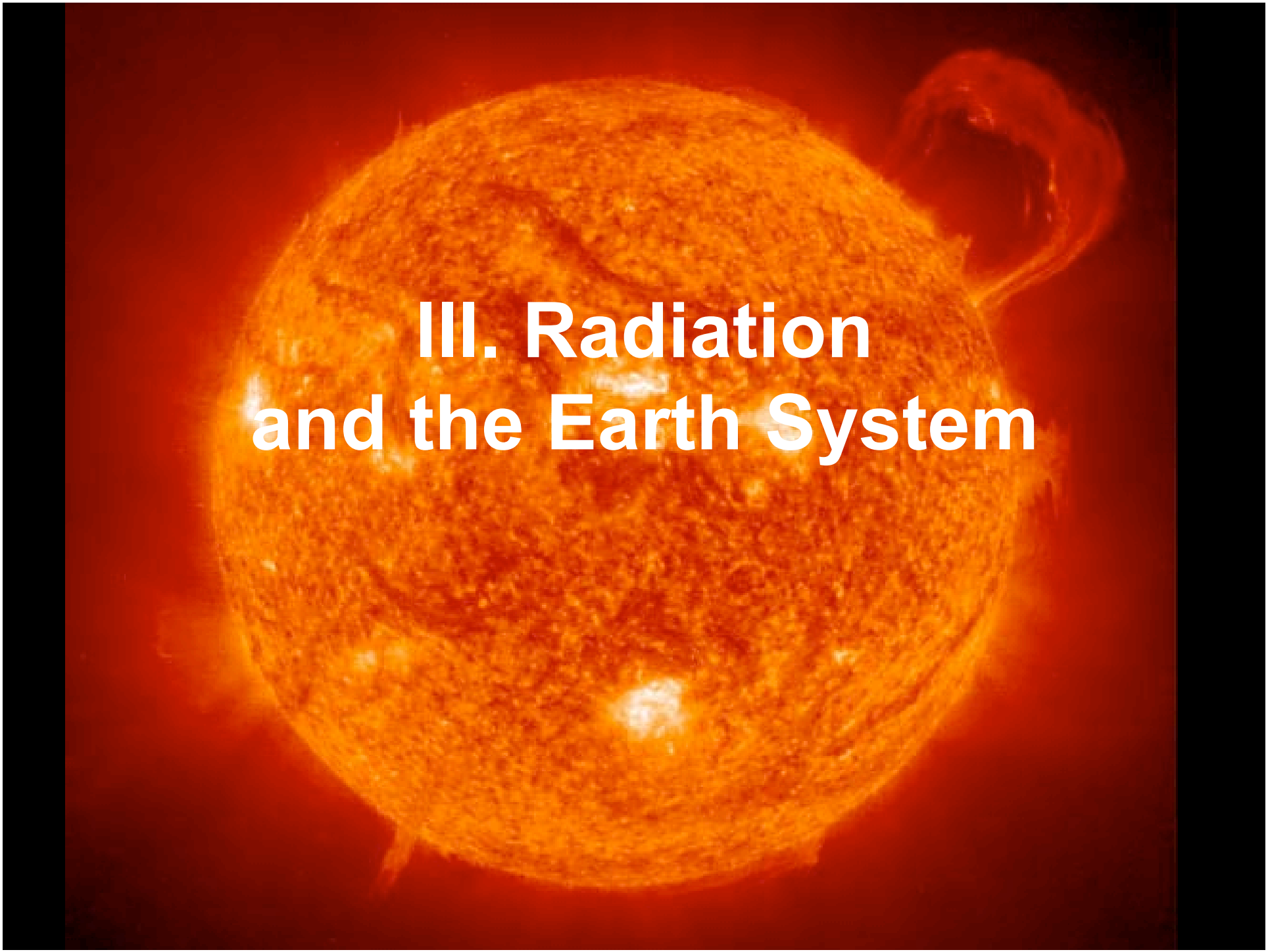


III. Radiation and the Earth System

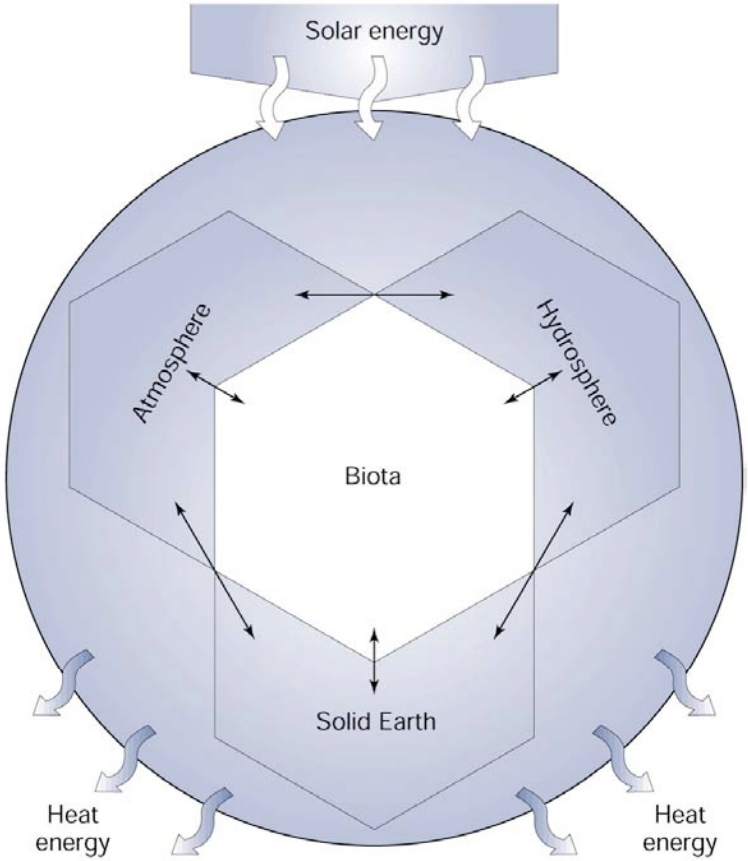
learning goals

- how energy is transferred from Sun to Earth and back out to space
- the properties of electromagnetic radiation (light and heat energy)
- the concept of energy flux
- the concept of blackbody behavior
- the Stefan Boltzmann Law

(recall) the climate system

energy *coming in from the Sun*

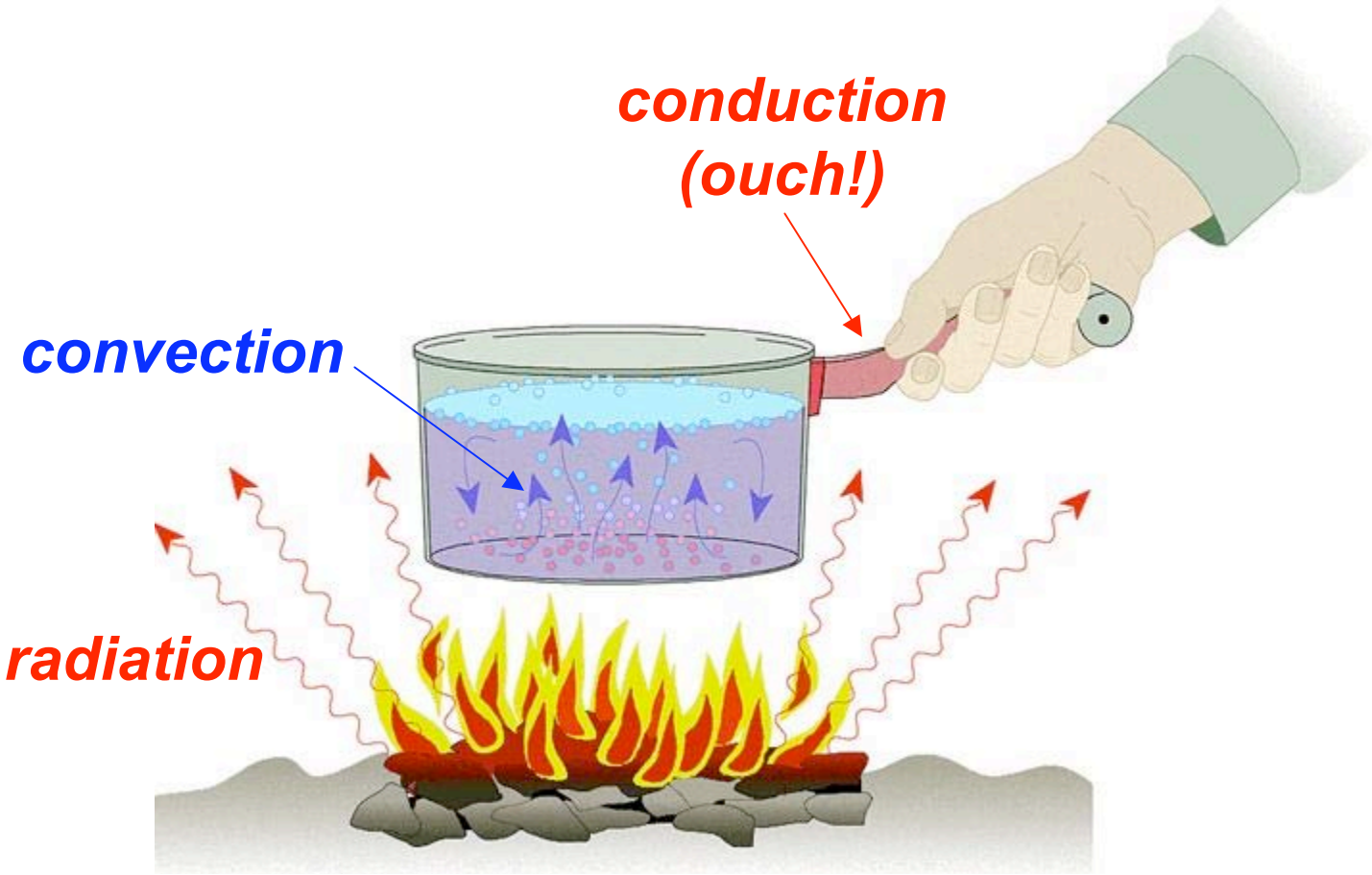
energy *coming in and going out*



in a ***system*** *that is naturally close to* ***equilibrium***

energy *coming out from the Earth*

how is heat energy transferred?

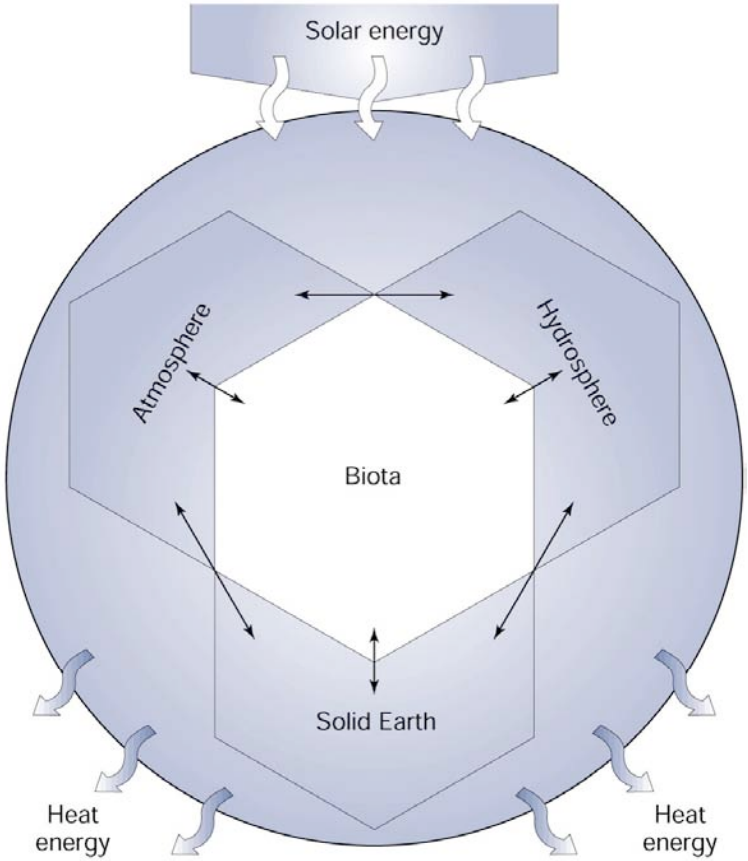


which describes how energy is transferred from the Sun to the Earth (and from Earth to space)?

the climate system

energy *coming in from the Sun*

energy *coming in and going out via* ***radiation***



in a ***system*** *that is naturally close to* ***equilibrium***

energy *coming out from the Earth*

What is this radiation

- ***Light!***

- ***Light carries heat through a vacuum (such as the "space" between the Sun and Earth)***

