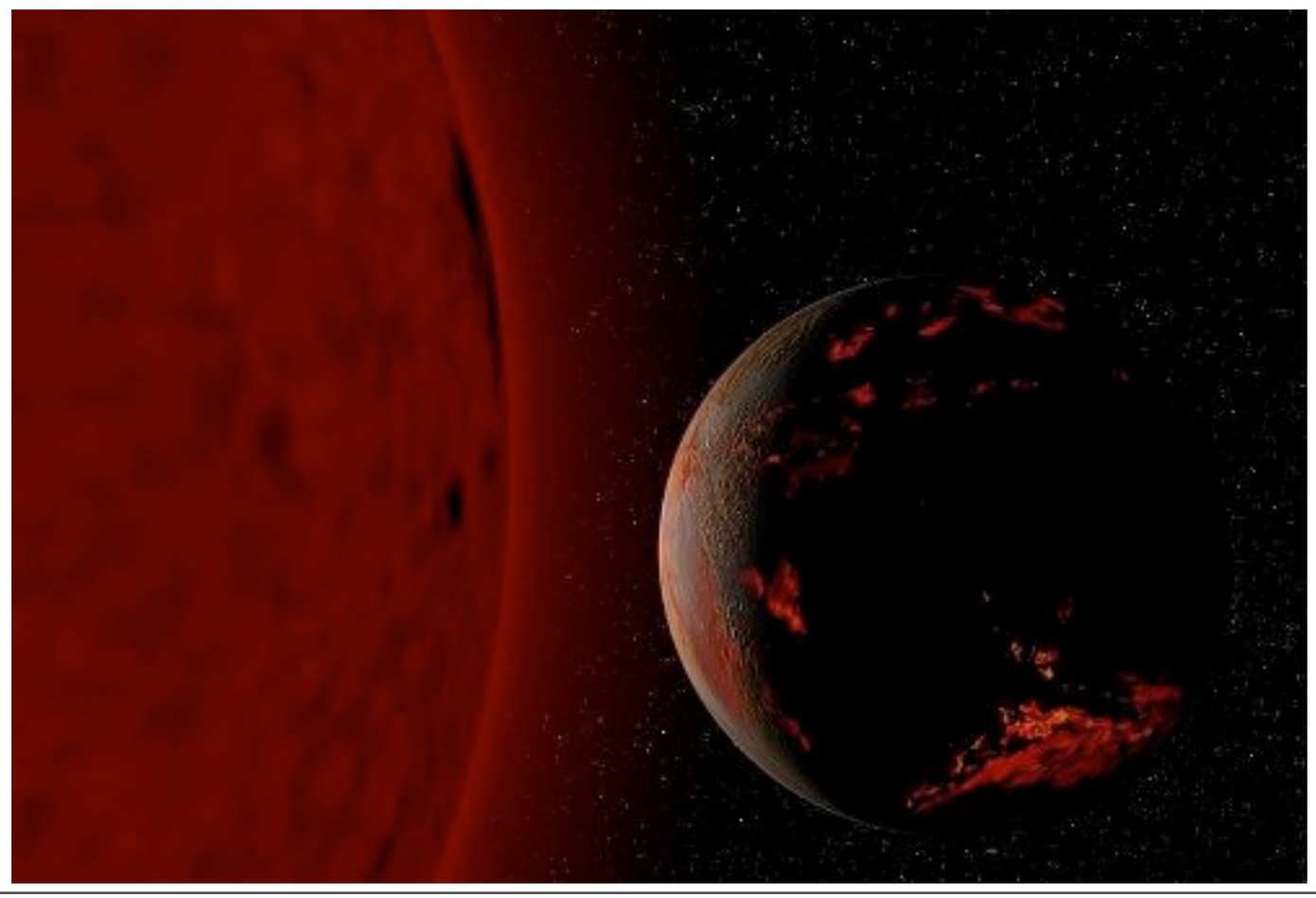
Astronomy 150: Killer Skies
Lecture 16, February 24

Assignments:

- HW5 due next Friday at start of class
- HW4 and Planetarium Report due
- Night Observing continues next week
- Computer Lab 1 due next Friday

Last time: the Future Sun: Part I

Today: the Future Sun: Death Throes



Night Observing

Night Observing continues next 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

Report form required!

- download and print out before you go
- Complete report due on or before Mar. 16

Astrometry of Asteroids Lab

A chance to work with real data

Software:

- Installed on ICS lab computers (Windows)
- Or download to your PC

Manual & worksheet on class website

Work in groups up to 3

The lab is more mathematical than anything else in the course

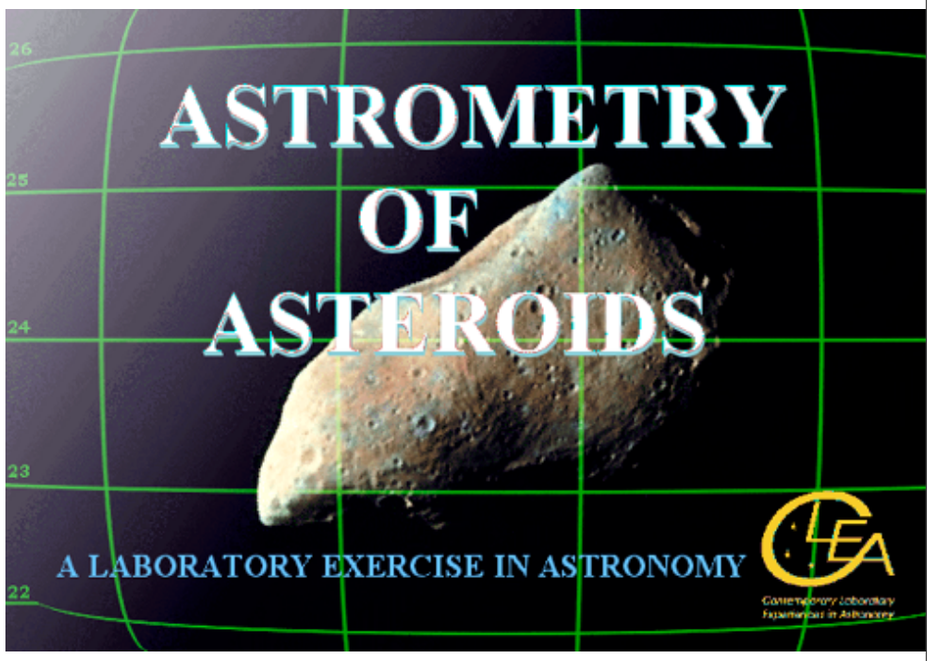
- but instructions explain everything step-by step, so:
- allow yourself time! can take 2 hours or more
- don't wait till the last minute!

to give you time:

- no class next Wednesday Feb 29--work on lab instead!

Completed worksheet due by Fri., March 2

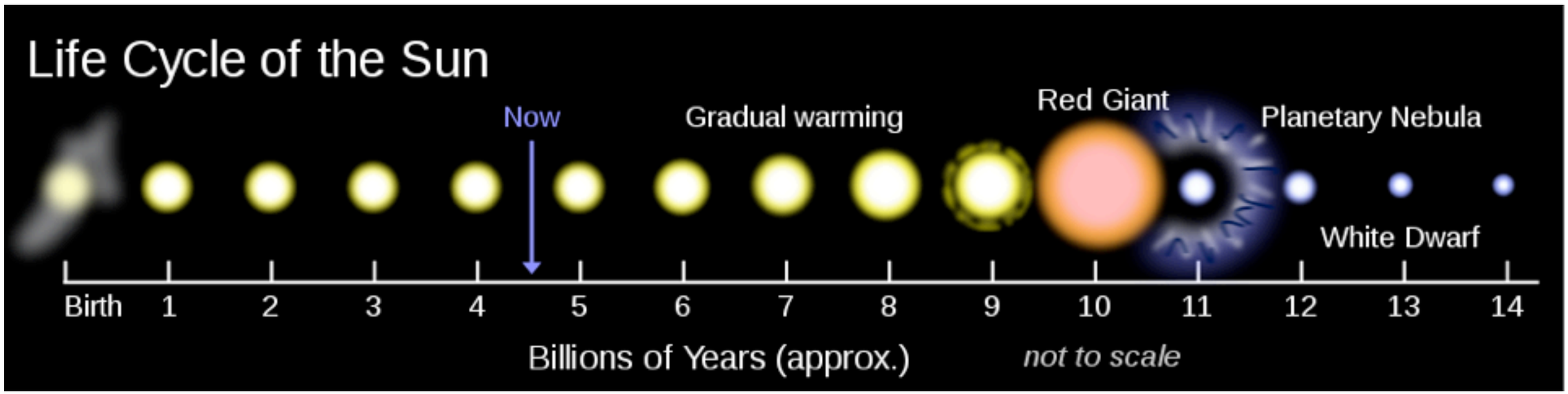
Help session: 3/1, 5-7pm, Oregon ICS lab



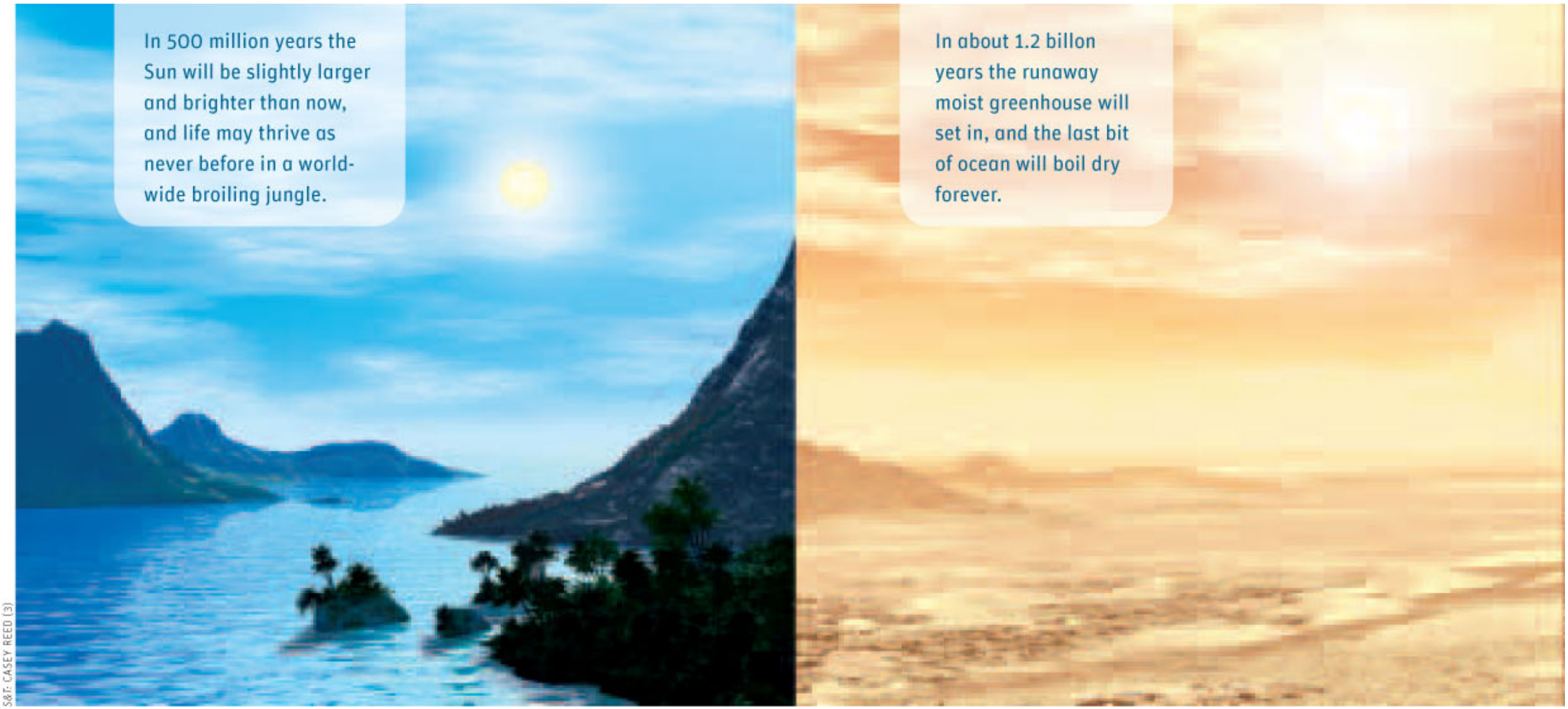
Sun is currently in “quiet adulthood”

