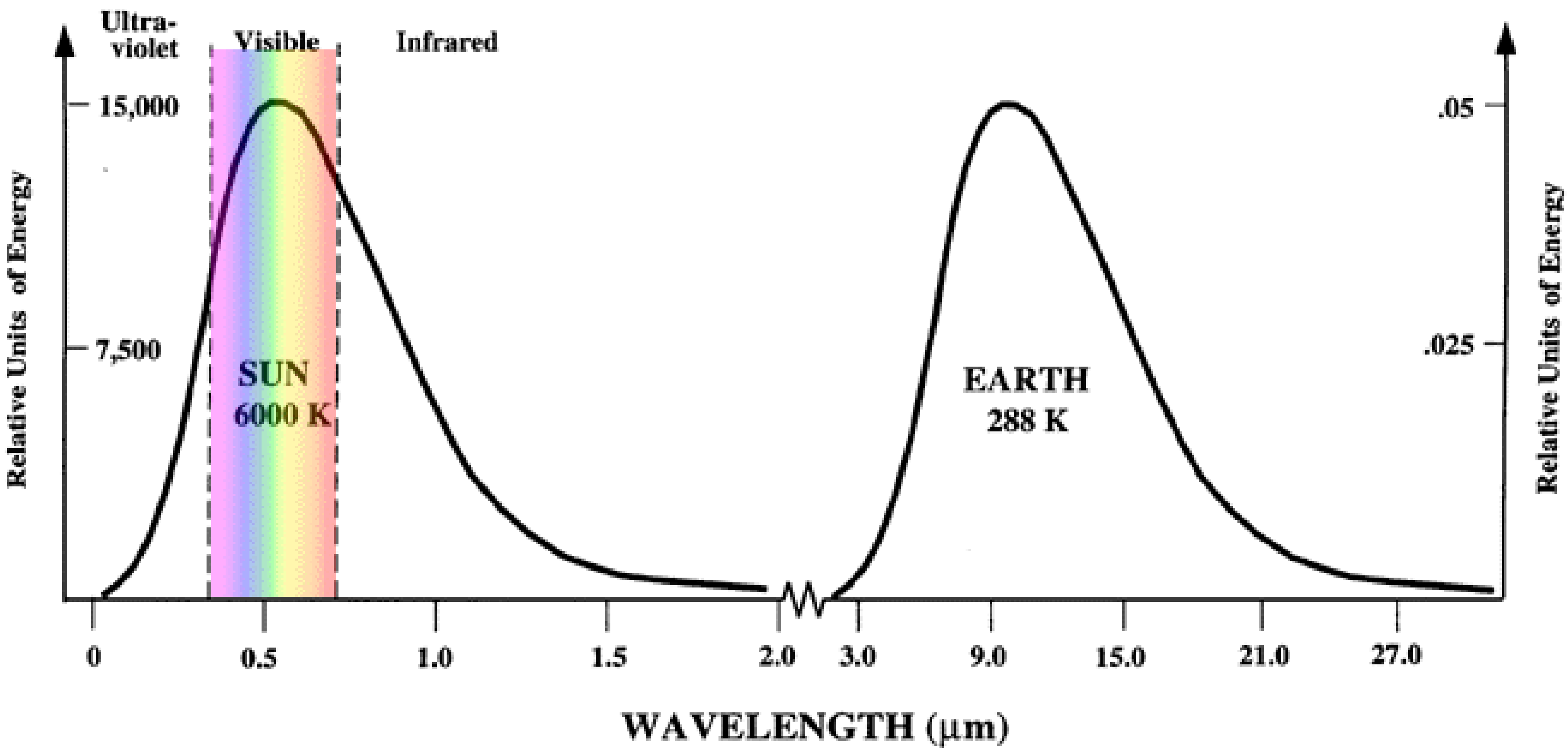
1 billion nanometers (nm) = 1 meter

Electromagnetic spectrum

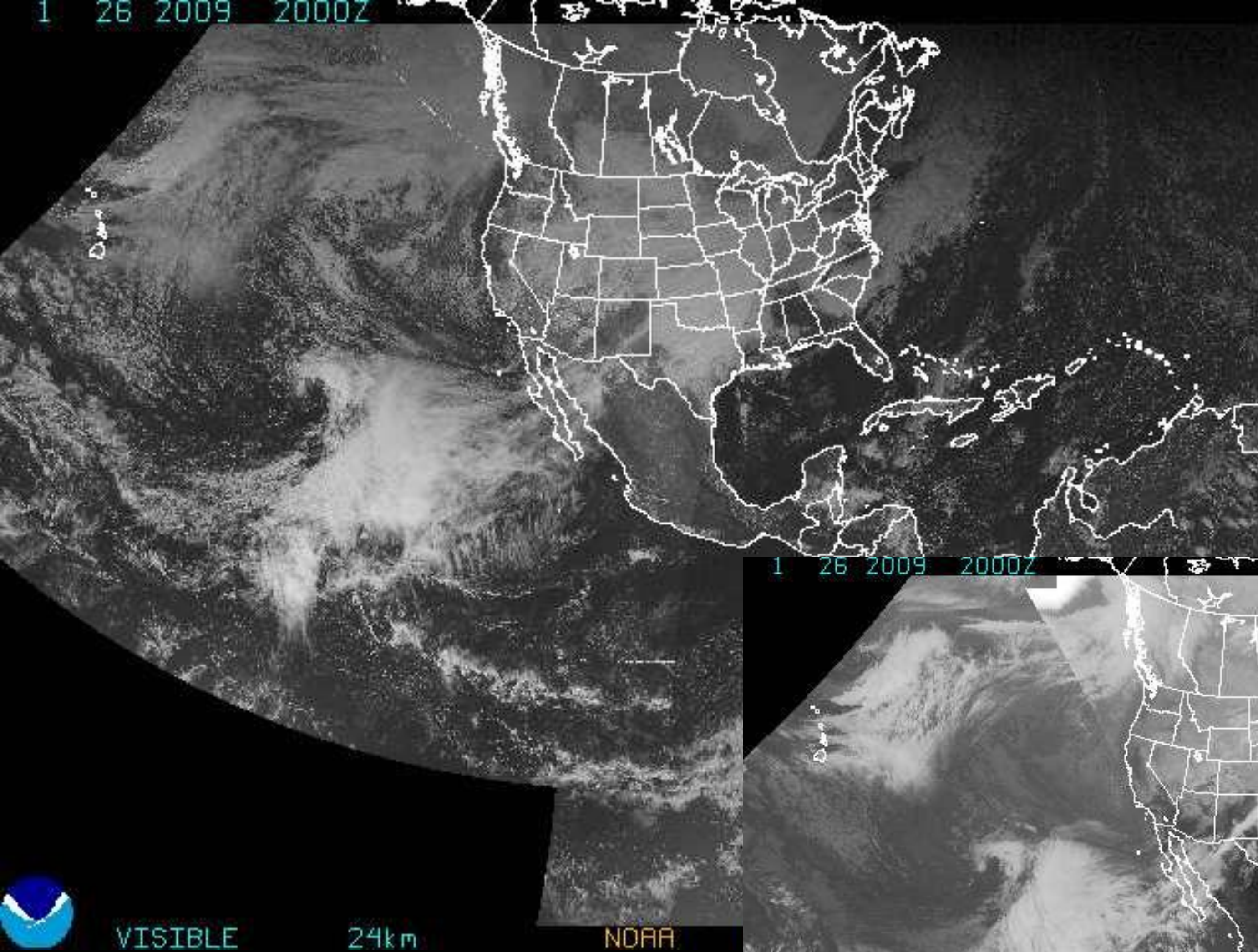