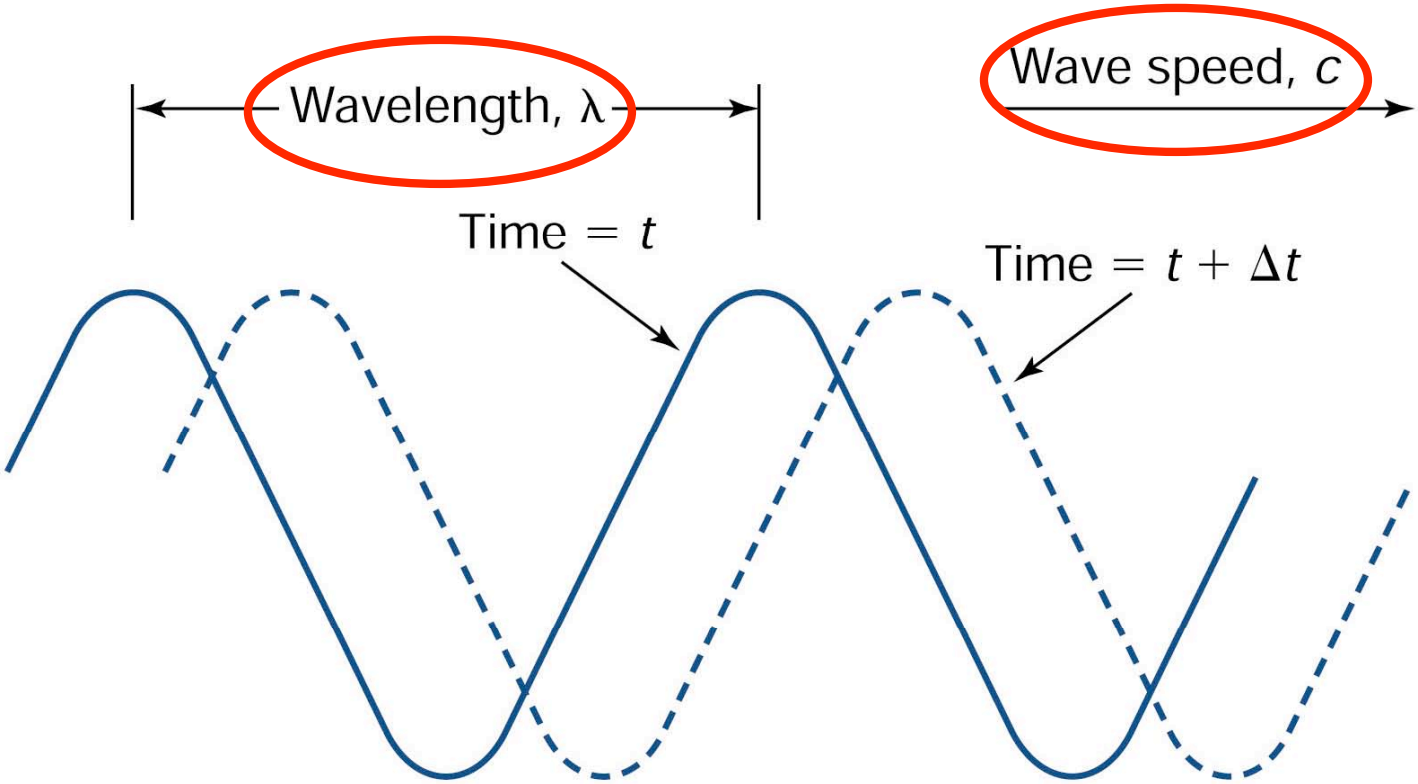
light

- can describe, *most of the time*, as a ***wave*** (*some of the time*, as a collection of particles, *called* ***photons***)

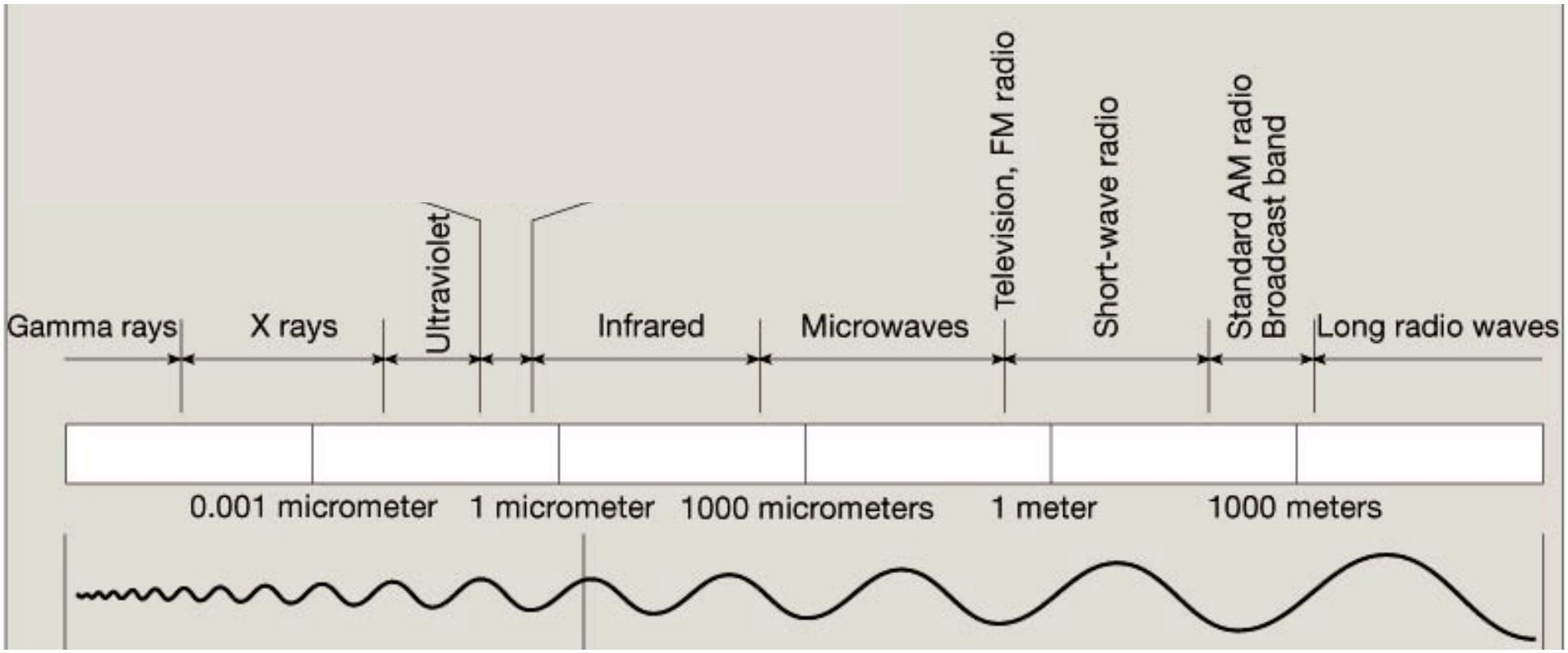
- ***light waves*** interact with both electric and magnetic fields, hence we refer to light as ***electro-magnetic radiation***

light

wave properties:



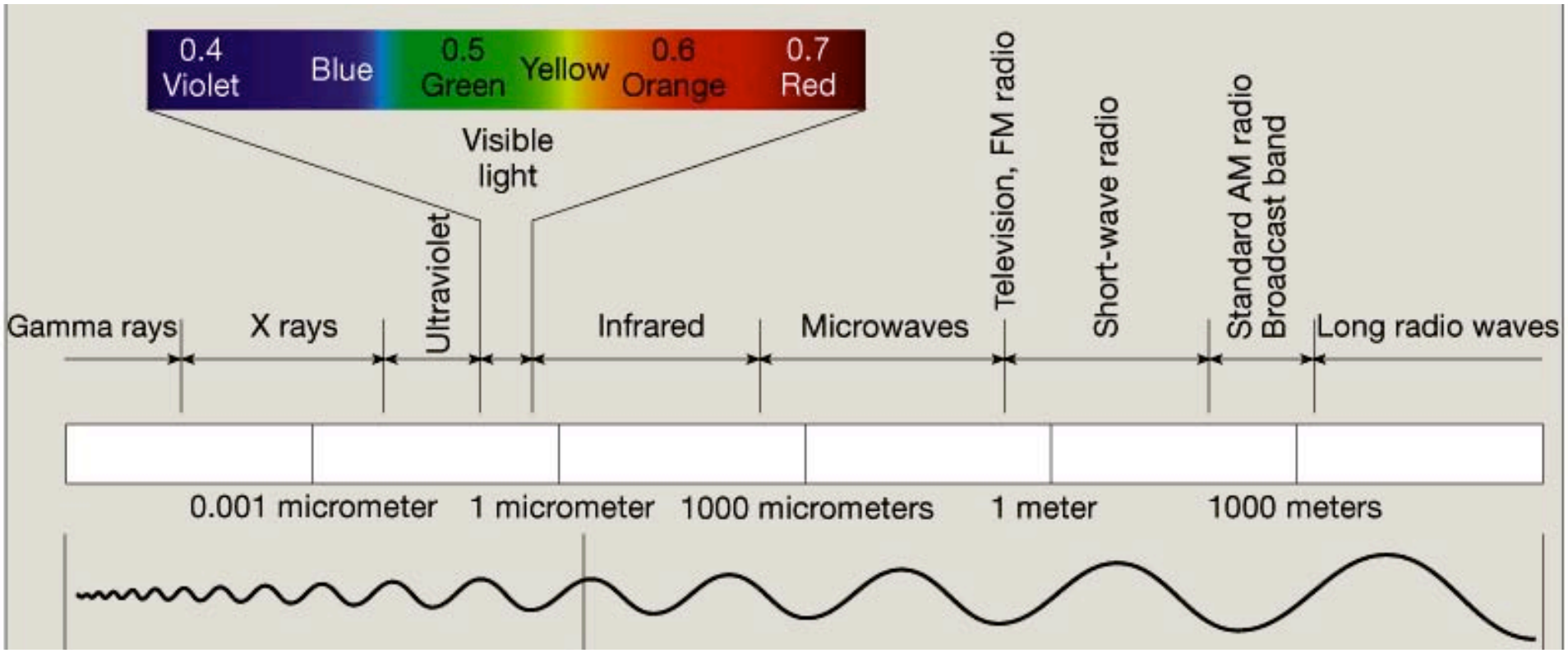
the spectrum (or range) of electromagnetic radiation



wavelength (λ)

1 million micrometers (or microns) equals 1 meter

remember: radiation IS light



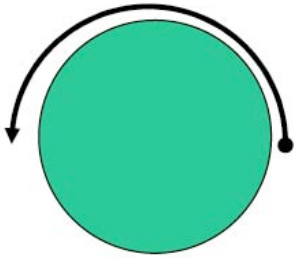
wavelength (λ)

we just can't see it all with the human eye

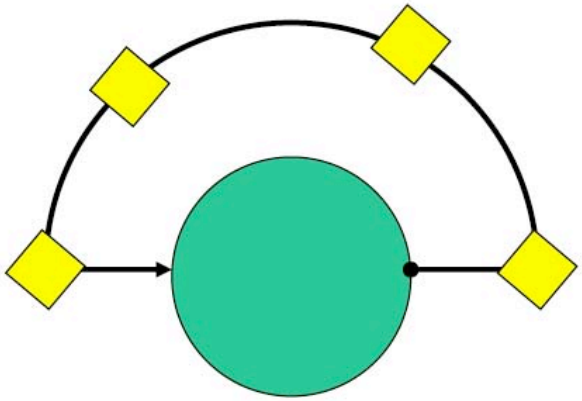
speed of light

- The speed of light is ~300,000,000 meters/sec. *Einstein tells us this is constant (in a vacuum).*

- Around the world in 0.14 seconds. An e-mail sent half-way round the world takes 0.07 seconds.