Evolves very slowly as it consumes Hydrogen in its core

- Grows slightly larger
- Gets slightly brighter
- Temperature gets slightly hotter



Change in total solar radiation has an impact on Earth



S&T: CASEY REED (3)

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

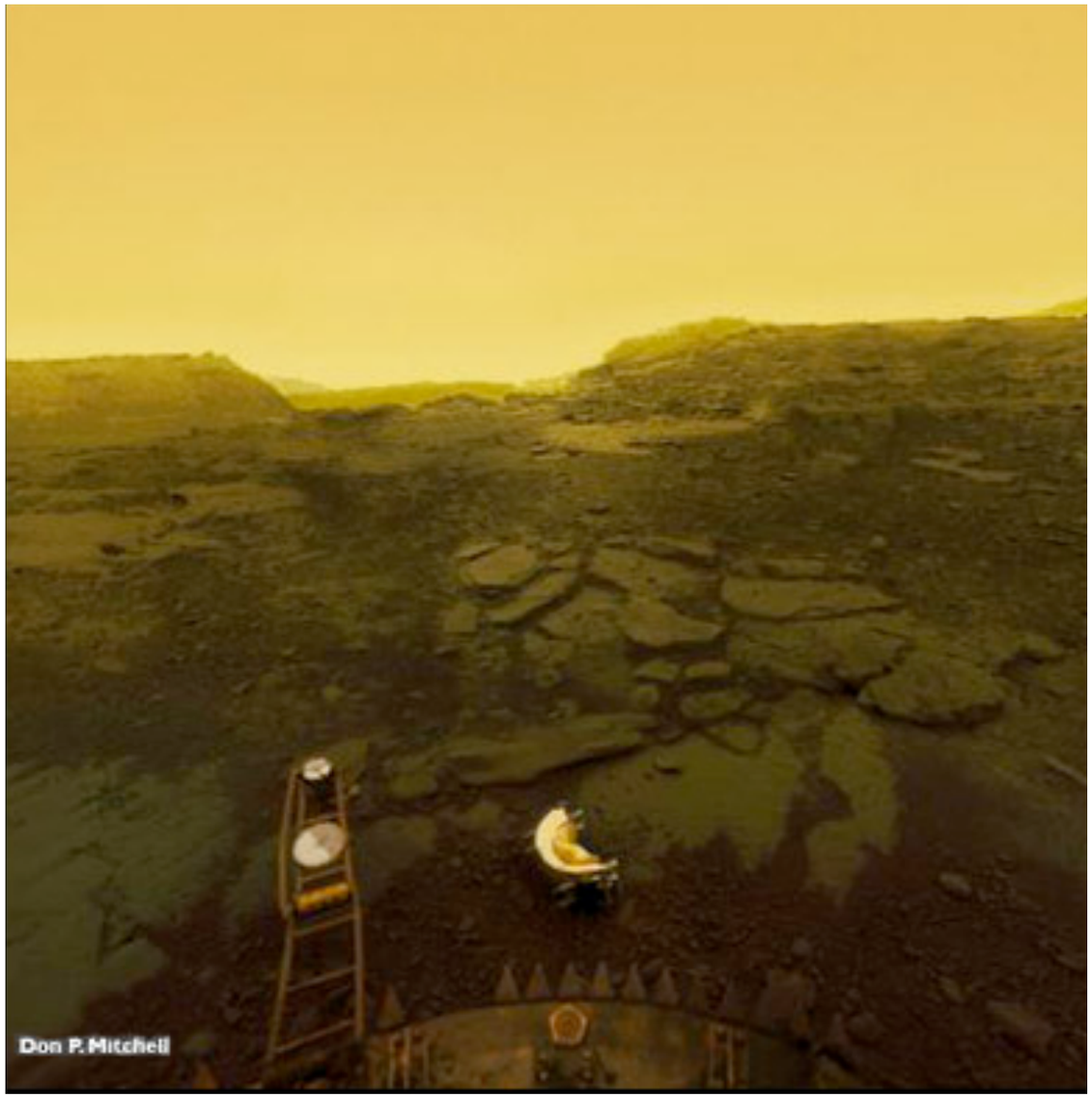
Venus on Earth:
3.5 billion years from today

Sun will be 40% brighter than today

Results in a runaway greenhouse effect

Oceans will evaporate into space

Conditions on the Earth will be like those on Venus today



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

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

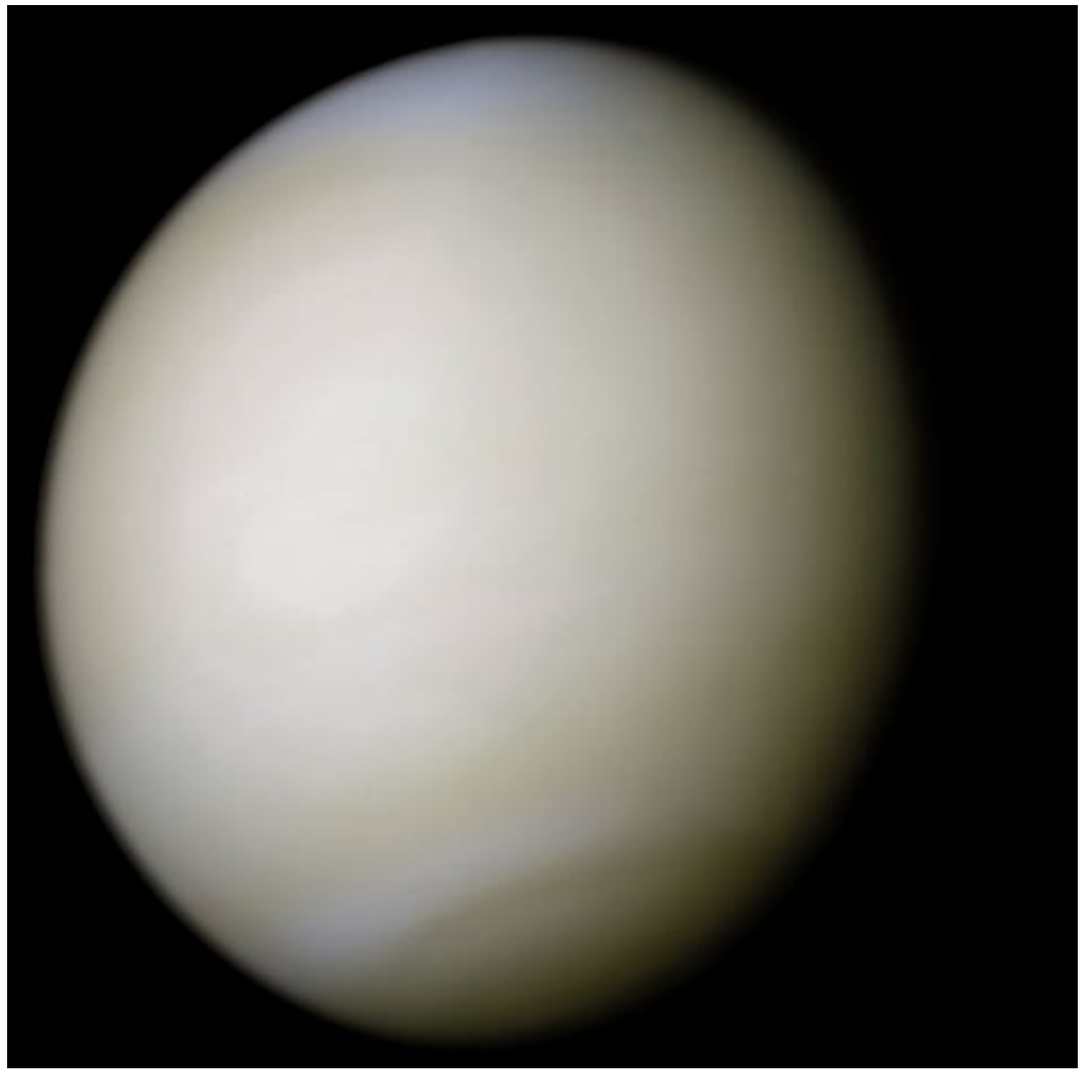
Venus is almost exactly same size as Earth, but...

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!

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



Venus' atmosphere is dominated by CO_2 with negligible H_2O

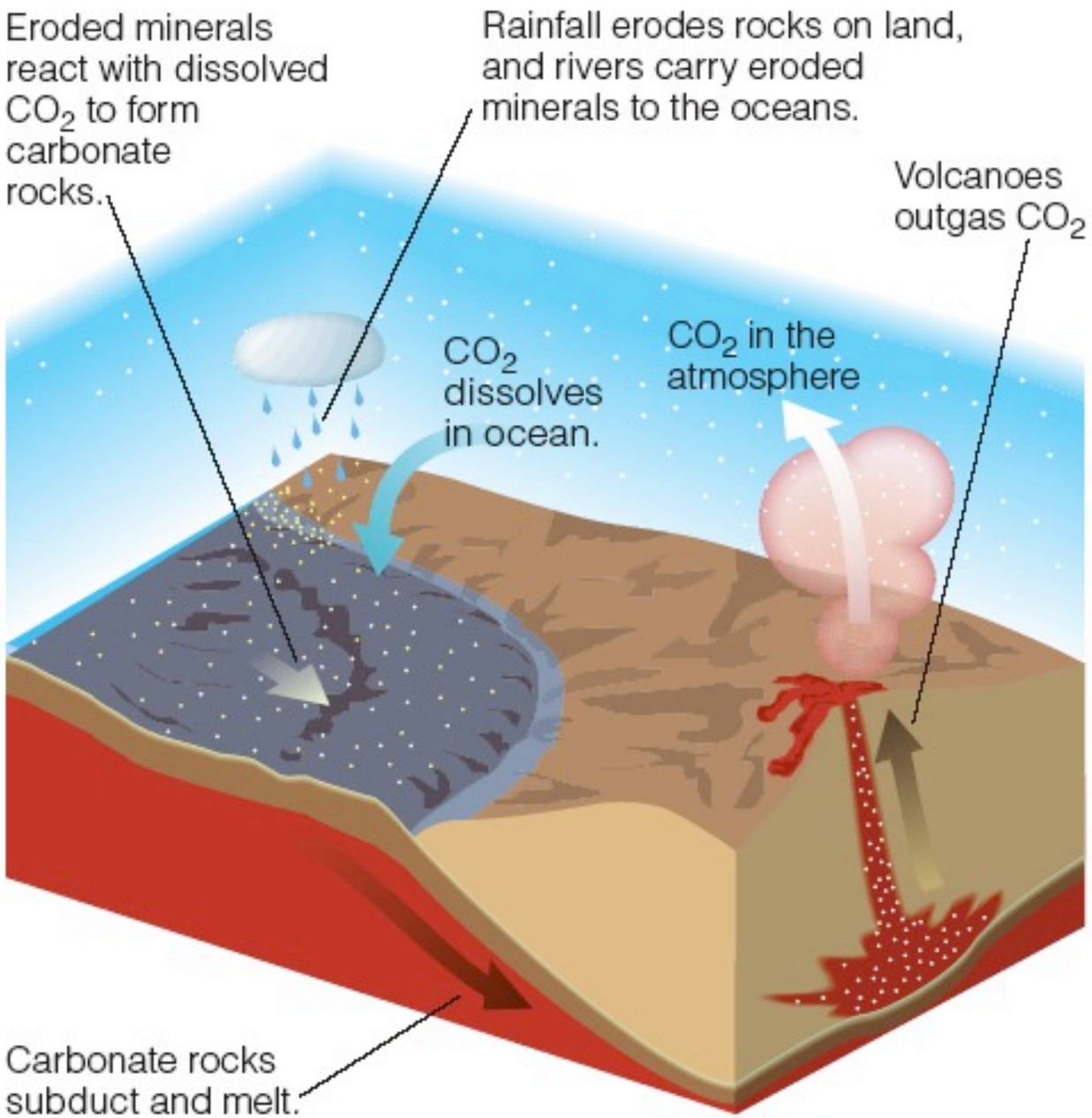
Earth's atmosphere is only 0.03% CO_2 and the surface is covered by H_2O

