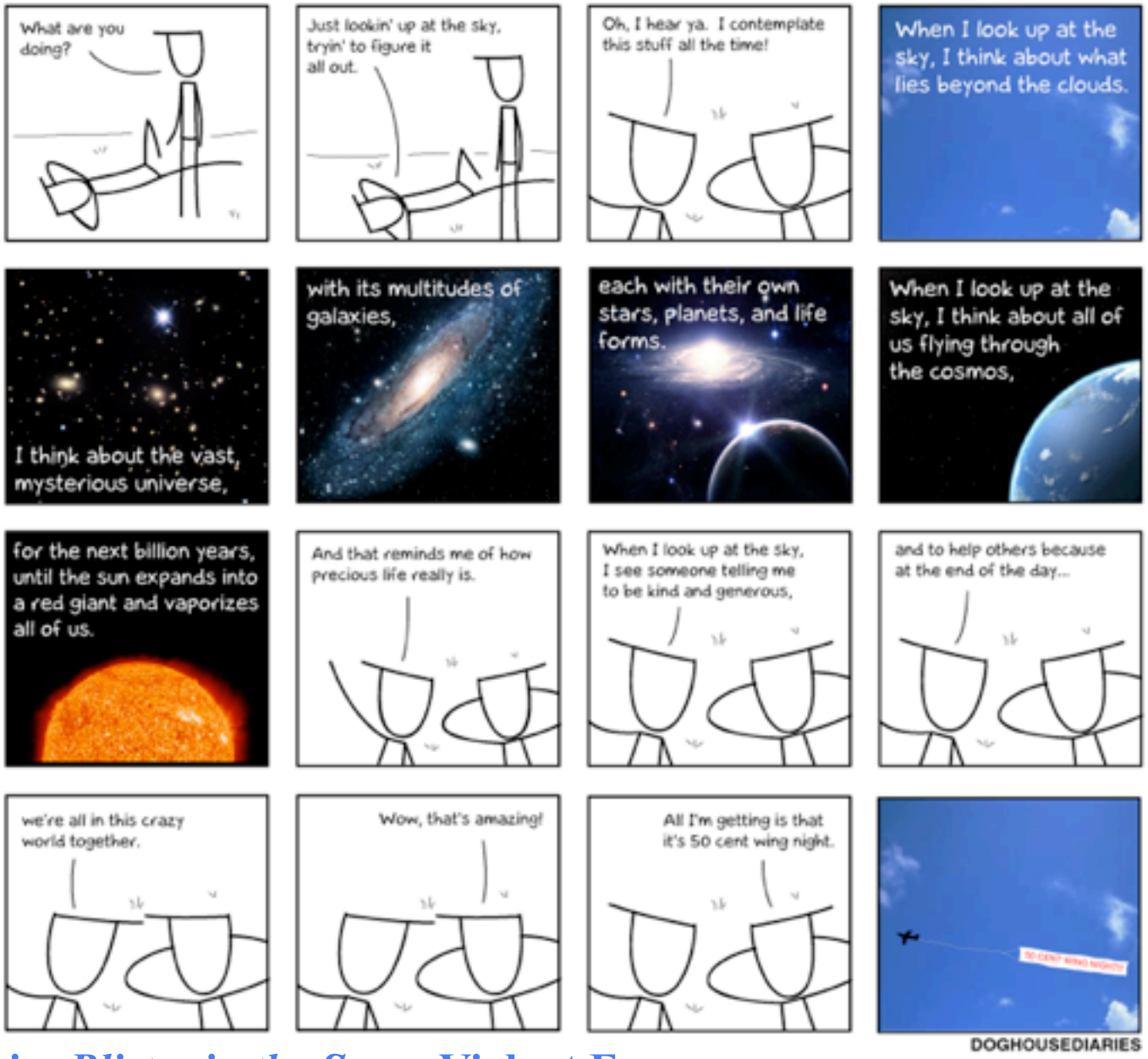
ASTR 150

- **Homework 4** due tonight
- Night Observing starts tonight
- Exam 1 Friday!

- Last time: The Sun 2
- Today: The end of the Sun



Music: *Blister in the Sun* – Violent Femmes

Hour Exam 1

Hour Exam 1 Friday, Oct 11, in class

information on course website

40 questions (cover material up to today)

May bring 1-page of notes

- both sides
- printed, handwritten, whatever

Most useful study materials

class notes

iClicker questions

homework questions

study guide

old exam

Focus on concepts, main ideas

Night Observing

Night Observing stars this week

- if you do it, need to go one night
- allow about 1 hour

When: Mon-Thurs, 7-9pm

3 observing stations:

- Large telescope in observatory dome
- 2 outdoor telescopes
- Night sky constellation tour

Subscribe to Night Observing Status Blog

http://illinois.edu/blog/view/413

Get weather cancellation updates

Assignment details on class website

Read rubric before you go!

- Complete report due on or before Oct. 25

i>clicker question
Vote your conscience

Last class we discussed greenhouse gasses and their effect on the Earth. Do you think that human emissions are affecting the Earth's greenhouse today?

A. Yes.
B. No.
C. I am not sure. We need more research on the matter before we make any policy decisions.

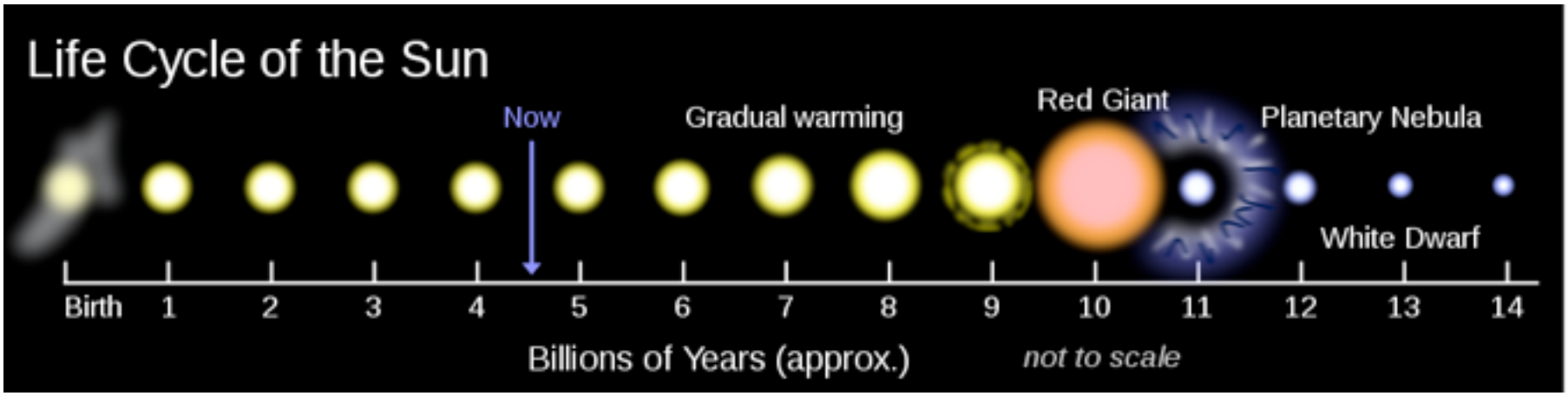
The evidence is pretty strong that the answer is A.