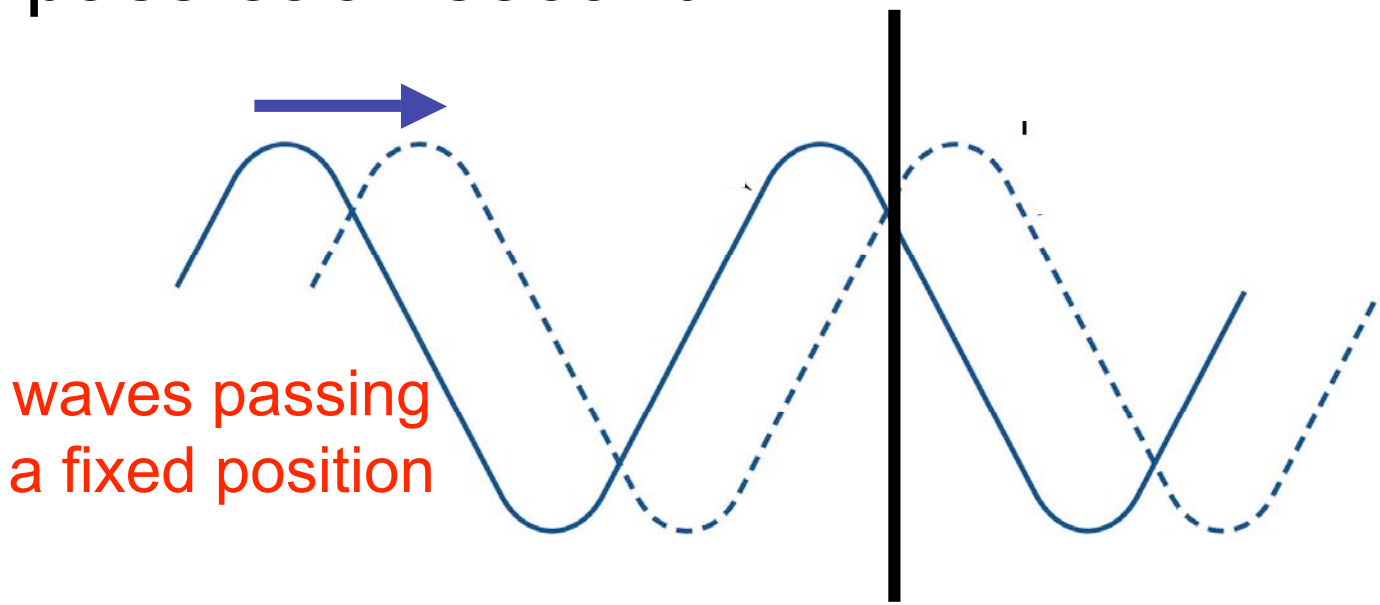
- The satellite route is much longer, with a transmission time up, around and back down of 0.5 seconds.



(thanks to Prof. David Noone (ATOC) for this teaching slide)

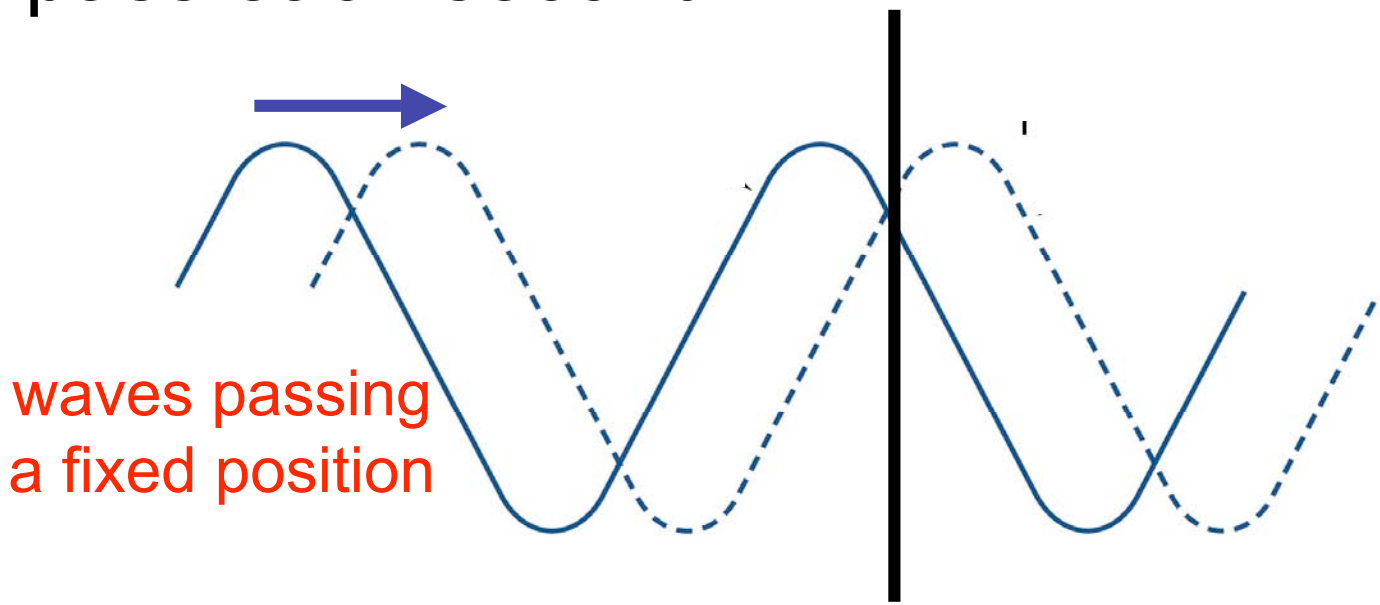
wavelength and frequency

- ***frequency*** is the number of wave crests that pass each second



wavelength and frequency

- ***frequency*** is the number of wave crests that pass each second



- since speed of light is constant, ***frequency*** and ***wavelength*** must be inversely related
- ***frequency = speed of light / wavelength***

derive

energy and light

- *amount* of energy is related to ***wave frequency*** (or, inversely, to wavelength)

- higher frequency (shorter wavelength) = more energy

- lower frequency (longer wavelength) = less energy

energy and flux

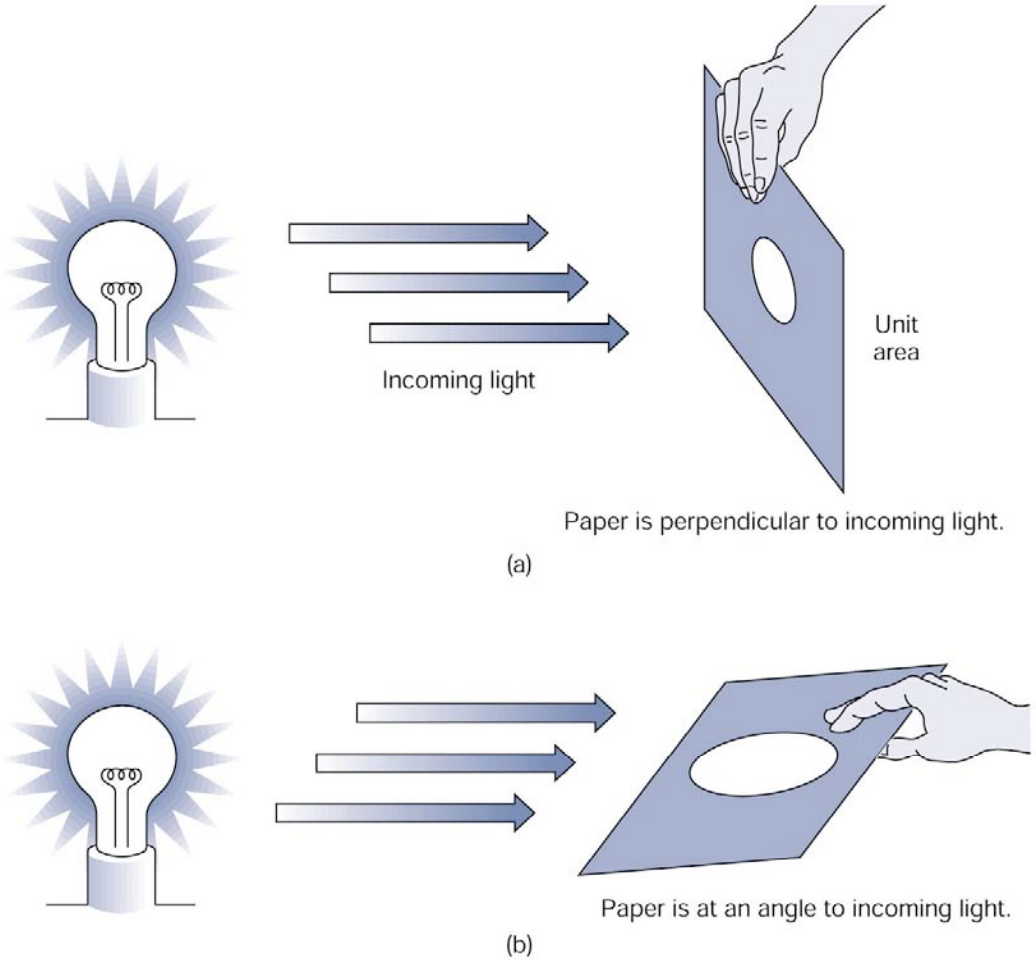
- ***flux*** tells us ***how much*** energy

- ***energy flux*** is the amount of energy striking a given area in a given amount of time (usually the area is a ***square meter)***

- consider, by analogy, the amount or ***flux*** of water passing thru a gate in the Grand Canyon

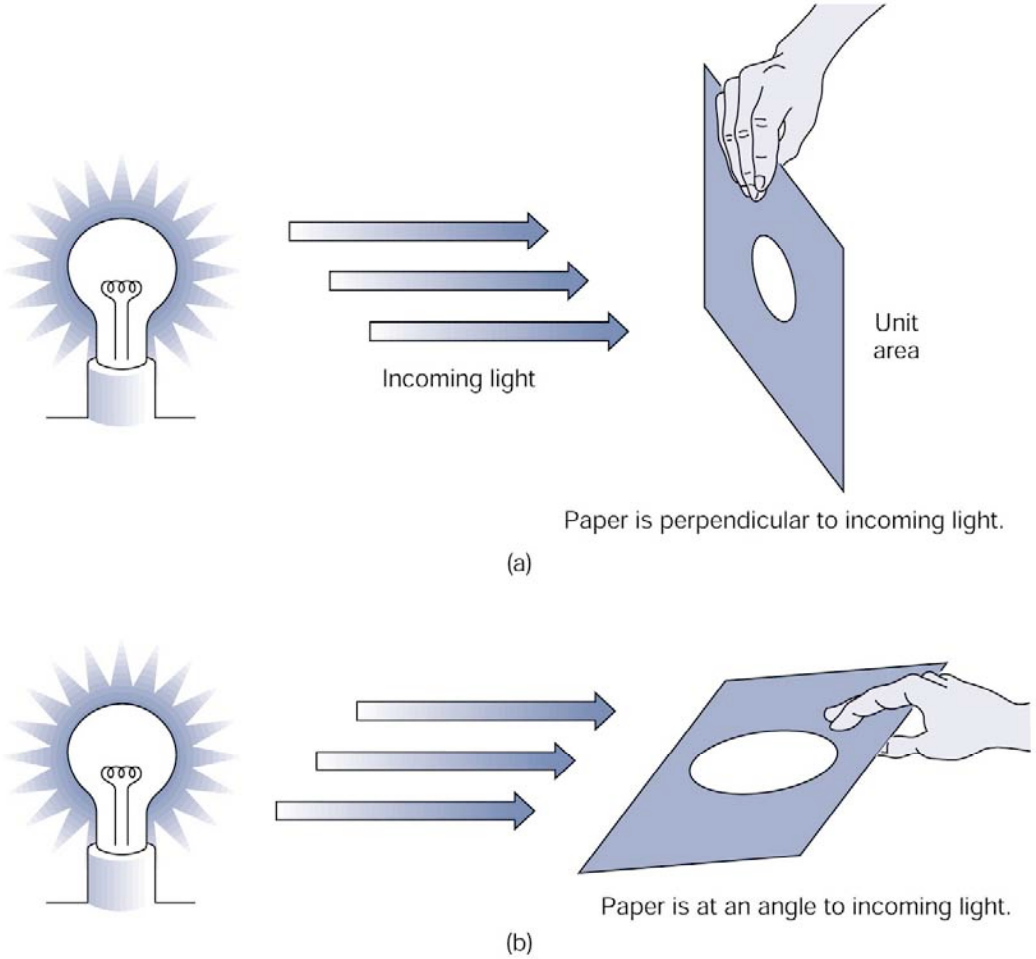
energy flux

which receives the greater flux from the bulb, the upright circle in a) or the tilted one (the ellipse) in b)?