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

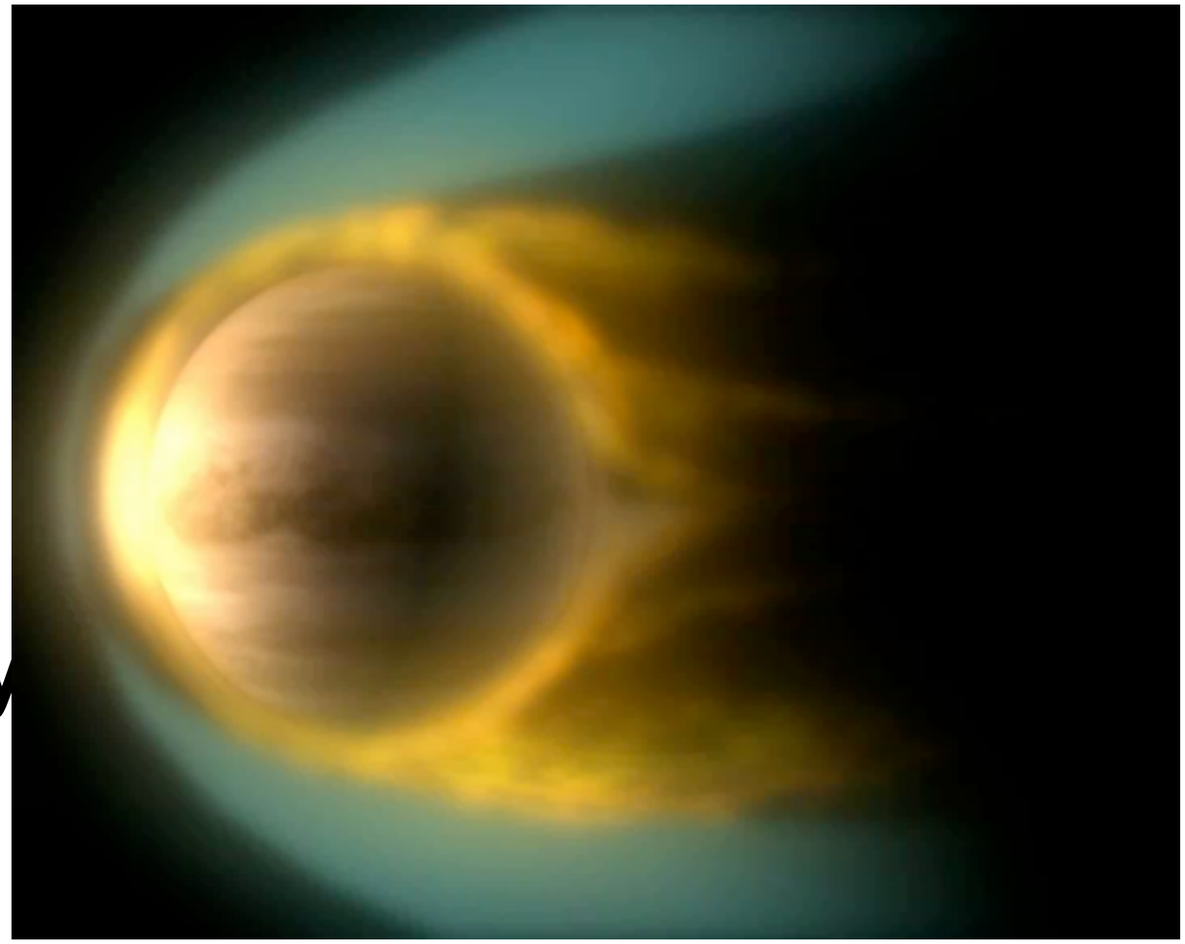
- **note that heating from future sun releases this CO_2 into atmosphere, also adds to increase in greenhouse effect**



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

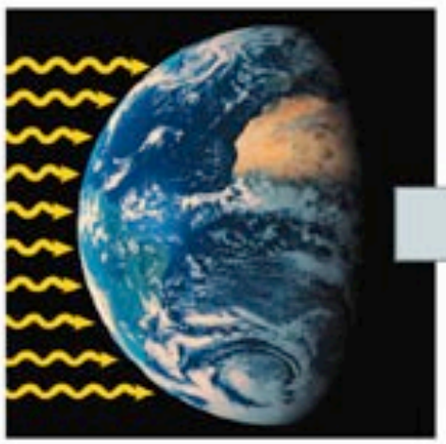
Where did Venus' water go?

- Water evaporated into the atmosphere
  - Too hot for liquid water
- Solar UV broke H_2O into H and O atoms
  - No ozone (O_3)!
- The solar wind strips away very light H atoms



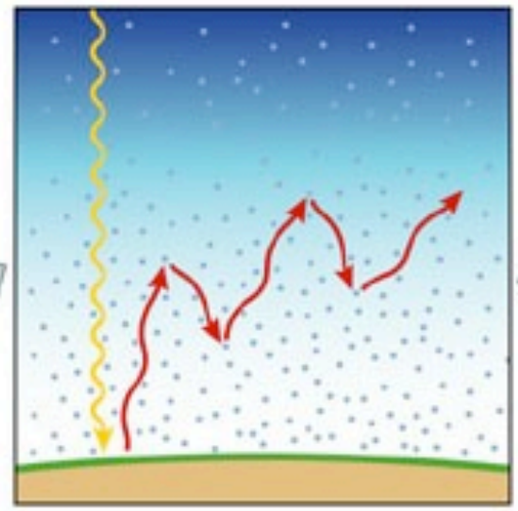
Interaction between Venus and the solar wind

What happens to Earth as the Sun increases in



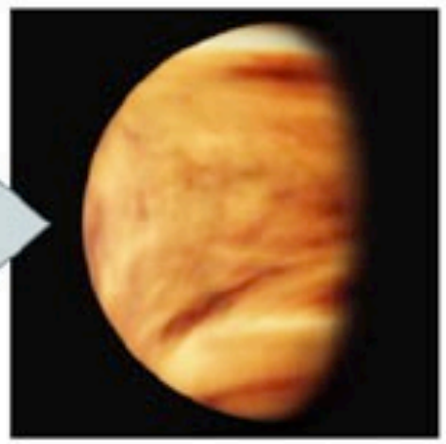
More intense sunlight immediately raises Earth's surface temperature by about 30°C.

Water vapor increases greenhouse effect, raising temperature further.



Runaway Greenhouse

Greater warmth increases evaporation, and warmer air holds more water vapor.



As the oceans finish evaporating, carbonate rocks decompose, releasing CO_2. Earth becomes hotter than Venus.

Life of Our Sun

This increase in total energy will have a major impact on the Earth!

- **Ice caps melt**
- **Costal regions flood**
- **Equator becomes inhabitable**
- **Antarctica becomes warm**

http://changeyourways.wordpress.com/2009/06/12/what-on-earth/

Life of Our Sun

Increased temperature means that the lighter elements, like water molecules in the air, will have enough speed to escape Earth completely.

The water of Earth begins to pack up and leave!

In 1.1 billion years, the continents will be deserts and the oceans are beginning to evaporate.

http://www.esquire.com/cm/esquire/images/Gd/desert-1108-lg.jpg

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 CO2

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

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:

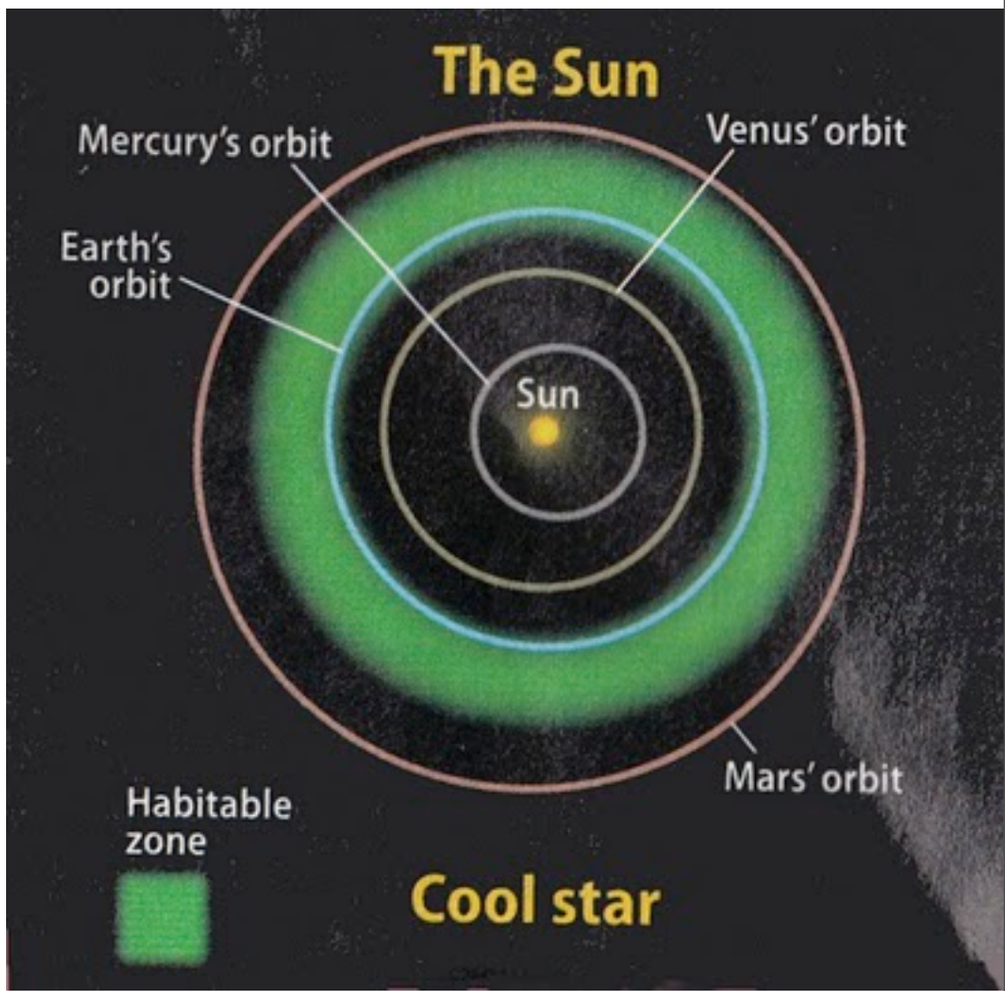
- "Goldilocks" region that is just right for liquid water to exist
- not too hot, not too cold
- main effect: distance from Sun--not too far, not too close
- but also: since temperature depends on greenhouse effect, so does habitable zone

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 will change

- 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

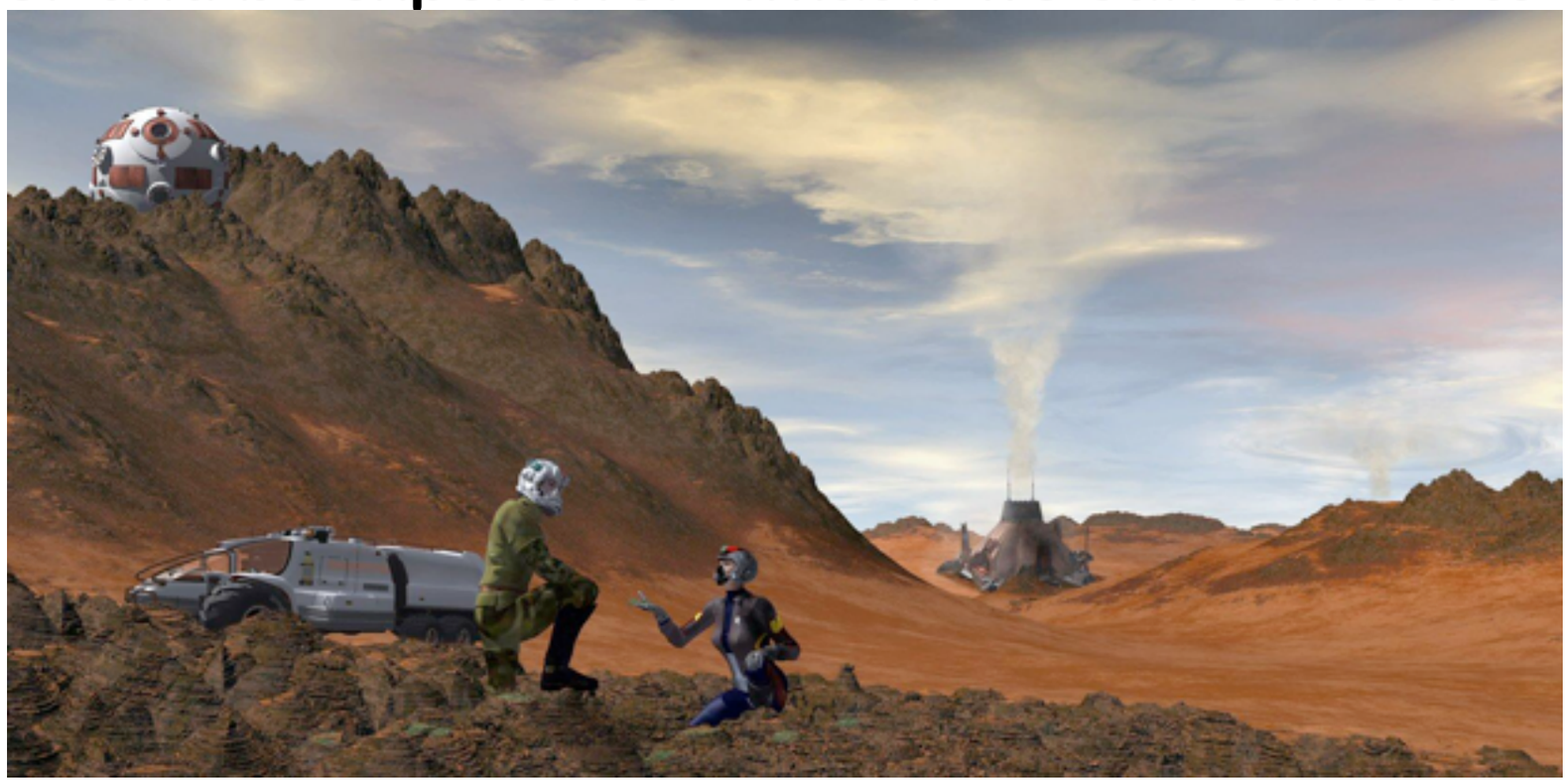
http://dizzydick.blogspot.com/2011/01/wondering-about-habitable-zone.html

