# Astronomy 150: Killer Skies
# Lecture 15, February 22

**Assignments:**

- HW4 posted, due Friday at start of class
- Night Observing tonight, tomorrow, and next week
- Planetarium:  report due Friday
- Exam scores posted

**Last time:  How does the Sun shine?**

**Today:  the Future Sun:  Part I**


# Night Observing

**Night Observing continues tonight!**

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

**This week and next: 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

**Software:**

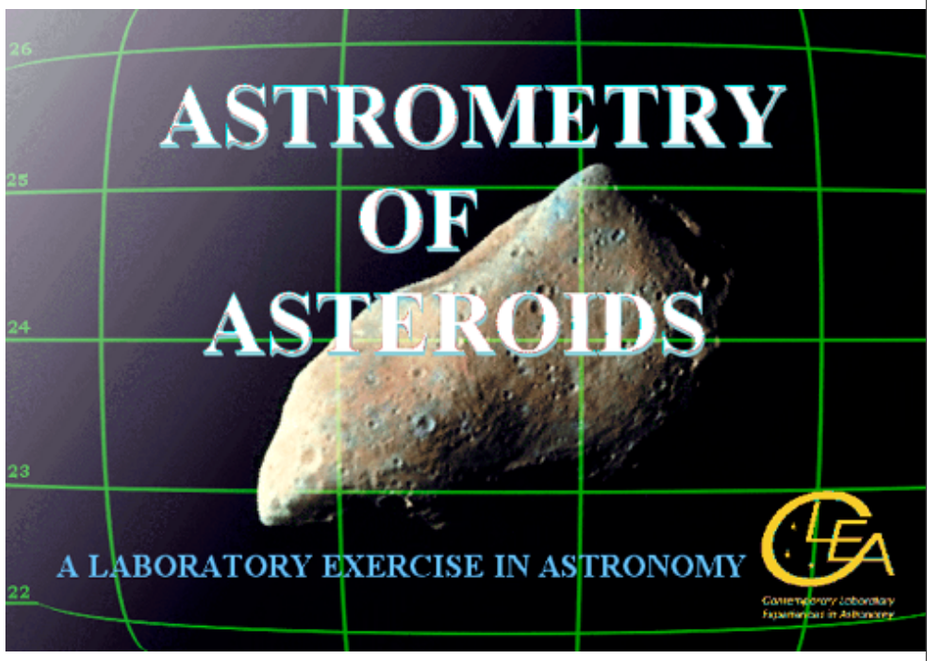
- Installed on ICS lab computers (Windows)
- Or download to your PC

**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!
- don't wait till the last minute!




**to give you time: no class next Wednesday Feb 29--work on this instead!**

**Completed worksheet due by Fri., March 2**

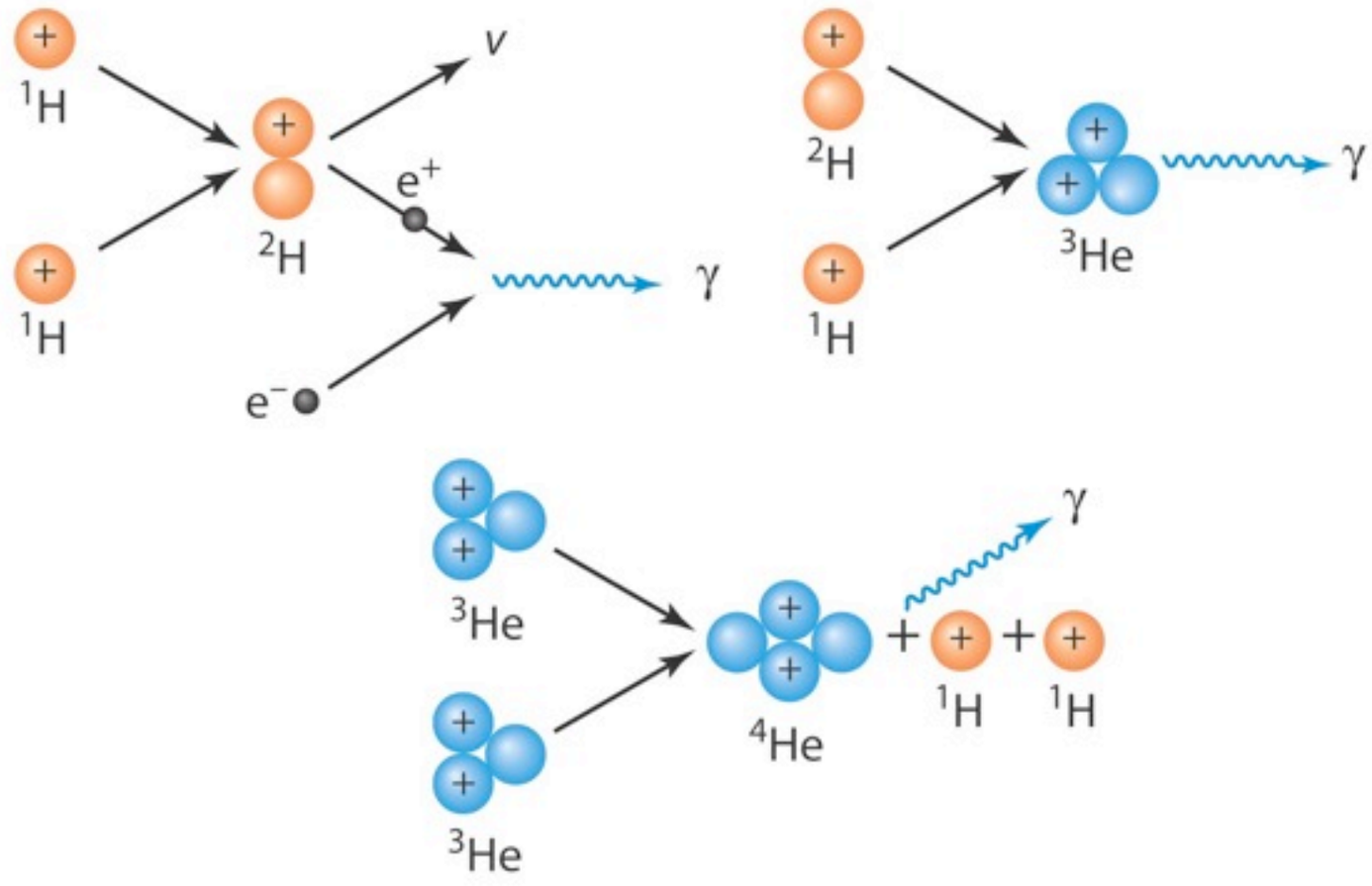
**Help session: 3/1, 5-7pm, Oregon ICS lab**

# Nuclear Fusion in the Sun's Interior

**The Sun is a nuclear reactor**

**generates energy and stays hot because nuclear reactions at the Sun's core release nuclear energy**

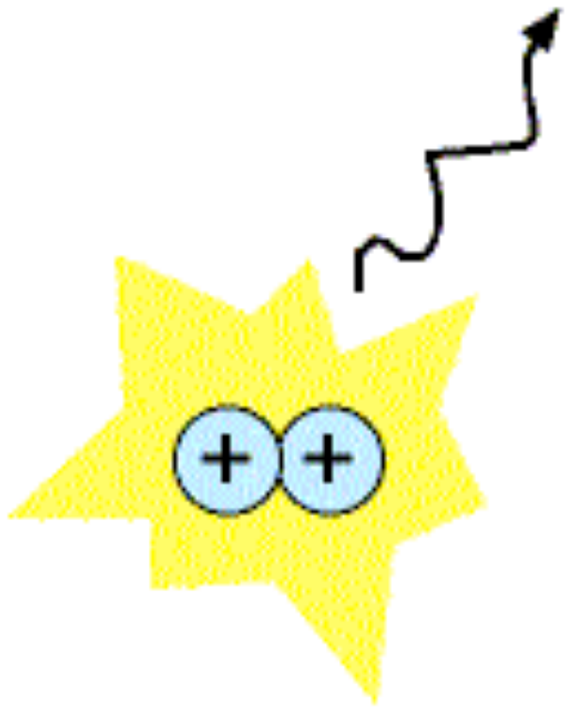
- **Hydrogen fused to make helium**
- **Sun's "fuel" is mass--in the form of hydrogen**
- **as the Sun "burns", 0.7% of this mass converted to energy**