Sun emits visible light
about 480 nm
(shortwave radiation)

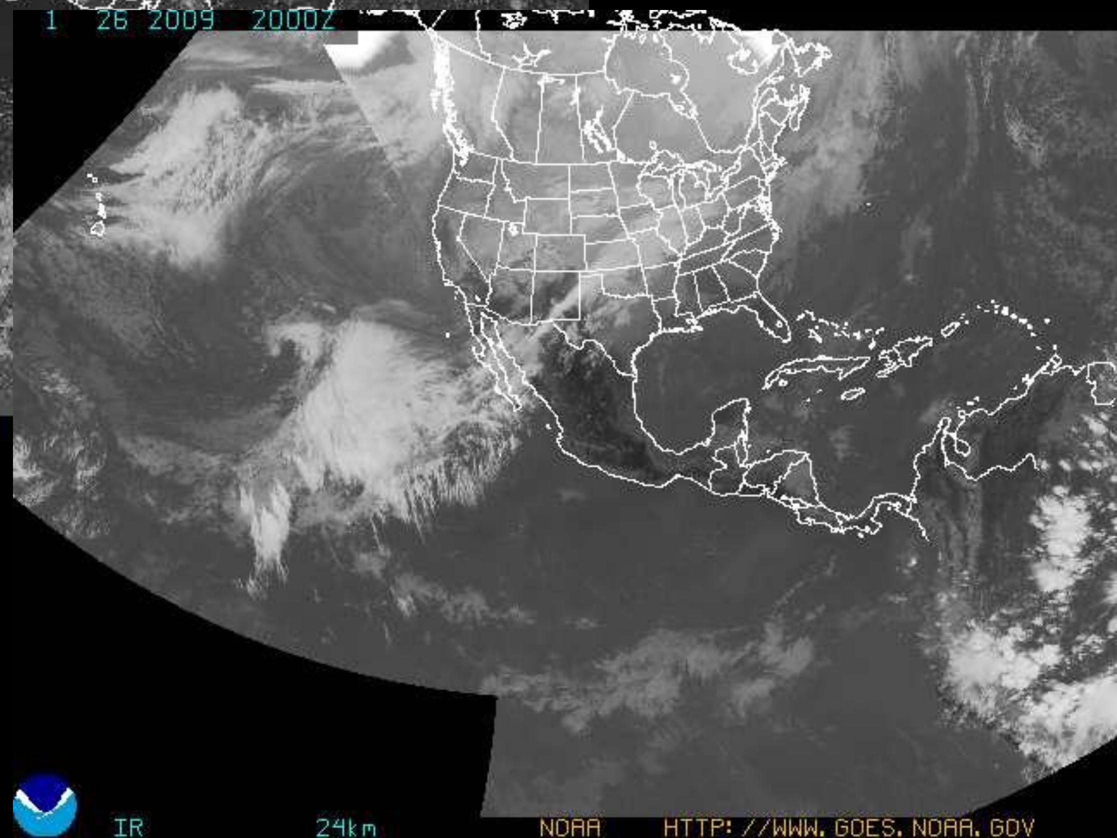
Earth emits infrared radiation
about 9700 nm
(longwave radiation)