Mitigation

1. **Move to someplace cooler! "U-Haul" solution**
   - I hear that Mars could be a nice place to live.
   - But note: 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 CO2 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

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:

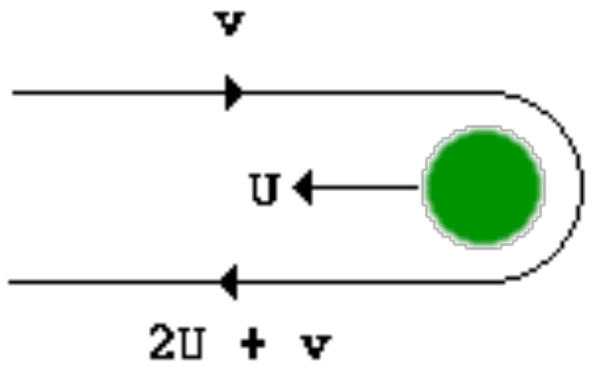
     send object near Earth

     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?

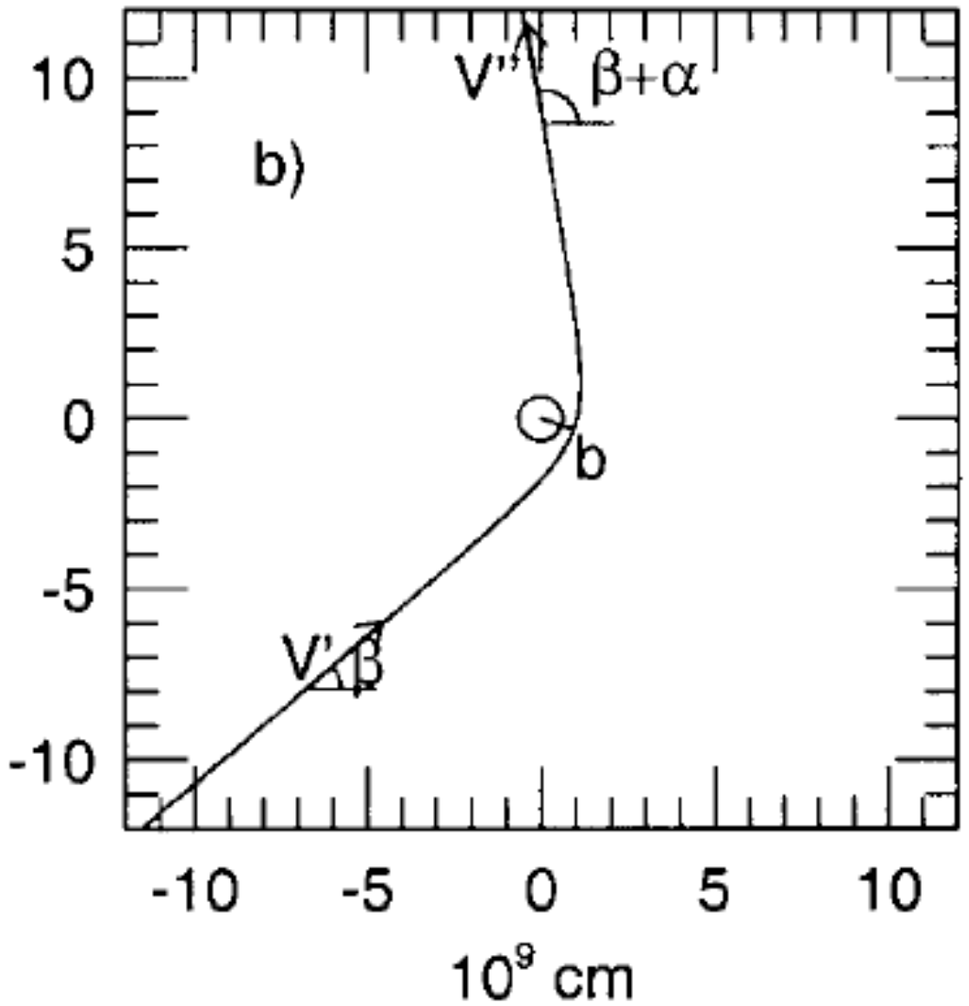
need to be something we can move around



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

Mitigation

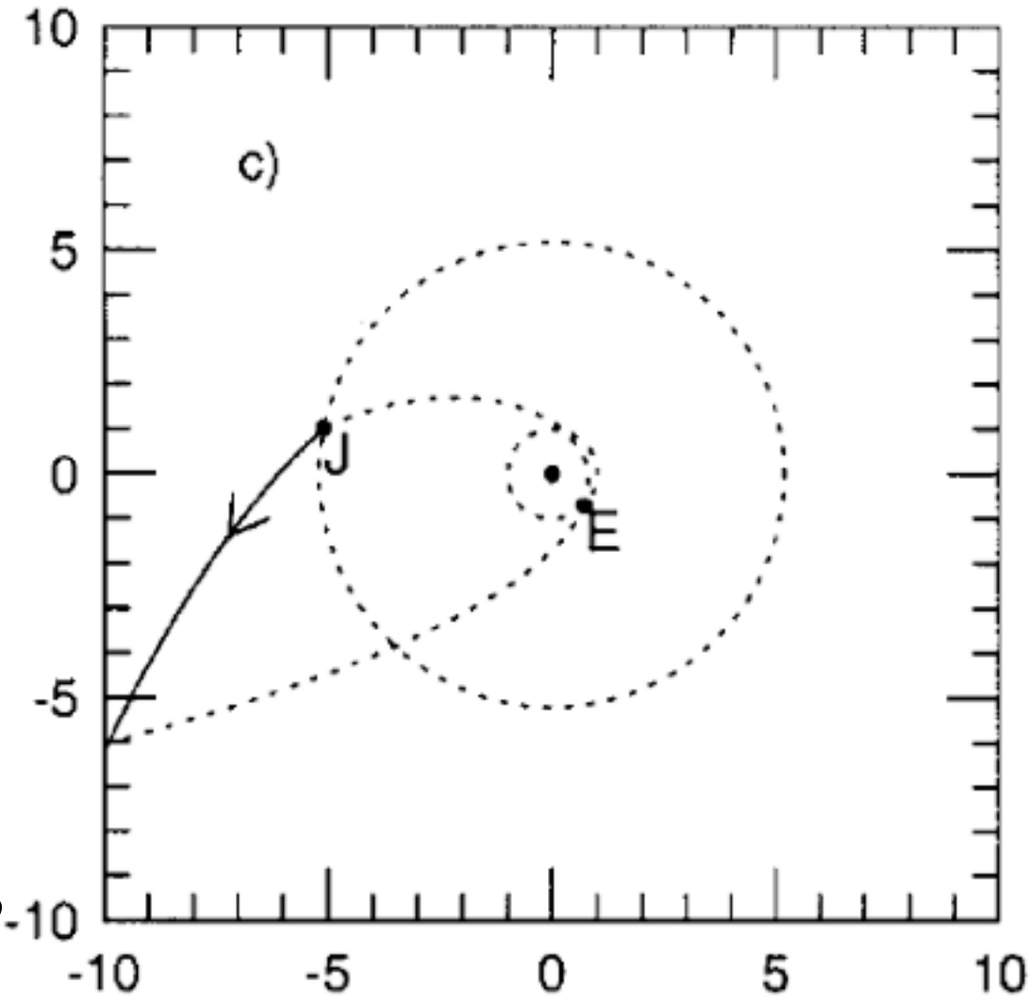
2. Move the whole Earth
   - Asteroids to the rescue?
   - Move many large asteroids in front of the Earth, sends them toward the Sun and the Earth outwards.
   - Need to do this every 6000 years to make Earth survive until the Sun hits the Red Giant phase.



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!**



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?

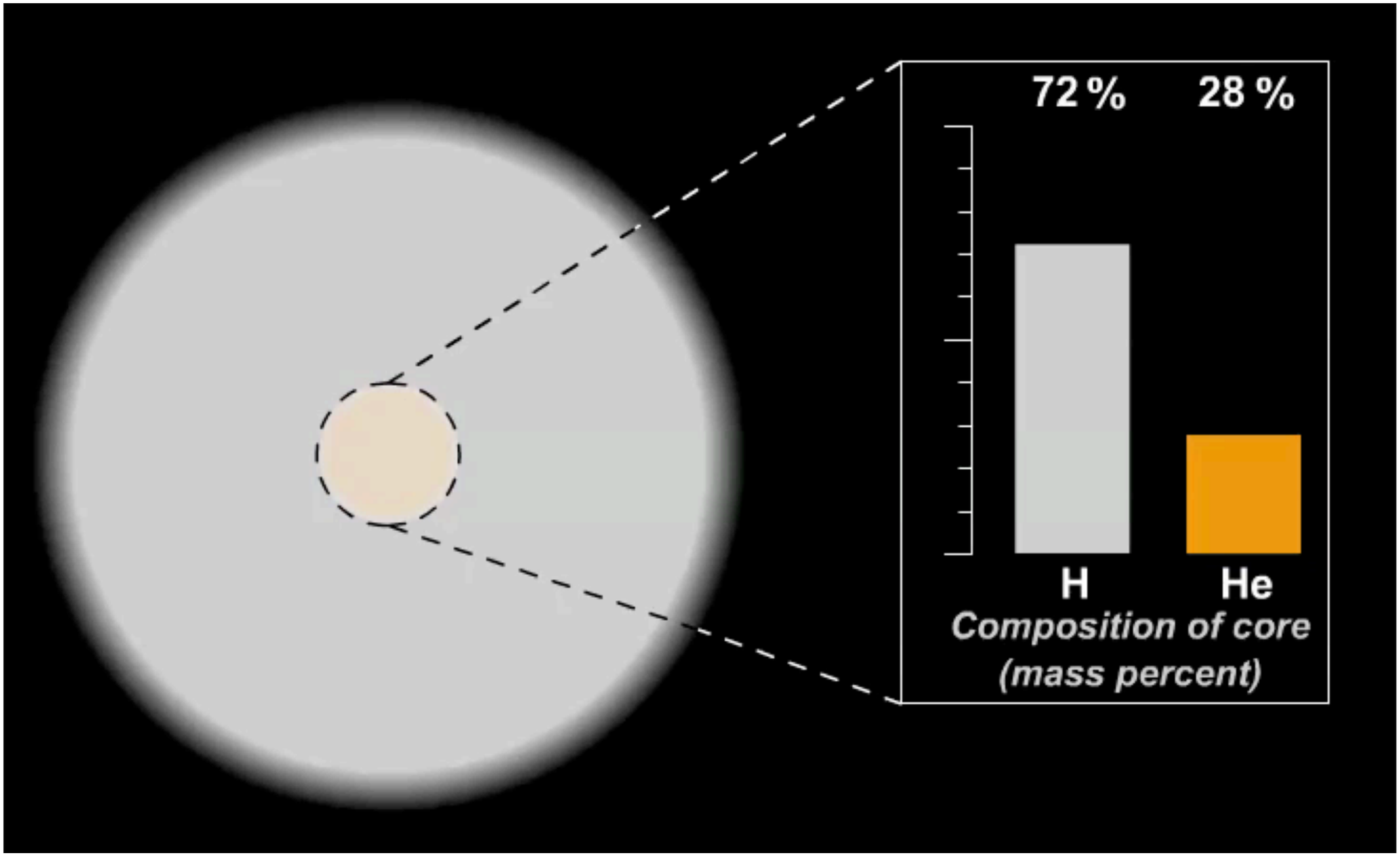
What happens when the fuel runs out? And how bad will it be for the Earth?