The Proton-Proton Cycle

# Fusion needs high temperatures and densities

High temperature:
large speeds

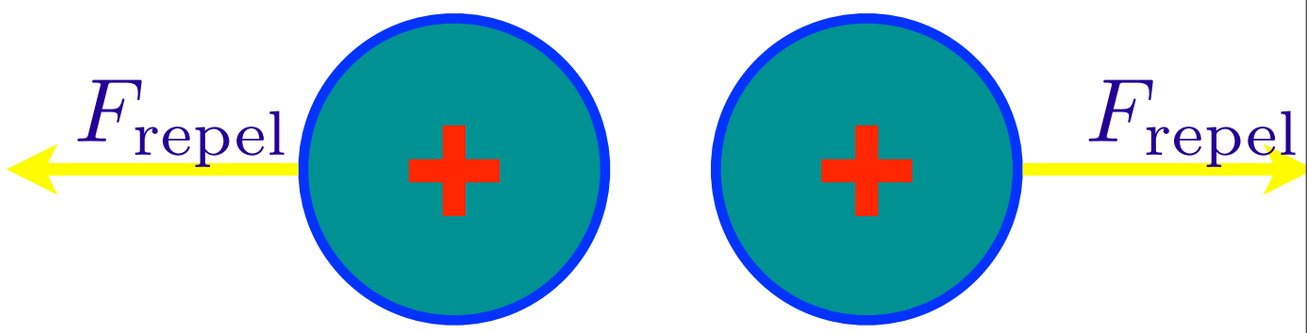


Nuclei able to get close enough for strong nuclear force to act: nuclei fuse & energy released.

# Why Nuclear Fusion Doesn't Occur in Your Coffee

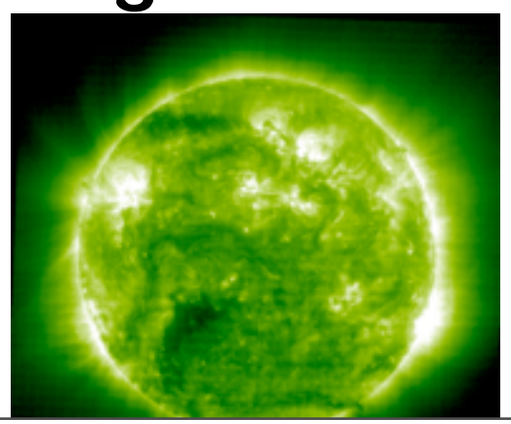
- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time

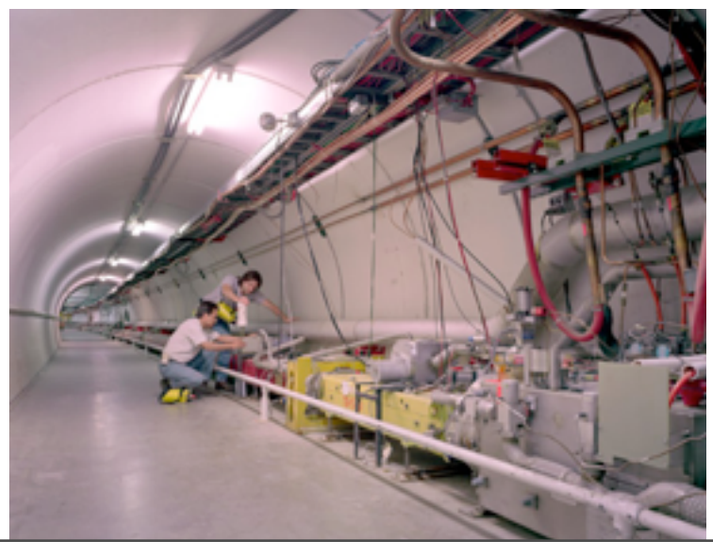
**Nuclear collisions must be very violent to overcome proton repulsion**




**Where does this happen?**
**On Earth: in accelerators**
**In cosmos:**

- centers of stars
- big bang





# The Evidence?

**How do we know this is all true?**

- after all--can't visit the core of the Sun!
- so is Solar fusion forever hidden to us?

**No! Recall the first step in the chain from H to He**

$$p + p \longrightarrow d + e^+ + \nu$$

**neutrinos produced!**

- what happens to them?

**Can try to look for the neutrinos!**

**Search in huge underground experiments**

- Q: Why huge? Why underground?

**Matter is almost transparent to neutrinos**

**It would take a block of lead over a quarter of a light-year long to stop one**

# The Evidence!
# Solar Neutrinos

**Neutrino Experiments:**

**huge vats of chlorine**

- **transformation** $\nu + \text{chlorine} \rightarrow \text{argon}$
- **collect argon atoms**

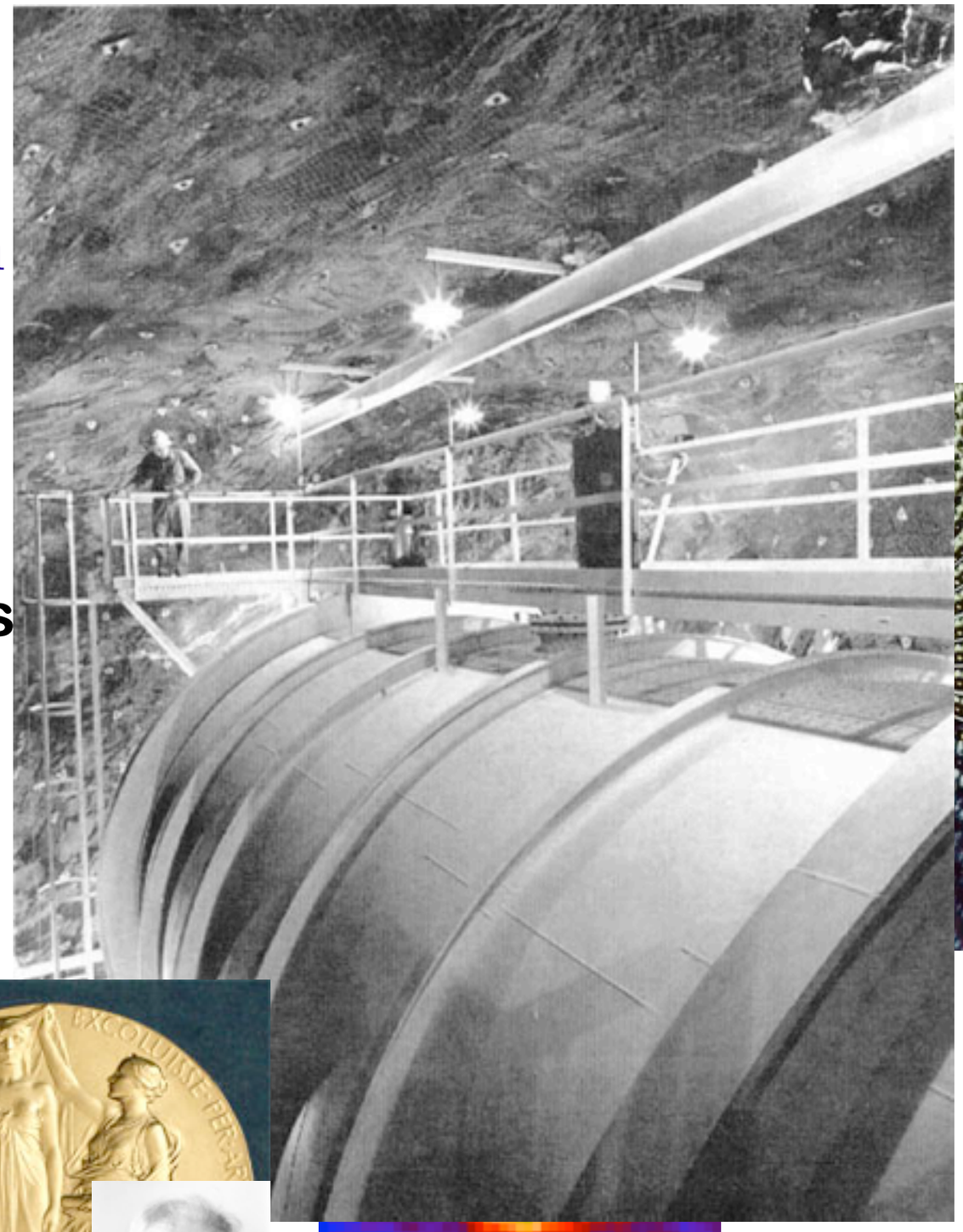
**huge vats of ultrapure water**

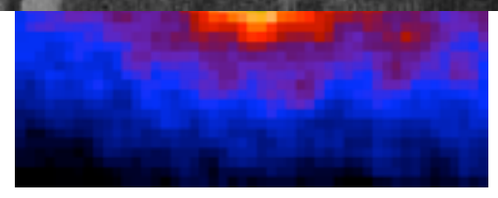
- **collisions:** $\nu + e^- \rightarrow \nu + e^- + \text{light}$
- **"kicked" electrons emit light flashes**
- **can see flashes -- show where neutrino was going**