Comparison of the emission spectra of the sun and the earth. Note the huge disparity in the amount of energy emitted by the sun (left-hand scale) and the earth (right-hand scale).



d sunlight)



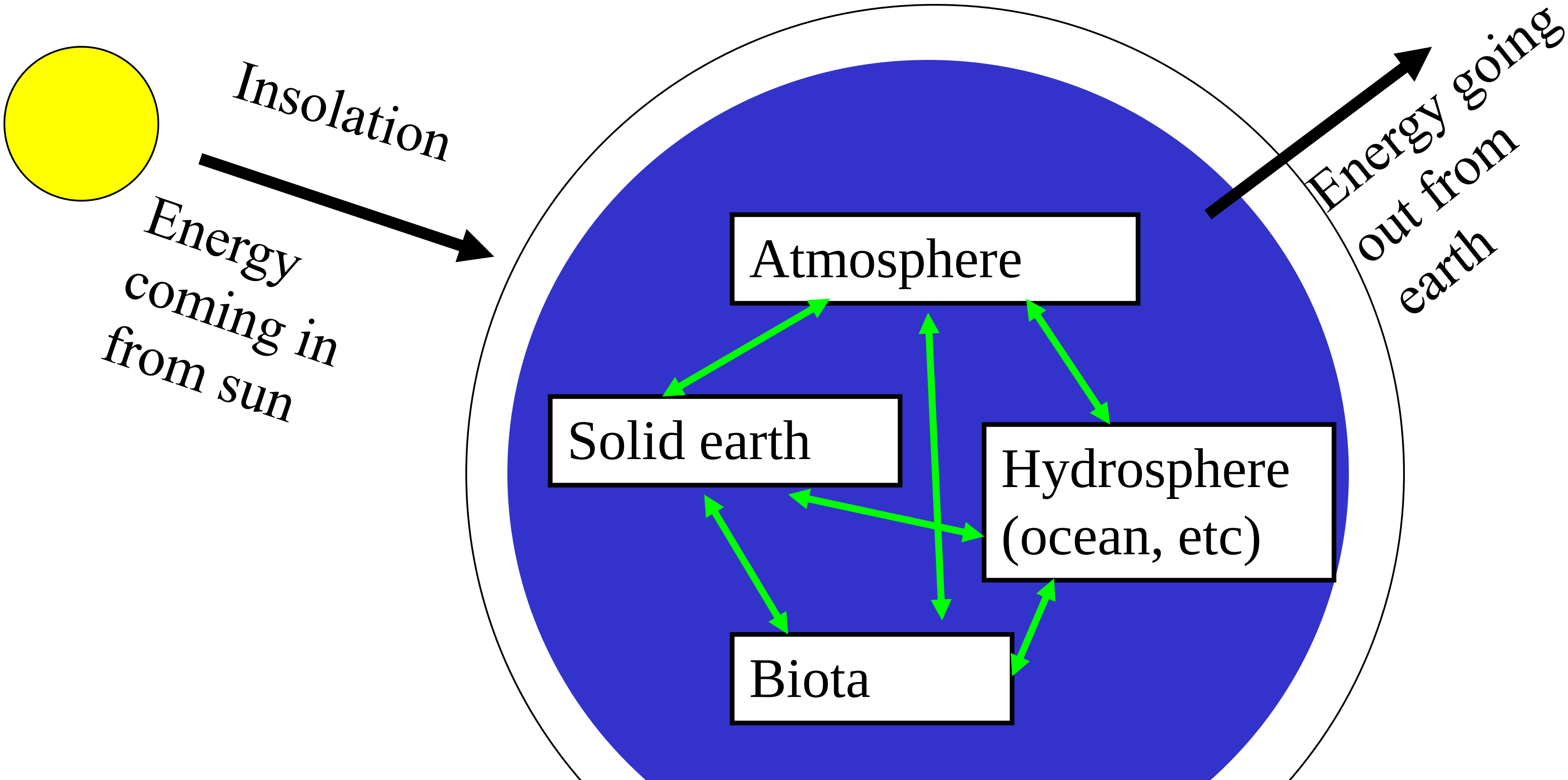
Infrared

(emitted by stuff)

Which of the following emit radiation into space

a) Antarctic ice sheet
b) People
c) Carbon dioxide
d) None of them
e) All of the all

On earth, who is doing the emitting?