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.

The Sun has used up about half its initial hydrogen



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

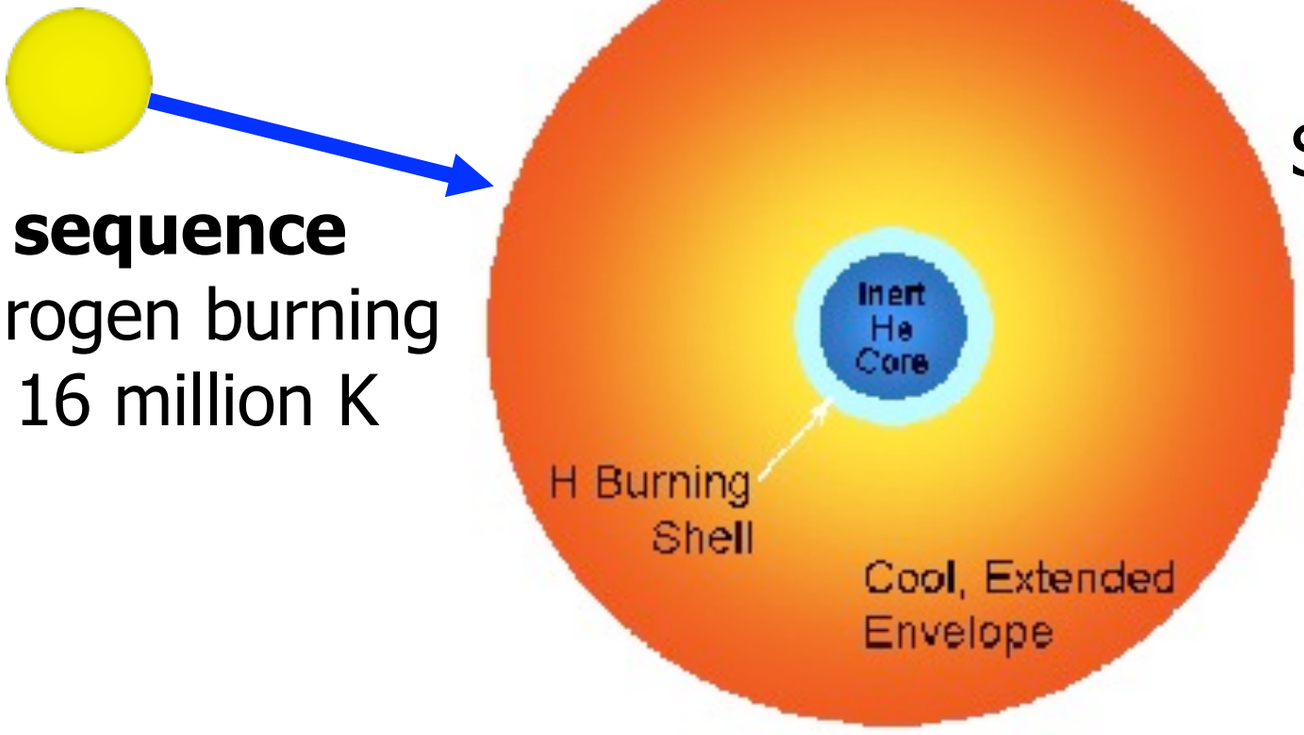
How the Sun responds to this situation is interesting and complicated

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

Life of a Sunlike Star



Main sequence
Core hydrogen burning
T_{core} ~ 16 million K

Red giant
Shell hydrogen burning

How much Gas do we have left?

Total energy available is easily calculated by mass of hydrogen in Sun and energy released by each hydrogen conversion.

We only have about 6 billion years left!

http://skeptically.org/sitebuildercontent/sitebuilderpictures/.pond/suv-econ-gas-pump.jpg.w300h294.jpg

Hungry, Hungry Sun

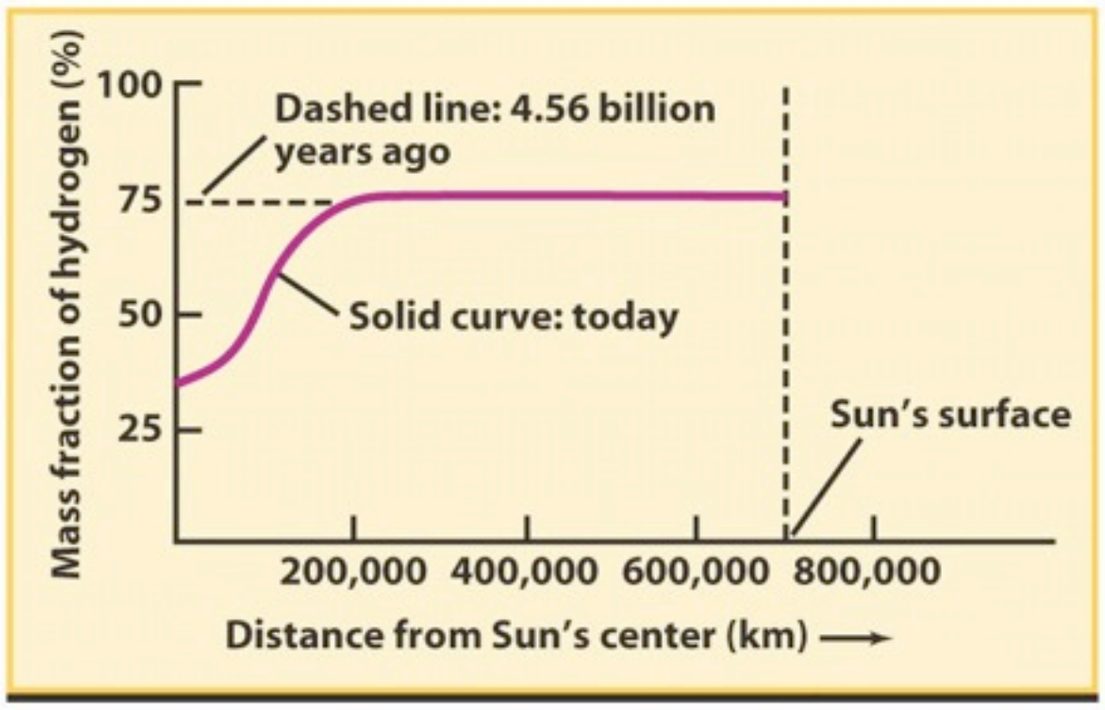
On the main sequence for ~11 billion years.

The core is where fusion occurs- H ⇒ He

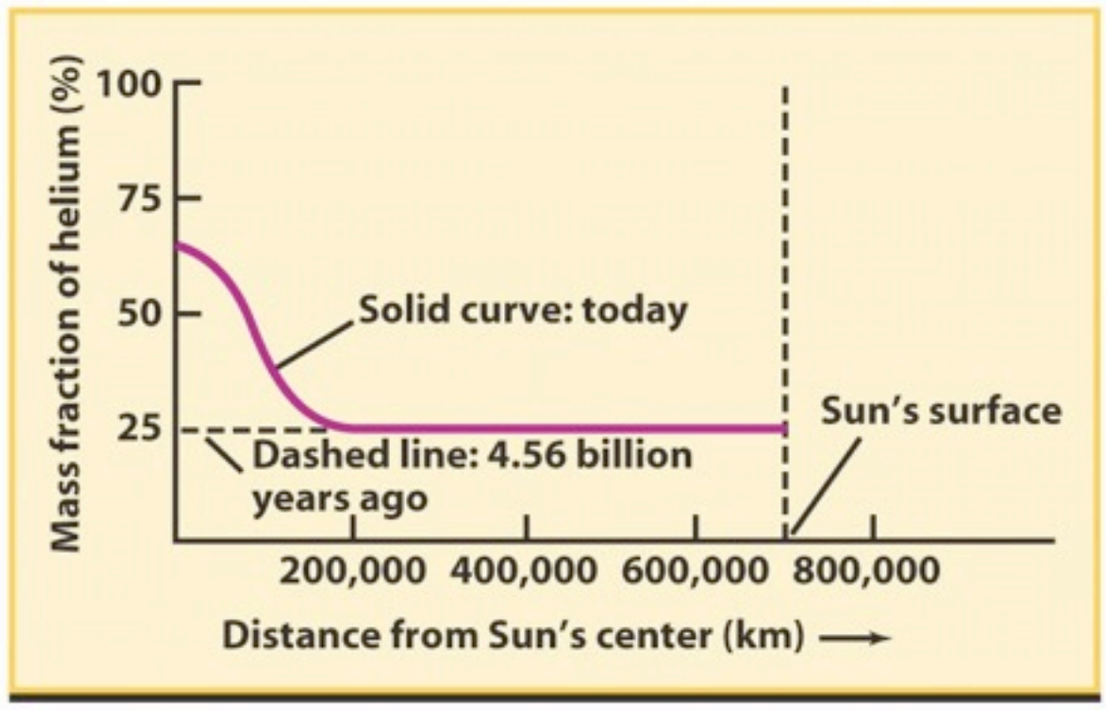
Eventually, runs out of hydrogen in the core.

- Rest of Sun is mostly hydrogen, but not in the core.