**Neutrinos from Sun detected!**

**Nobel Prize!**

- **proof that Sun is powered by nuclear fusion!**
- **neutrino experiments are telescopes!**





**of the Sun taken with neutrinos!**

# Poetry Slam:
# Cosmic Gall
# by John Updike

little

hardly

Neutrinos, they are very small.
They have no charge and have xxxxxmass
And xxxxdo not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold shoulder steel and sounding brass,
Insult the stallion in his stall,
And scorning barriers of class,
Infiltrate you and me! Like tall
and painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
and pierce the lover and his lass
From underneath the bed-you call
It wonderful; I call it crass.

**What's right? wrong?**

Telephone Poles and Other Poems, John Updike, Knopf, 1960

# i>clicker question

Imagine: the Sun has a slight rise in core temperature.

Fusion reactions very sensitive to temperature, and so have a huge increase.

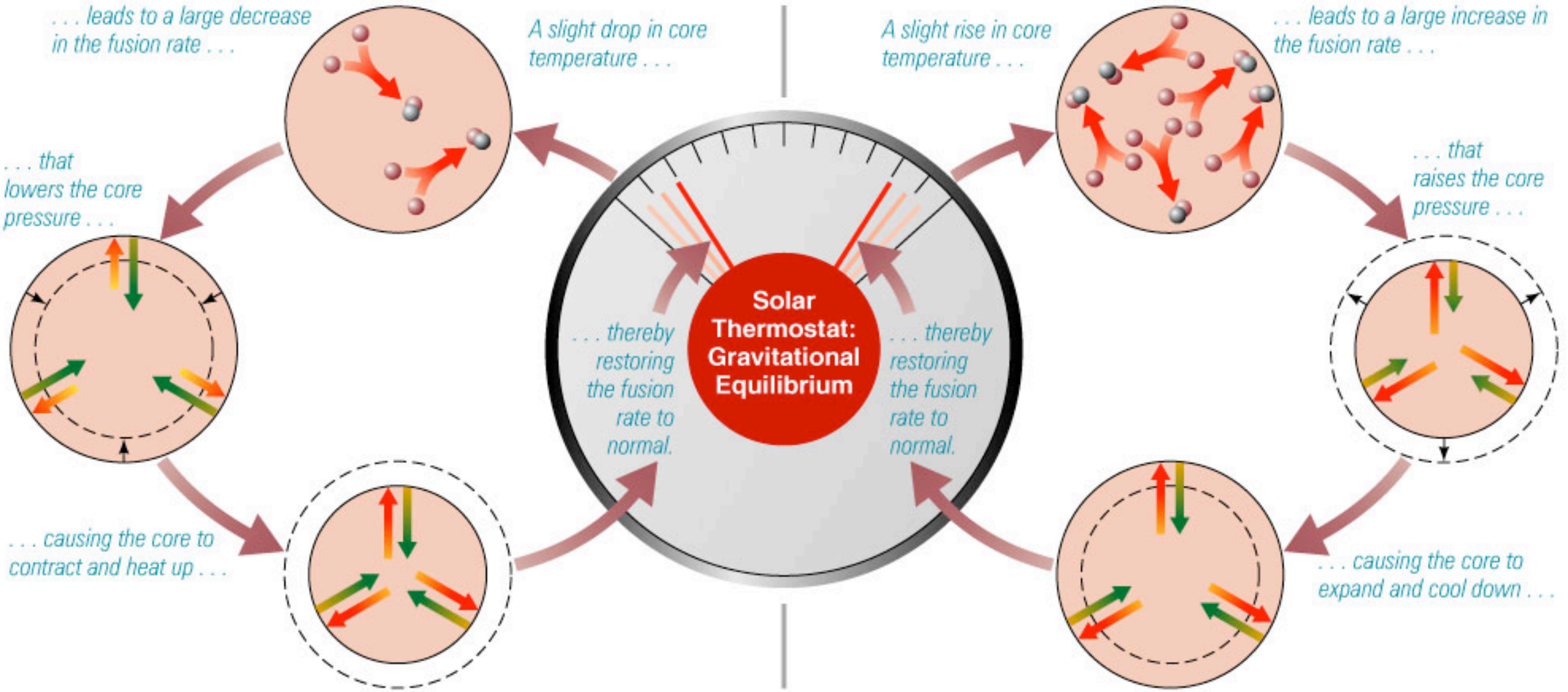
How will the Sun respond to this rapid rise in fusion energy?

A. The core would compress and heat up slightly

B. The core would expand and cool

C. The Sun would blow up like a hydrogen bomb

# Solar Thermostat



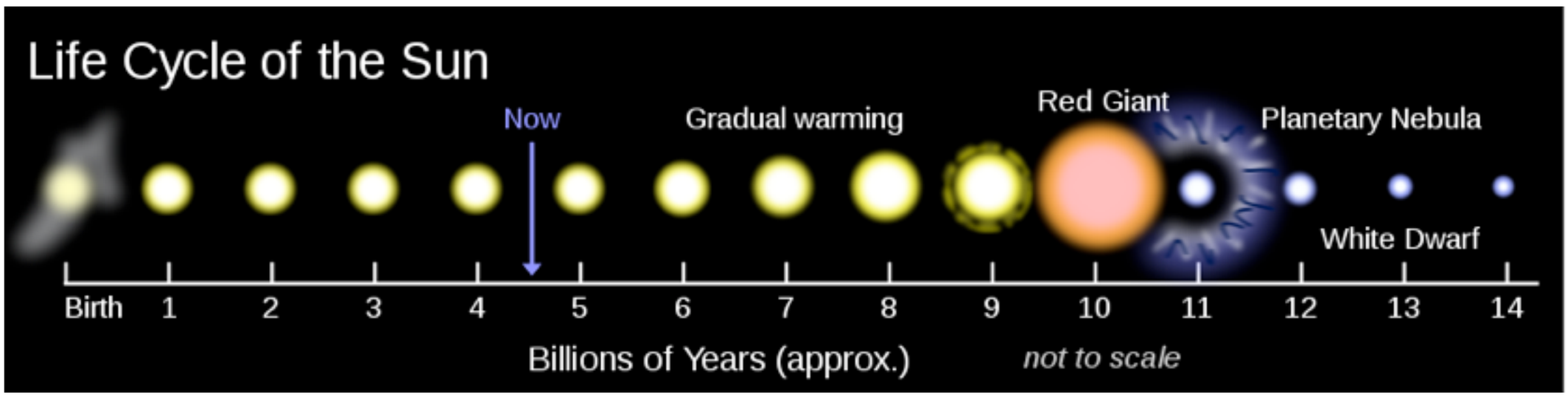
# The Future History of the Sun
# Part I

# 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

For Earth, change in total solar radiation has an impact



# Why is the Sun getting brighter?

Each fusion reaction reduces the number of particles in the Sun

- 4 H become 1 He!

