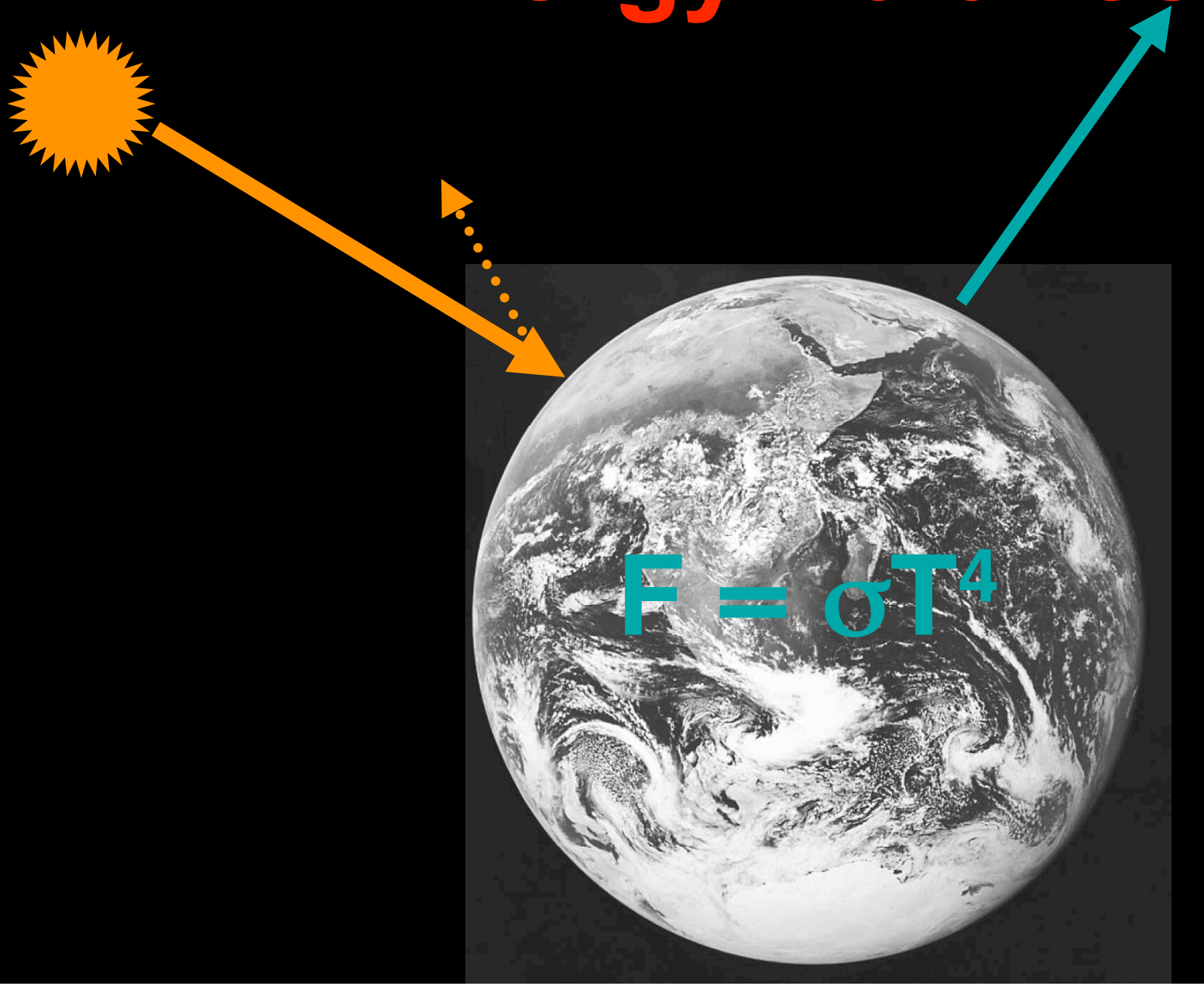
IV. Energy Balance



reminders from last class

- the Earth approximates a “blackbody”, both absorbing and emitting radiation
- the Earth receives incoming radiation from the Sun at relatively short wavelength (hi-energy)
- the Earth emits radiation at relatively long wavelengths (lower energy)
- Earth’s incoming and outgoing radiation are approximately in balance
- everything emits, i.e.:

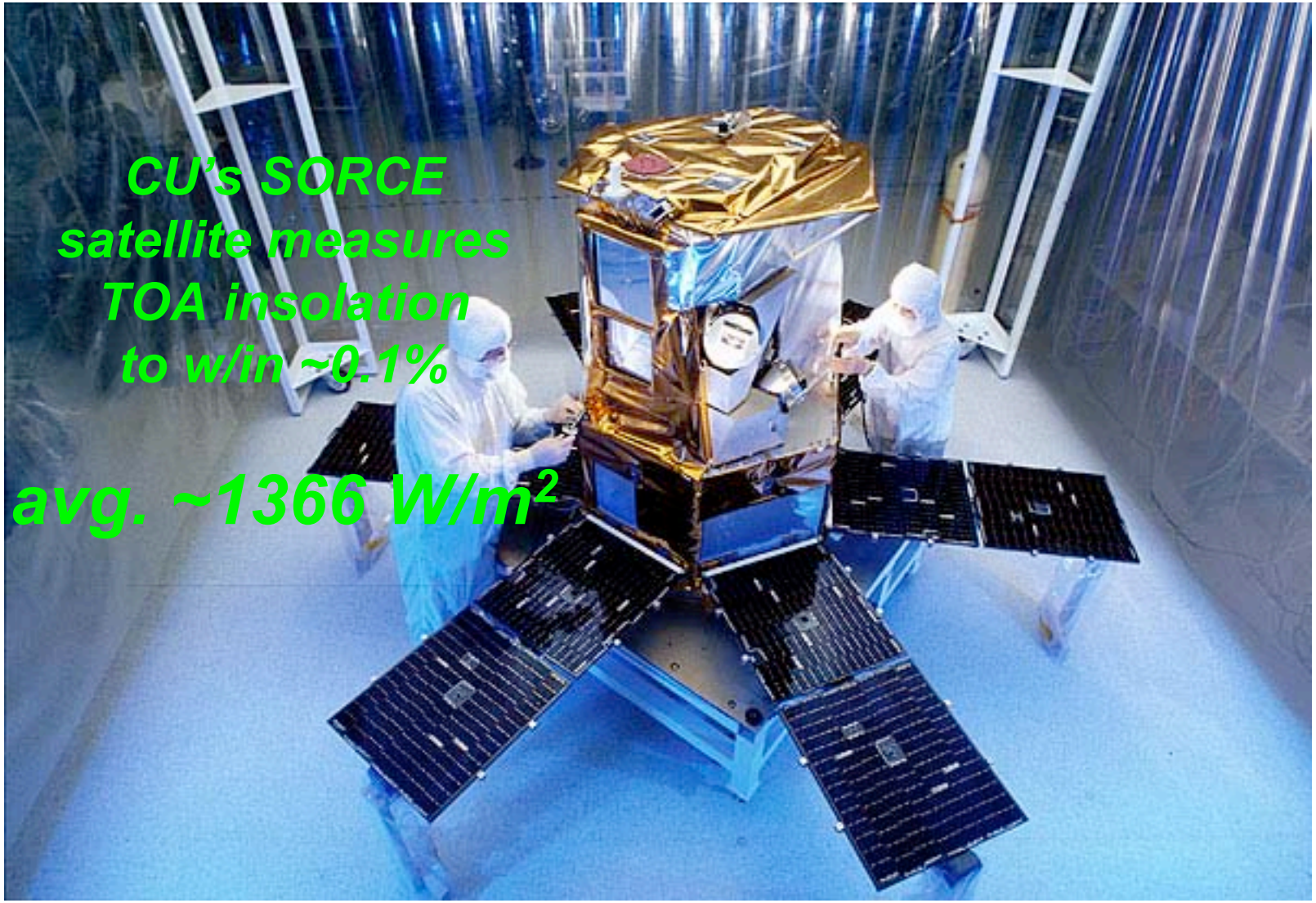
$$F = \sigma T^4$$

learning goals

- fates of incoming and outgoing radiation (transmission, reflection, and absorption)
- the concept of albedo (fractional reflectivity of a surface) incl. typical values of important surfaces
- the concept of energy balance
- mechanisms of selective absorption of radiation in the atmosphere
- knowledge of the main “Greenhouse gases”
- understanding of the origin and magnitude of the natural Greenhouse Effect

fates of incoming radiation

- ***last class we described solar radiation reaching the top of Earth's atmosphere***



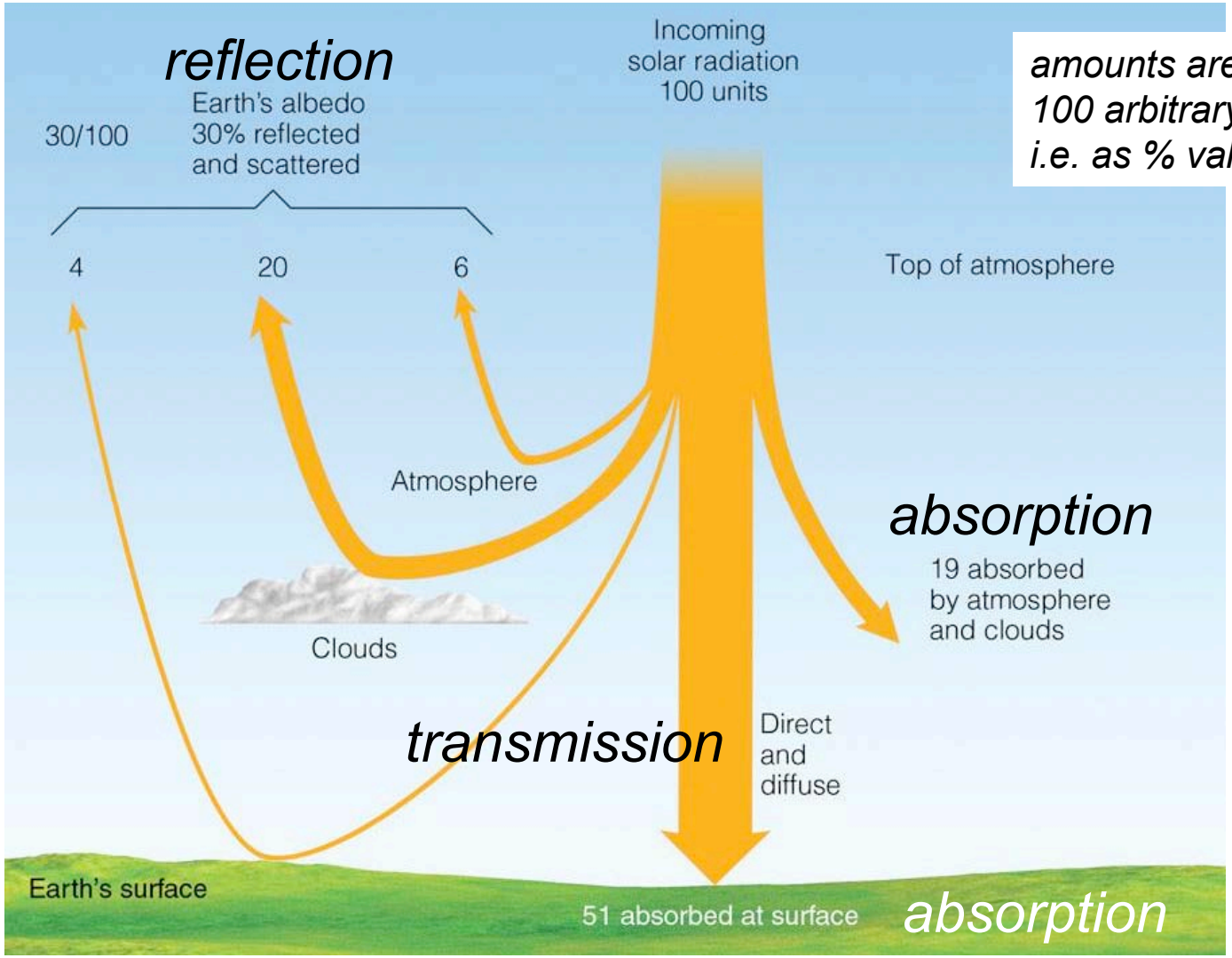
fates of incoming radiation

- ***last class we described solar radiation reaching the top of Earth's atmosphere***

what happens next?