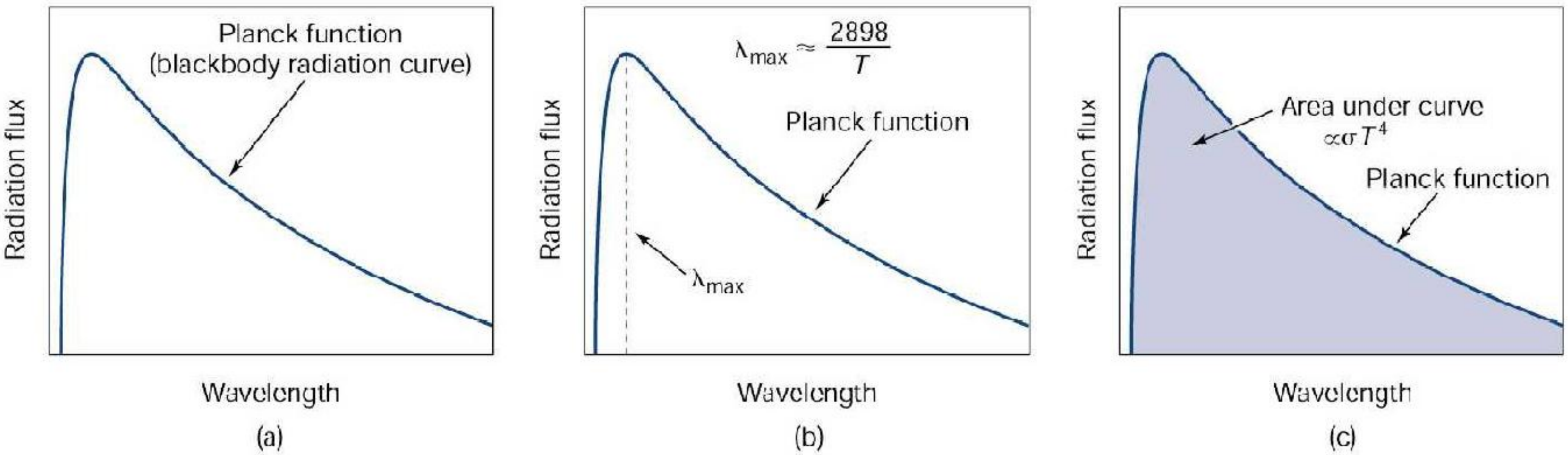
EVERYTHING!

Ground, ocean, gases, clouds, …

i.e., anything that has temperature

In particular, ***the ground***, ***water vapor***, ***clouds***, $\boldsymbol{CO_2}$

Black body emission



Add up radiation of all wave lengths

(Total energy is the area under the curve)

Stefan-Boltzmann Law

$$E = \sigma T^4$$

(σ = 5.67x10^{-8} W/m^2/K^4)

Stefan-Boltzmann Law

$$E = \sigma T^4$$

Blackbodies that are **hotter** emit **more** **radiation**

Example: Earth, T ~ 300 K

$E = 5.67\text{x}10^{-8}$ x 300^4 = **457 W/m²**

Example 2: Sun, T ~ 6000 K

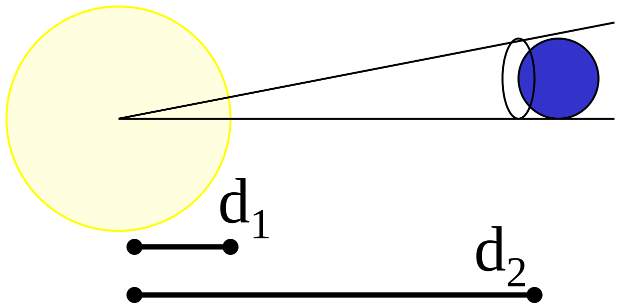
$E = 5.67\text{x}10^{-8}$ x 6000^4 = **73,483,200 W/m² !!!**