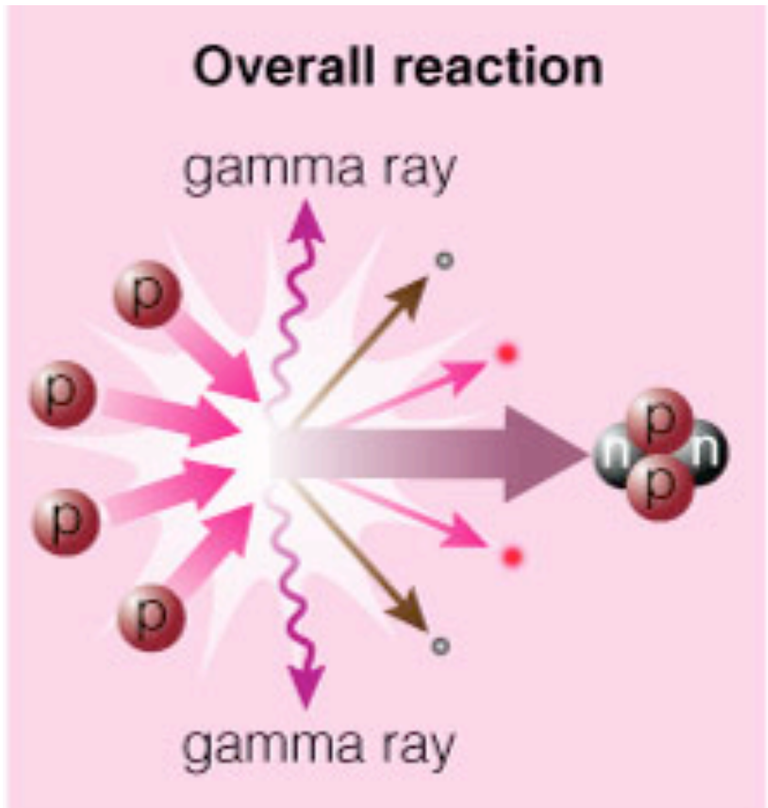
Gas pressure is based on the number of particles and their average temperature

So, helium production reduces the pressure in the core

the Sun responds to this lower pressure

Q: how?

Hint: gravity never goes away!



# The Sun Adjusts to Fewer Particles

**Hydrogen burning: fewer particles**

**Fewer particles: less pressure**

**But same gravity:**

- **Sun loses pressure/gravity balance (hydrostatic equilibrium)**
- **Sun's core contracts**

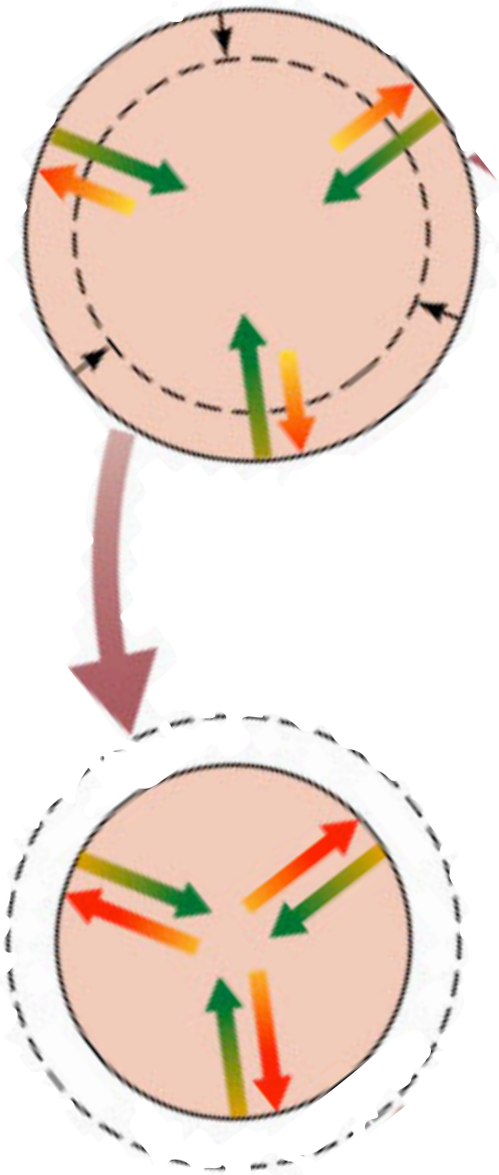
**Contraction compresses gas in Sun**

- **raises temperature! (think bicycle pump)**
- **Sun's core temperature slowly but constantly increasing!**

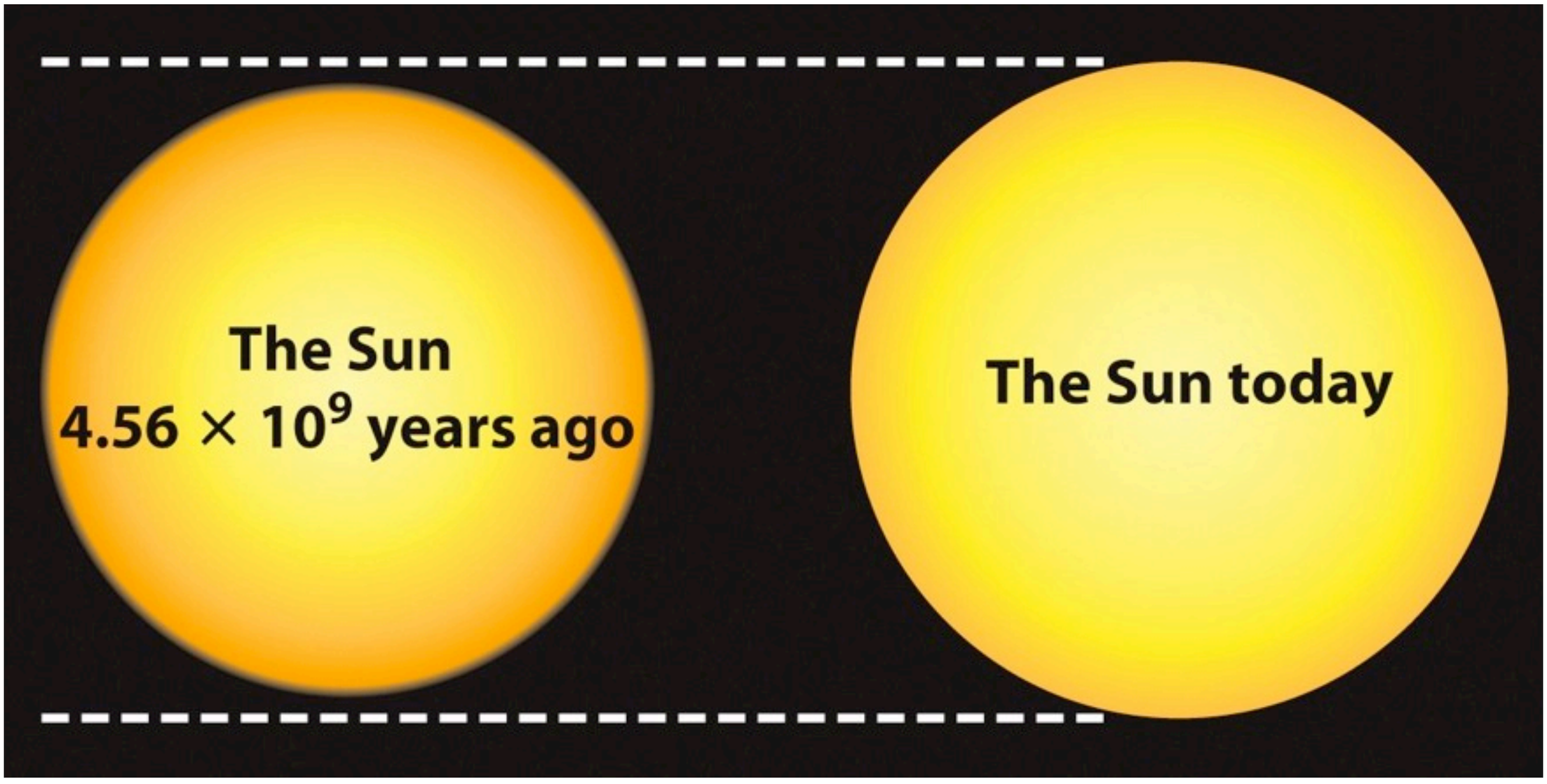
**Nuke reactions faster when temperature higher**