fates of incoming radiation

about half is transmitted thru the atmosphere to the surface, and.....



amounts are given vs. 100 arbitrary units, i.e. as % values

fates of incoming radiation

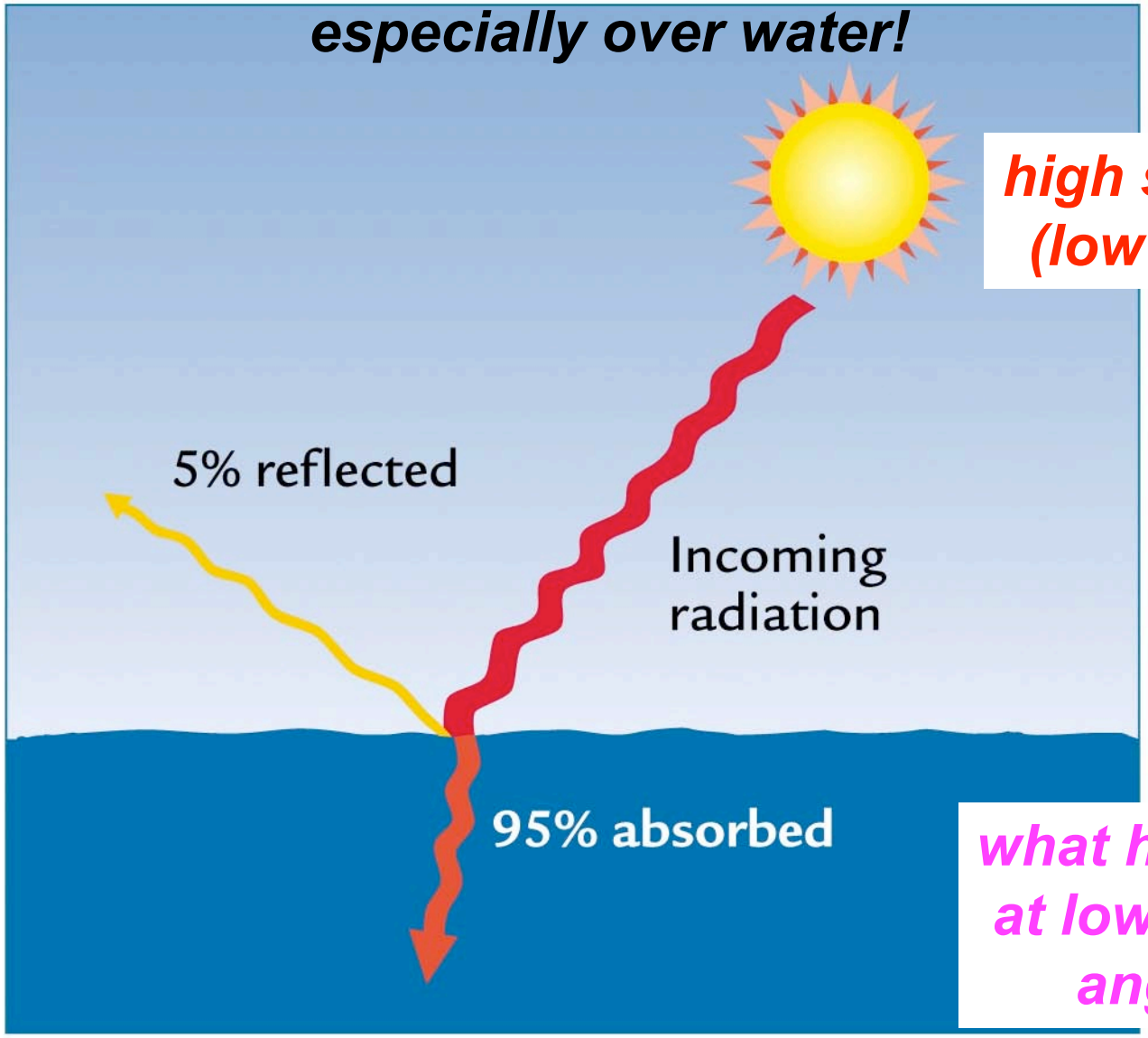
- ~30% of incoming radiation is ***reflected*** back to space
- this ***fractional reflectivity*** is called the ***albedo***
- the ***global*** or ***planetary albedo*** is the fractional reflectivity of the Earth system as a whole
- in fact, all components of the Earth system have their own albedo
- what is the albedo of some typical components?

albedo (fractional reflectivity, α)

Type of Surface	*Albedo*
Sand	0.20–0.30
Grass	0.20–0.25
Forest	0.05–0.10
Water (overhead Sun)	0.03–0.05
Water (Sun near horizon)	0.50–0.80
Fresh snow	0.80–0.85
Thick cloud	0.70–0.80
Low thin cloud	0.30-0.50

lighter surfaces have higher albedo than darker ones

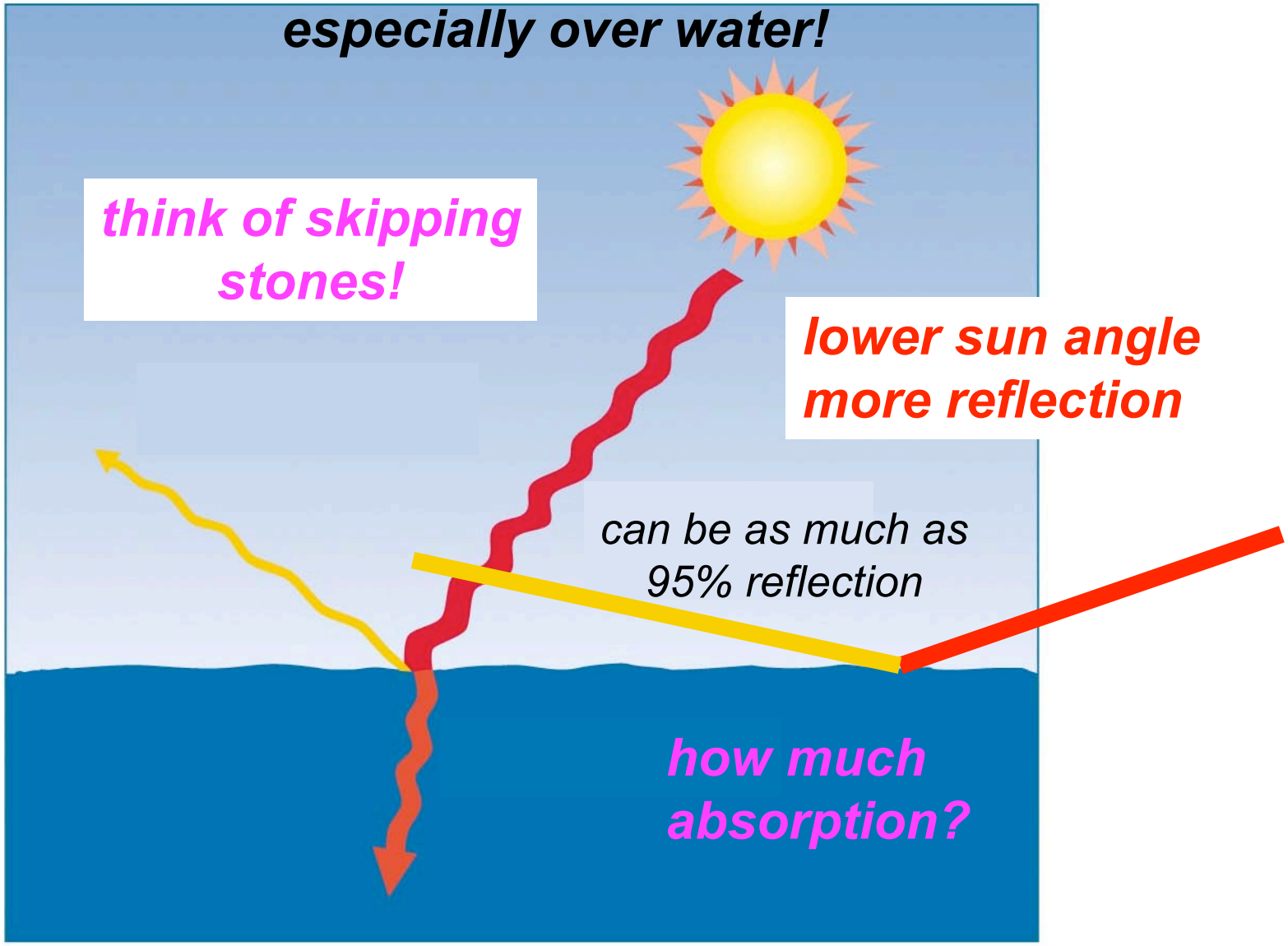
sun angle influences albedo



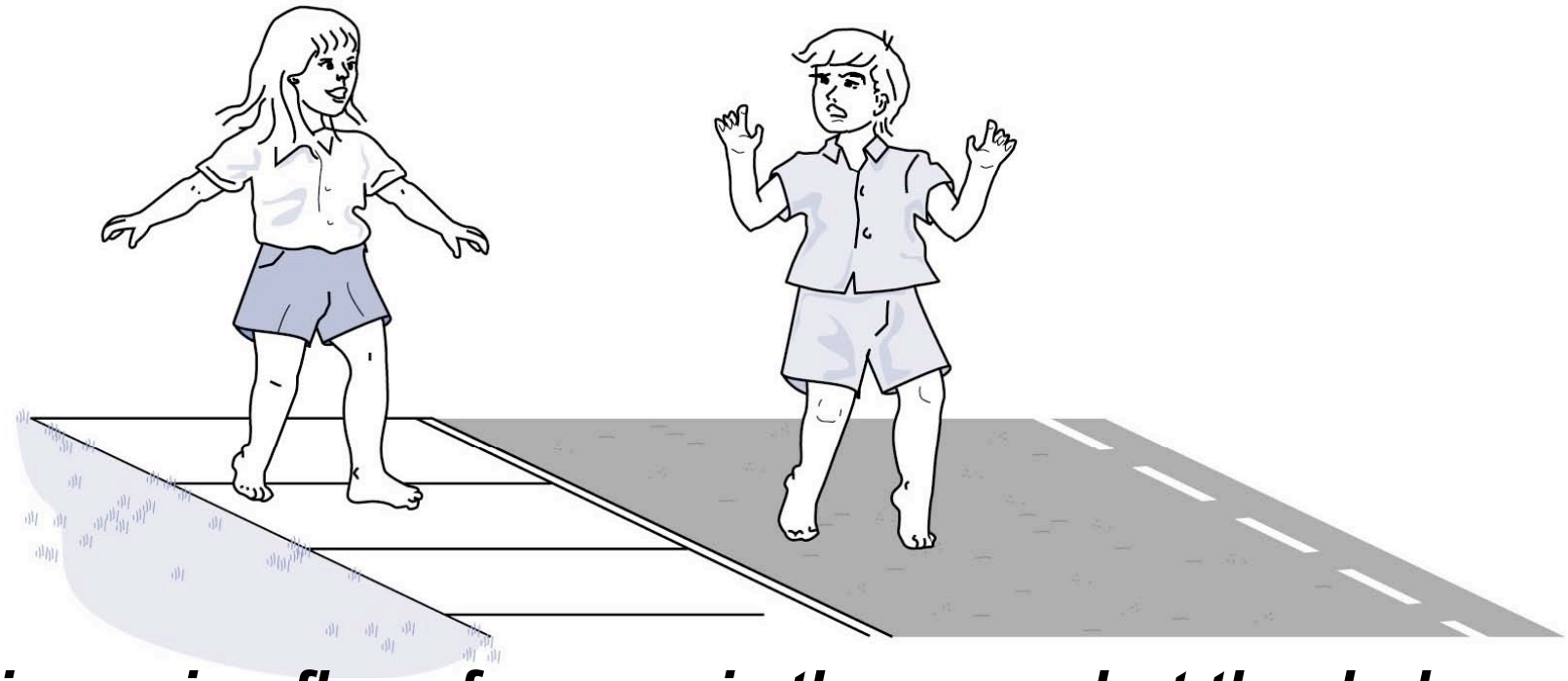
high sun angle (low latitude)

what happens at lower sun angle?

sun angle influences albedo



does albedo matter?