And it's not hot enough to fuse helium!.....yet



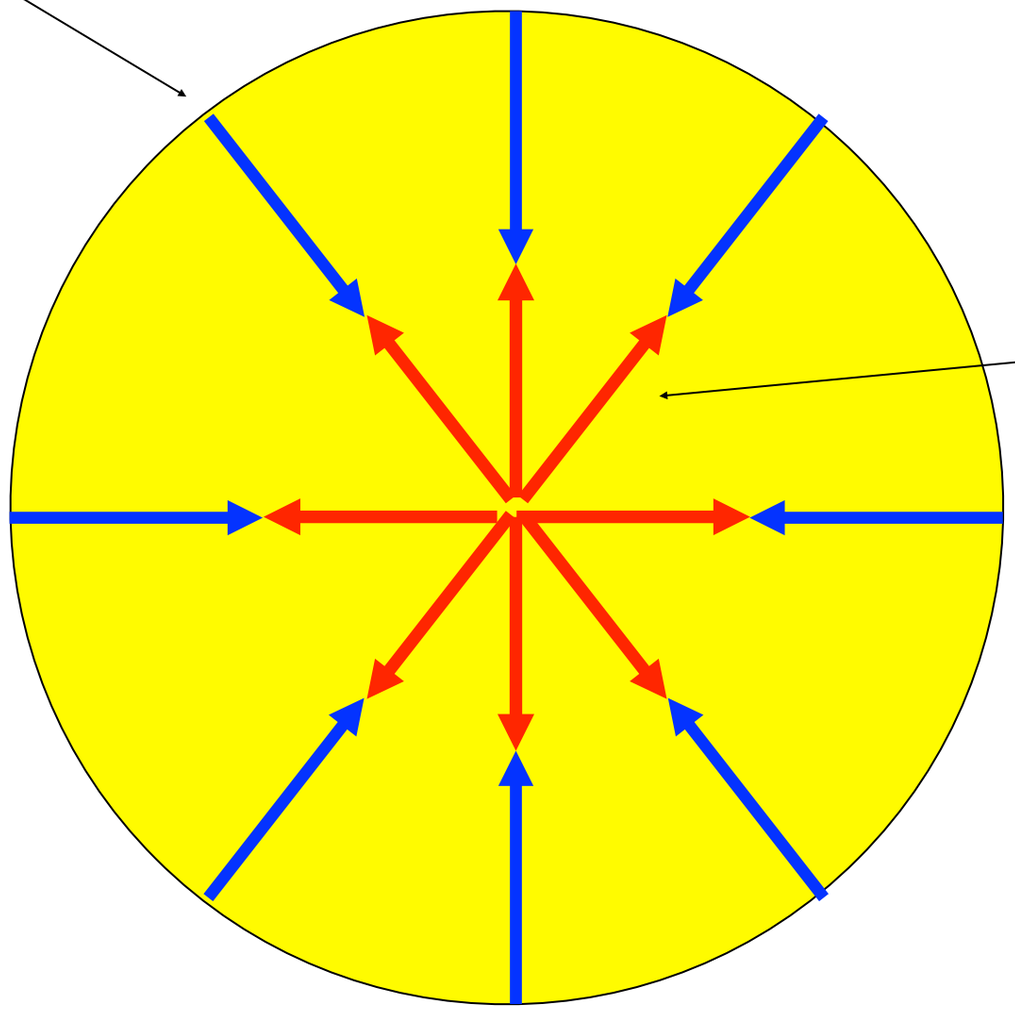
(a) Hydrogen in the Sun's interior



(b) Helium in the Sun's interior

The Battle between Gravity and Pressure

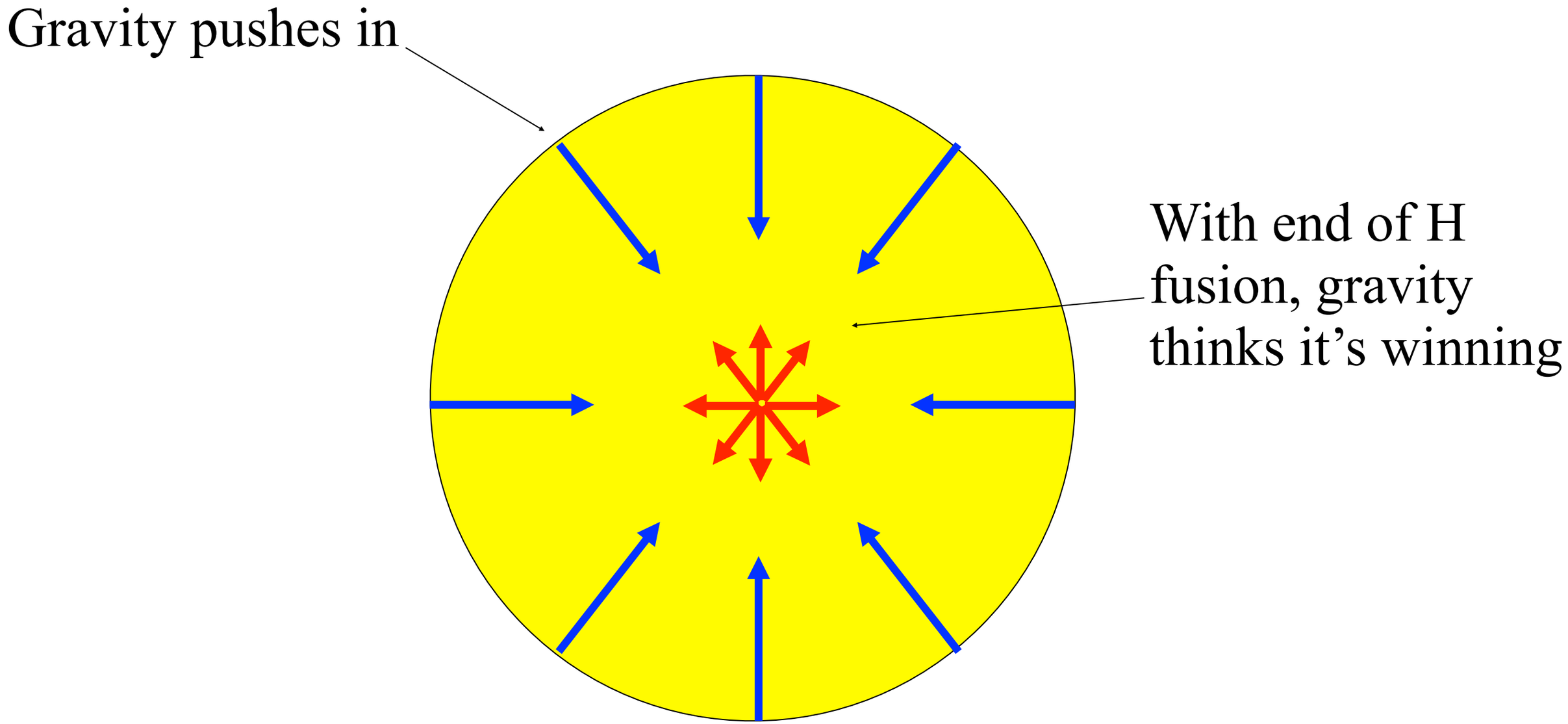
Gravity pushes in



Heat pressure
from H→He
fusion pushes out.

Hydrostatic equilibrium: Balanced forces

The Battle between Gravity and Pressure



Unbalanced forces

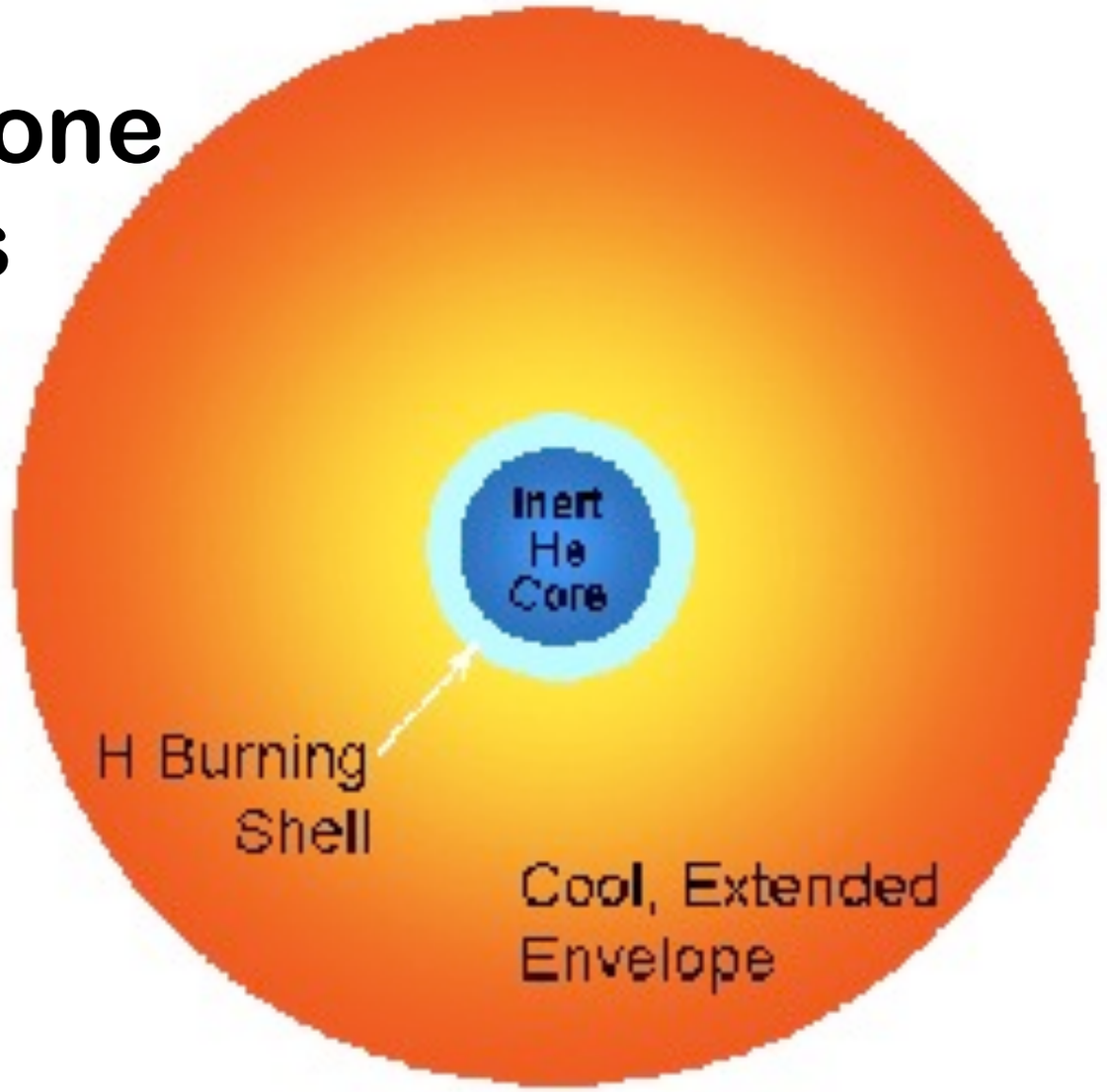
The Red Giant Phase:
6 Billion Years

When the hydrogen is gone in the core, fusion stops

Equilibrium is shot.

Core starts to contract under its own gravity

This contracting heats the core, and hydrogen fusion starts in a shell around the core

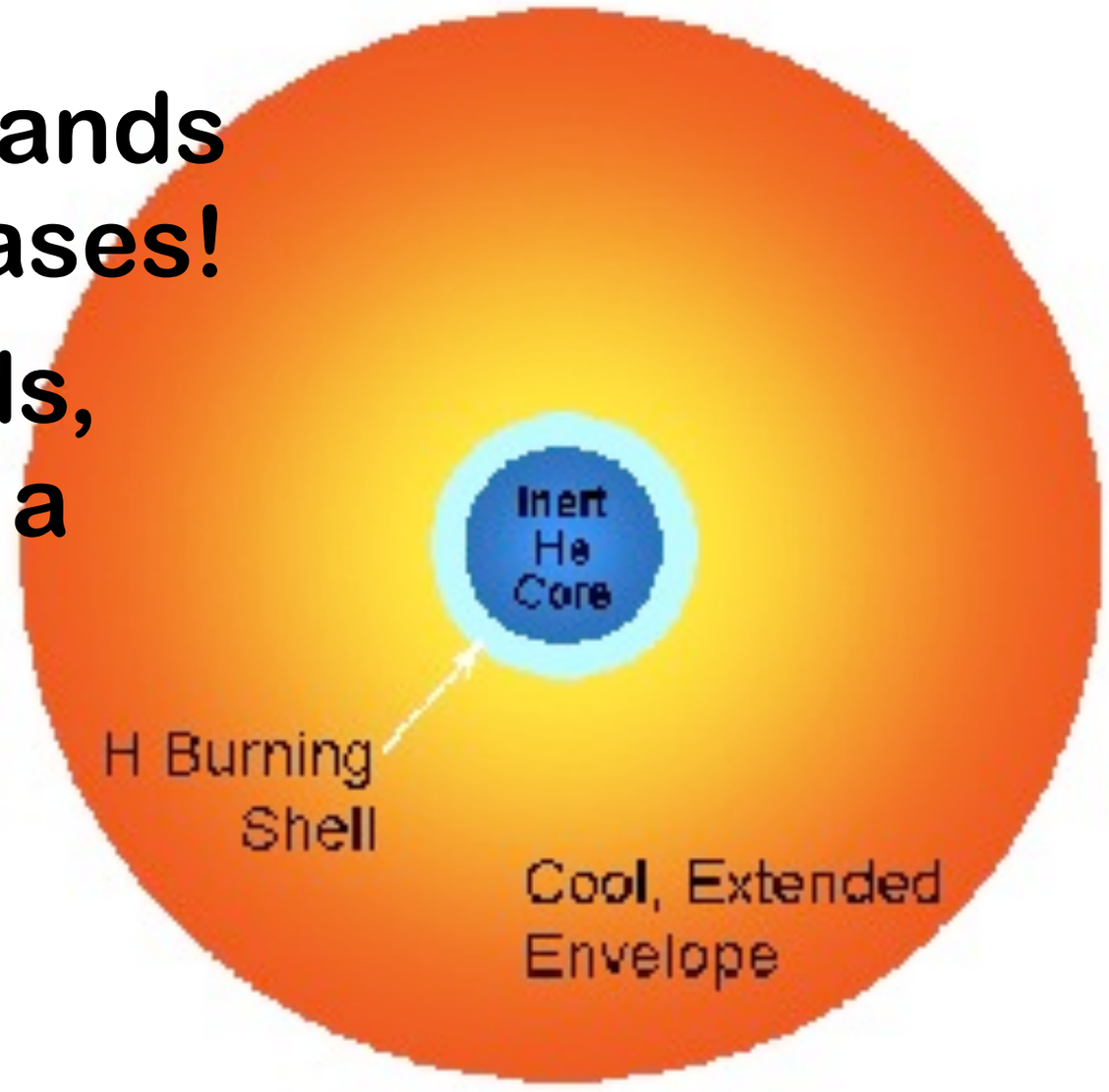


The Red Giant Phase:
6 Billion Years

Energy is released, expands envelope ⇒ Lum. increases!