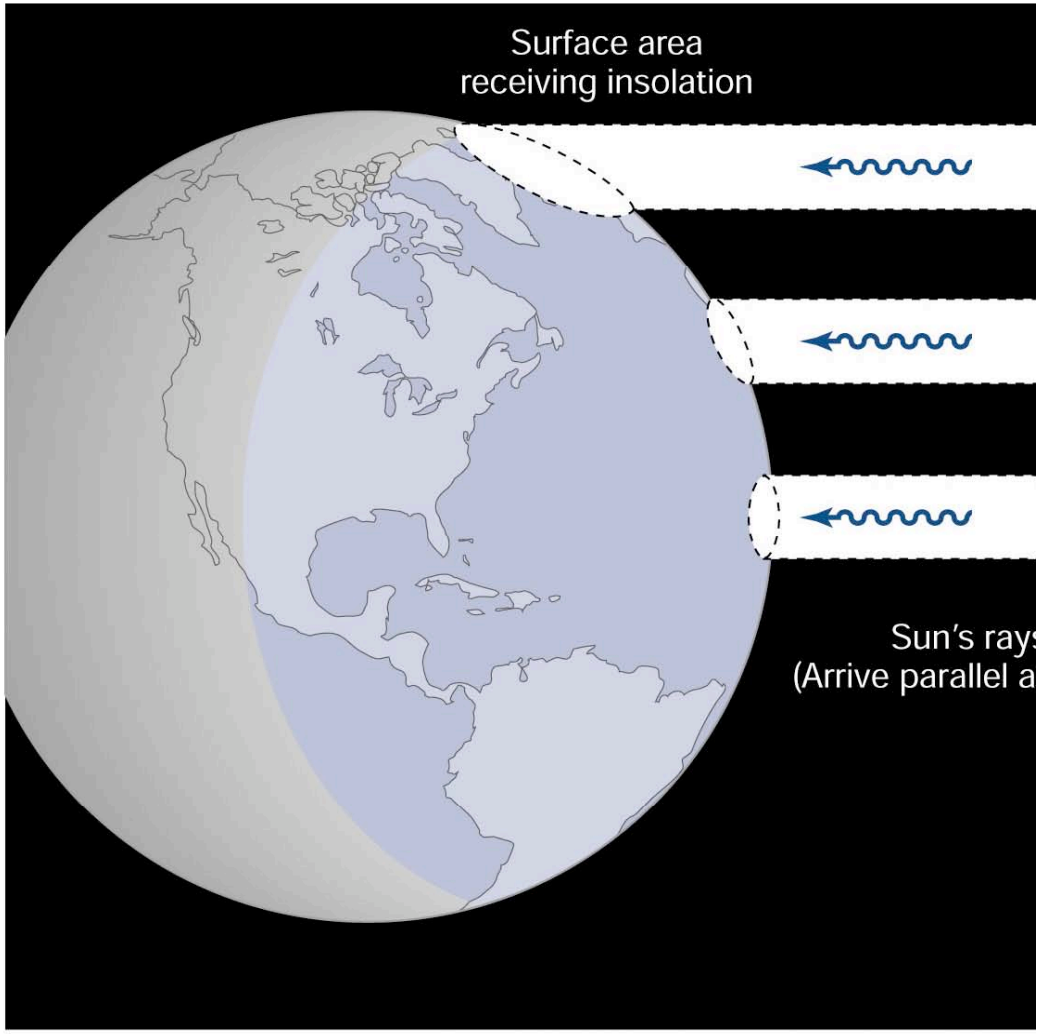


energy flux

in b) the same amount of energy strikes a larger area, thus the flux is smaller



clicker question:
why are the poles colder than the tropics?



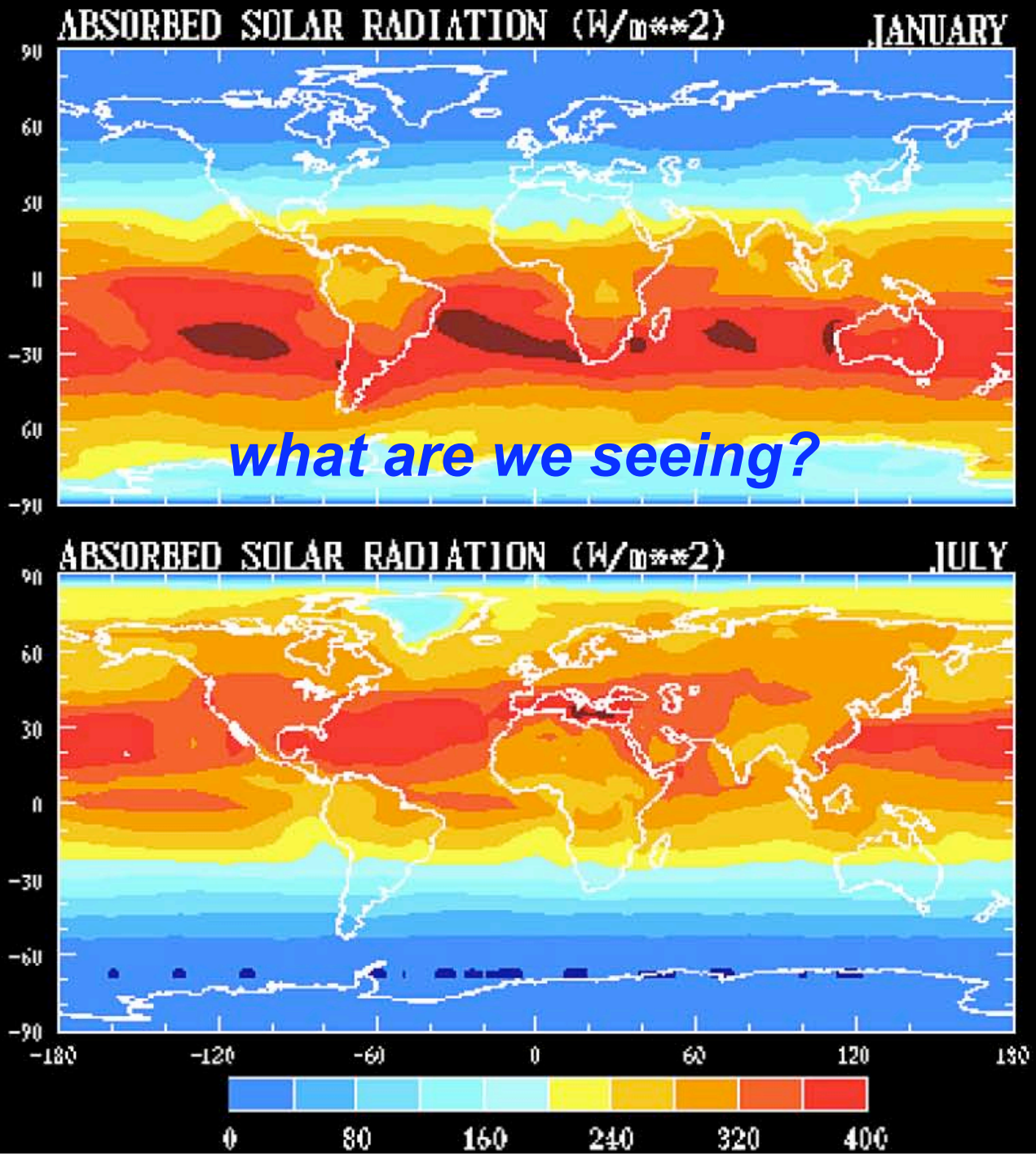
a) <u>the flux of radiation is smaller</u>

b) the flux of radiation is larger

c) they are farther from the sun

d) they are mountainous

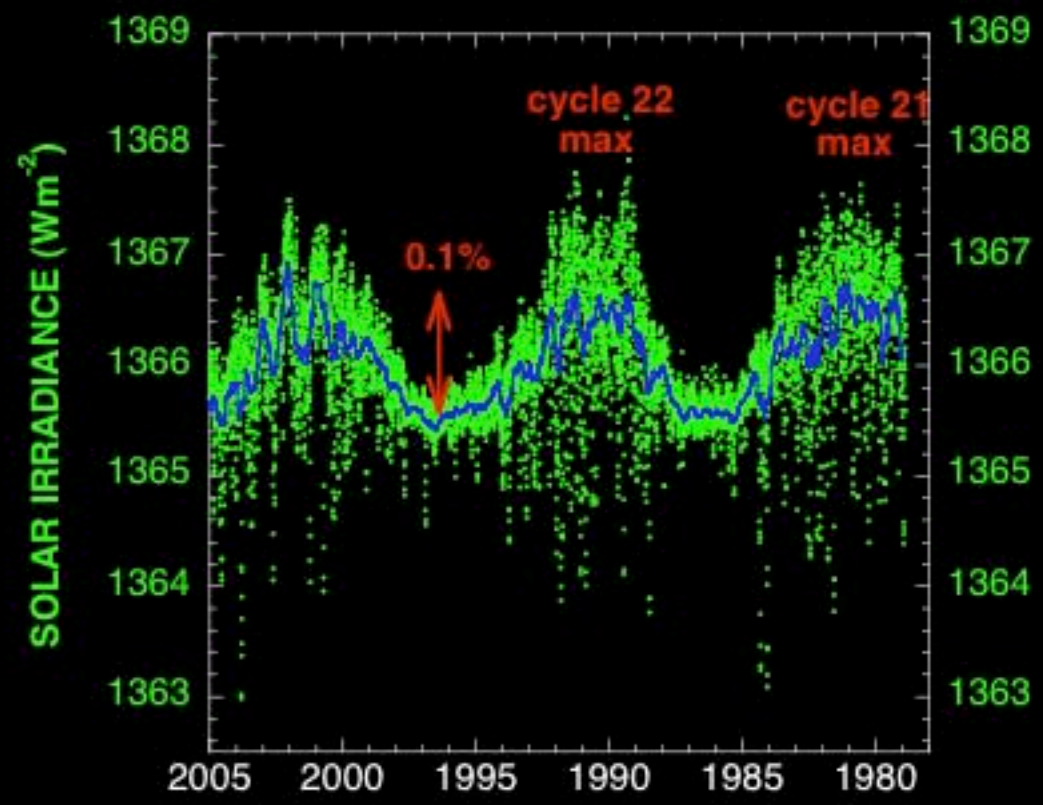
e) the atmosphere is denser


ABSORBED SOLAR RADIATION (W/m**2)
JANUARY
90
60
30
0
-30
-60
-90
what are we seeing?
ABSORBED SOLAR RADIATION (W/m**2)
JULY
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
0
80
160
240
320
400