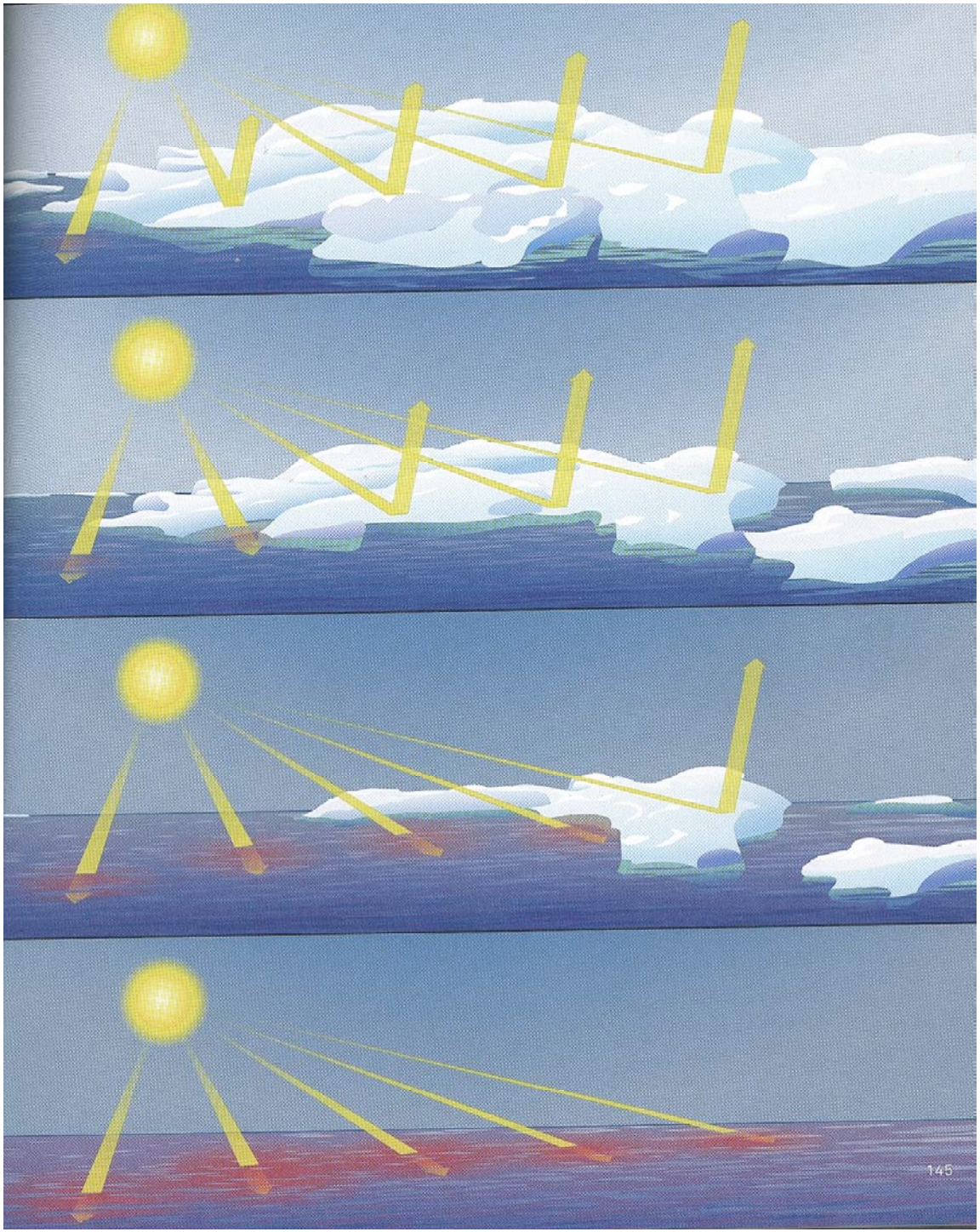


the incoming flux of energy is the same, but the darker surface is hotter

recall feedback process discussed last week ?

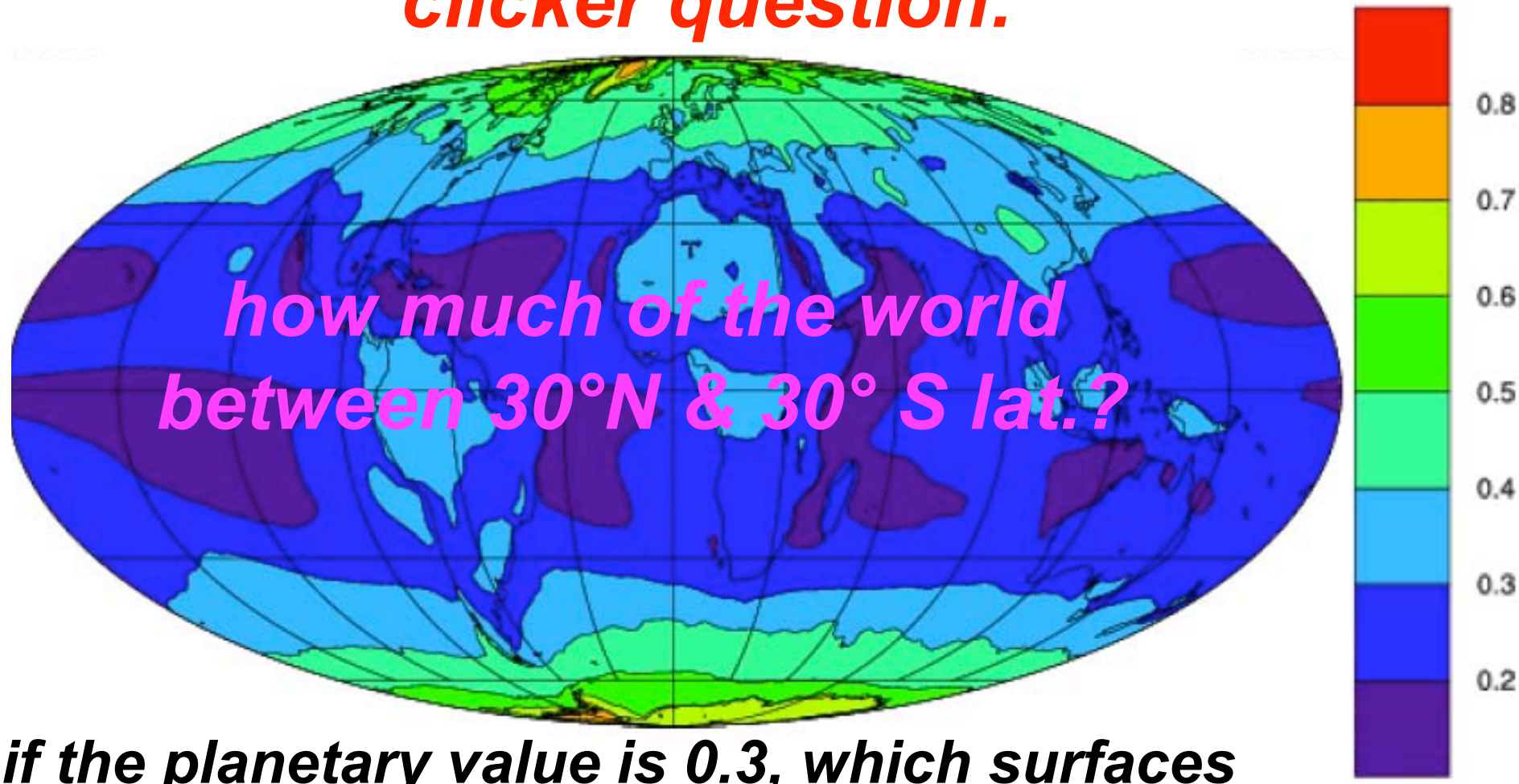
sea ice is bright and reflects ~90% of the suns rays, sea water is dark and absorbs ~90% of the suns rays.

source: A. Gore's "AIT"



global annual mean albedo fraction

clicker question:

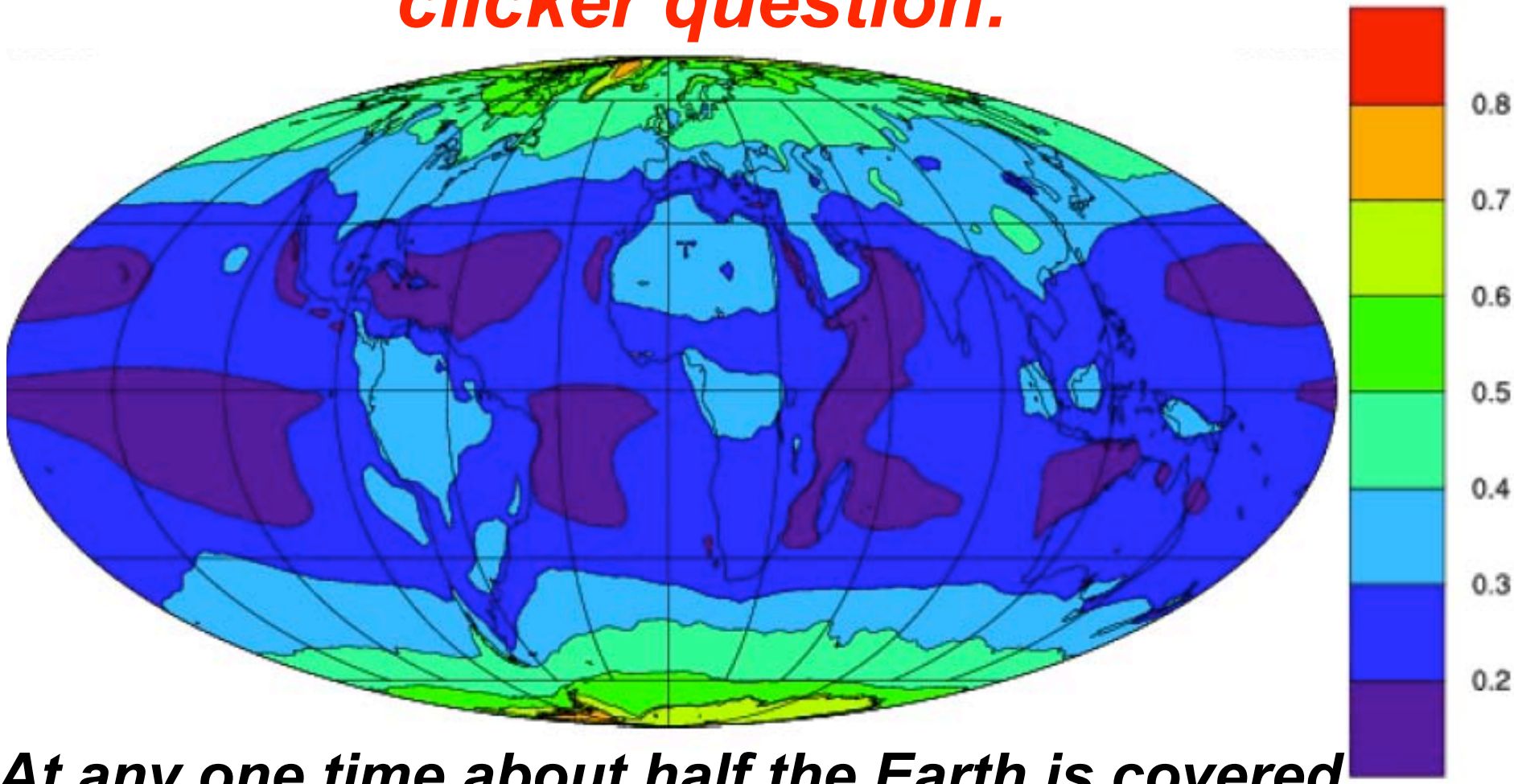


how much of the world between 30°N & 30° S lat.?