As the envelope expands, it cools – so it becomes a red giant.

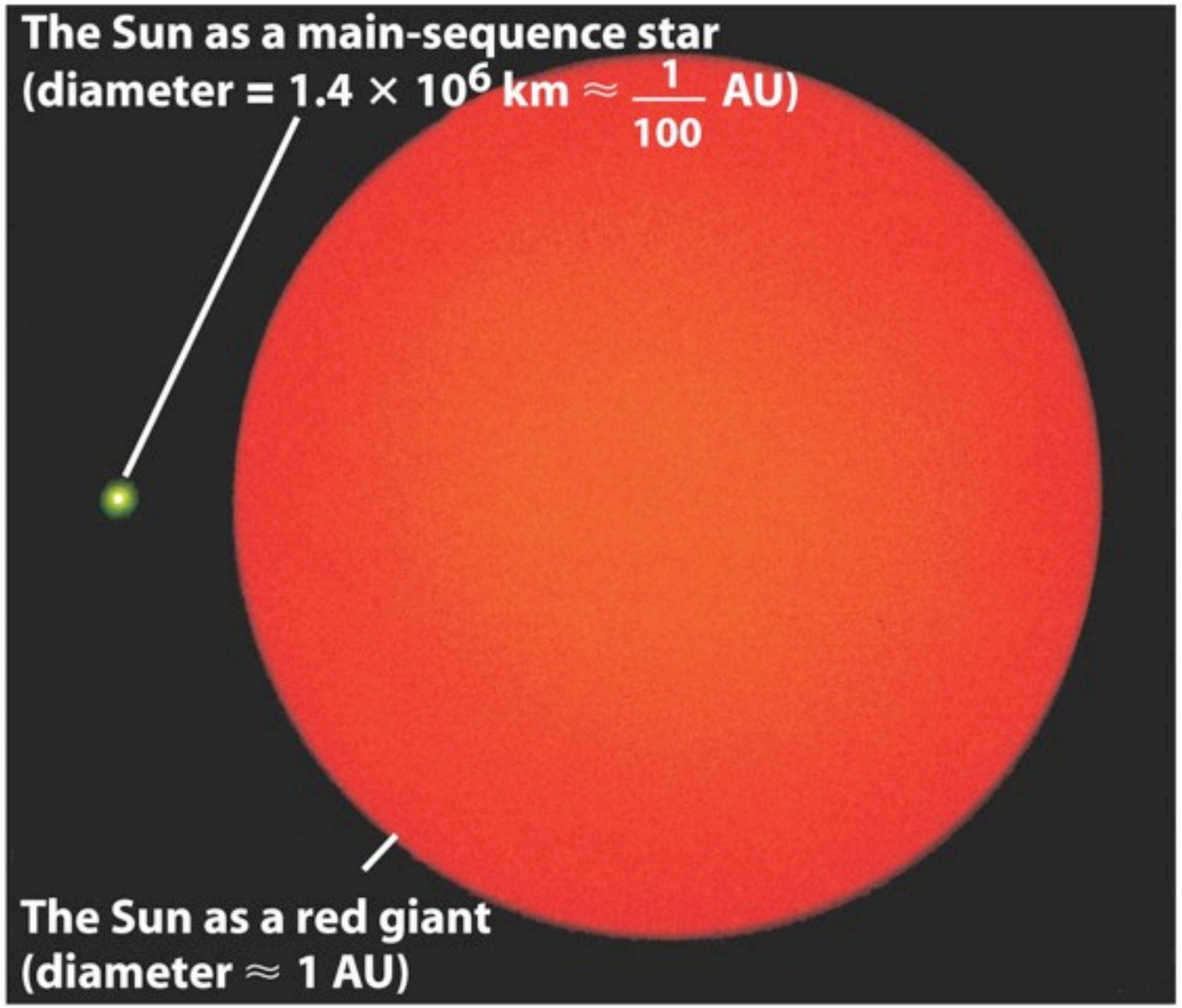
This process takes 50-100 million years.



Cartoon version (way too fast)
http://www.youtube.com/watch?v=fOM7DMxOiAk&feature=related

In 6-7 Billion years

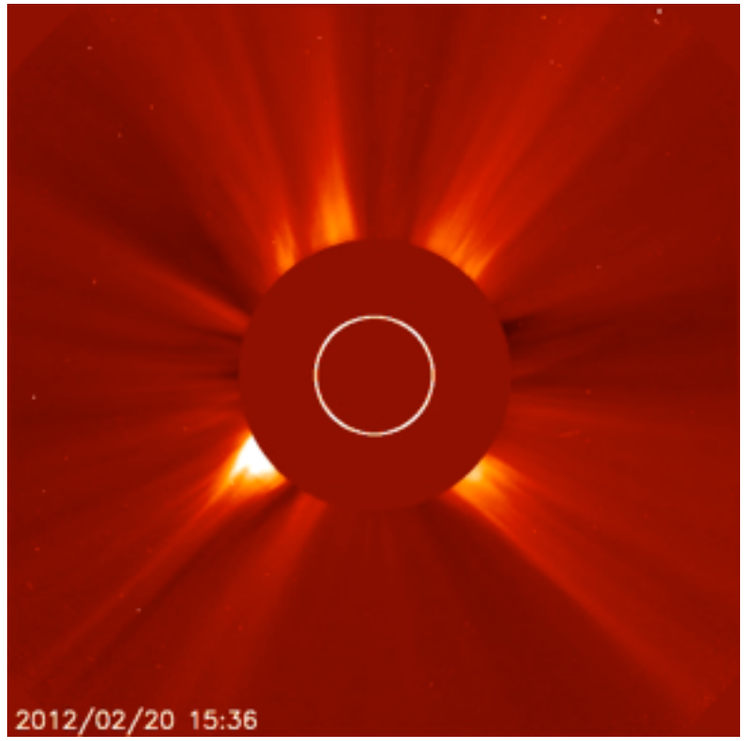
- The Sun will expand to 100-250 times bigger than it is now!
- The same mass but now it's bigger.



The Sun today and as a red giant

as usual, Niel De Grasse Tyson says it best...
http://www.youtube.com/watch?v=3rH4bMylBKg

In 6-7 Billion years



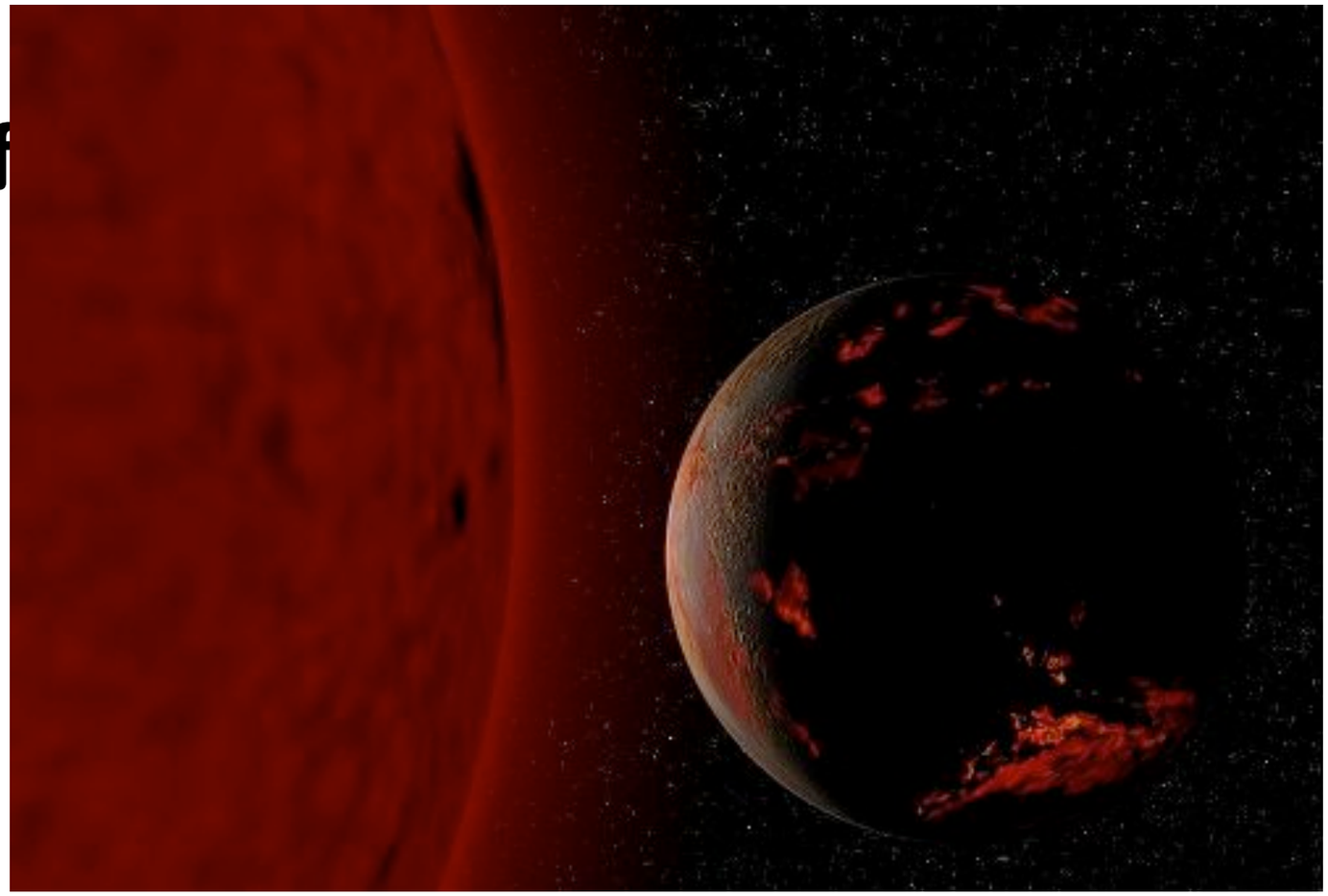
The Sun Today

- The surface gravity decreases and the Sun has more luminosity.
- The solar wind turns into a stellar wind, and it looses material as it expands, about 10^7 times more than now.
- It's blowing it all away!