solar radiation at top of atmosphere

CU's SORCE satellite

solar radiation at top of atmosphere

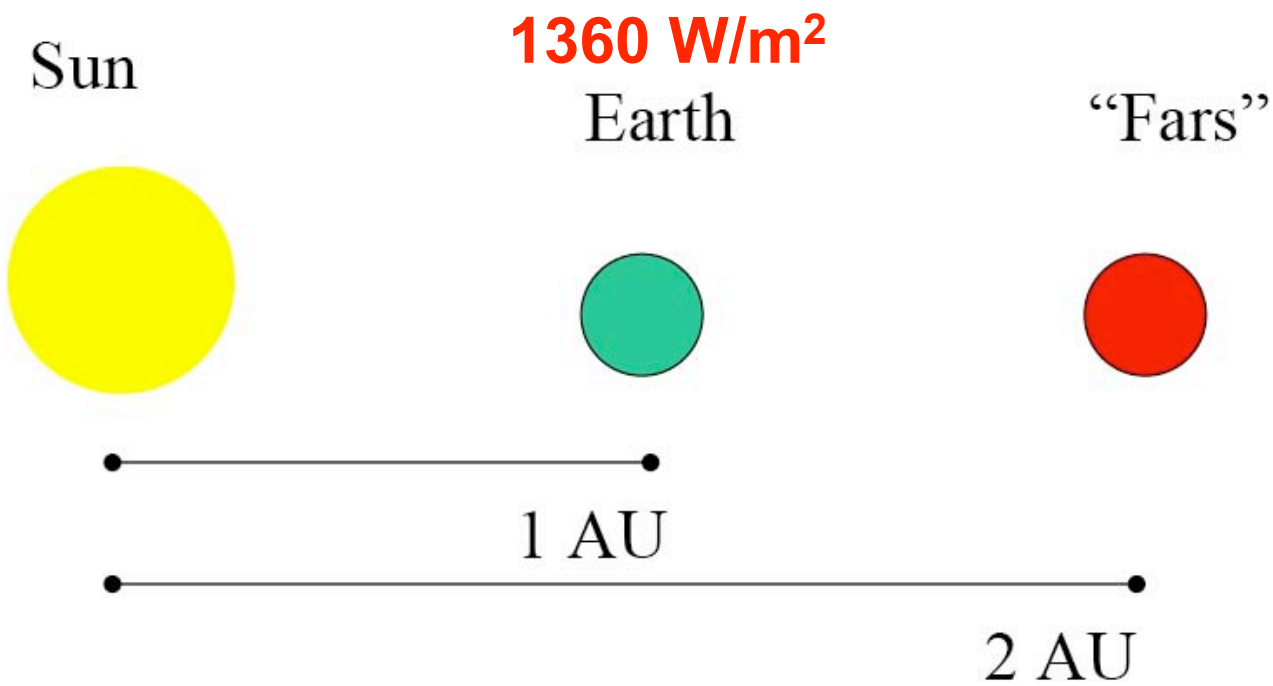


satellite data

~1366 Watts per square meter
energy of 136 100W bulbs in 1 sq. meter

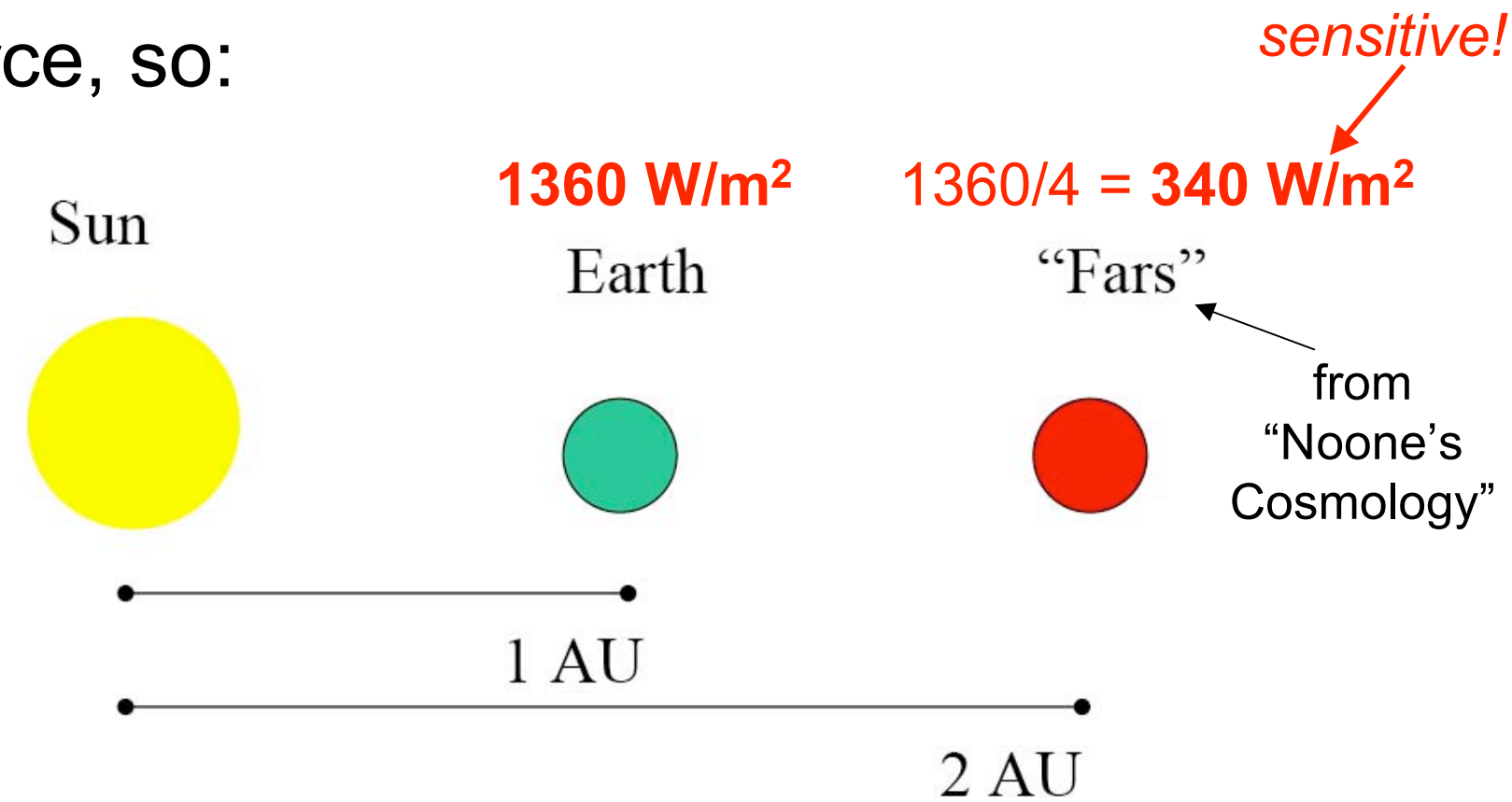
energy flux and distance

- the ***flux*** of energy decreases by the ***square of the distance*** from the source, ***what will it be at "Fars"?***

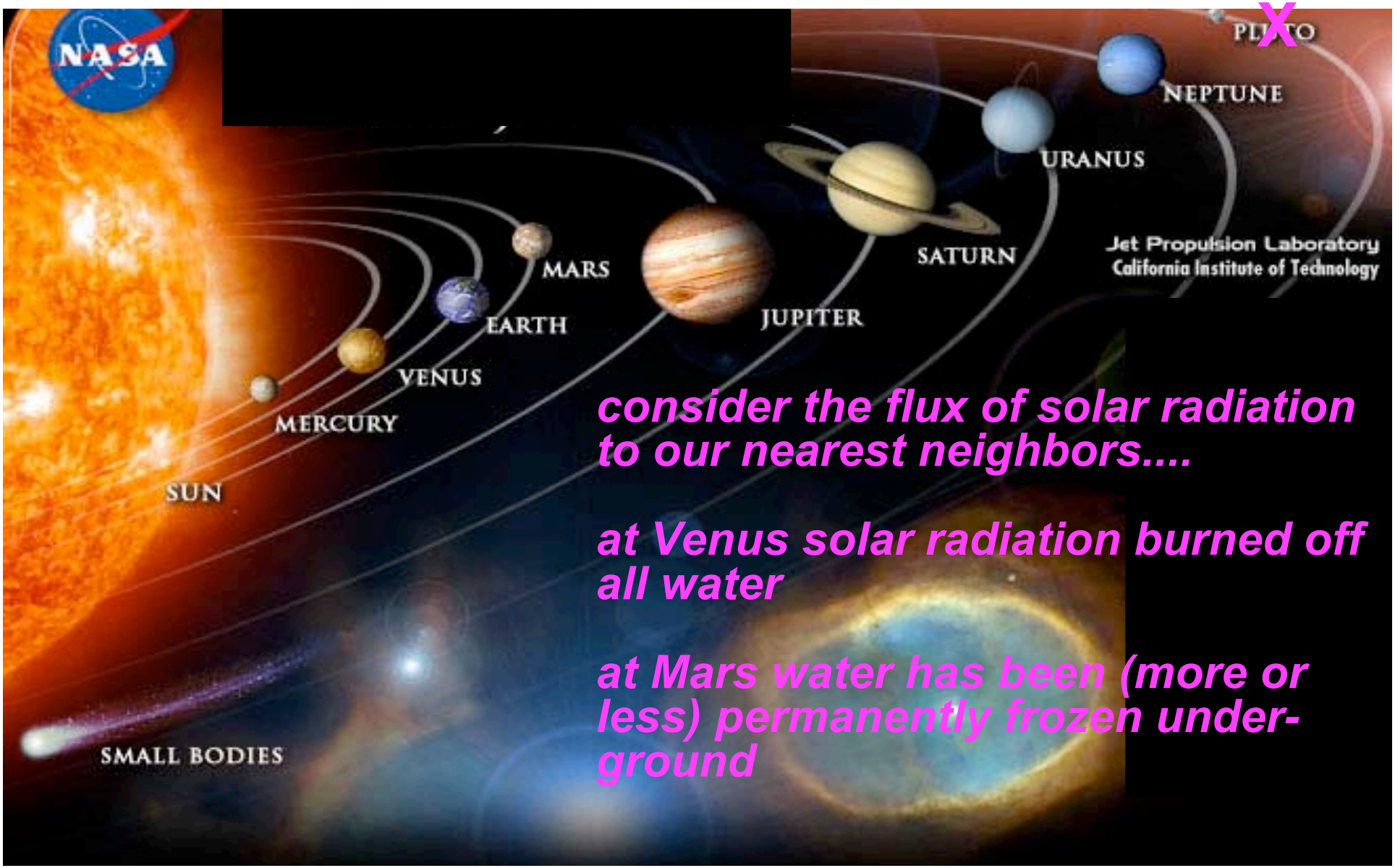


energy flux and distance

- the ***flux*** of energy decreases by the ***square of the distance*** from the source, so:



incoming solar radiation
Venus, Earth, & Mars

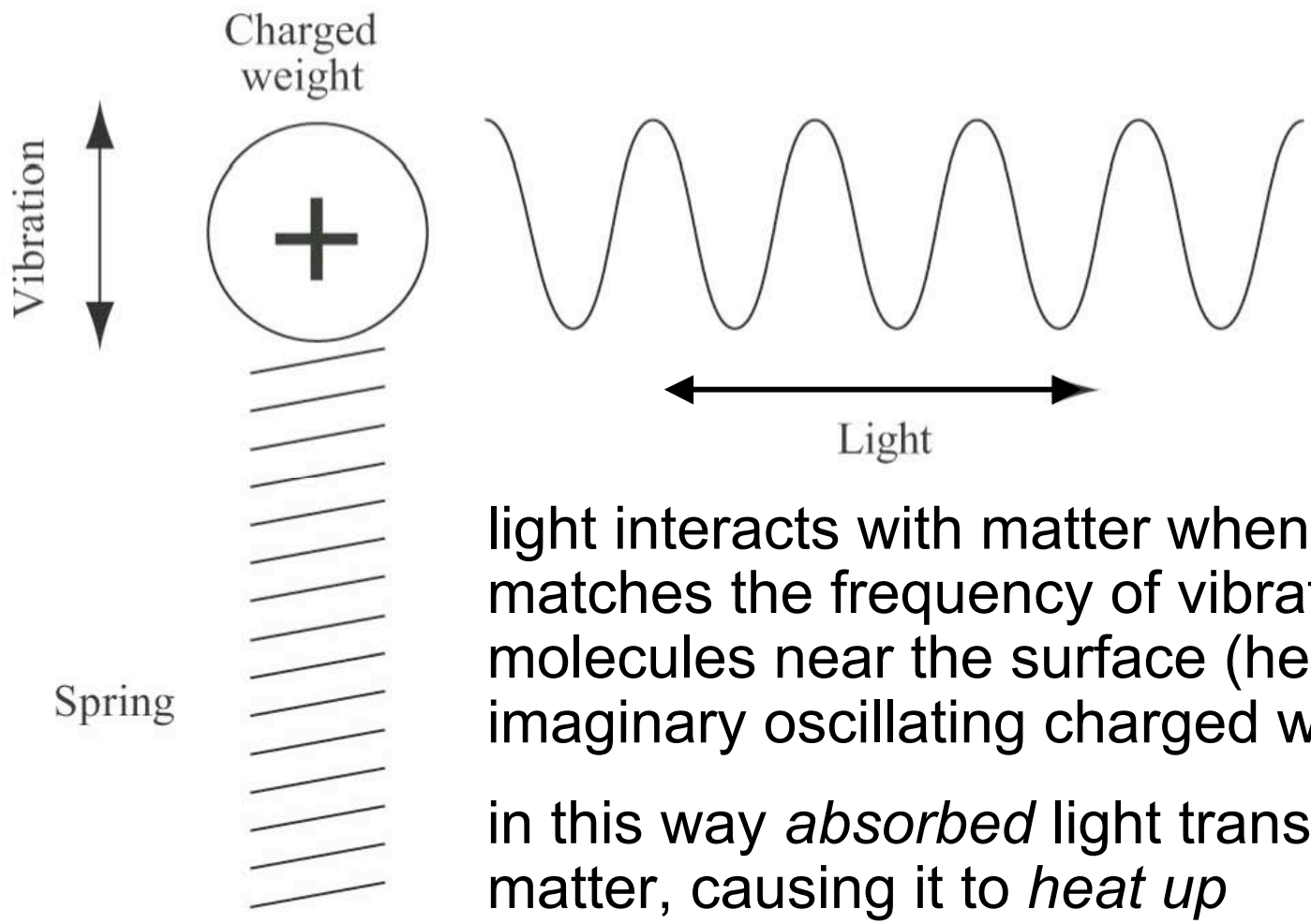


consider the flux of solar radiation to our nearest neighbors....

at Venus solar radiation burned off all water

at Mars water has been (more or less) permanently frozen under-ground

light interacts w/ matter



light interacts with matter when its frequency matches the frequency of vibration of molecules near the surface (here depicted as imaginary oscillating charged weights)

in this way *absorbed* light transfers heat to matter, causing it to *heat up*

conversely, matter radiates in proportion to it's temperature

it's a two-way street

blackbody behavior

- ***what happens when we see color?***
- ***white?***
- ***black?***
- so, a ***"blackbody"*** ***absorbs*** all radiation