**More reactions:**

- **More energy release!**
- **Sun more luminous and brighter!**



# The Sun was less luminous in the past




**The Sun is now 40% brighter and 6% bigger in diameter than as a zero-age star**

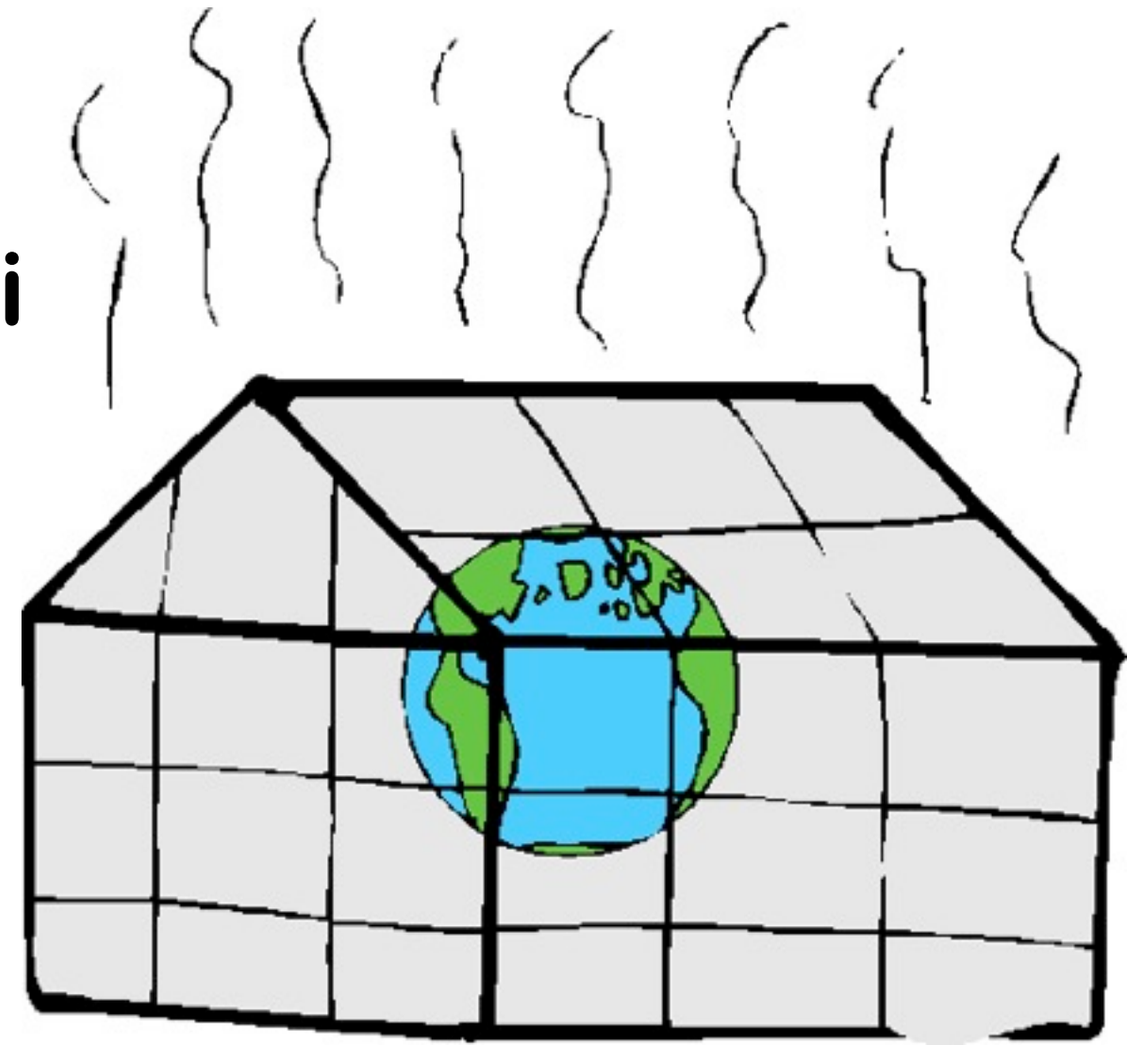
# Mid-Life Crisis for the Earth

In ~1 billion years, our Sun will be 10% more luminous than today

Increase in solar energy wi have major impacts

Adds 5℃ (10℉) to the average temps

Leads to increase in greenhouse effect



http://www.solcomhouse.com/Greenhouse_Effect.gif


HBO
GLOBAL
WARMING
OR:
NONE LIKE IT HOT!

# Interlude: the Glow of Heat

## Crucial fact for astronomy and for life

- Hot objects glow!
- temperature -- light connection!
  - "blackbody radiation" -- more on this later

## The glow itself depends on temperature

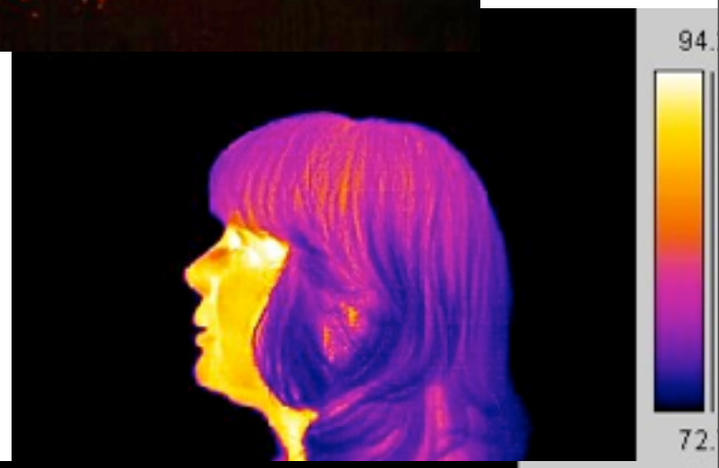
- intensity: hotter objects glow brighter
- color (wavelength): hotter objects bluer, cooler objects redder

## at room temperature: glow so red, can't be seen by naked eye!

- "infrared" light (IR)

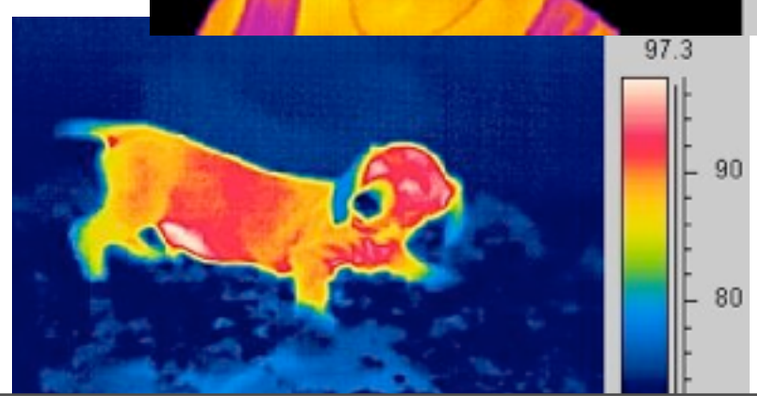
## Experiments:

- look at any ordinary remote through digital camera
- look at people and animals with camera sensitive to infrared




IR humans


IR puppy



# Infrared Light

Infrared light:  invisible but very real!

- since you can't see it, don't have gut feeling for how it works

Objects near room temperature glow in IR

- people, animals, buildings, the ground
- the whole Earth glows in IR, radiating energy upwards!

What happens to this glow?

Must pass through atmosphere

- dominant components of air (nitrogen, oxygen) are transparent to infrared light
- but atmosphere contains trace molecules which absorb IR light and energy
- good IR absorbers:  "greenhouse gasses"

  carbon dioxide $CO_2$

  water $H_2O$

# Greenhouse Effect: an Atmospheric Blanket

**Atmosphere is transparent to Sunlight**

- you can see Sun!