http://www.astropix.com/wp/wp-content/uploads/2006/12/2006_02.JPG

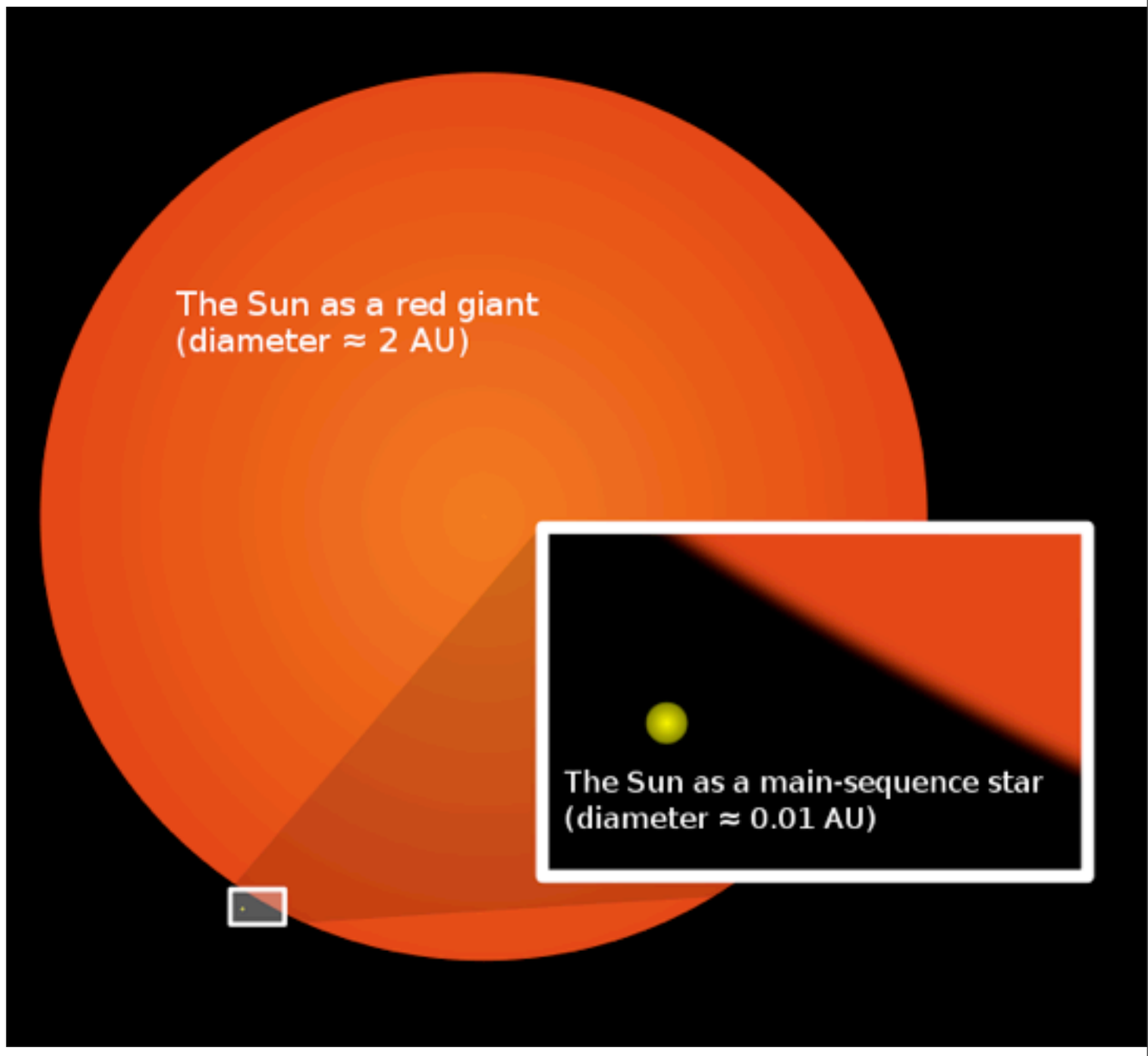
In 6-7 Billion years

- During the time it expands it loses a significant fraction of mass.
- So, the planets move outward.
- Planets race away as the Sun expands.
- Who wins?
- We aren't yet sure.



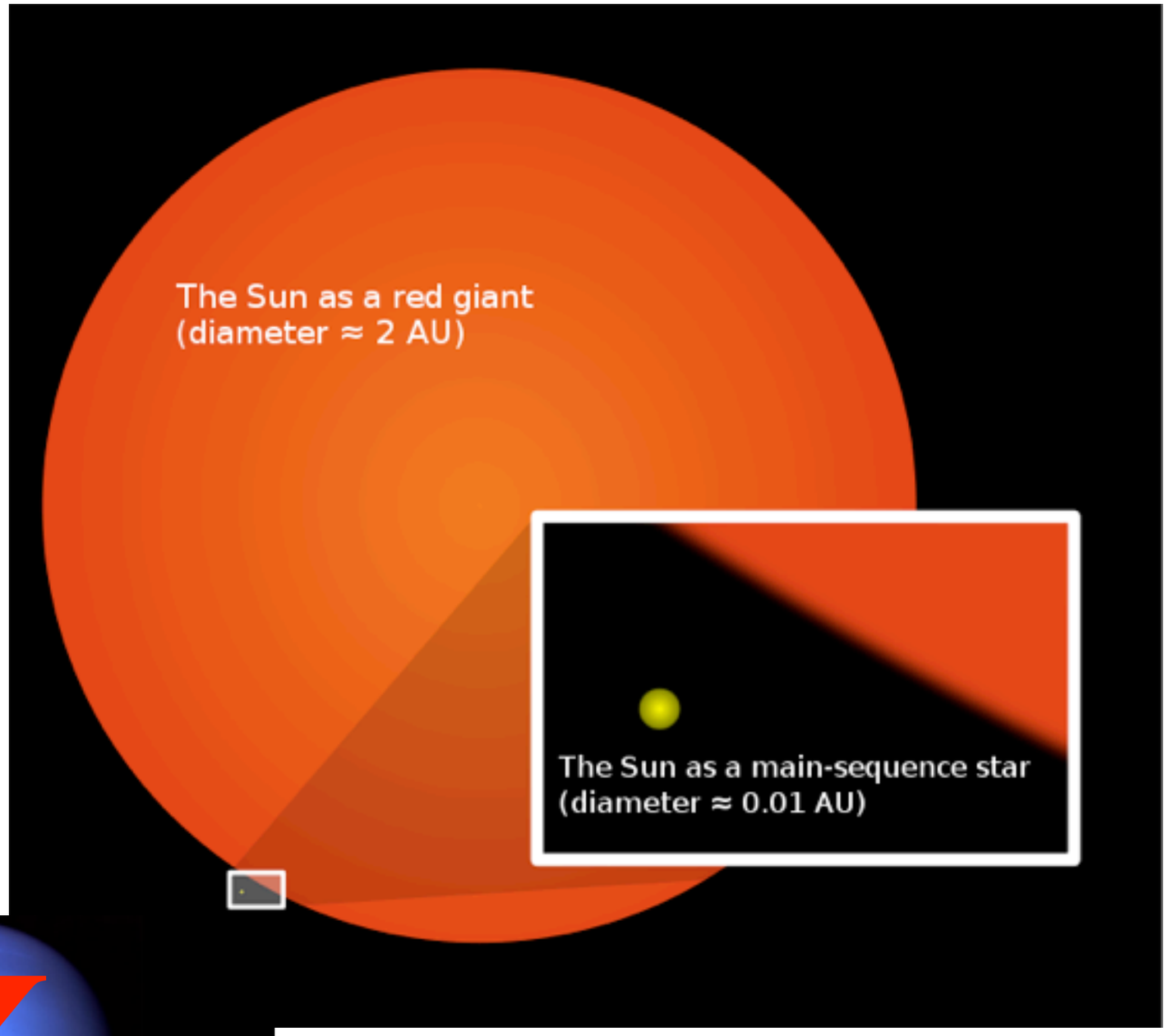
In 6-7 Billion years

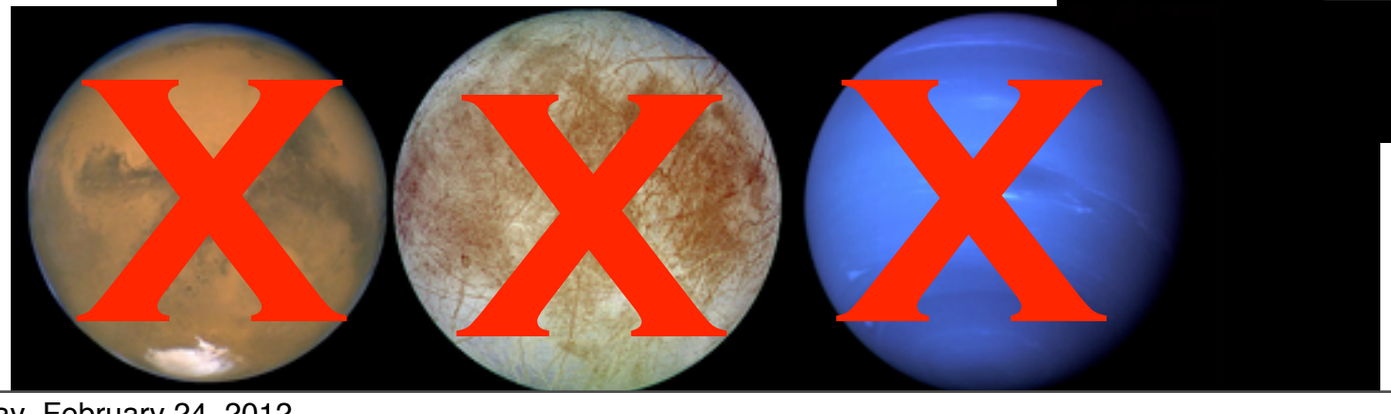
- We used to think that the Sun would gobble the Earth.
  - Mercury? Gone.
  - Venus? Probably gone.
  - Earth? Maybe gone.
- But: even if not, with the Earth's oceans and atmosphere gone, crust still melts.
- Not good…



In 6-7 Billion years

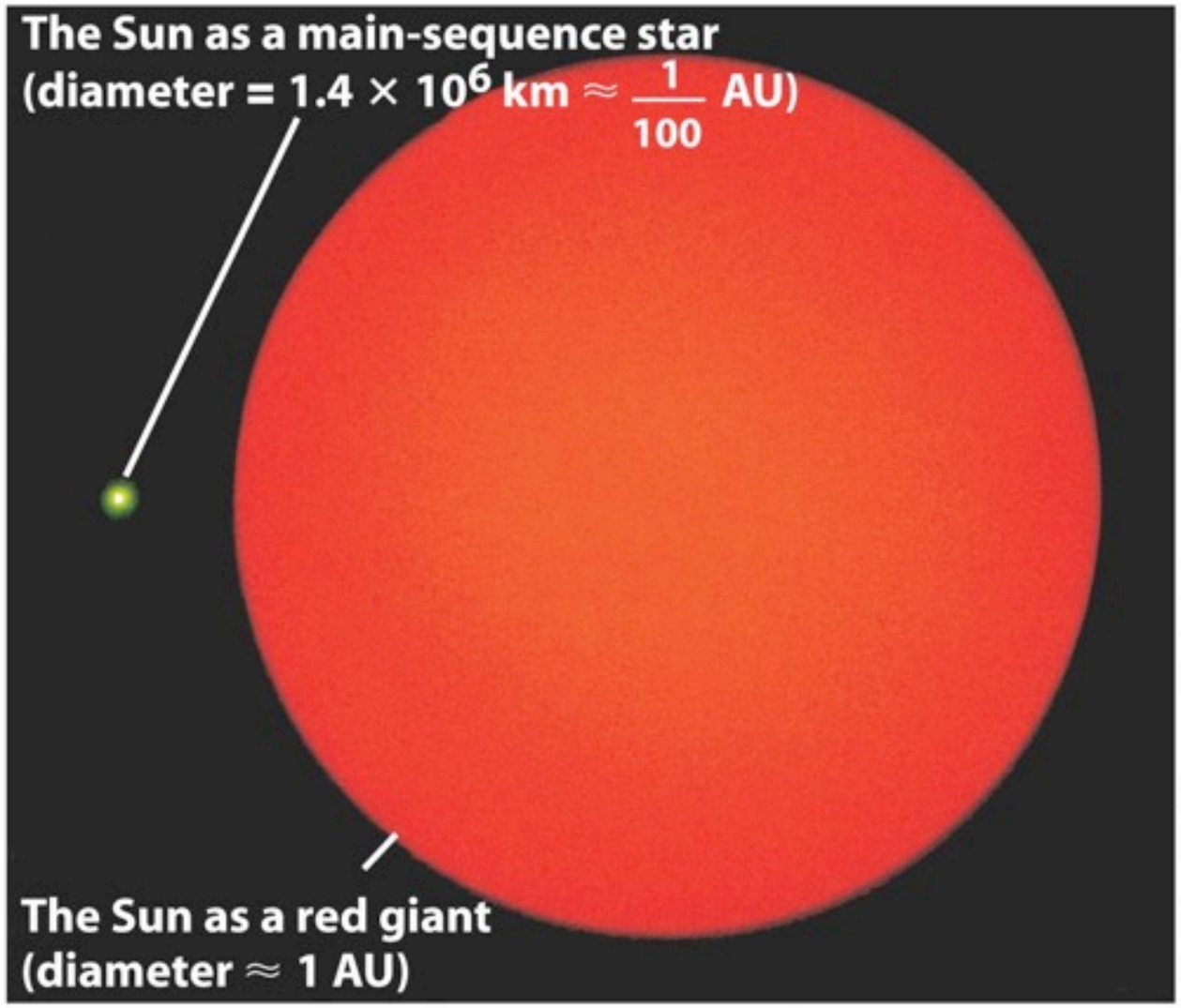
- Mars?
  - For sure too hot.
- Jupiter's Moons?
  - Still too hot
  - Europa's water vaporizes
- Even the moons of Uranus and Neptune may be too hot.





Mitigation

- Habitable zone moves out to huge distances
- We would have to move the Earth out to Pluto or further!
- Probably not possible.
  - Interactions with Jupiter may eject us from Solar System
- Even then, Sun no longer in equilibrium, will oscillate in size and brightness.
- Good news: we got billions of years to figure it out!



The Sun today and as a red giant