See http://www.climatechange2013.org

Sun is currently in “quiet adulthood”

Sun evolves very slowly as it consumes Hydrogen in its core

- Grows slightly larger
- Gets slightly brighter



Otherwise, very little else happens, so far as the Sun is concerned.

Effects on the Earth

As the Sun becomes more luminous and brighter...

- heats up Earth
- evaporates some of surface water, becomes water vapor

  hot and humid, yikes!

But water is a greenhouse gas

So more water in air means

thicker blanket = stronger greenhouse

- Earth warms up more
- but this evaporates yet more water into the air
- ...which makes the Earth warm more
- ...and so on: vicious circle

A 10% luminosity increase in Sun destabilizes the Earth's temperature and climate

...and that's not all...

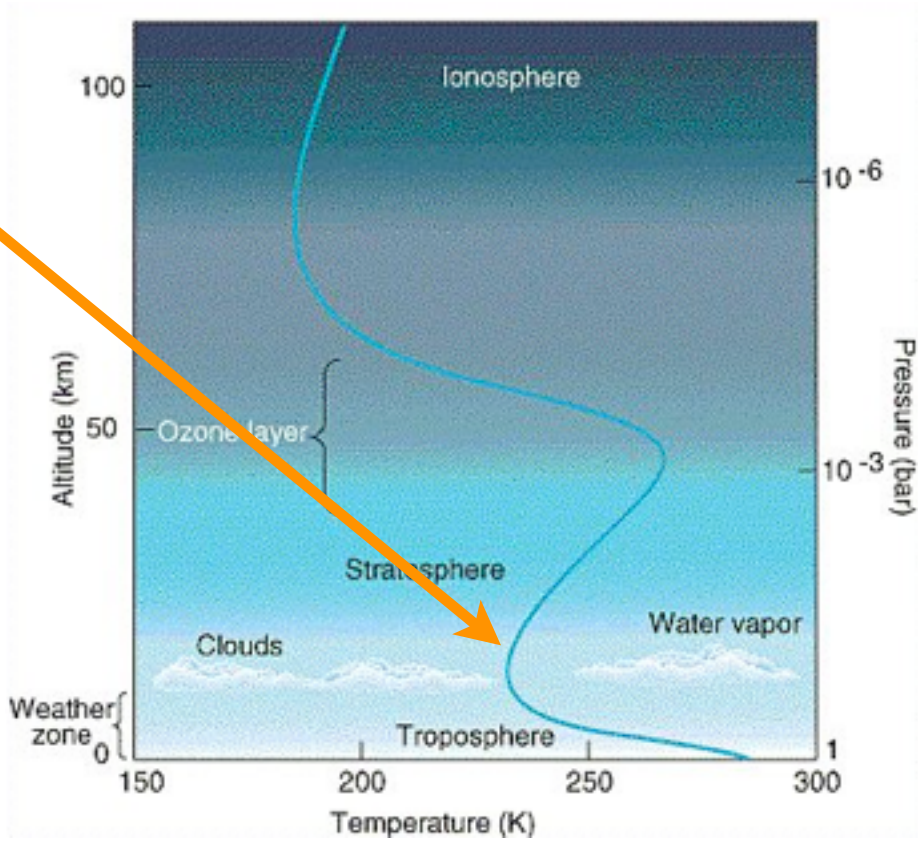
Earth becomes a moist greenhouse

Today, Earth's atmosphere has a cold trap

- Keeps water near the surface

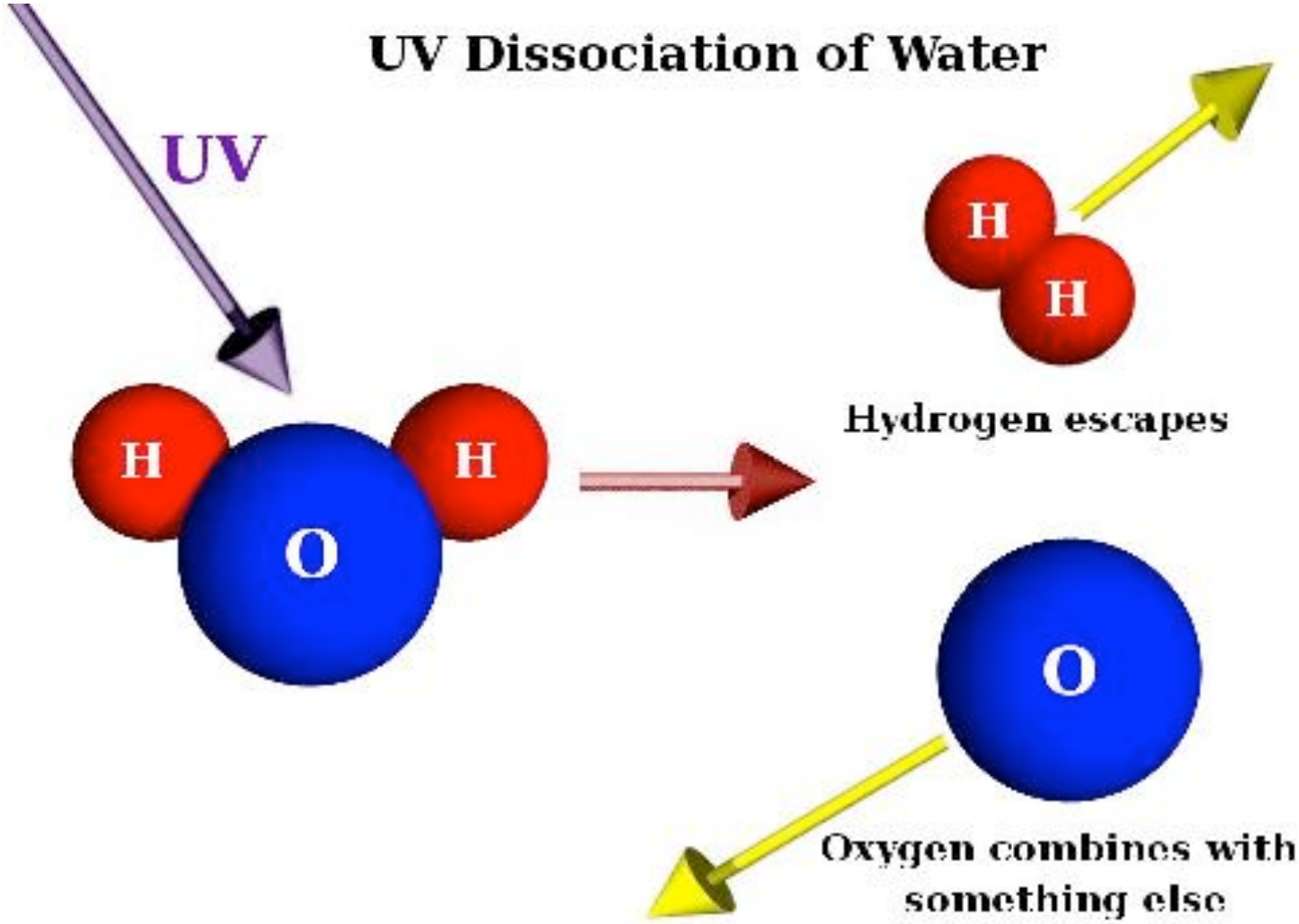
Higher temperatures will eliminate this cold trap