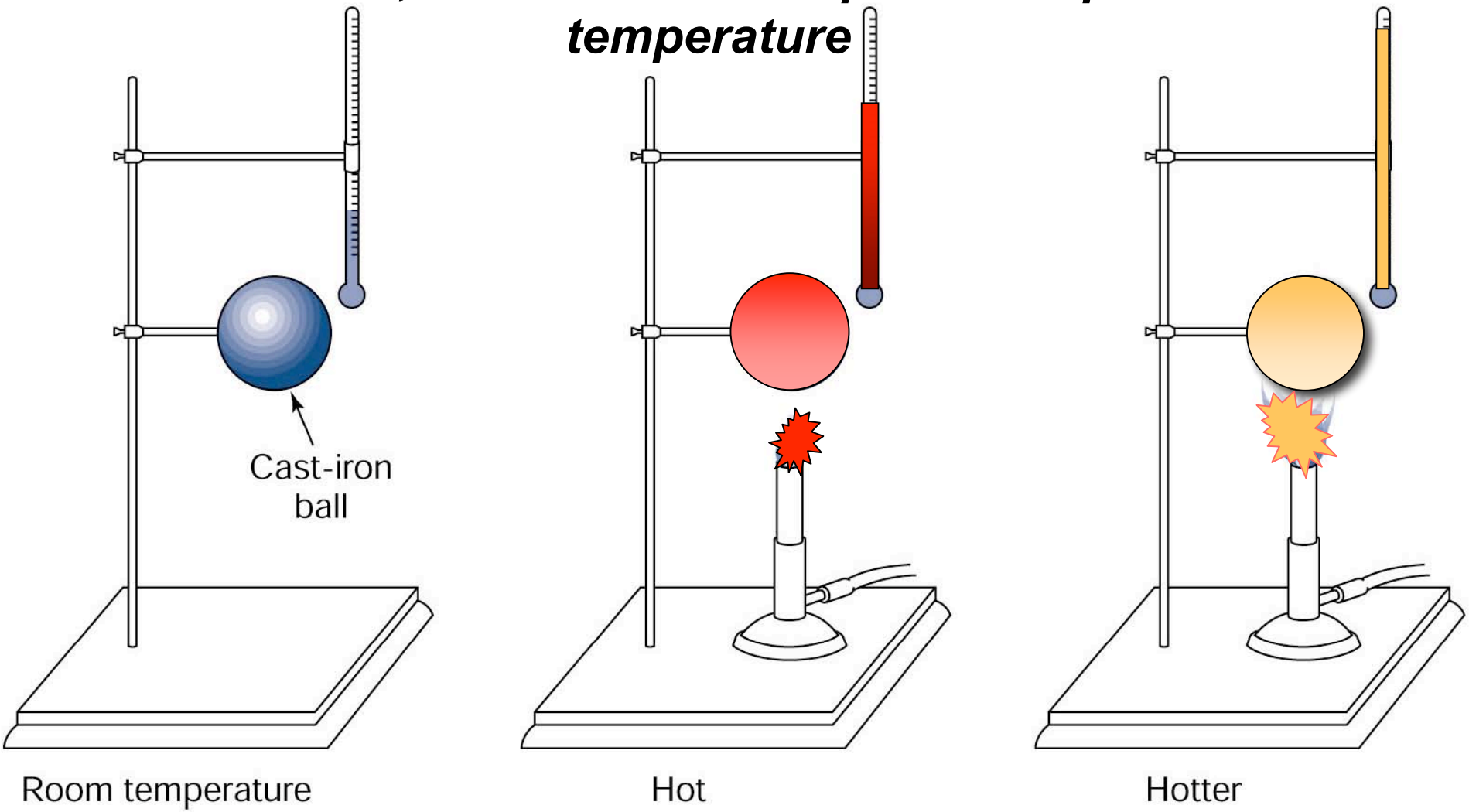
blackbody radiation

- ***to maintain equilibrium, it must therefore also emit radiation***

- ***let's now consider this equilibrium emission of radiation***

blackbody radiation

in each case, the blackbody soon emits as much radiation as it receives,and does so at a specific "equilibrium" temperature



clicker question

a blackbody

(discuss w/ your neighbor)

- *a*) perfectly absorbs radiation
- *b*) emits radiation to achieve equilibrium
- *c*) tends to get cold
- d) tends to get hot
- *e*) <u>both *a* and *b*</u>

blackbody radiation

rules of thumb:

hotter bodies emit at shorter wavelengths and have more energy

the total emissions (the flux of radiation) is directly related to the temperature of the emitting body, i.e. .....

the Stefan-Boltzmann Law

states that the energy emitted from blackbody varies as the 4th order of its temperature, such that:

$$F = \sigma T^4$$

F goes as T times itself 4 times, so F must be very sensitive to T!

where:

F is the flux of emitted radiation in W/m^2
T is temperature (on Kelvin scale)
and σ is a constant (the Stefan Boltzmann constant)

note: sometimes, as in your text, the term “Intensity” is used instead of Flux, and “I” replaces “F” in the equation above

the Stefan-Boltzmann Law

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F is the flux of emitted radiation in W/m^2
T is temperature (on Kelvin scale)
and σ is a constant (the Stefan Boltzmann constant)

if the temperature doubled how much would the flux of radiation go up?

the Stefan-Boltzmann Law

states that the energy emitted from blackbody varies as the 4th order of its temperature, such that:

$$F = \sigma T^4$$

where:

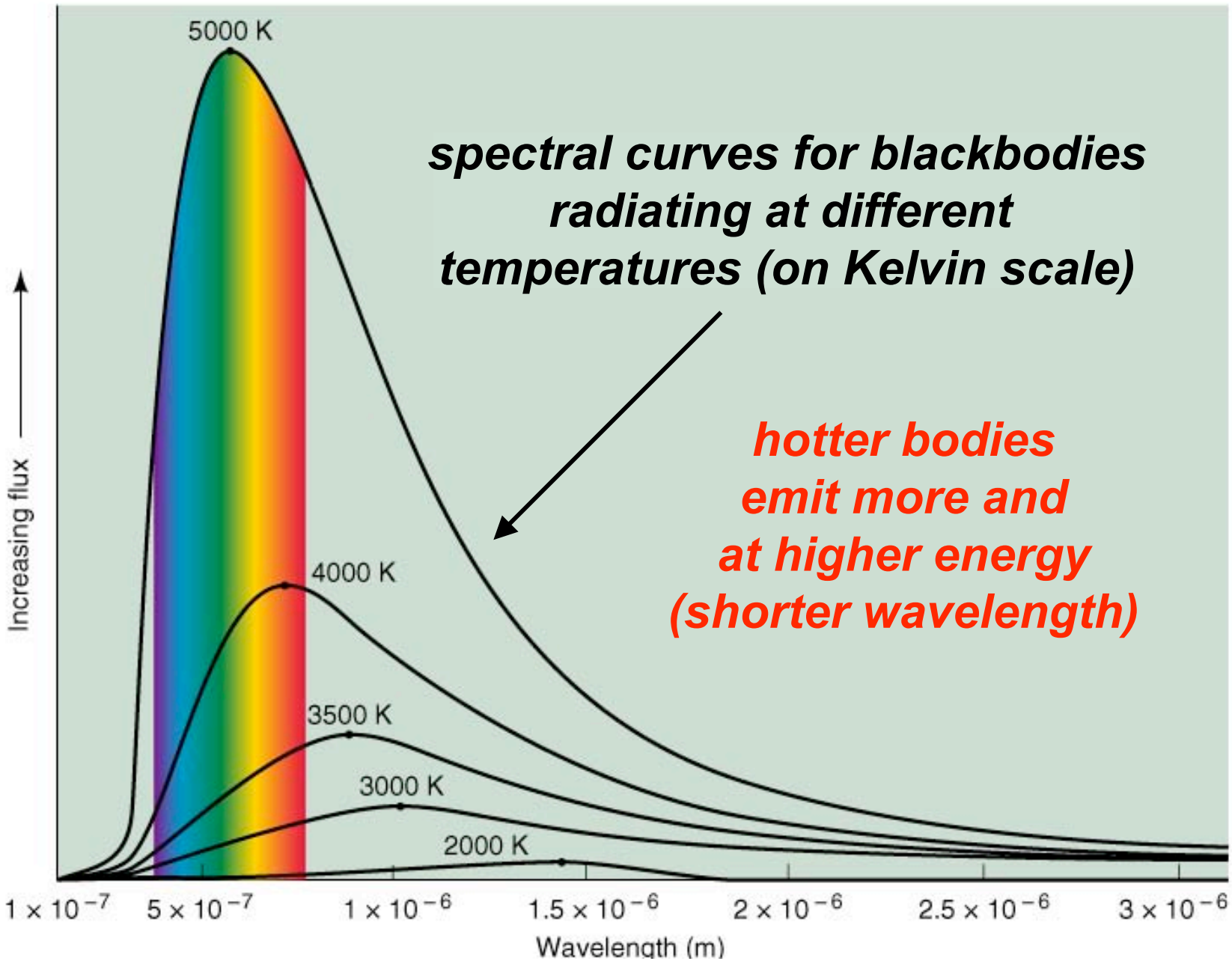
F is the flux of emitted radiation in W/m^2
T is temperature (on Kelvin scale)
and σ is a constant (the Stefan Boltzmann constant)

we will come back to this repeatedly

why?

everything emits and this tells us how much!

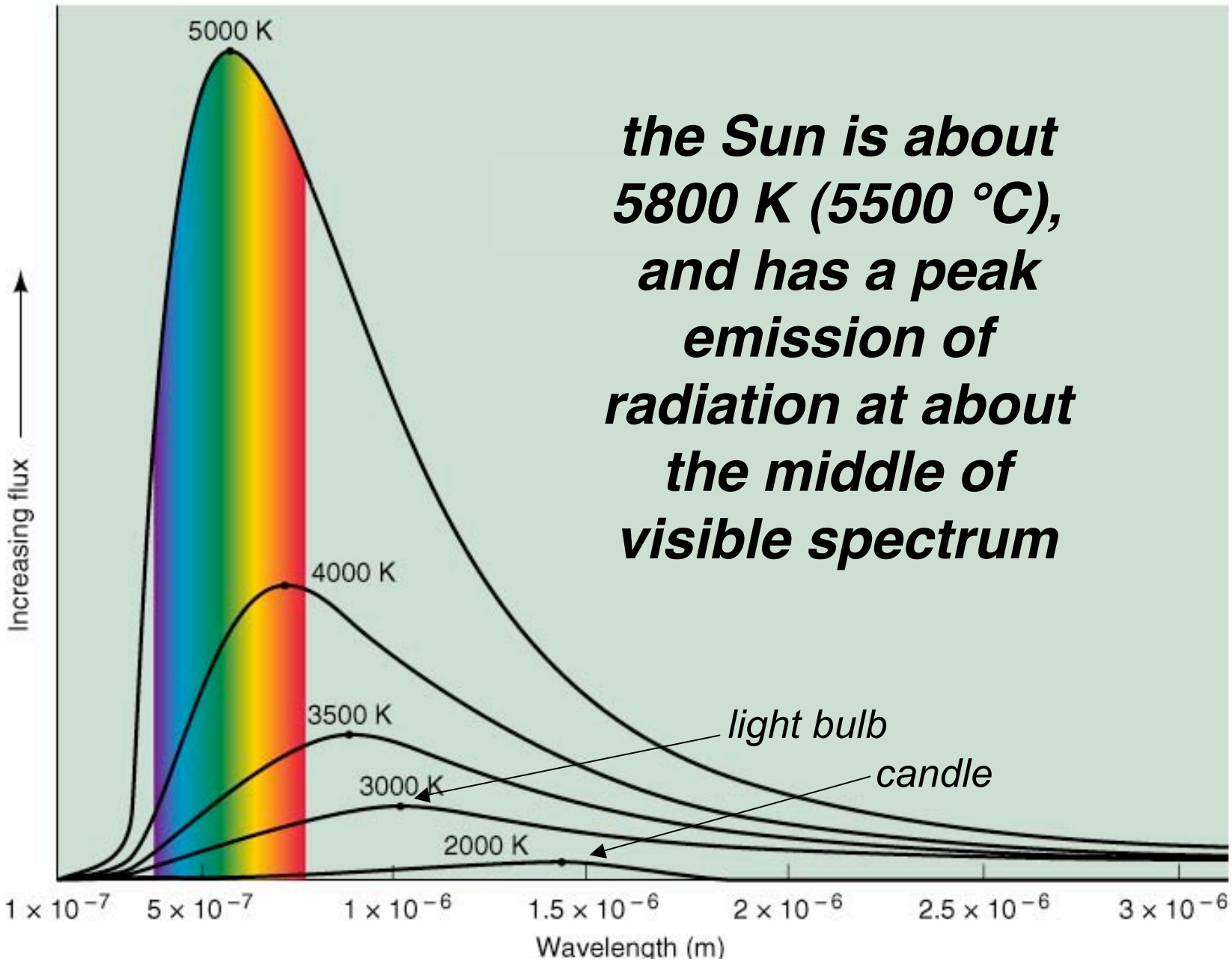
blackbody radiation



spectral curves for blackbodies radiating at different temperatures (on Kelvin scale)