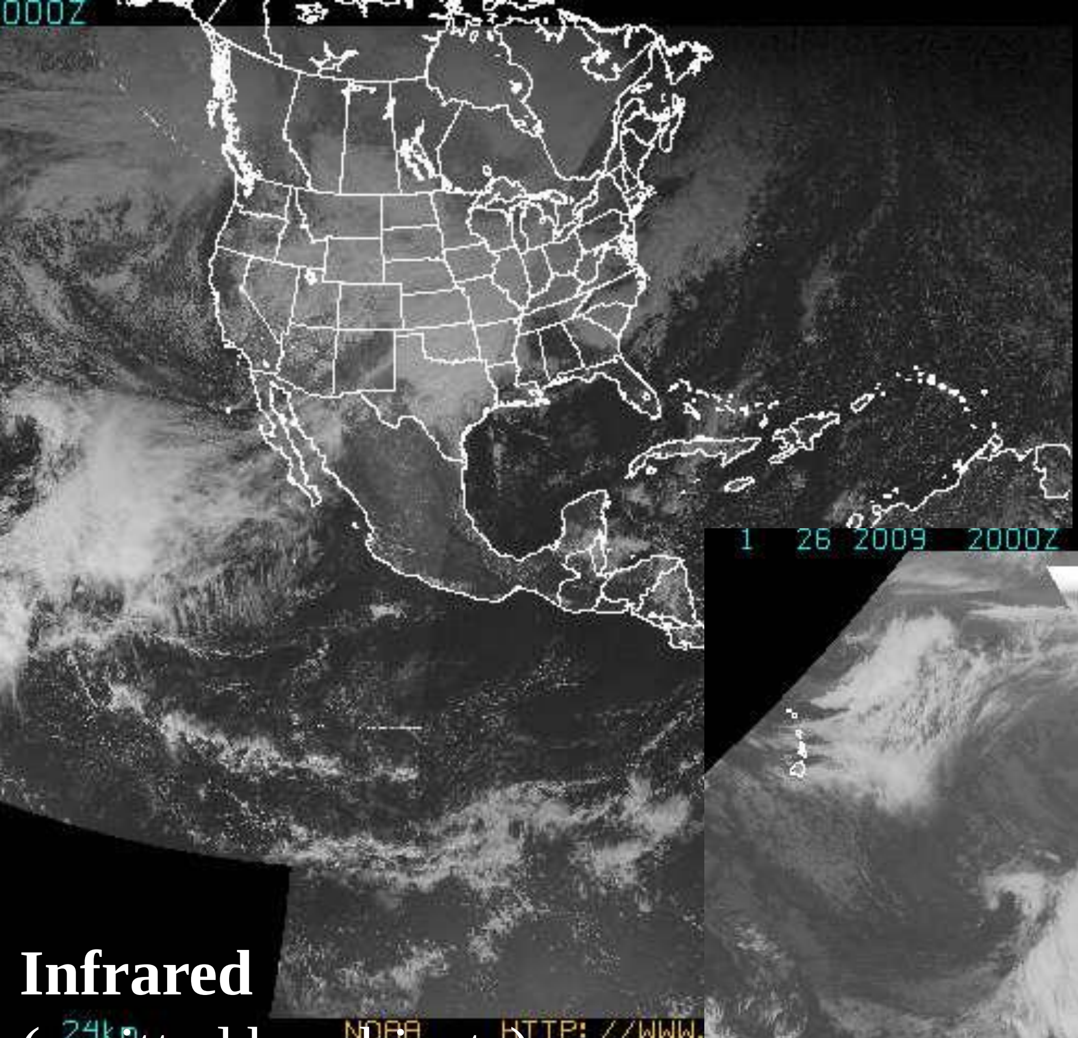
Why is this not the solar constant?

(S = 1361 W/m²)

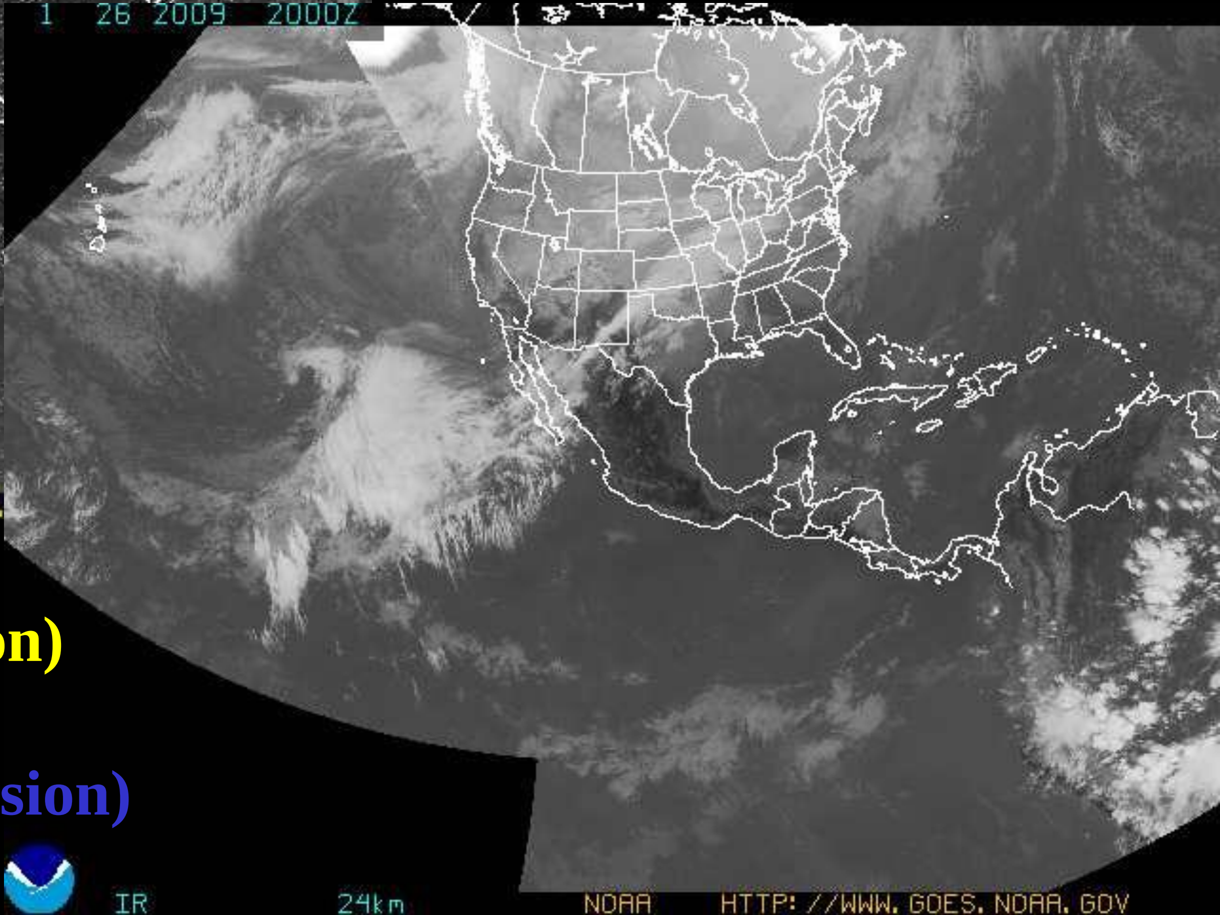
Inverse square law.