- Allows water vapor into the upper atmosphere
- A moist greenhouse



Temperature profile of Earth's atmosphere

There is a "cold trap" at modest altitude in Earth's atmosphere where the temperature drops below the freezing point of water. (See this temperature profile.) Because of the trap, rising water vapor condenses into droplets or ice crystals and ultimately falls back to the surface. This prevents escape of water to the stratosphere & therefore destruction by solar UV radiation. Water is retained near the surface. Below the ozone layer.



Water in the upper atmosphere gets destroyed by Sun's ultraviolet rays

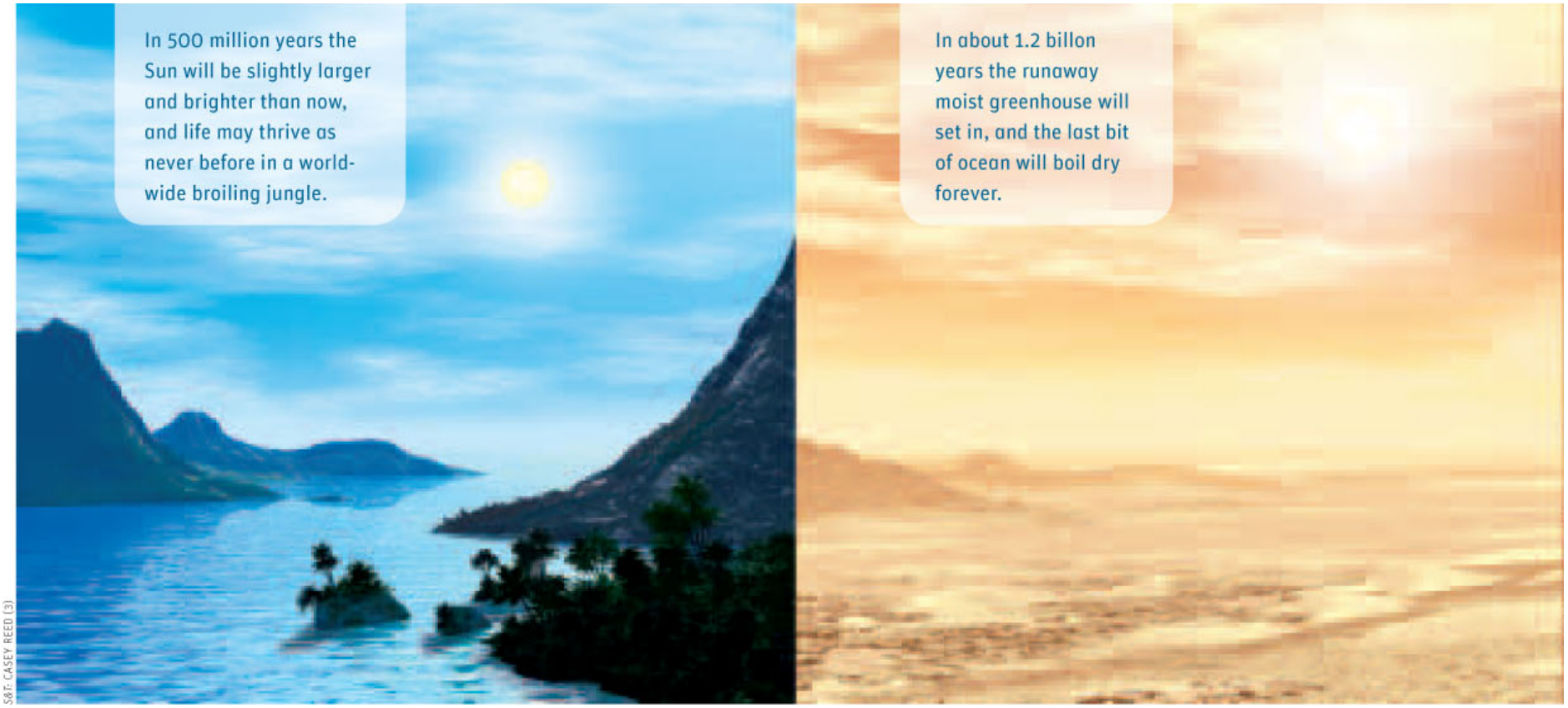
Moist Greenhouse Earth Dries Out

Water vapor is lost to space

Continents become deserts, oceans begin to evaporate

- The end of large surface life on Earth
- Some marine life will survive in the oceans
- but the Sun keeps getting brighter...