**Sunlight delivers energy to Earth--keeps us warm**

**Warm Earth glows in infrared, sending energy back into space**

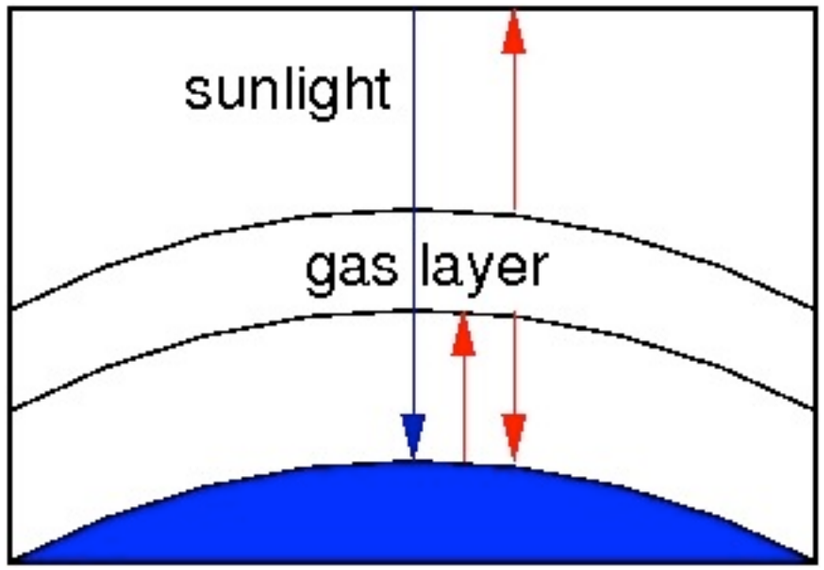
**But greenhouse gasses in atmosphere absorb some of the IR from Earth**

- trap heat like blanket
- additional warming to Earth: greenhouse effect

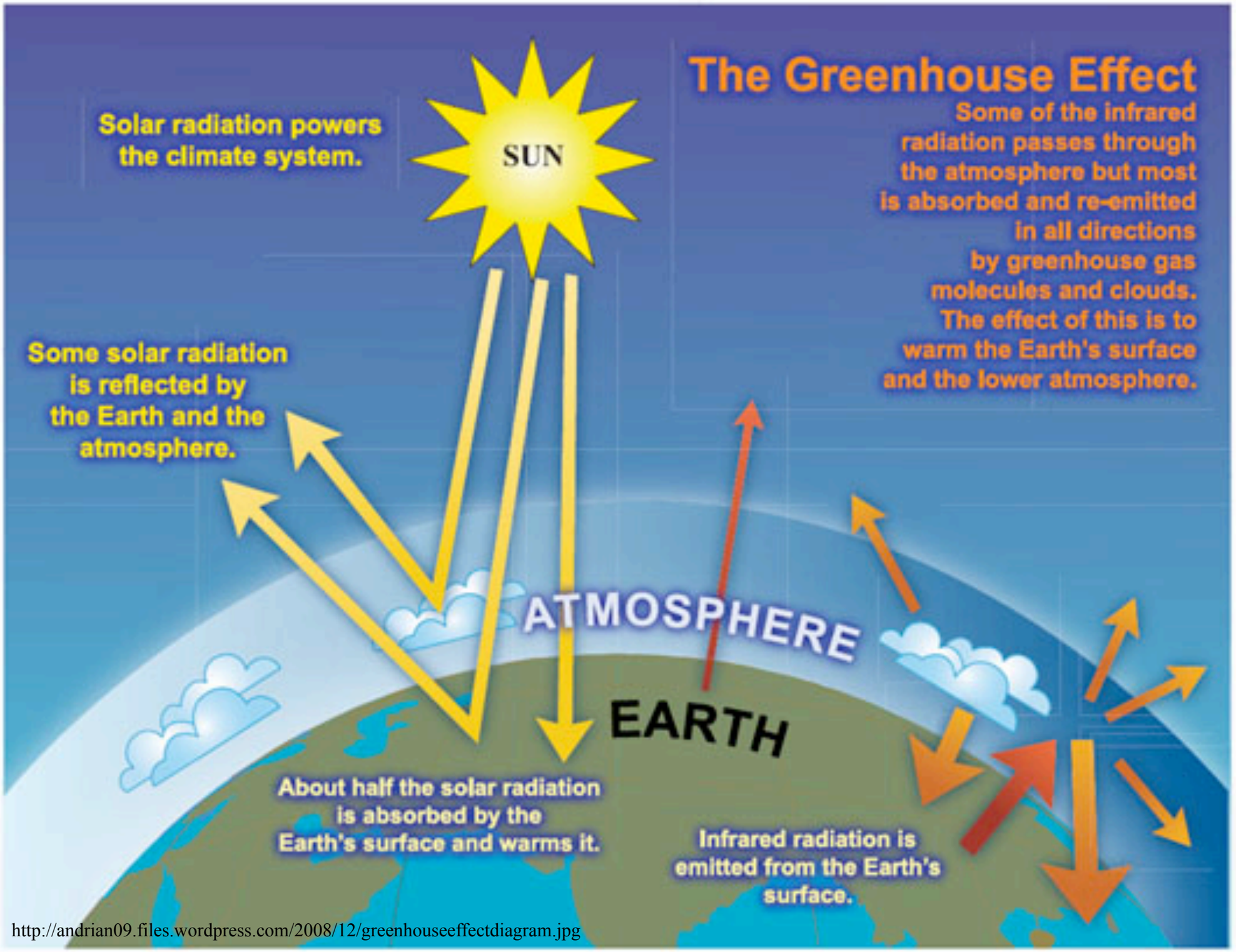
**Happens naturally!**

- Even without humans, atmosphere had some $CO_2$
- resulting modest greenhouse effect keeps Earth from freezing

**but can have too much of a good thing--adding $CO_2$ can make things too hot**



# Greenhouse Effect: Converting Light into Heat




http://andrian09.files.wordpress.com/2008/12/greenhouseeffectdiagram.jpg

# iClicker Poll:
# Earth and the Brightening Sun

**The future Sun will be brighter, delivering more energy to the Earth and making global temperatures higher.**

**Water itself is a greenhouse gas when in atmosphere.**

**As Earth gets hotter, the evaporated water will make the greenhouse effect _____ and will _____ the Earth's temperature and climate**

A. stronger, stabilize
B. stronger, destabilize
C. weaker, stabilize
D. weaker, destabilize

# The Future Greenhouse Effect

As the Sun becomes more luminous and brigther...

- 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...