if the planetary value is 0.3, which surfaces contribute most by area to this average value a) ice, b) snow, c) vegetated ground, d) <u>oceans & clouds</u>, e) deserts

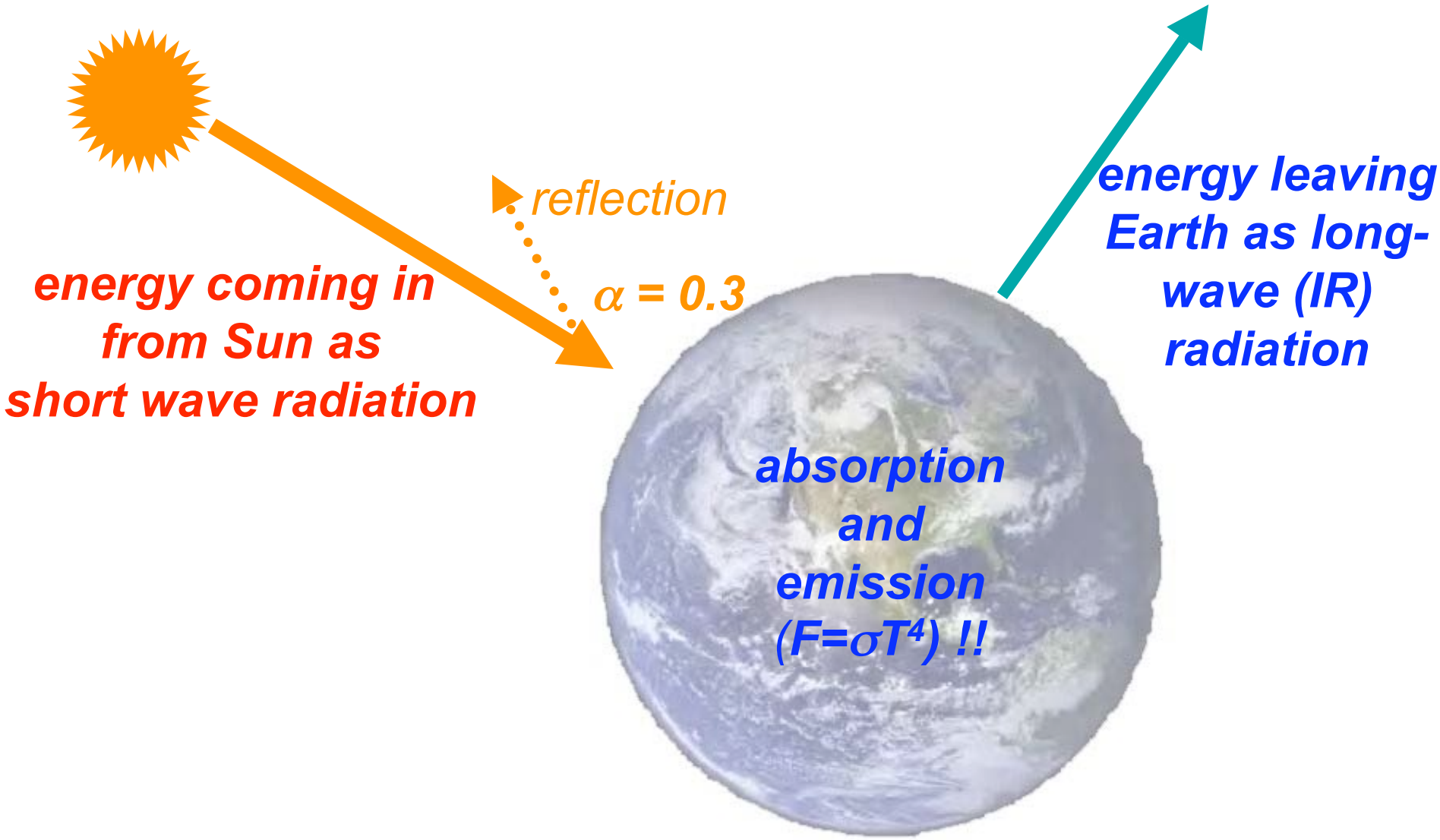
global annual mean albedo fraction

clicker question:



At any one time about half the Earth is covered in cloud. For this reason the annual average albedo of the two hemispheres is about the same despite the large difference in land area.

energy balance

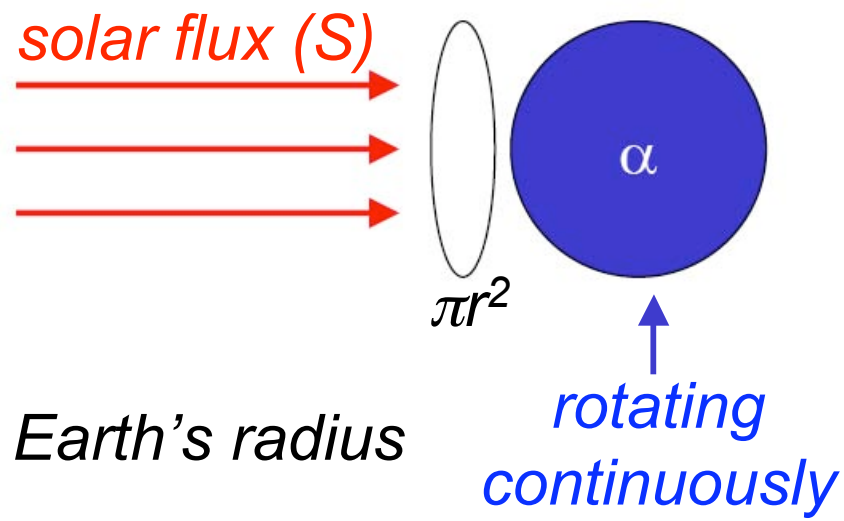


Earth's temperature will adjust so that fluxes of emitted and absorbed radiation will balance

radiative balance

the earth viewed from sun is a disc, so the solar input of energy is:

$$IN = S(1-\alpha) \times \pi r^2$$

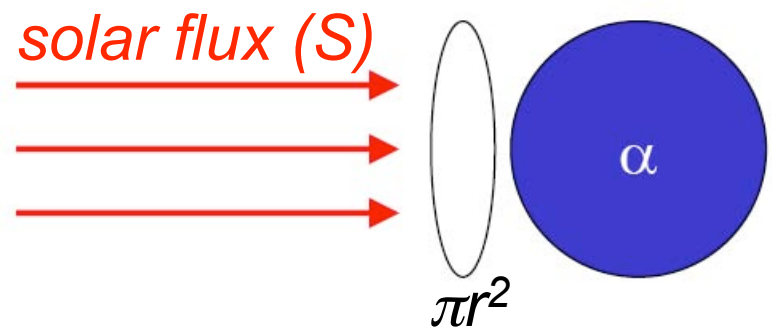


r *is Earth's radius*

radiative balance

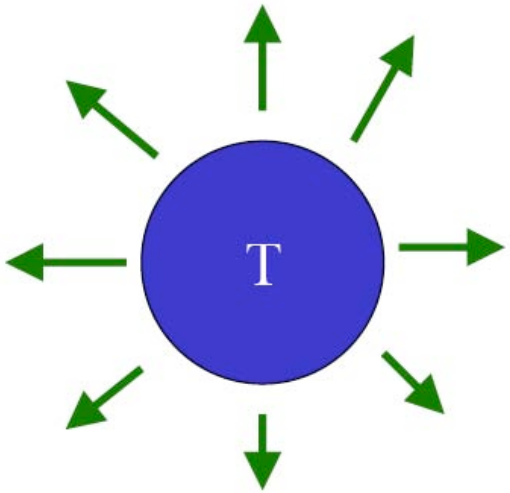
the earth viewed from sun is a disc, so the solar input of energy is:

$$IN = S(1-\alpha) \times \pi r^2$$



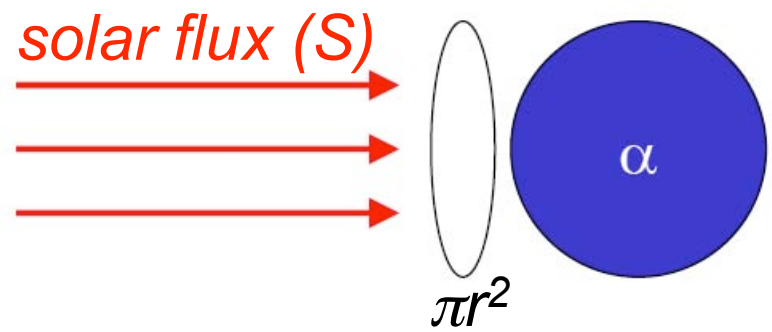
but the Earth as a blackbody radiates in all directions according to its temperature, so the energy out is:

$$F = \sigma T^4 \times 4\pi r^2$$
$$OUT = \sigma T^4 \times 4\pi r^2$$



Earth radiating in all directions, i.e. $4\pi r^2$

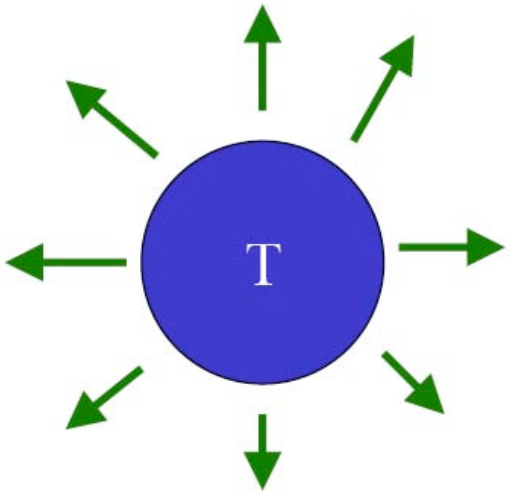
radiative balance



$$IN = OUT$$

$$S(1-\alpha) \times \cancel{\pi r^2} = \sigma T^4 \times 4\cancel{\pi r^2}$$

$$S(1-\alpha)/4 = \sigma T^4$$



Earth radiating in all directions, i.e. $4\pi r^2$

effective radiation temperature

- *we now have everything we need to determine what the Earth's temperature should be given the amount of radiation coming in from the Sun*

- *S, the solar radiation flux at the top of the atmosphere is 1360 W/m^2*

- *α, the planetary albedo is 0.3*

- *σ, the Stefan Boltzmann constant is known (and is in your text!)*

- *using $S(1-\alpha)/4 = \sigma T^4$, we can re-arrange the equation and solve for T, the temperature (on the Kelvin scale)*

effective radiation temperature

the calculated result is

255 K or -18 °C

what do you think the actual measured temperature of the Earth surface is??

effective radiation temperature

the calculated result is
255 K or -18 °C

but the measured temperature
is 288 K or +15 °C

33 °C (K) higher?

How can this be?

welcome to the greenhouse!