Change in total solar radiation has an impact on Earth



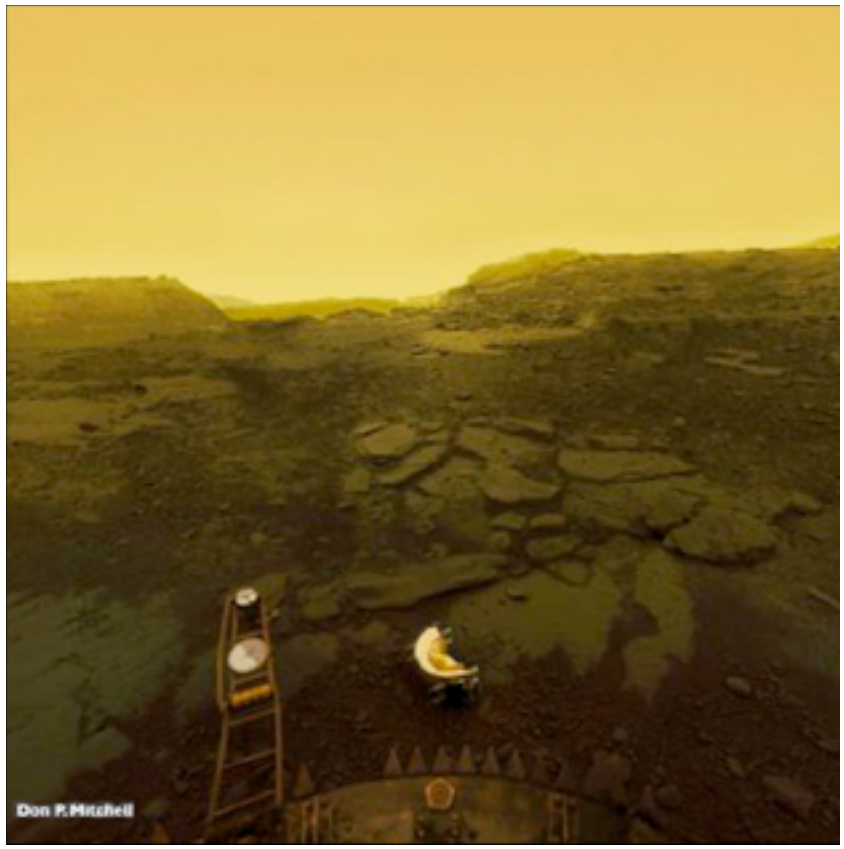
Earth warms over the next 1.2 billion years, eventually leading to a <u>moist greenhouse</u>

The Sun will increase in luminosity by 10% over the next billion years
At first, the warming could be good for life - live may thrive as tropical temperatures spread to higher latitudes
As the Earth warms, oceans begin to evaporate, more water is in the air. The Earth's atmosphere will dry out as water vapor is destroyed by solar UV light and lost to space.

Move Underground?

Venus on Earth: 3.5 Billion years from today

- Sun will be 40% brighter than today
- Results in a runaway greenhouse effect
- Oceans evaporated into space
- Conditions on the Earth will be like those on Venus today



http://wanderingspace.net/2006/11/the-surface-of-venus-revealed/

Note: Gyr = gigayear = 1 billion years
The oceans will evaporate into space, and conditions on the Earth will be like those on Venus today.
Such conditions will probably mean the end of all forms of terrestrial life.

Venus, Earth's "Evil Twin" and a warning to us…

Venus is almost exactly same size as Earth, but…

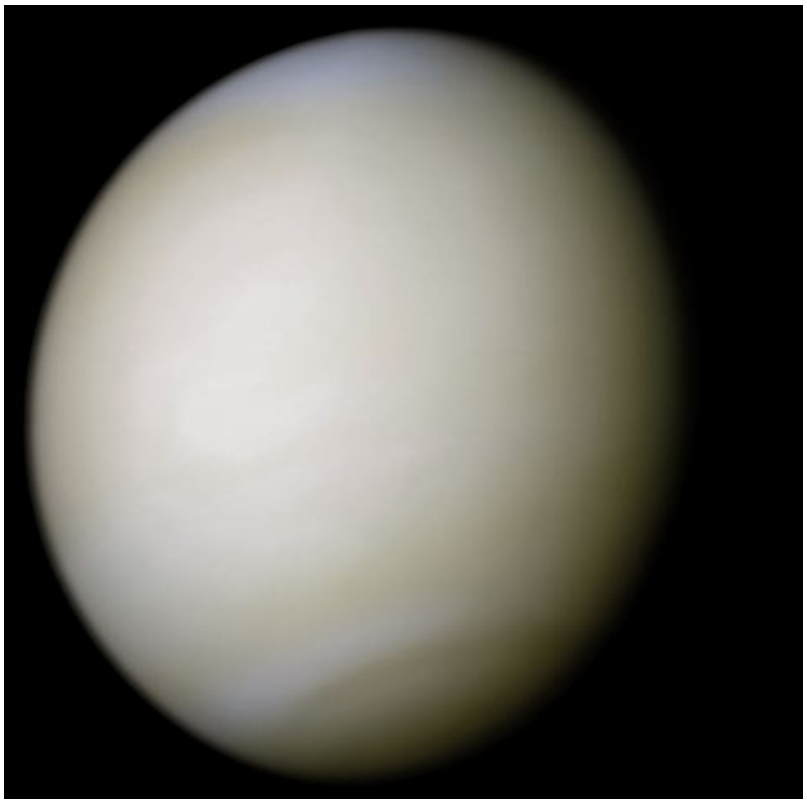
HOT!! 470° C = 925° F

Very thick atmosphere

- 90 times Earth's atmospheric pressure!
- 96% CO_2 and 4% N_2
- but negligible water
- Massive amounts of CO_2 create runaway greenhouse
- Covered in thick clouds made of sulfuric acid!

Radius 0.95 Earth, Mass 0.81 Earth, Distance from Sun 0.72 AU,
The same pressure you would experience 2700 ft underwater
Only negligible amounts of water vapor (0.002%)
470° C warmer than it would be without greenhouse effect!
Venus is the hottest planet in the Solar System
On Earth, greenhouse gasses keep Earth 32 C warmer than it would be

Why is Earth's atmosphere different from Venus' today?