Distance between Sun's corona and Earth





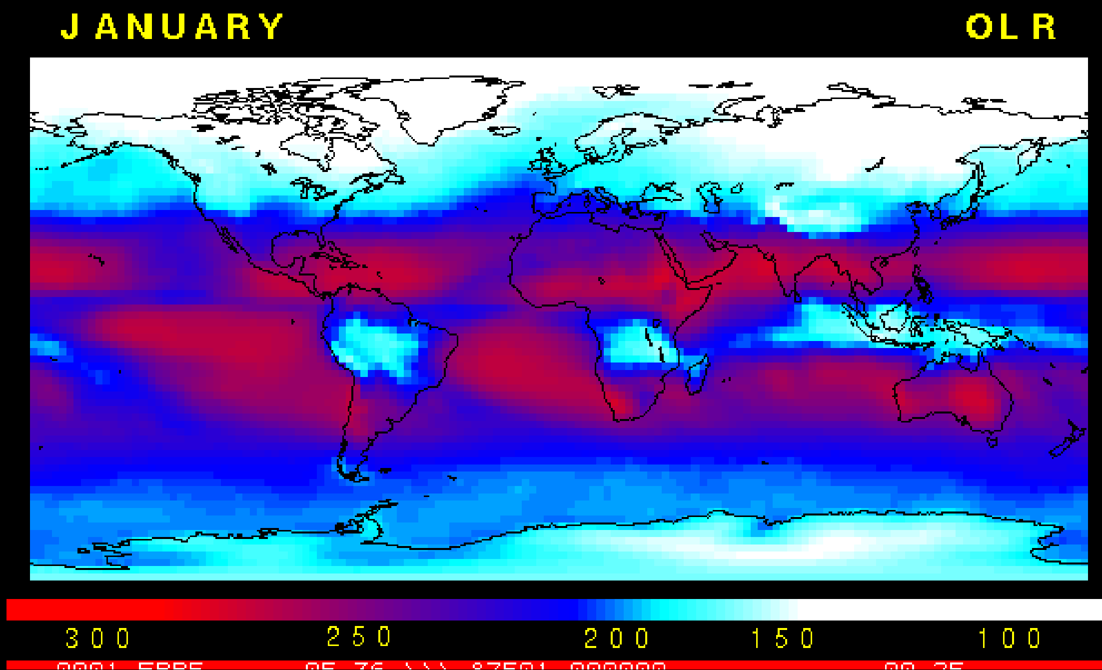
Visible
(reflected sunlight)