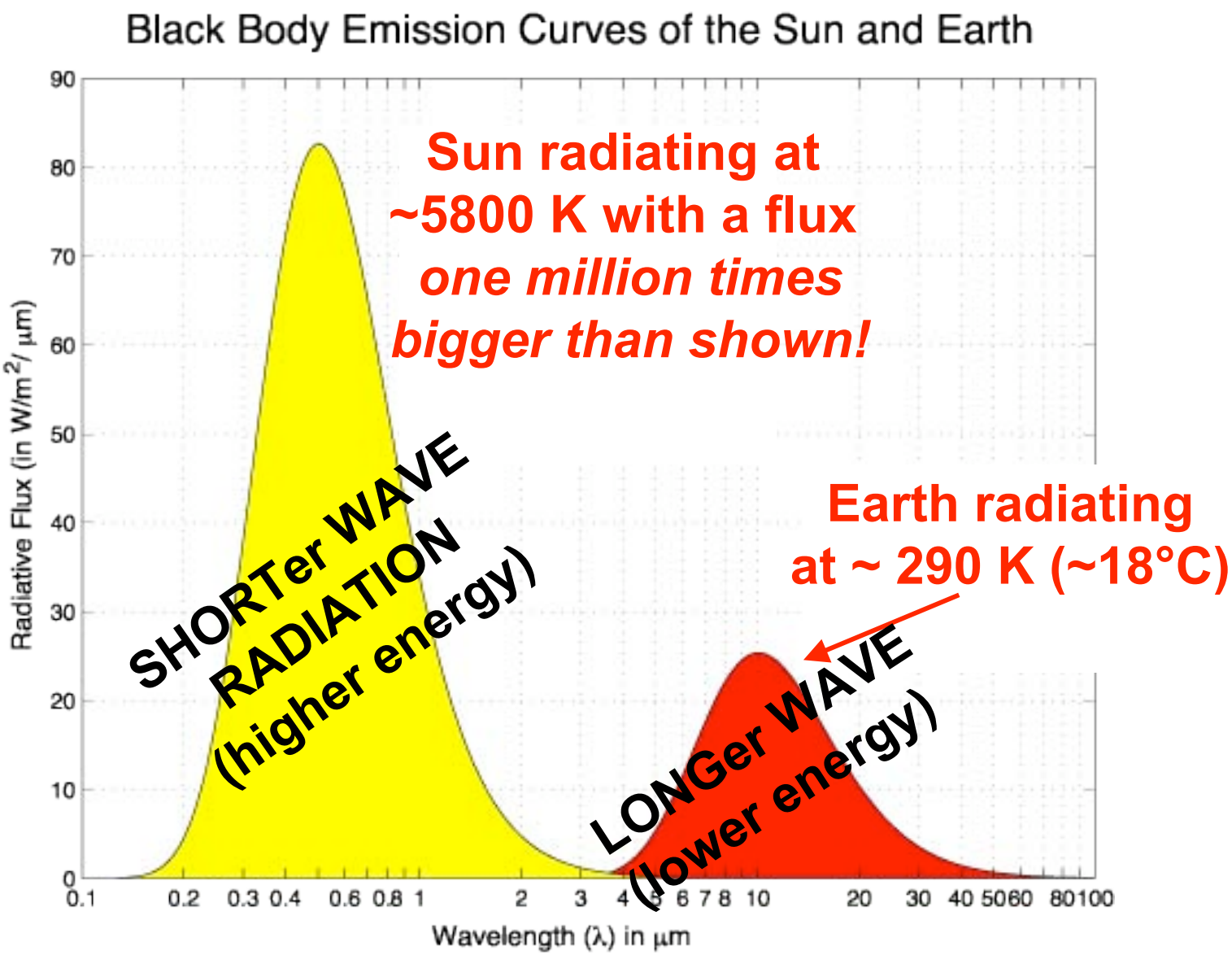
hotter bodies emit more and at higher energy (shorter wavelength)

blackbody radiation



the Sun is about 5800 K (5500 °C), and has a peak emission of radiation at about the middle of visible spectrum

radiation from Sun v. Earth



note the hotter body radiating more and at higher energy

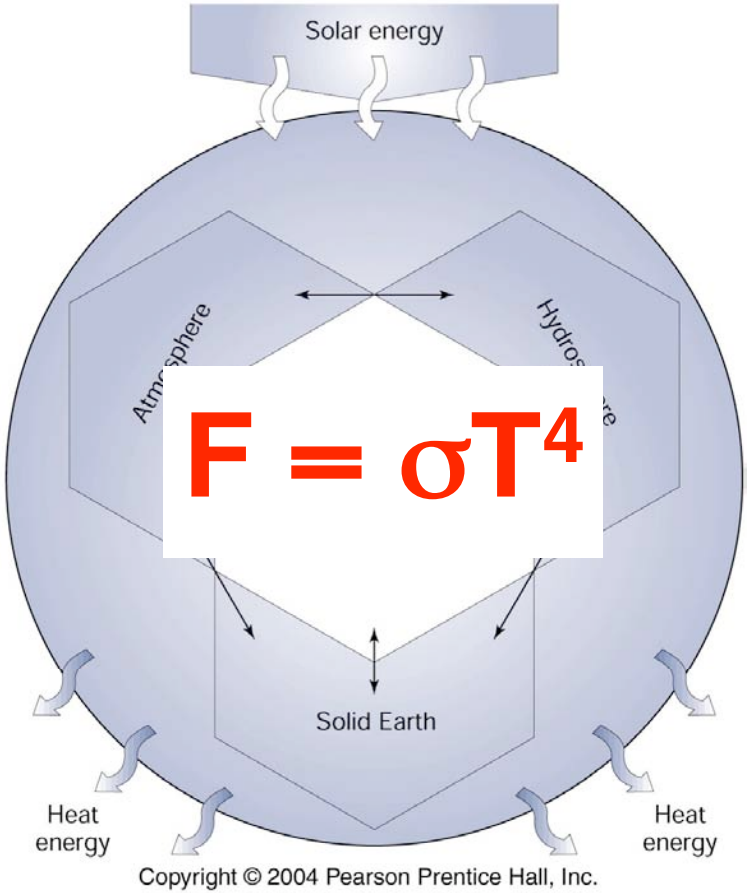
note on the Kelvin scale

- on this scale, the freezing point of water (0 °C or 32 °F) is 273 K
- at 0 K molecules do not move and have nearly no energy
- any temperature above 0 K defines a state with some molecular motion and energy
- scientists concerned with the transfer of energy find the K scale most useful

the Earth behaves (nearly) as a blackbody with incoming and outgoing energy fluxes that are (nearly) in balance

energy *coming in from the Sun*

energy *coming in and going out via* ***radiation***



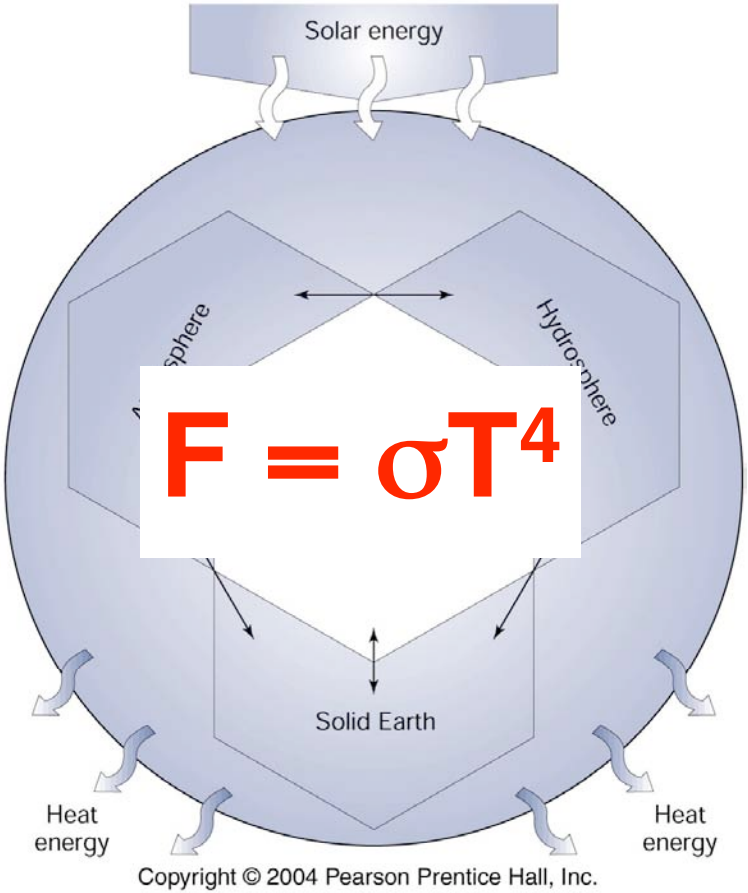
$$F = \sigma T^4$$

in a ***system*** *that is naturally close to* ***equilibrium***

energy *coming out from the Earth*

clicker question:
is there a feedback?

energy *coming in from the Sun*



$$F = \sigma T^4$$

energy *coming out from the Earth*

a) yes, positive

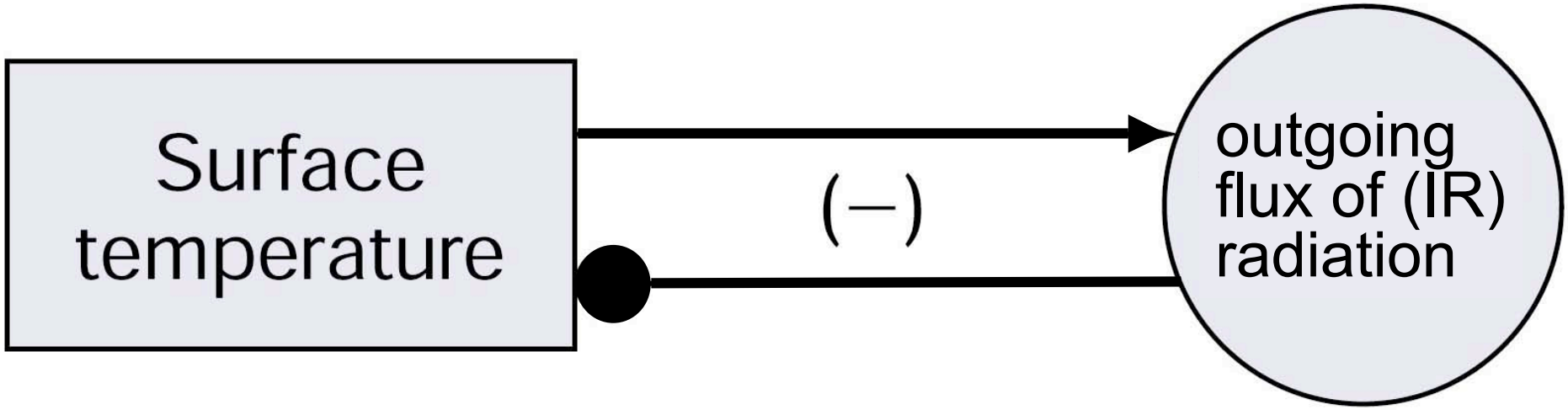
b) <u>yes, negative</u>

c) no, the system heats up forever

d) no, the system cools forever

e) can't tell (yet)