Venus' atmosphere is dominated by CO_2 with negligible H_2O

Earth's atmosphere is only 0.03% CO_2 and the surface is covered by H_2O

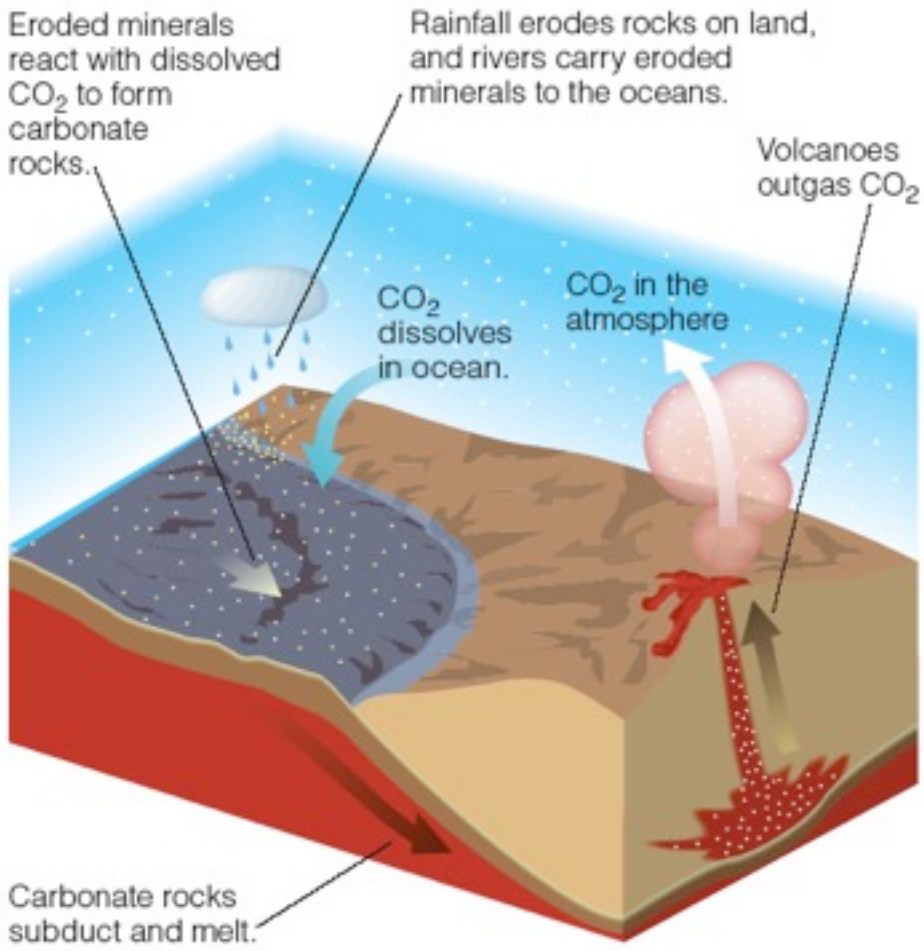
Remember the big queston – Venus & Earth started out with the same raw materials, and in very much the same amounts
So, Earth should have just as much CO2 as Venus
Venus should have had just as much H2O as Earth

Where is Earth's CO_2?

Most of Earth's CO_2 is locked away in carbonate rocks (like limestone)

Part of the CO_2 Cycle

- **note that heating from future sun releases this CO_2 into atmosphere, also adds to increase in greenhouse effect**



Venus lacks oceans to dissolve the carbon dioxide and lock it away in rock on the seafloor!

Venus' lack of oceans means the CO2 is still in the air.
If Earth had no oceans, it would have a majority CO2 atmosphere!
So, what happened to Venus' water?

What happened to Venus?

- Water evaporated into the atmosphere
  - Too hot for liquid water
- Solar UV broke H_2O into H and O atoms
- The solar wind strips away very light H atoms

Venus' water was stripped away by the solar wind.
Hydrogen atoms, being lightweight, can be easily accelerated to escape speed
Heavier particles in the atmosphere aren't accelerated to escape speed so easily, so venus still has a thick atmosphere

Life of Our Sun

As the Sun, uses up the hydrogen in the core, the Sun increases by 40% in brightness in 3.5 billion years.

By that time, all of the oceans are gone!

The baking sediments at the bottom of the oceans, release CO_2

Earth will become Venus-like!

Then the heat makes even those heavier molecules leave the Earth.

The Earth will be a barren rock in about 4 billion years!

http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Too Hot for Humans

Death of Concrete Structures

Yikes!
So what is to be done?

The Habitable Zone

Life on earth needs liquid water to survive

- and thus moderate temperatures
- too cool and everything ices over
- too hot and all the water boils

Habitable zone:

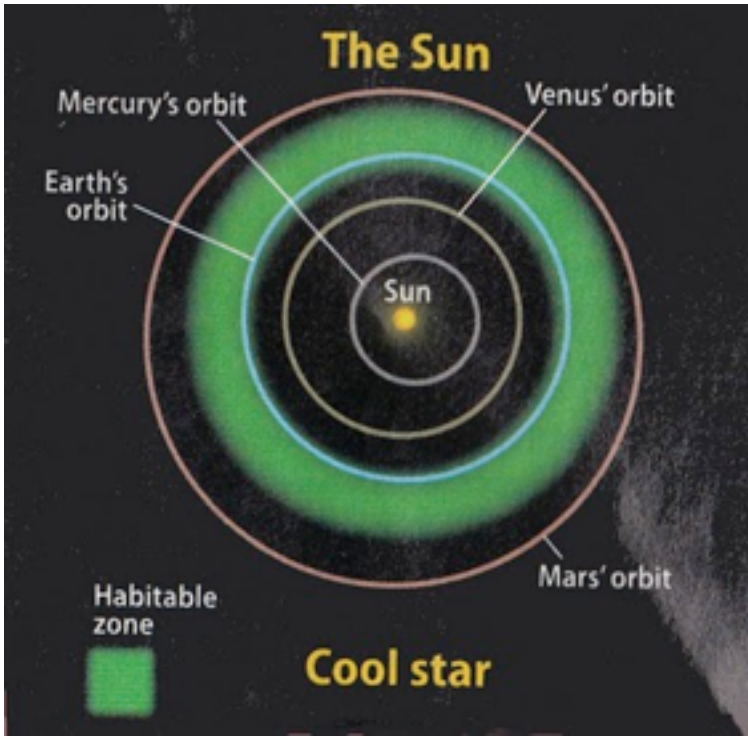
- "Goldilocks" region that is just right for liquid water to exist
- not too hot, not too cold
- main effect: distance from Sun--not too far, not too close
- but also: since temperature depends on greenhouse effect, so does habitable zone

Today:

- Earth at 1 AU is in this zone (duh!)
- all other planets outside of it: too hot or too cold

But: the future Sun changes zone

- planet temperatures rise and fall with Sun's energy output = luminosity
- Habitable zone will shift
- After 1 billion years, Sun more luminous, habitable zone moves beyond Earth, out to Mars
- later: HZ will move farther out...and eventually back inwards