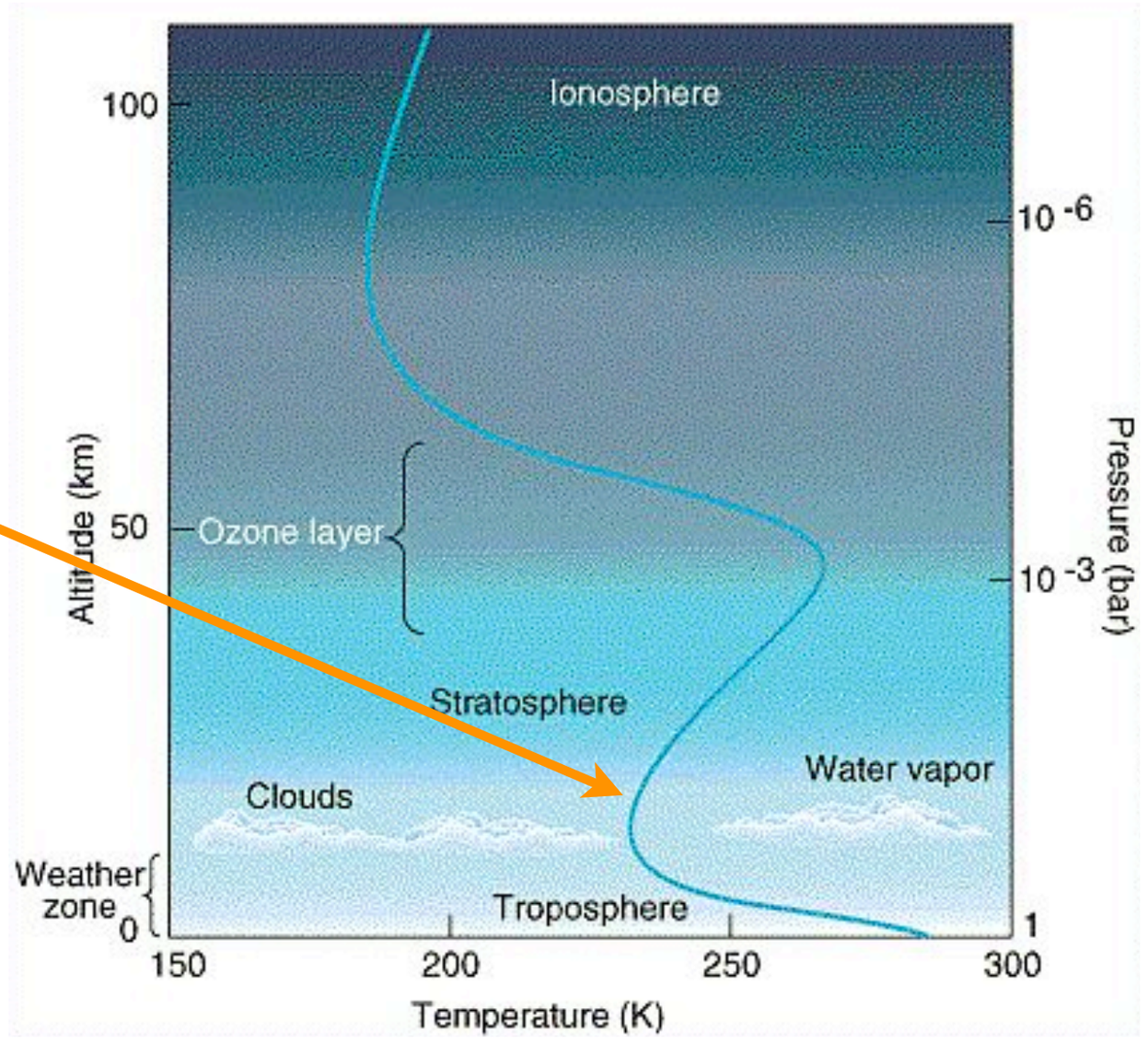
# Earth becomes a moist greenhouse

**Today, Earth's atmosphere has a cold trap**

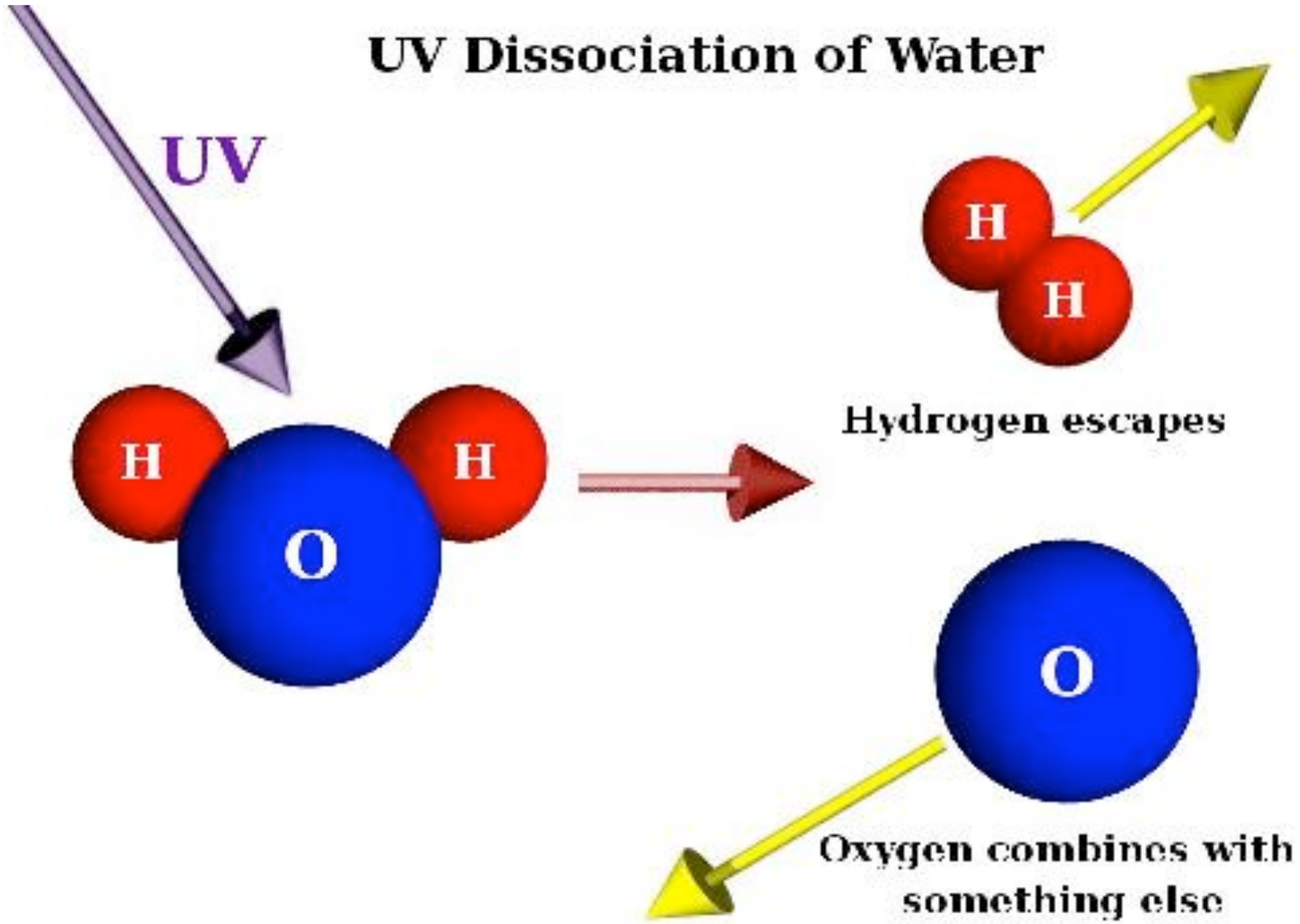
- **Keeps water near the surface**

**Higher temperatures will eliminate this cold trap**

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




Temperature profile of Earth's atmosphere




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

# Moist Greenhouse Earth Dries Out

## Water vapor is lost to space

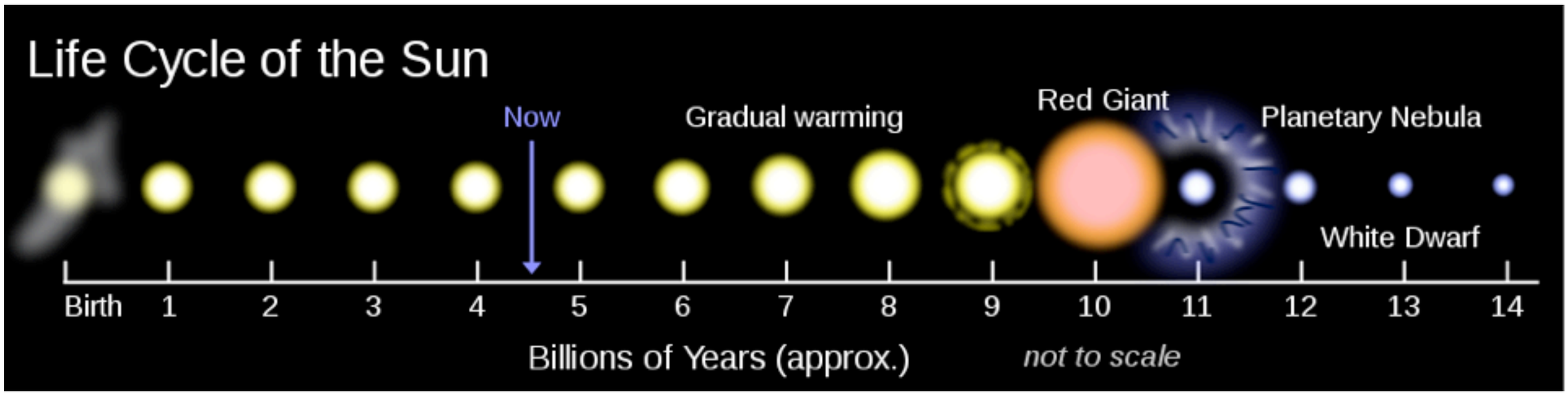
**Continents become deserts, oceans begin to evaporate**