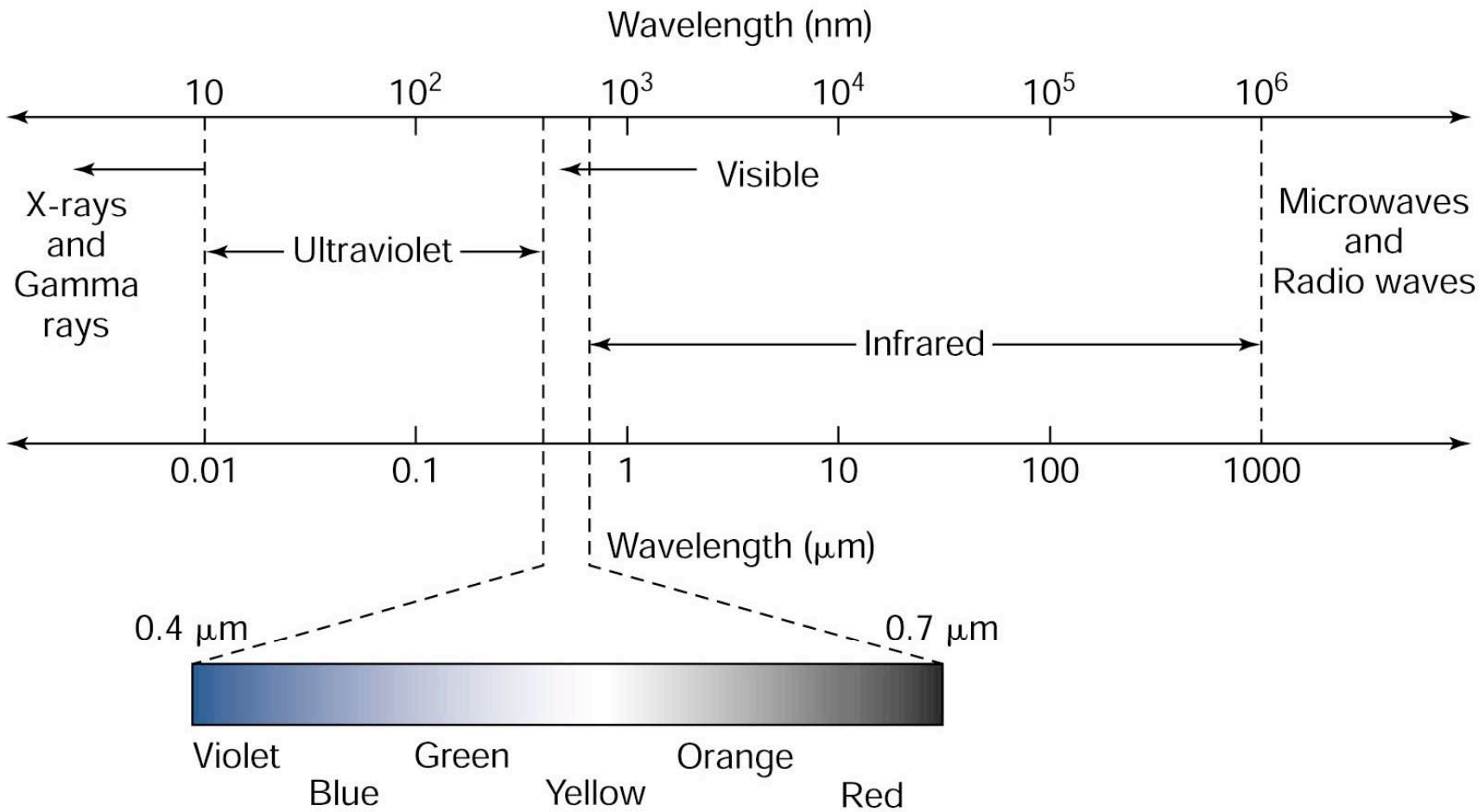
mother of all feedbacks



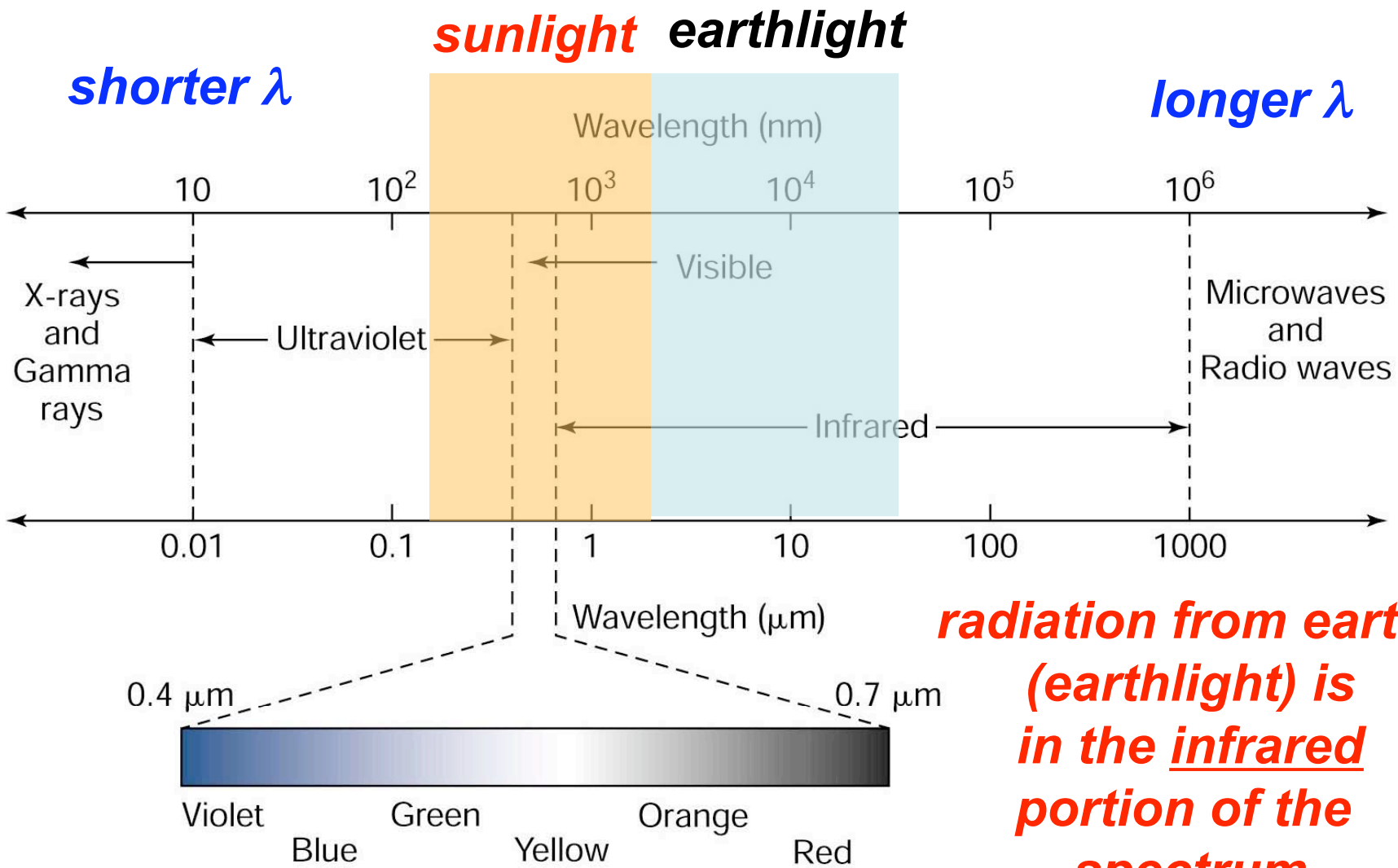
operates at all scales

without it we'd be toast, literally....

recall the spectrum of radiation



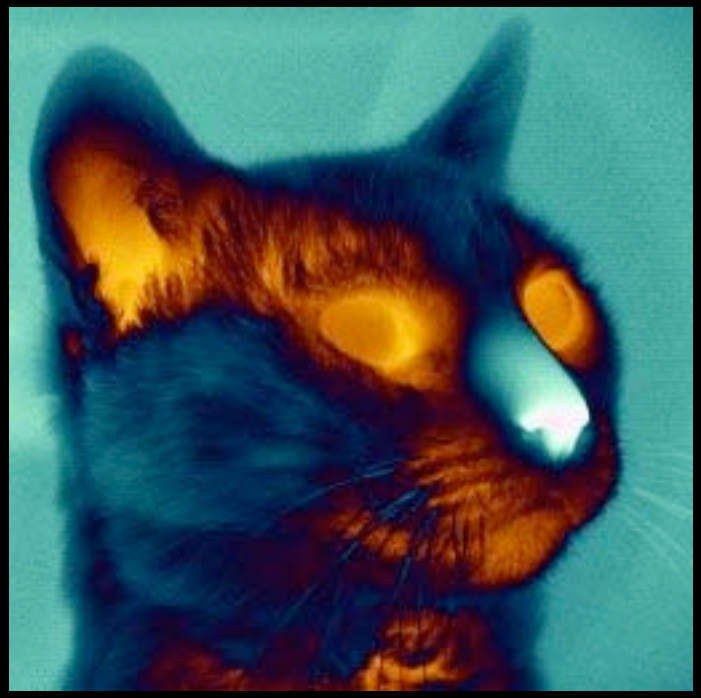
recall the spectrum of radiation



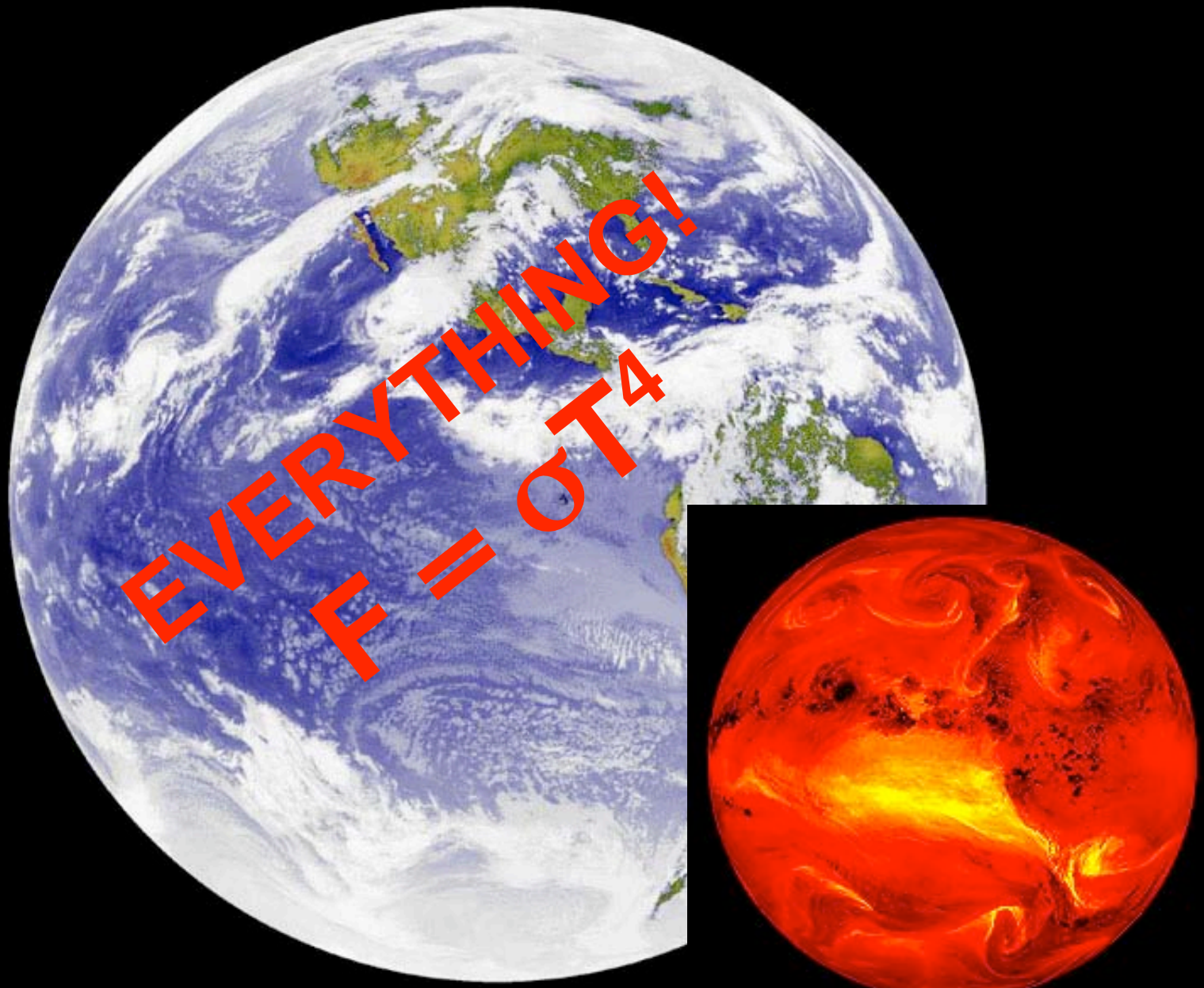
radiation from earth (earthlight) is in the <u>infrared</u> portion of the spectrum

energy coming in and going out is a system that is near equilibrium.....

what kind of radiation?



what does the emitting on Earth?



now we have basics needed to:

- investigate Planetary Energy Balance
- calculate the size of the natural Greenhouse Effect
- investigate the Global Energy Budget
- we'll start this next lecture
- reading: Ch. 3

must know terms and concepts

electromagnetic radiation
wavelength
frequency
photon
spectrum
long wave, short wave
infrared
energy or radiation flux
absorption
emission
the Stefan Boltzmann Law (what it tells us)
absolute temperature expressed in Kelvins
solar irradiance (= amount of solar radiation)