Habitable Zone Today

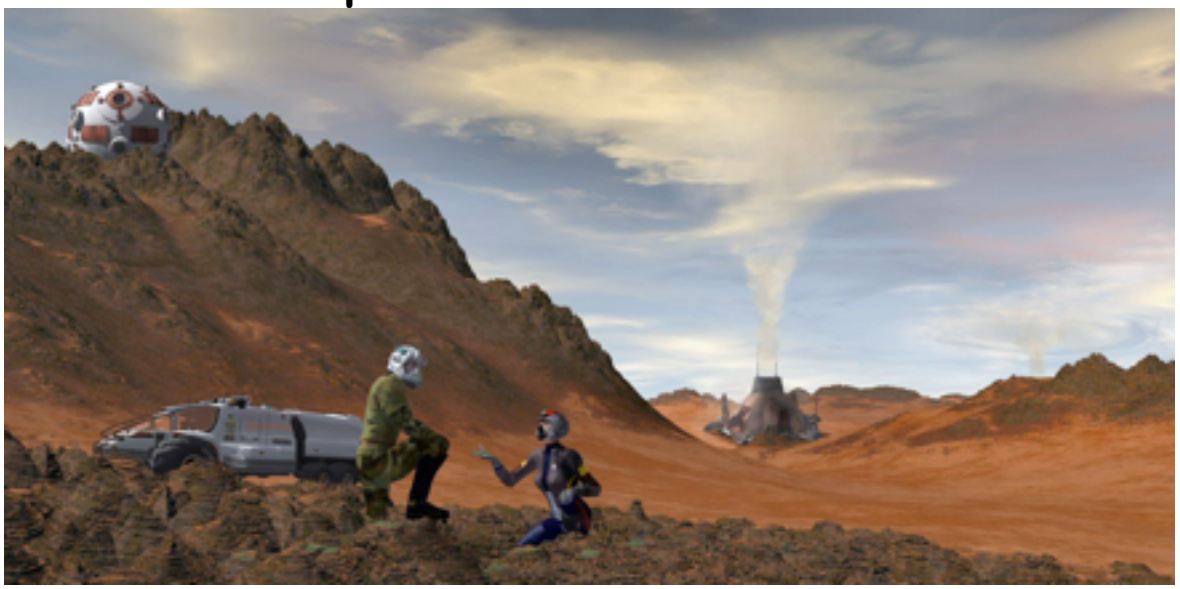
http://dizzydick.blogspot.com/2011/01/wondering-about-habitable-zone.html

Mitigation: Part 1

1. **Move to someplace cooler! "U-Haul" solution**
   - I hear that Mars could be a nice place to live.
   - But just because Mars is in the habitable zone and can support liquid water, this does not mean that Mars is "move-in ready"
   - Mars will be "in a good neighborhood", but will be a "fixer-upper"
   - Need to terraform Mars: make it Earth-like

     today, Mars has a thin CO_2 atmosphere, without oxygen

     and no surface water, though possibly ice underground
     - would need to create oxygen atmosphere and find or make liquid water on global scale--a big job!
     - this could take a while! and be expensive! what if we can't afford to move everybody?

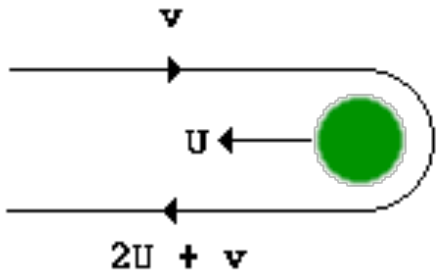


http://www-cache.daz3d.com/sections/contests/upload_files/3195.jpg

Mitigation: Part 1

2. **Move the whole Earth!**
   - There is no place like home, so move it to a nicer place, farther away from the Sun.
   - Use gravity assist or the sling shot technique:
     - send object near Earth
     - its gravity will exert force on Earth
     - force will accelerate Earth, change velocity and kinetic energy
     - if changed the right way, can move Earth outward!
   - But what objects can we use?

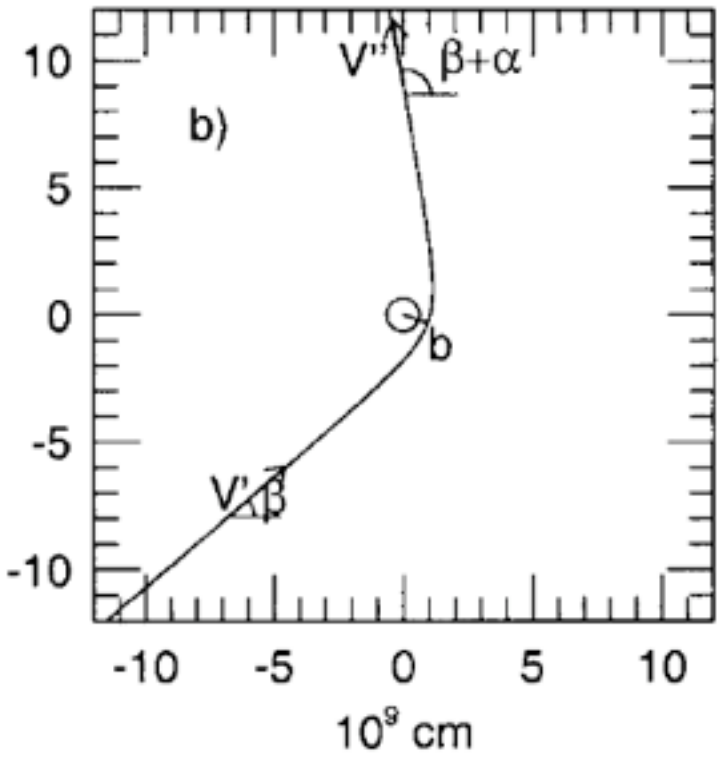
need to be something we can move around



http://upload.wikimedia.org/wikipedia/commons/8/8e/Grav_slingshot_simple_2.gif

Mitigation

2. **Move the whole Earth**
   - **Asteroids to the rescue?**
   - **Move many large asteroids in front of the Earth, sends them toward the Sun and the Earth outwards.**
   - **Need to do this every 6000 years to make Earth survive for a while longer.**