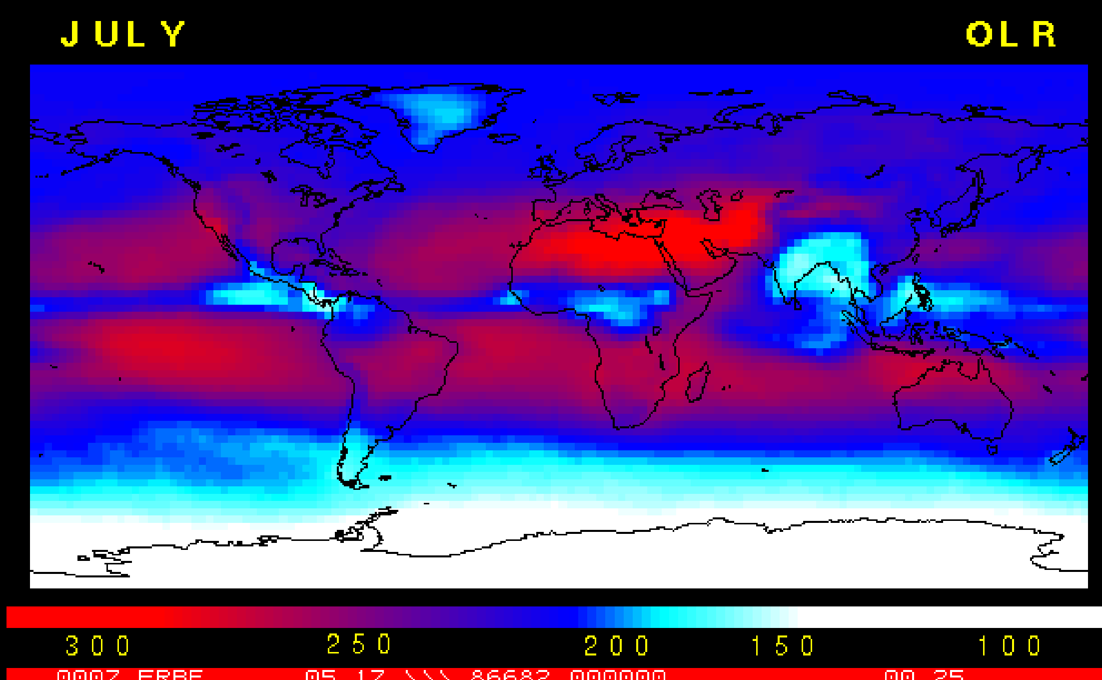
Infrared
(emitted by objects)

Cold objects (low emission) colored bright

Warm objects (high emission) colored dark



Average outgoing longwave radiation



Compare with solar radiation from last week's class

Final answer

Which of the following are emit radiation into space

a) Antarctic ice sheet
b) People
c) Carbon dioxide
d) None of them
e) All of the all

Final answer

Which of the following is NOT true

a) Wavelength of light is related to temperature

b) Amount of energy emitted is related to temperature

c) Solar constant depends on the speed of light

d) Energy leaving Earth is always about equal to solar radiation coming in because of a negative feedback

e) If the distance from the earth to the Sun changes, so would the equilibrium temperature