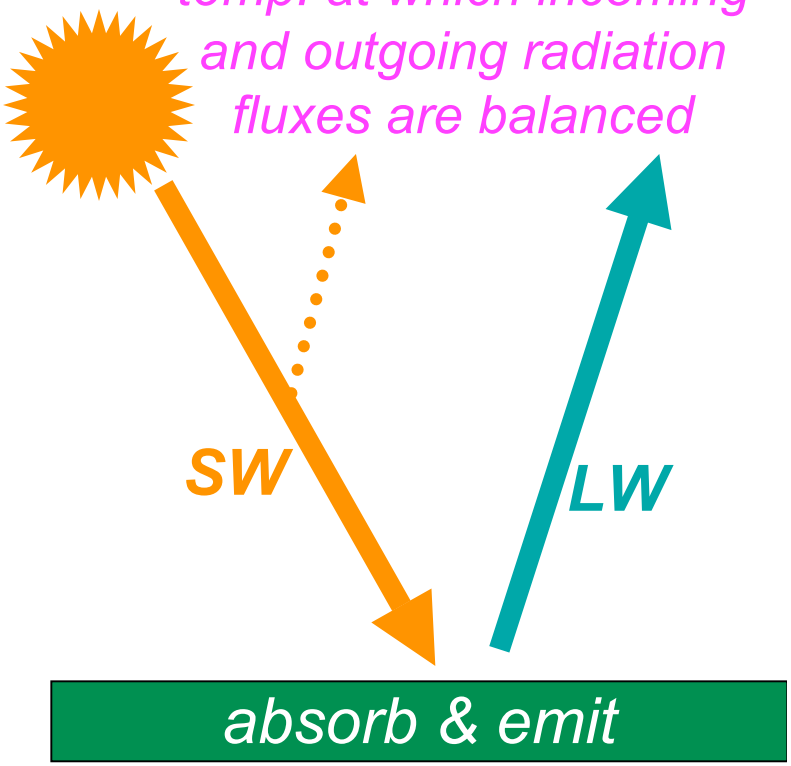
- this mathematical exercise demonstrates the existence of the ***natural "Greenhouse Effect"***

- as we shall now see, it is due to the envelope of atmospheric gases that absorb and re-emit radiation at specific wavelengths

- without it, the earth would be too cold to sustain life as we know it.....

welcome to the greenhouse!

Stefan Boltzmann Law helps us describe temp. at which incoming and outgoing radiation fluxes are balanced

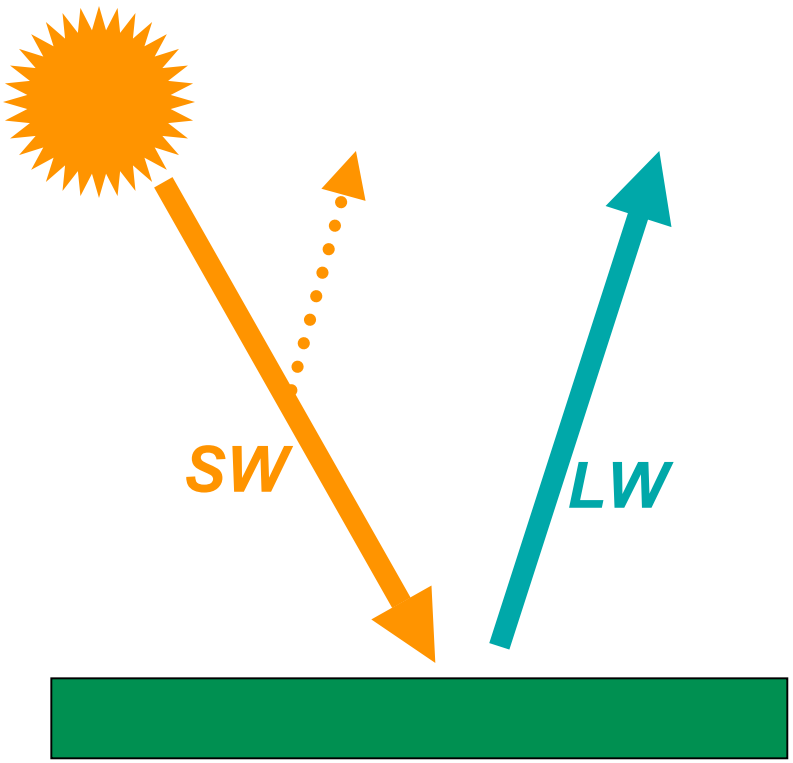


$F=\sigma T^4$!!

w/o atmosphere

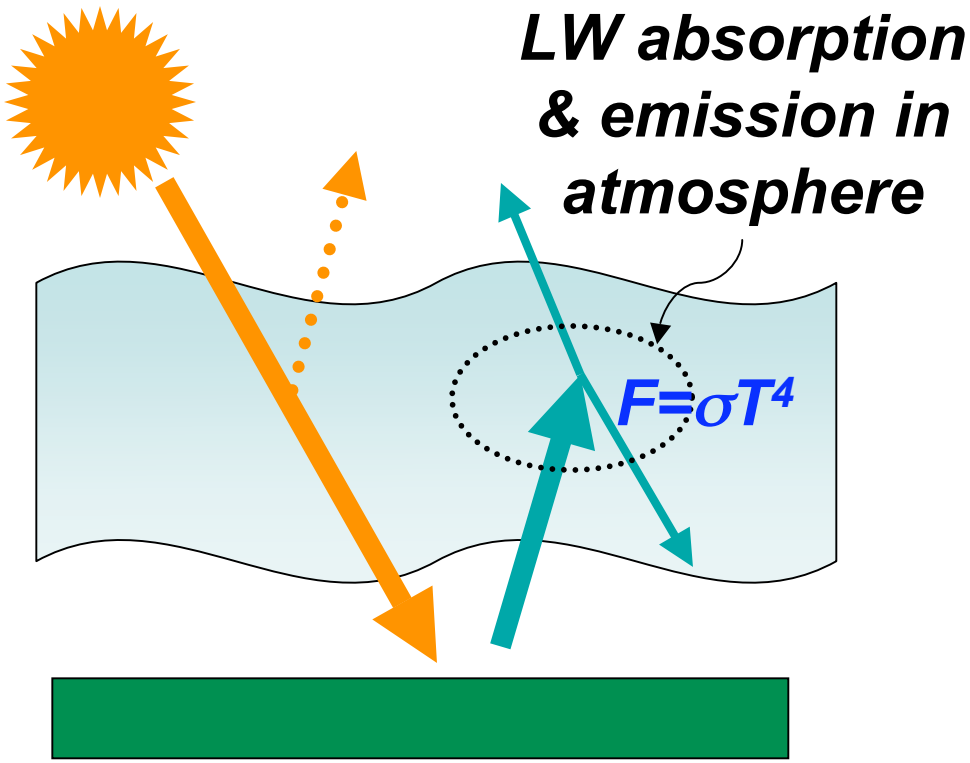
T = -18 °C

welcome to the greenhouse!



$F=\sigma T^4$!!

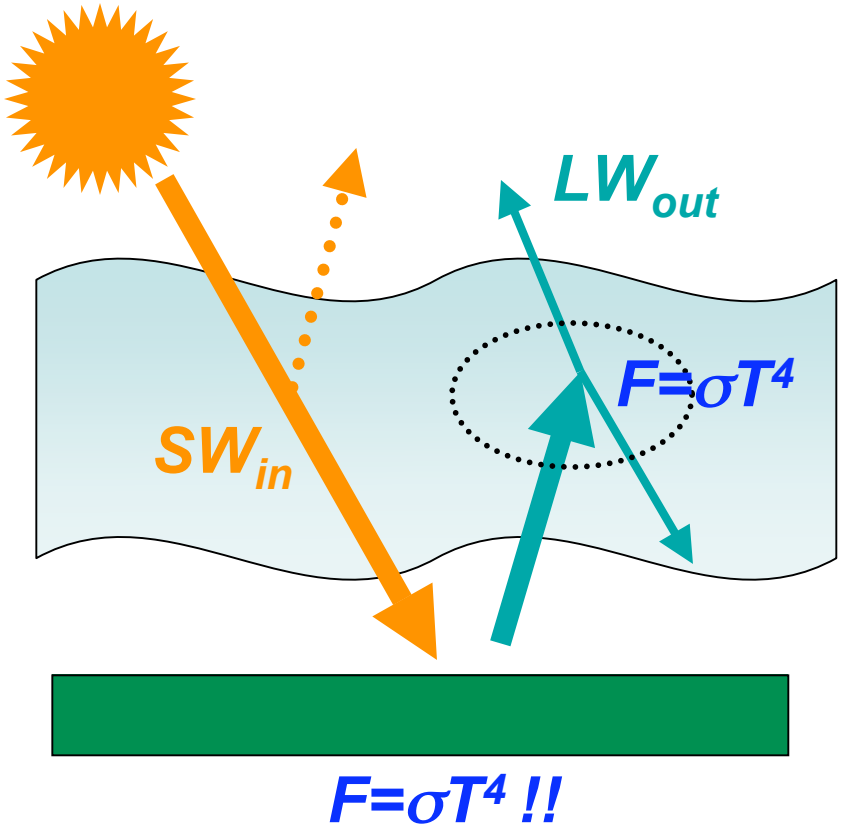
w/o atmosphere
T = -18 °C



$F=\sigma T^4$!!

w/ atmosphere
T = 15 °C

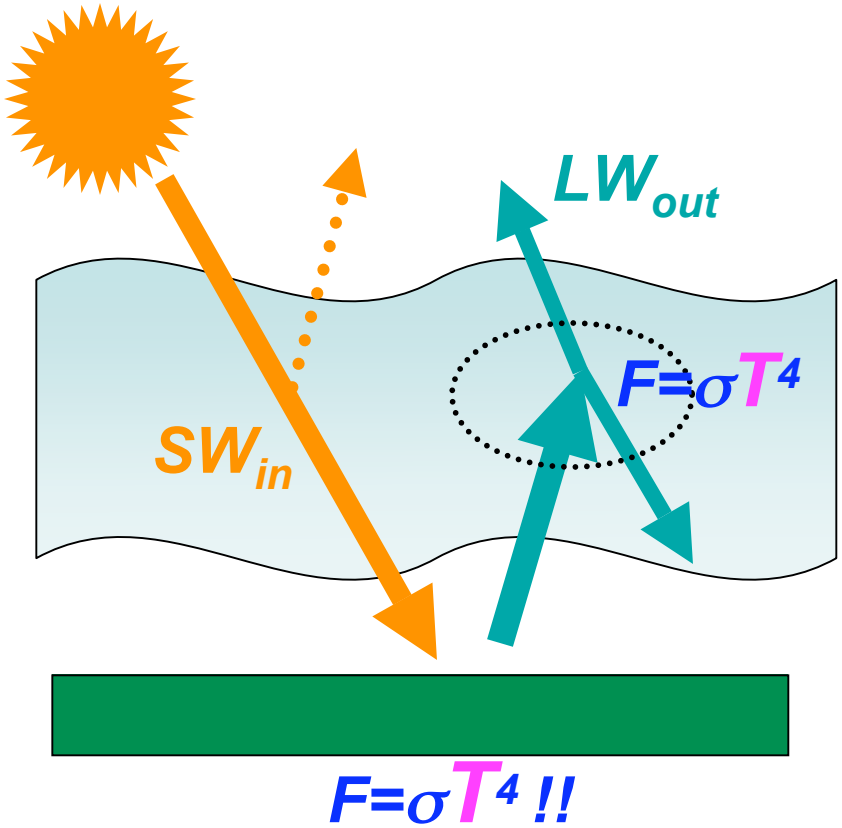
what must happen?



the incoming flux of SW radiation and outgoing flux of LW radiation are briefly out of balance

what must happen to restore balance?

what must happen?



toggle this!

the incoming flux of SW radiation and outgoing flux of LW radiation are briefly out of balance

T must go up = Greenhouse Warming

what is a greenhouse gas?