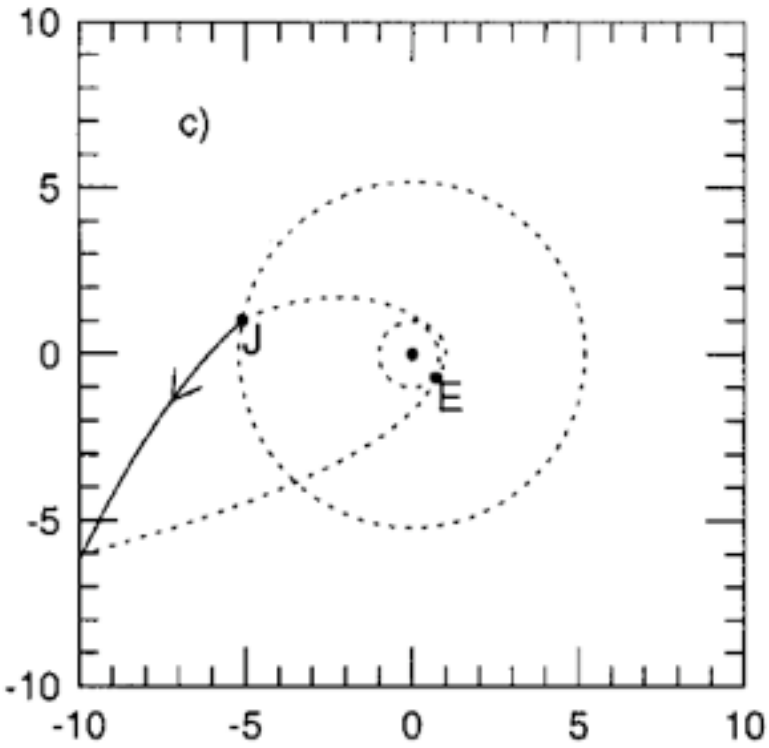


Korycansky et al. 2001

Mitigation: Part 1

2. Move the whole Earth

- For billions of years!
- We don't have enough large asteroids.
- We'll have to recycle--use same asteroid more than once
- The idea is to transfer energy from Jupiter's orbit to Earth's orbit.
- Could keep us safe for a good 6 billion years!
- But what happens then?



Korycansky et al. 2001

Important Questions

Today's Sun: "Main Sequence" life stage

- stable
- burning hydrogen to helium

The Sun remains stable and on the main sequence as long as it has hydrogen to fuse in the core… it evolves and will likely kill all life on Earth, but up until now, it has still been on the main sequence.

How long will the fuel last?

What happens when the fuel runs out? And how bad will it be for the Earth?

i>clicker question

If you were to look at 1 kilogram of material taken from the surface of the Sun and 1 kilogram taken from the center, which of the following statements would be true of these two kilograms?

A. They both have the same amount of hydrogen and are in fact mostly hydrogen.

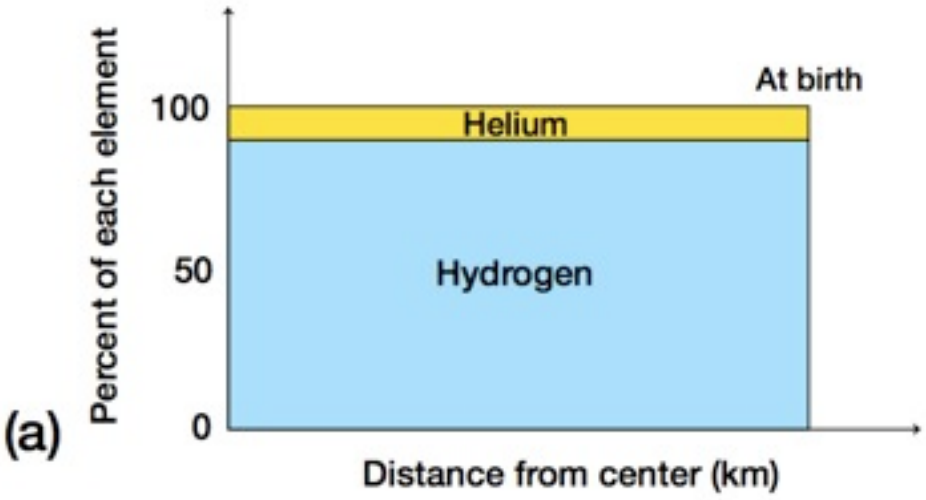
B. The kilogram from the surface contains more hydrogen than the one from the center.

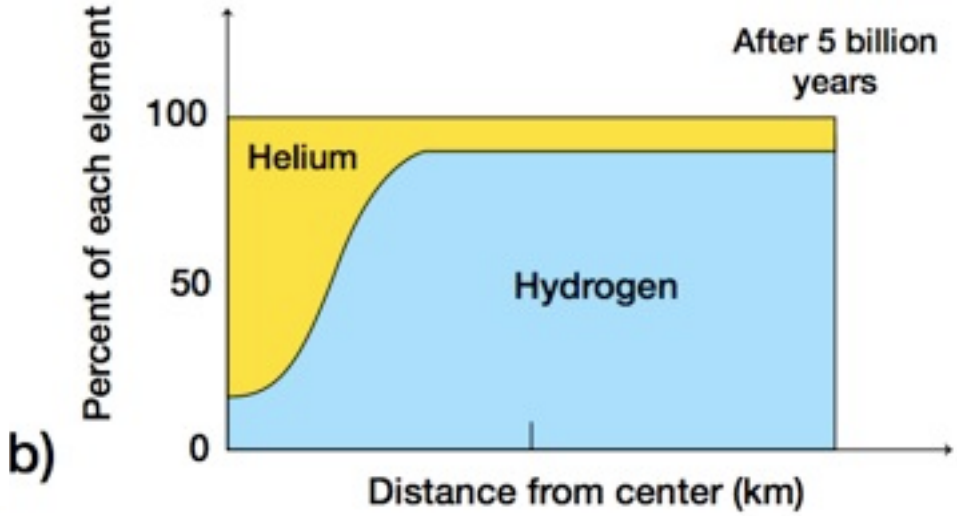
C. Neither of them contain any hydrogen.