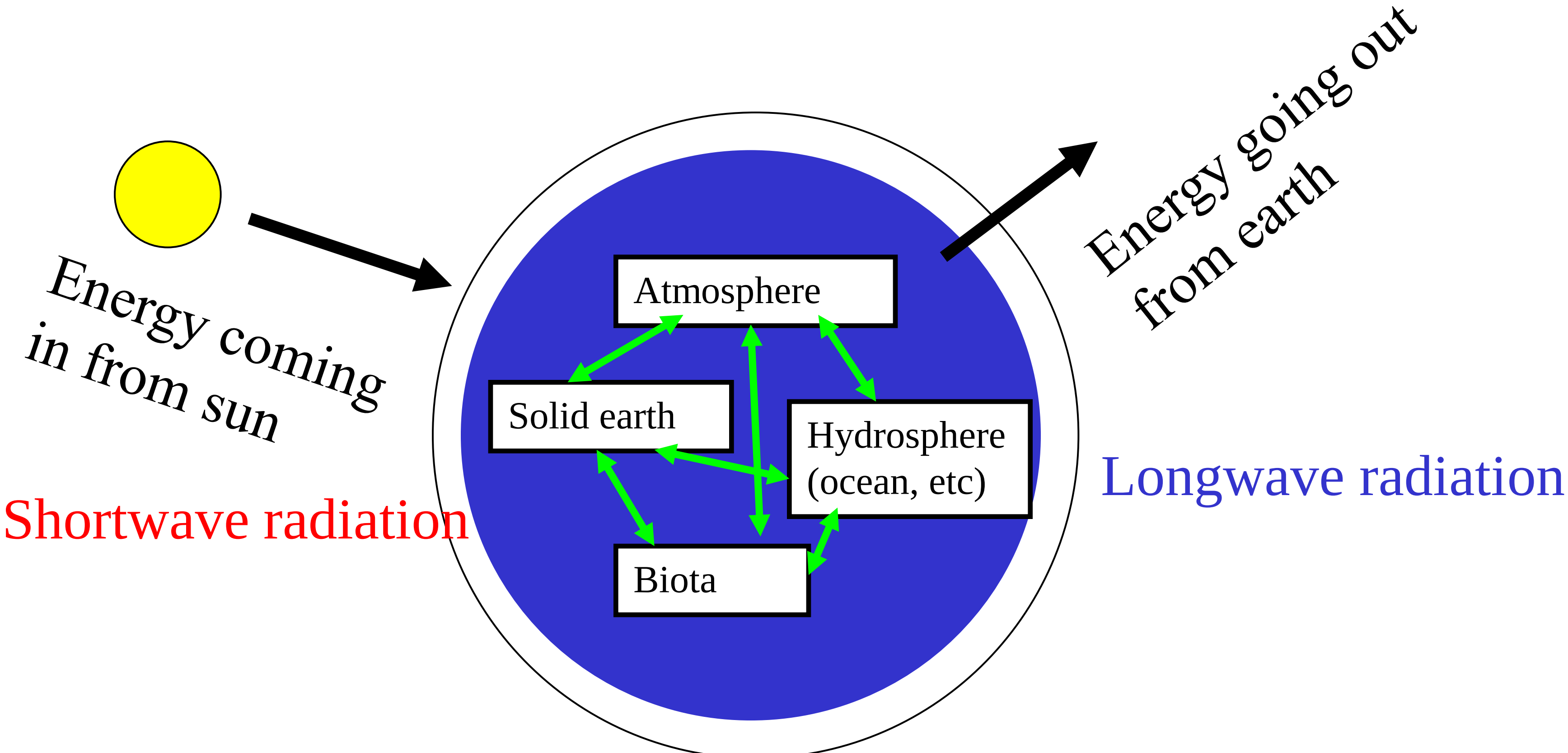
$$E = \sigma T^4$$

Everything emits!

We have defined solar radiation as shortwave and radiation coming from temperatures like that of earth as longwave.

Longwave radiation is often also called infrared, or terrestrial radiation.

Energy balance

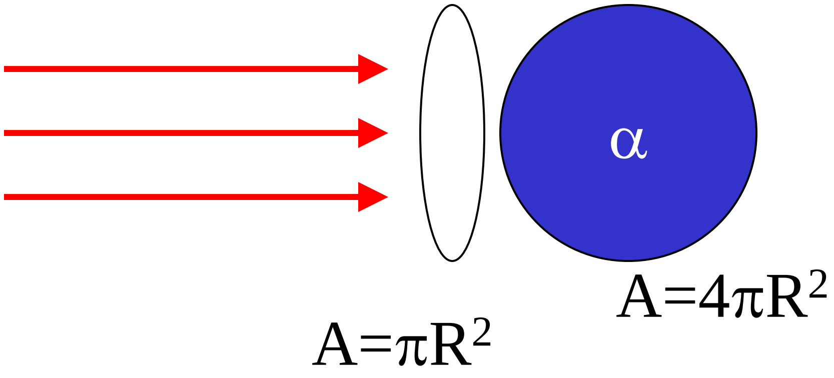


Energy balance means incoming equals outgoing

But what happens inside the Earth system?

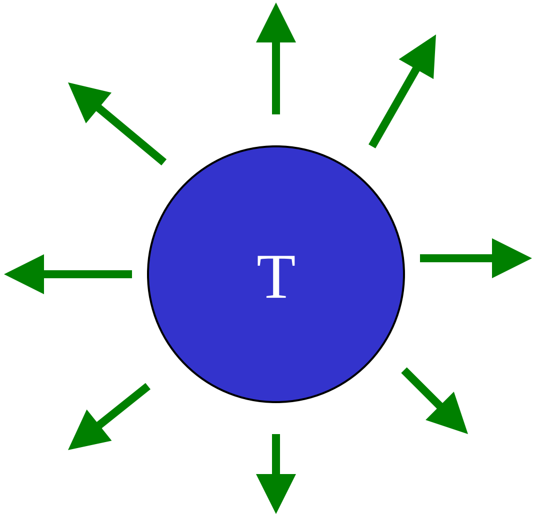
Radiative balance

Solar input of energy
(note, only on sunny side)



$$I = (1-\alpha)\frac{S}{4}$$

Longwave loss of energy
(note all directions)



$$E = \sigma T^4$$

So for balance, *incoming = outgoing*

$$(1-\alpha)\frac{S}{4} = \sigma T^4$$

Example: Earth

solar in = longwave out

$$(1-\alpha)\frac{S}{4} = \sigma T^4$$

- We know S = 1370 W/m^2
- We know α = 0.31
- Solve for T

$$T = \sqrt[4]{\frac{(1-\alpha)}{\sigma}\frac{S}{4}}$$

T = 254K

This is the *radiative equilibrium temperature*

Boltzman feedback

- Atmosphere colder than equilibrium
  emits LESS energy than is incoming, and warms up.
- Atmosphere warmer than equilibrium
  emits MORE energy than incoming, so cools down

- Since the Stefan-Boltzman law is $E=\sigma T^{4,}$ even a small deviation from equilibrium will give a strong recovery.

- BUT this is only the temperature at the top of the atmosphere!
  What controls the temperature at the ground
  (*hint: something to do with tomatoes…*
  and the topic of next class)

Summary points

Blackbodies are perfect absorbers
Blackbodies are perfect emitters

… but, ***all bodies*** emit radiation

Amount of radiation emitted by a blackbody depends on temperature

Stefan-Boltzman Law: $E = \sigma T^4$

Amount of energy is very sensitive to the temperature
(2 times T, gets 16 times E!)

Warmer objects, e.g., Sun, emit shorter wave lengths
(*higher energy photons*)

Colder objects, e.g., Earth, emit longer wave lengths
(*lower energy photon*)

Stefan-Boltzman Law is ***VERY*** important for climate as it controls the loss of energy from earth, and gives rise to ***energy balance***. It provides the ***big negative feedback*** needed for equilibrium!