- unlike solids (blackbodies), gases are *selective* absorbers and emitters of radiation

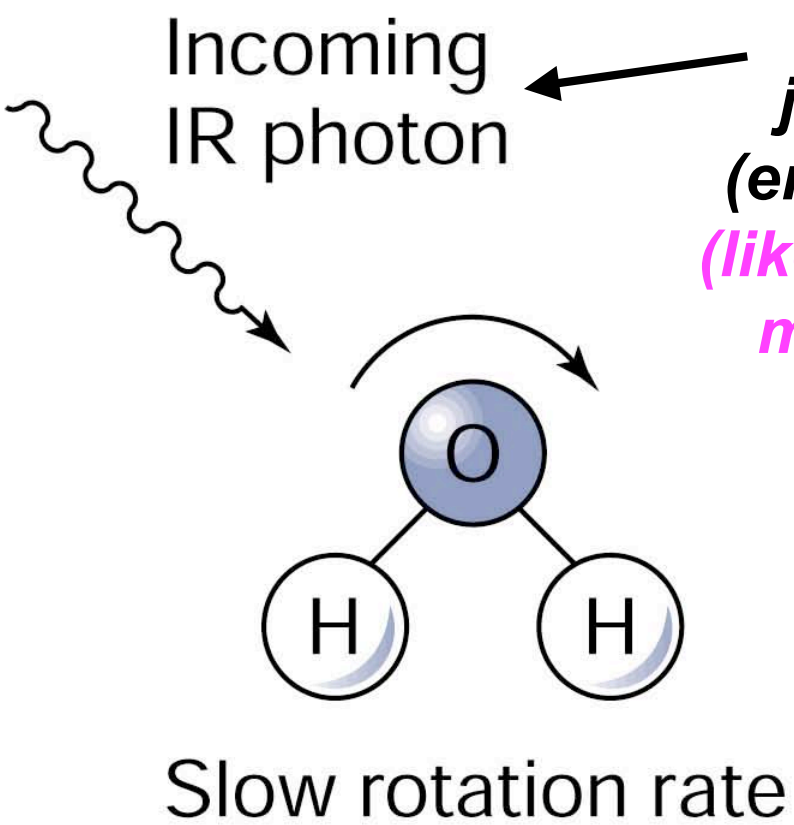
- greenhouse gases are generally transparent to SW (incoming) radiation, but opaque to some LW Earth (outgoing) radiation

what are the important GH gases

• H_2O (water vapor)	evaporation & precipitation
• CO_2 (carbon dioxide)	biology, human activities, biomass burning
• CH_4 (methane)	human activity (dumps, cattle), wetlands
• O_3 (ozone)	solar absorption, chemical destruction
• N_2O (nitrous oxide)	microbes, lightning, biomass burning,fertilizers
• CFC-11&12	refrigerants

(more next time on concentration relative to other gases in atmosphere)

how does absorption work?

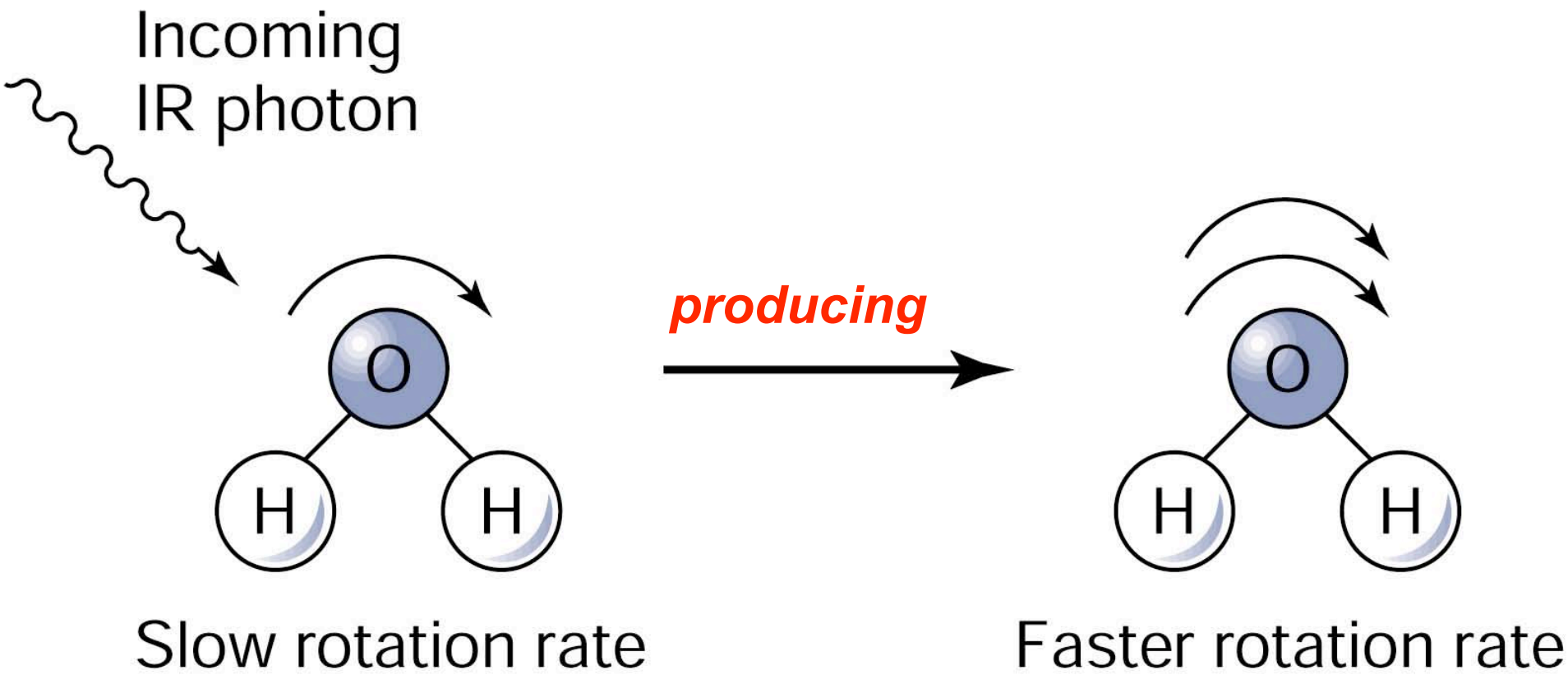


one that has just the right wavelength (energy) to interact with H_2O

(like your microwave, but with much shorter wavelength)

consider water vapor

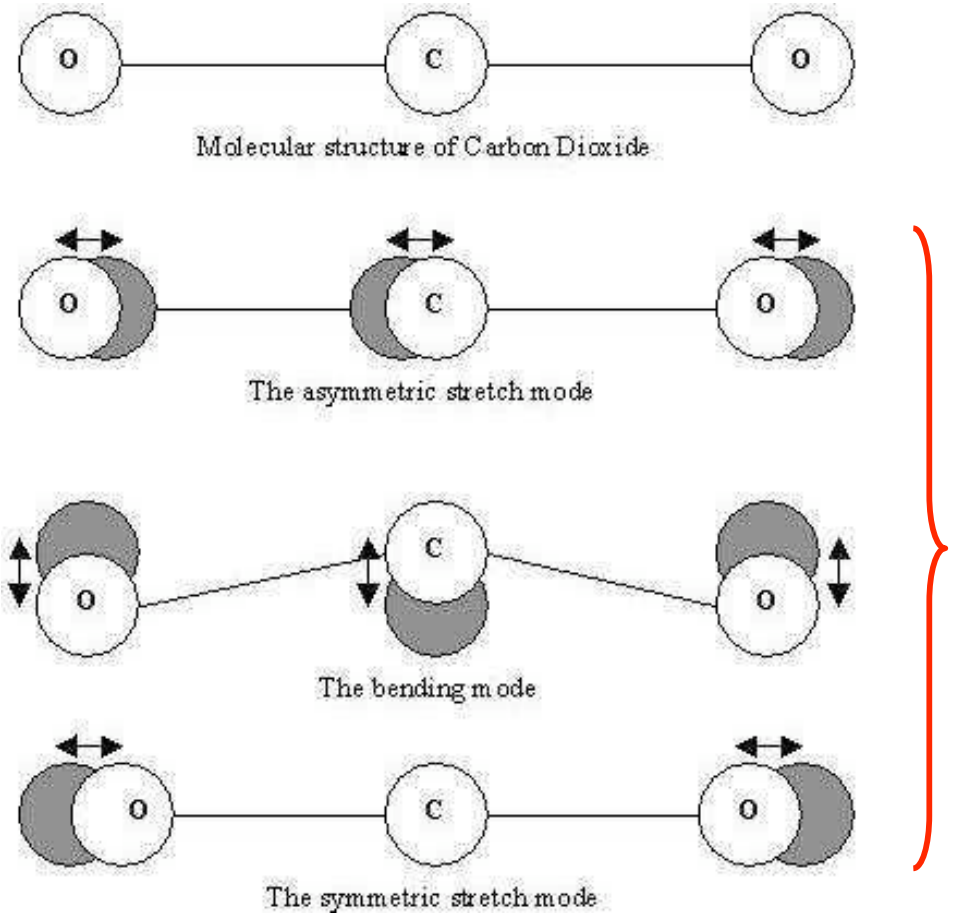
how does absorption work?



the now faster molecule has more energy,
and can re-emit radiation to loose that energy

absorption by CO_2

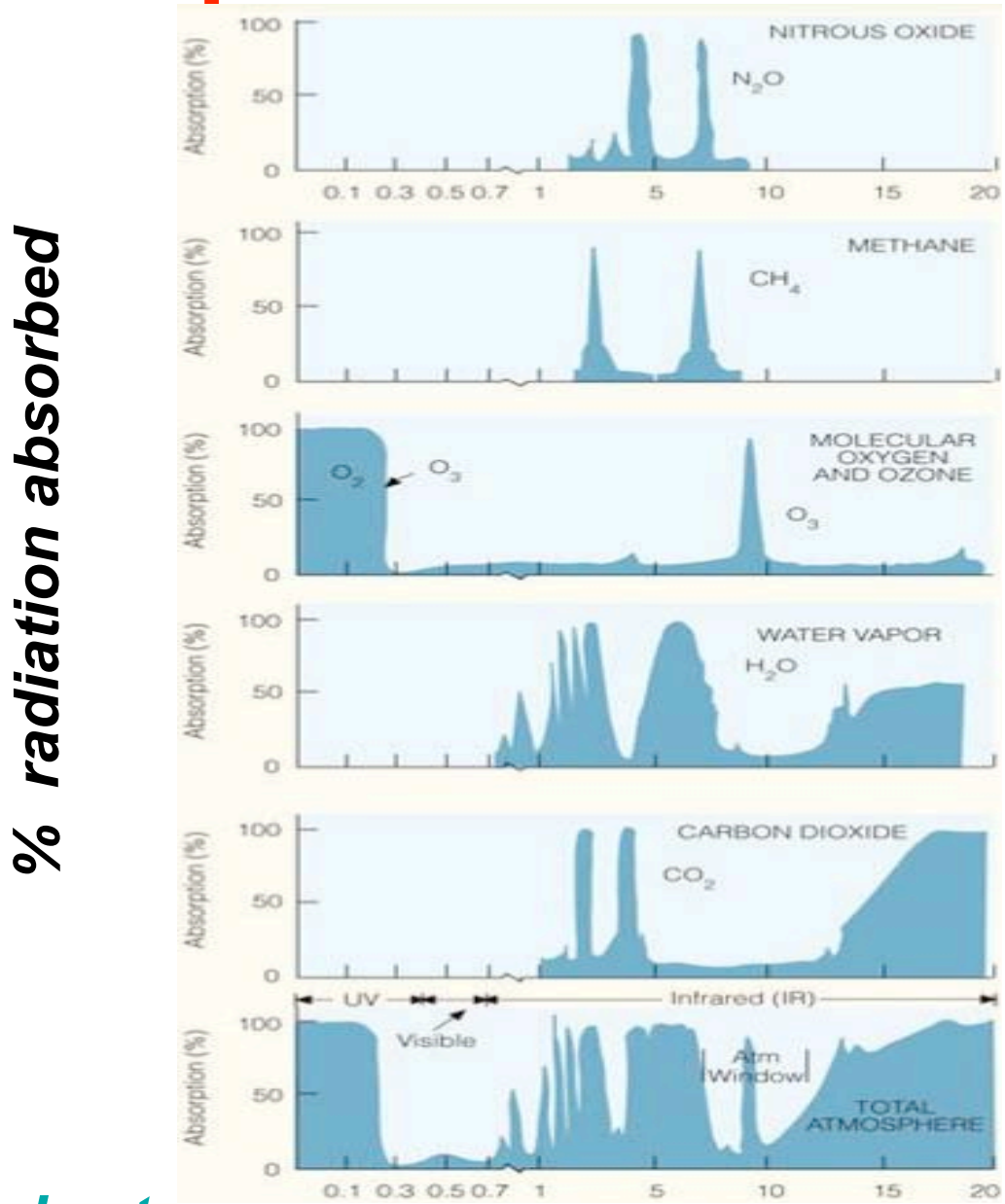
IR photon (~15 μm)