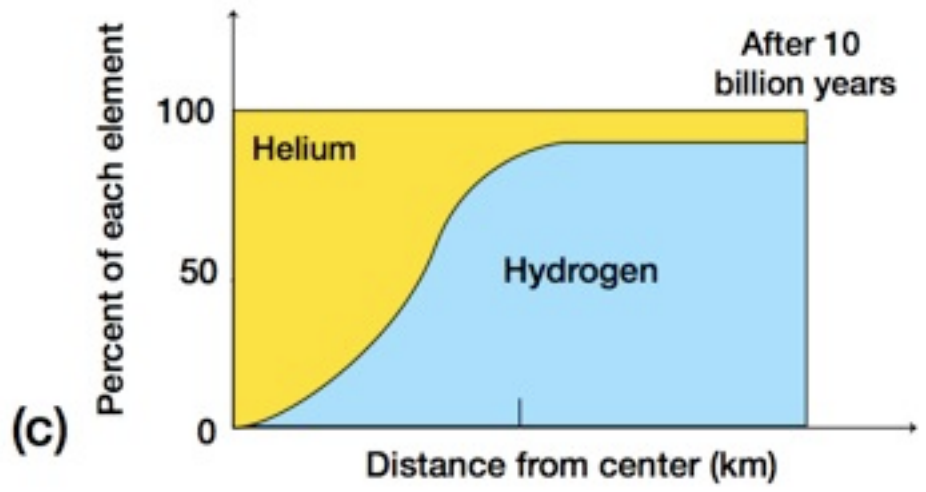
D. The kilogram from the surface contains less hydrogen than the one from the center.

Answer B
Why? The photosphere is 72% hydrogen and 26% helium, 2% other stuff.
In the inner portions of the Sun, nuclear fusion has modified the composition by converting hydrogen into helium, so the innermost portion of the Sun is now over 60% helium, with the metal abundance unchanged. Because the interior of the Sun is radiative, not convective (see Structure above), none of the fusion products from the core have risen to the photosphere.

The Sun has used up about half its initial hydrogen supply







What happens when the hydrogen runs out?

The Sun runs out of Helium in the core in about 5 billion years!

At the birth of the Sun, there is constant ratio of hydrogen to helium. As the core starts to fuse, the hydrogen in the center is turned into helium, so there is more and more helium in the center. Eventually the hydrogen in the core runs out. Then, things get interesting.

The Death Throes of the Sun

Eventually the Sun will consume all of the hydrogen "fuel" in its core

- converting it all to helium "ash"
- but still surrounded by material that was too cool to undergo fusion
- and thus is still made mostly of hydrogen

How the Sun responds to this situation is interesting and complicated

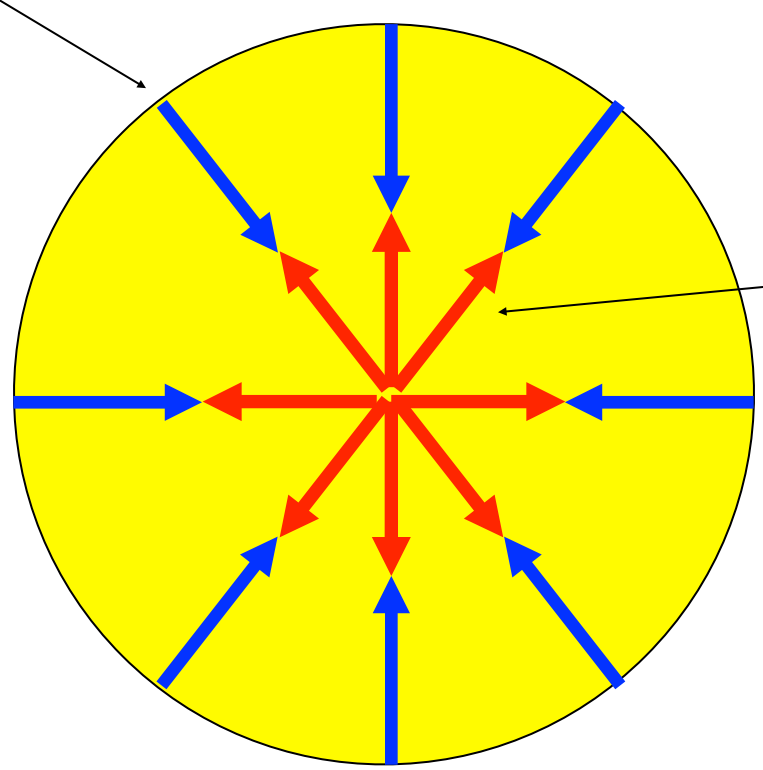
Buckle your seatbelt!

there will be a series of phases

- the Sun's temperature will go up and down
- sometimes the core will be "burning" = undergoing fusion, sometimes not
- the Sun's size will change from huge to small to huge to small

The Battle between Gravity and Pressure

Gravity pushes in

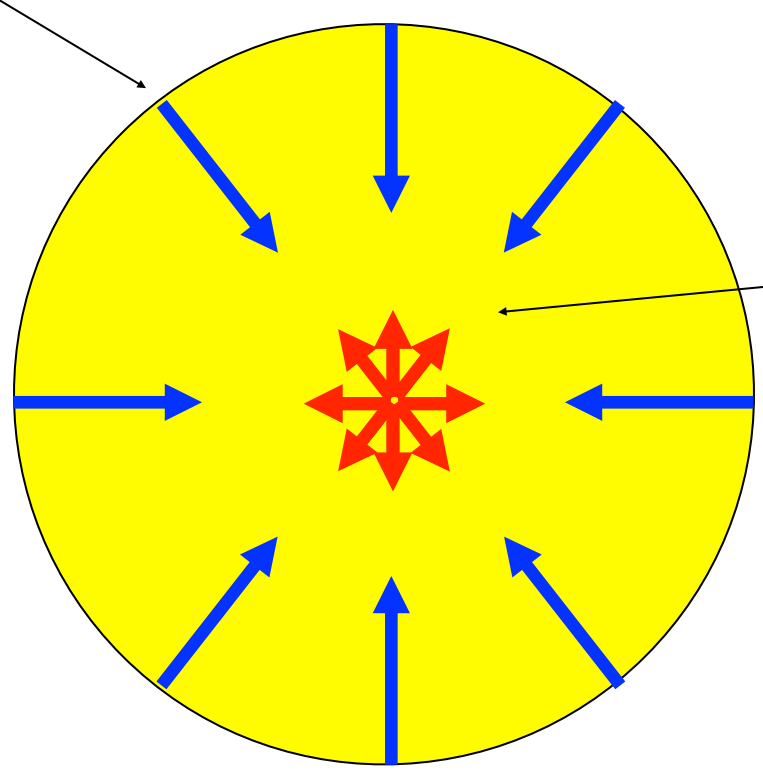


Heat pressure from H→He fusion pushes out.

Hydrostatic equilibrium: Balanced forces

The Battle between Gravity and Pressure

Gravity pushes in



With end of H fusion, gravity thinks it's winning

Unbalanced forces