more energetic

photon of select "wavelength" is absorbed to produce vibration and bending, adding energy that can be re-emitted as LW radiation

absorption in the atmosphere

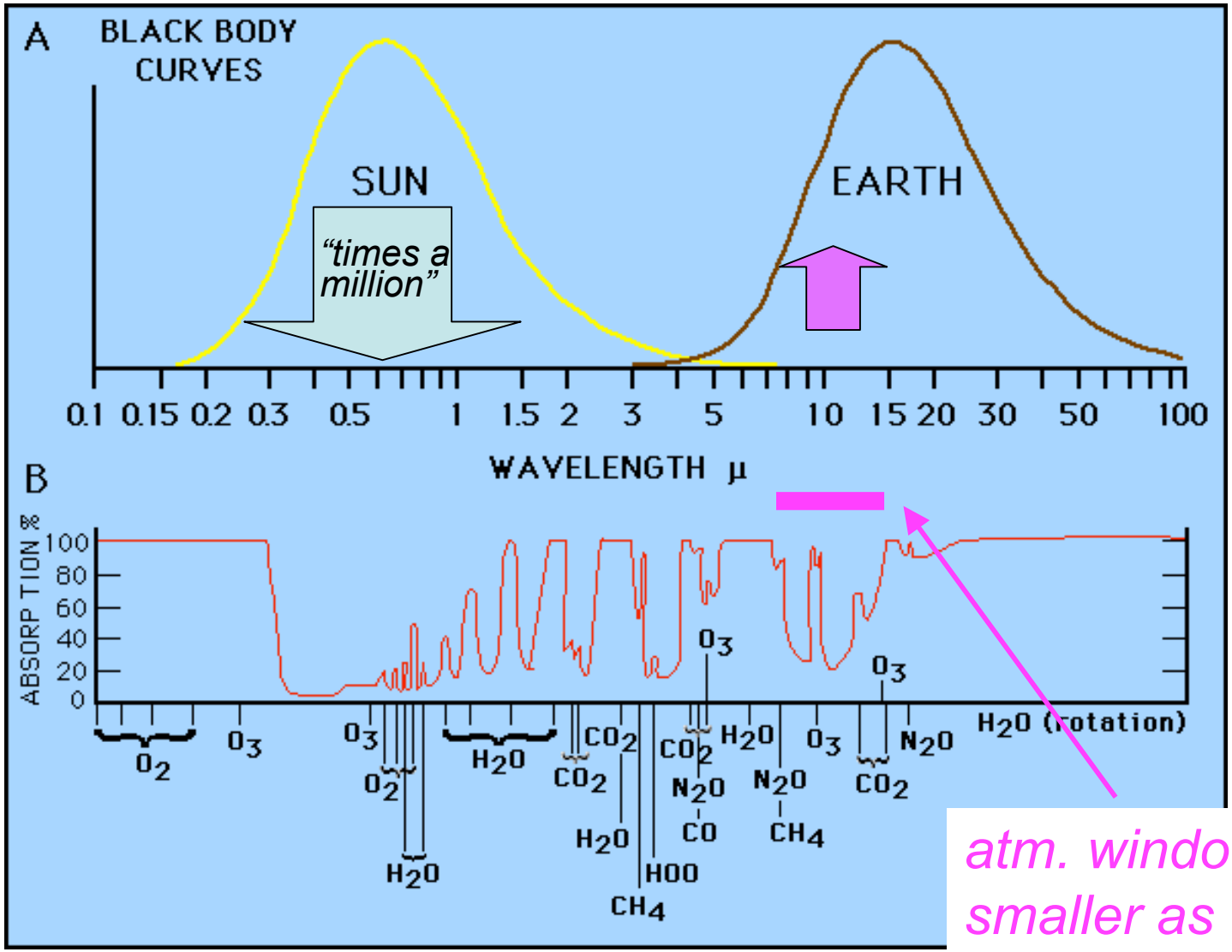


% radiation absorbed

what is this graph telling us?

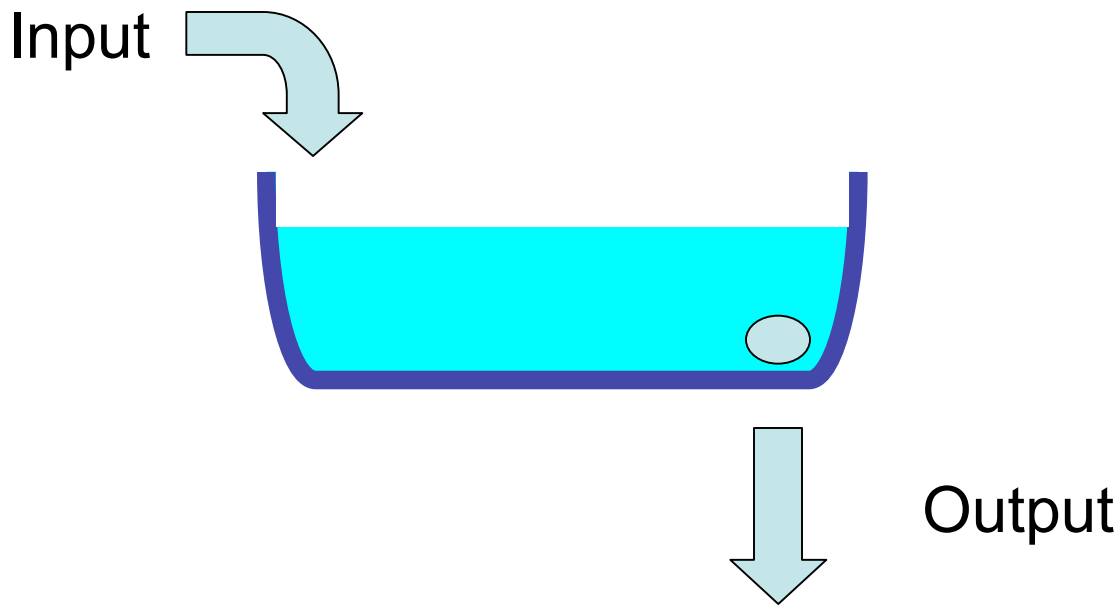
shorter *wavelength (μm)* *longer*

absorption in the atmosphere



atm. window gets smaller as GHGs are added

bath tub

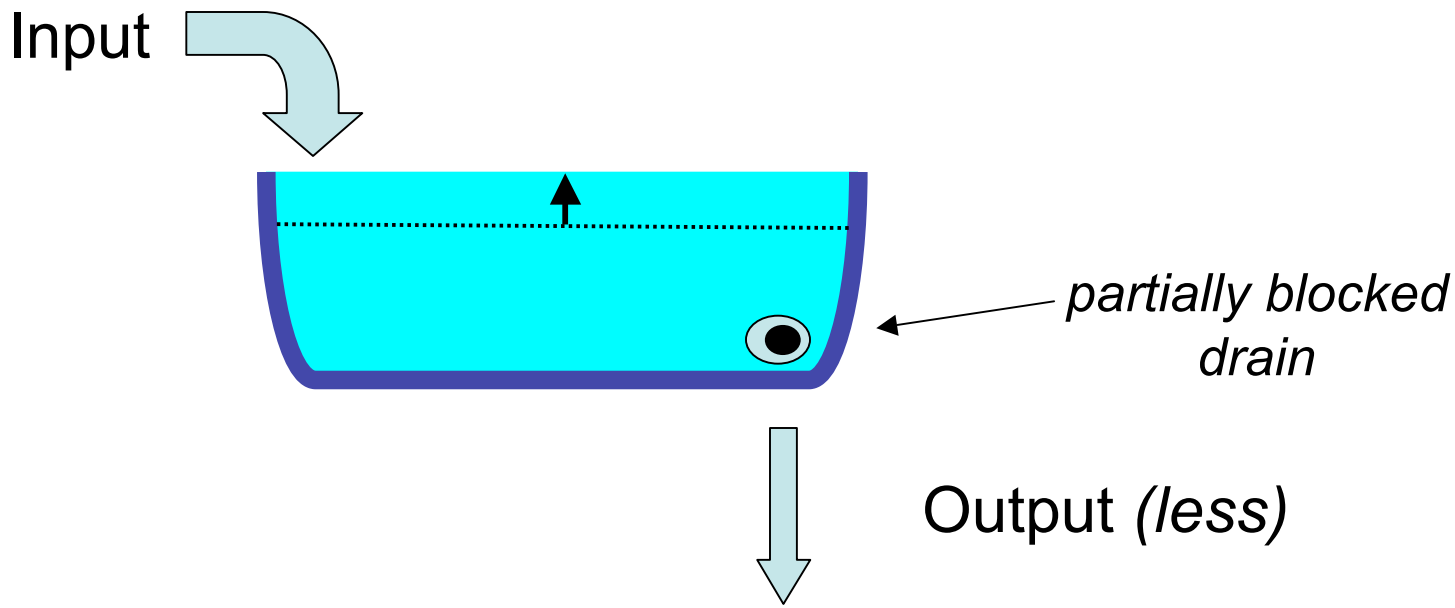


when the flow of water into the tub equals the flow out of the tub, the water level does not change

steady state conditions:

input = output

“greenhouse” bath tub

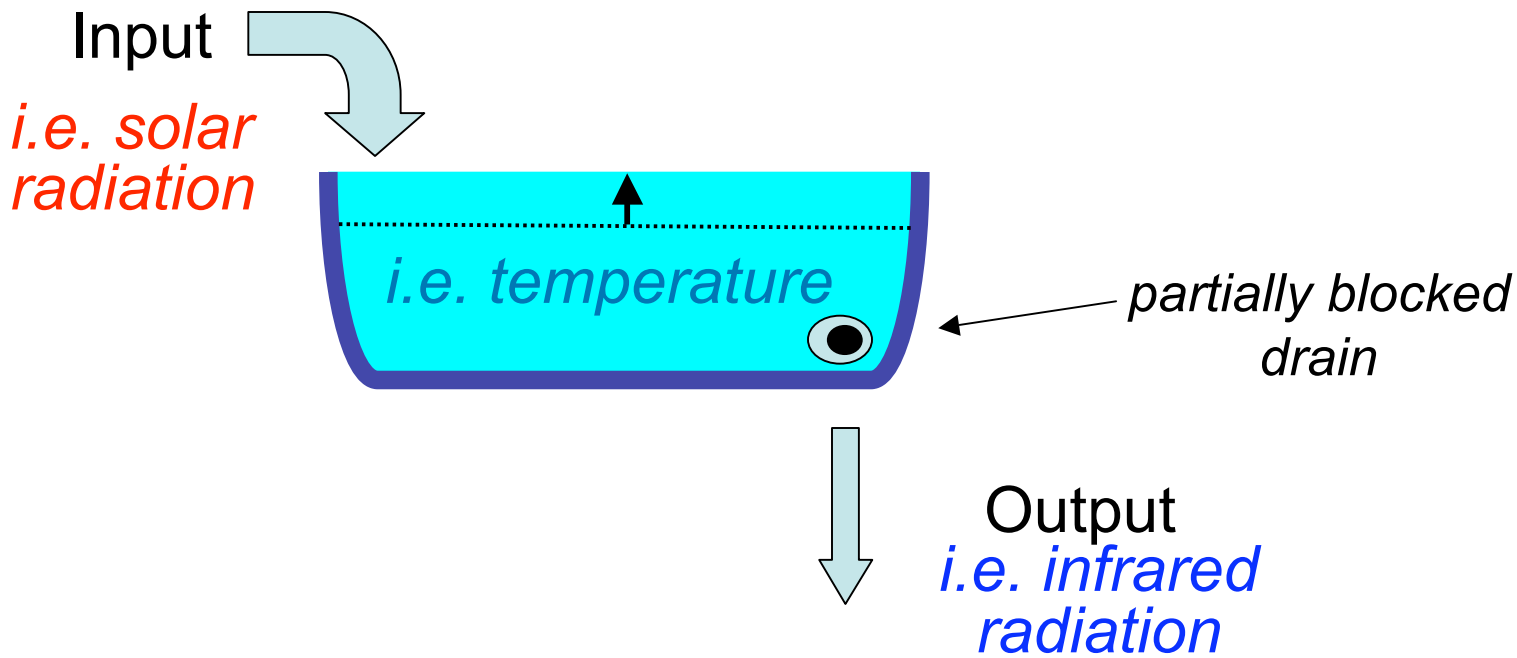


when the flow of water into the tub exceeds the flow out of the tub, the water level rises

in this system the water level rises forever

what happens in the climate system?

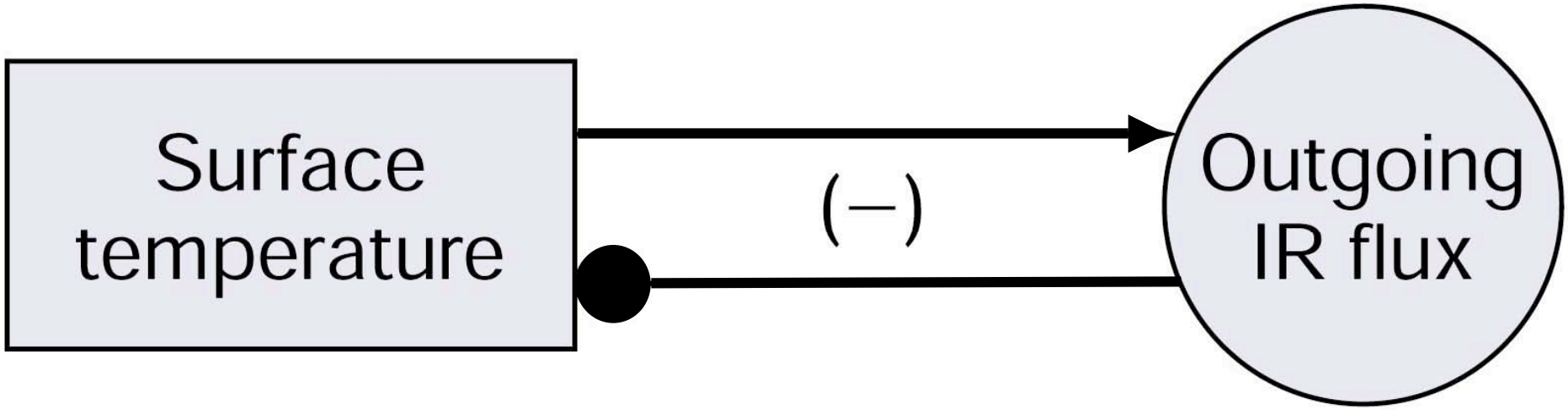
clicker question



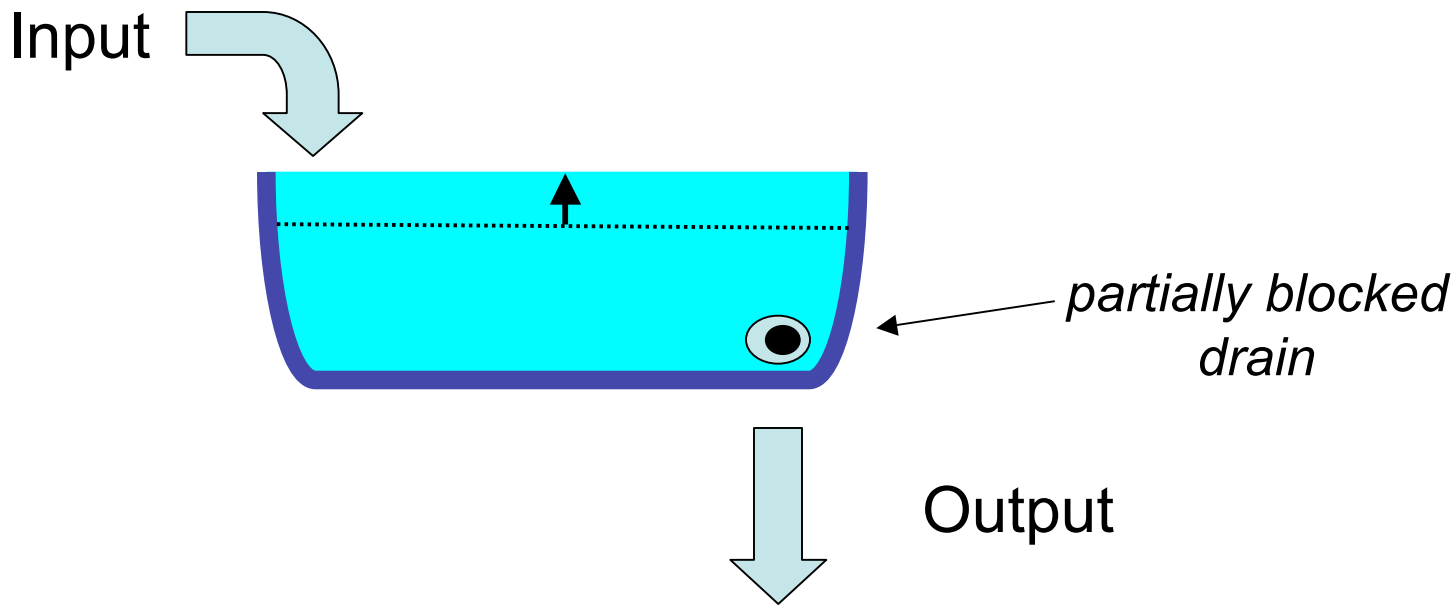
The water in this system rises forever. Using the analogy to the climate system we have developed, what process would allow the water depth to stabilize at a new level?

a) the input would adjust downward, b) the output would adjust upward, c) the temperature-infrared feedback would kick in, d) both a and c, e) both b and c.

mother of all feedbacks



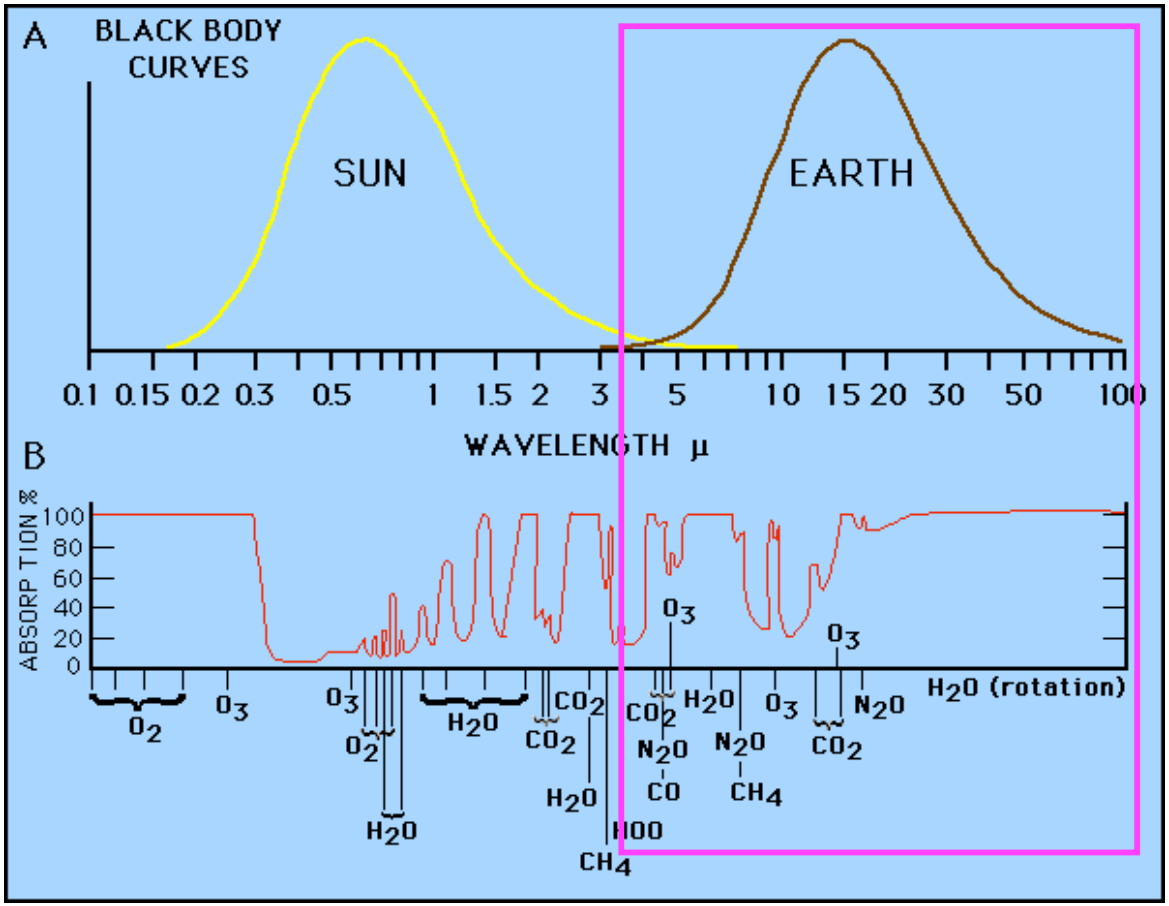
“greenhouse” bath tub



the output “pressure” effectively goes up through the operation of the temperature - infrared feedback ($F = \sigma T^4$!) but the new water level (i.e. temperature) is now higher than before

the real deal….

let's now use an on-line radiation model to see how the greenhouse really works….



Go to: http://forecast.uchicago.edu/Projects/modtran.html

In class we used the textbook author's online radiation model in order to demonstrate

1) how the addition of greenhouse gases influences the spectrum and amount of outgoing infrared radiation and

2) how changing surface temperature influences the amount of outgoing infrared radiation.

We found that we needed to raise surface temperature in order to maintain balance between incoming and outgoing radiation after greenhouse gases were added to the model atmosphere.

clicker question:

Which of the following gases would ABSORB radiation

A. Water vapour (H_2O)
B. Carbon dioxide (CO_2)
C. Ozone (O_3)
D. All of the above
E. None of the above

clicker question:

Which of the following gases would EMIT radiation

A. Water vapour (H_2O)
B. Carbon dioxide (CO_2)
C. Ozone (O_3)
D. All of the above
E. None of the above

key points

- we have demonstrated the magnitude and mechanism of the natural greenhouse effect!
- we have described the major heat flows within the global energy budget!

- ***next week:***
- we begin with a look at ***atmospheric composition and structure***
- reading: Ch 4 pp. 44-53 & Ch 19 pp 381-2.
- ***Homework: posted tonight, due Tuesday!***