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

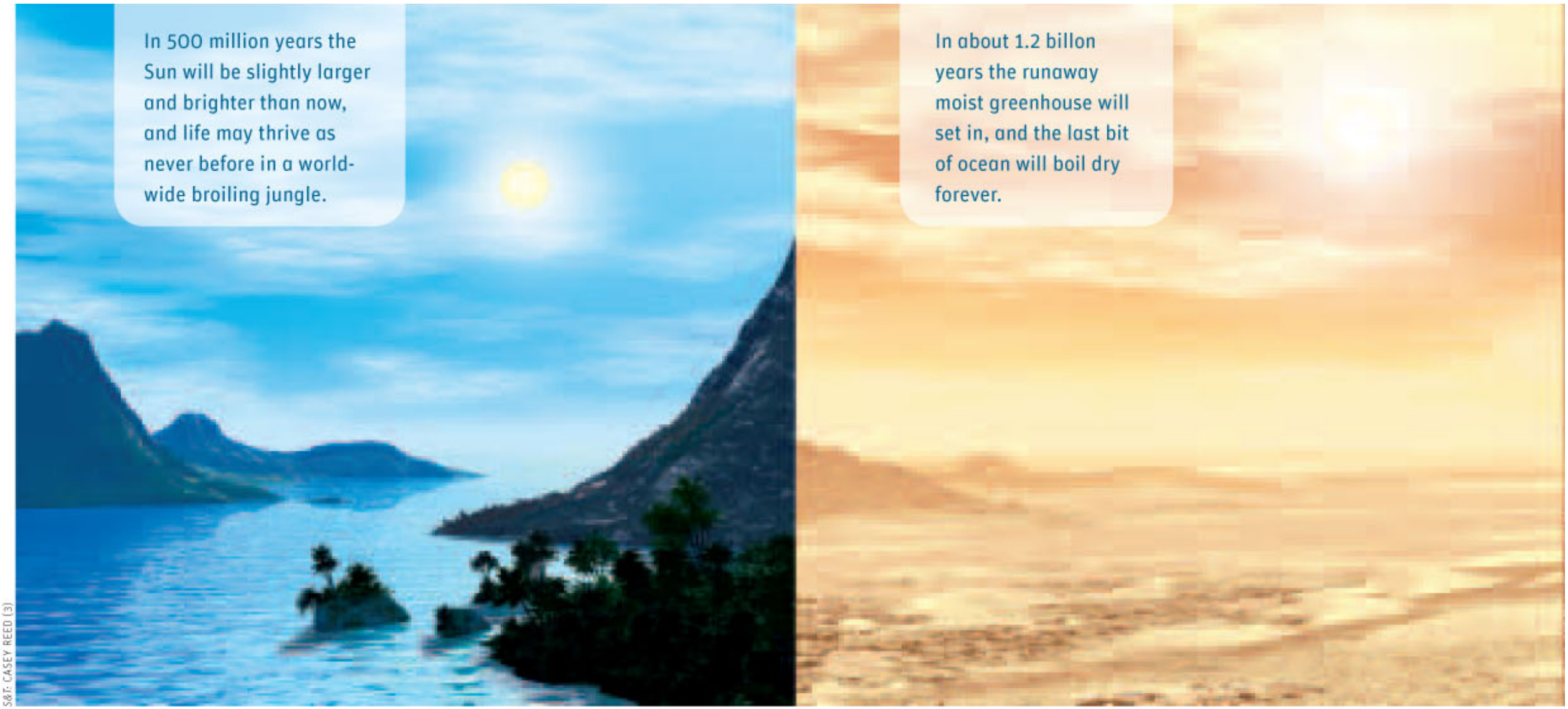
# Sun is currently in “quiet adulthood”

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 Gyr from today

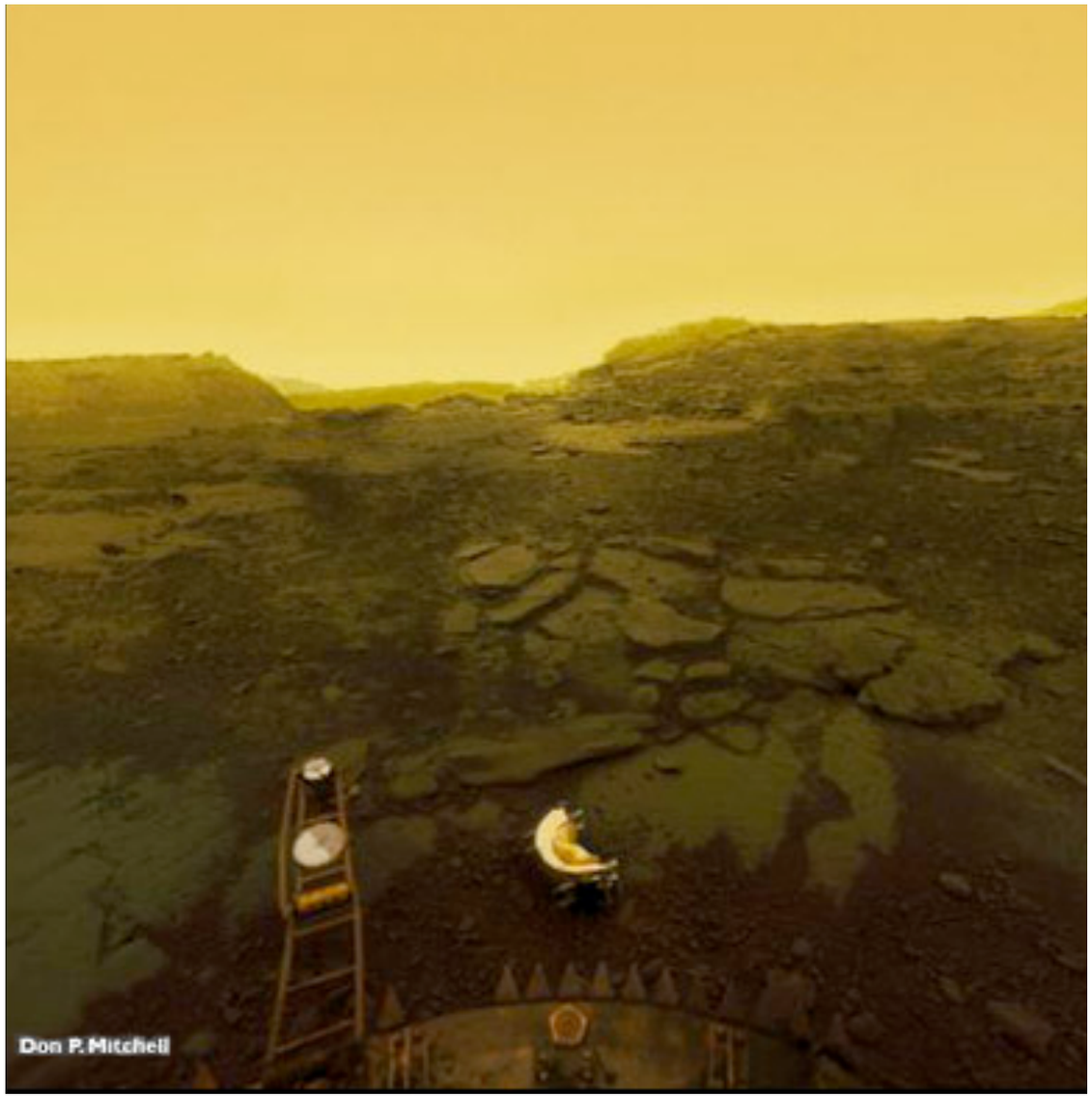
**Gyr = gigayear = 1 billion years**

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...

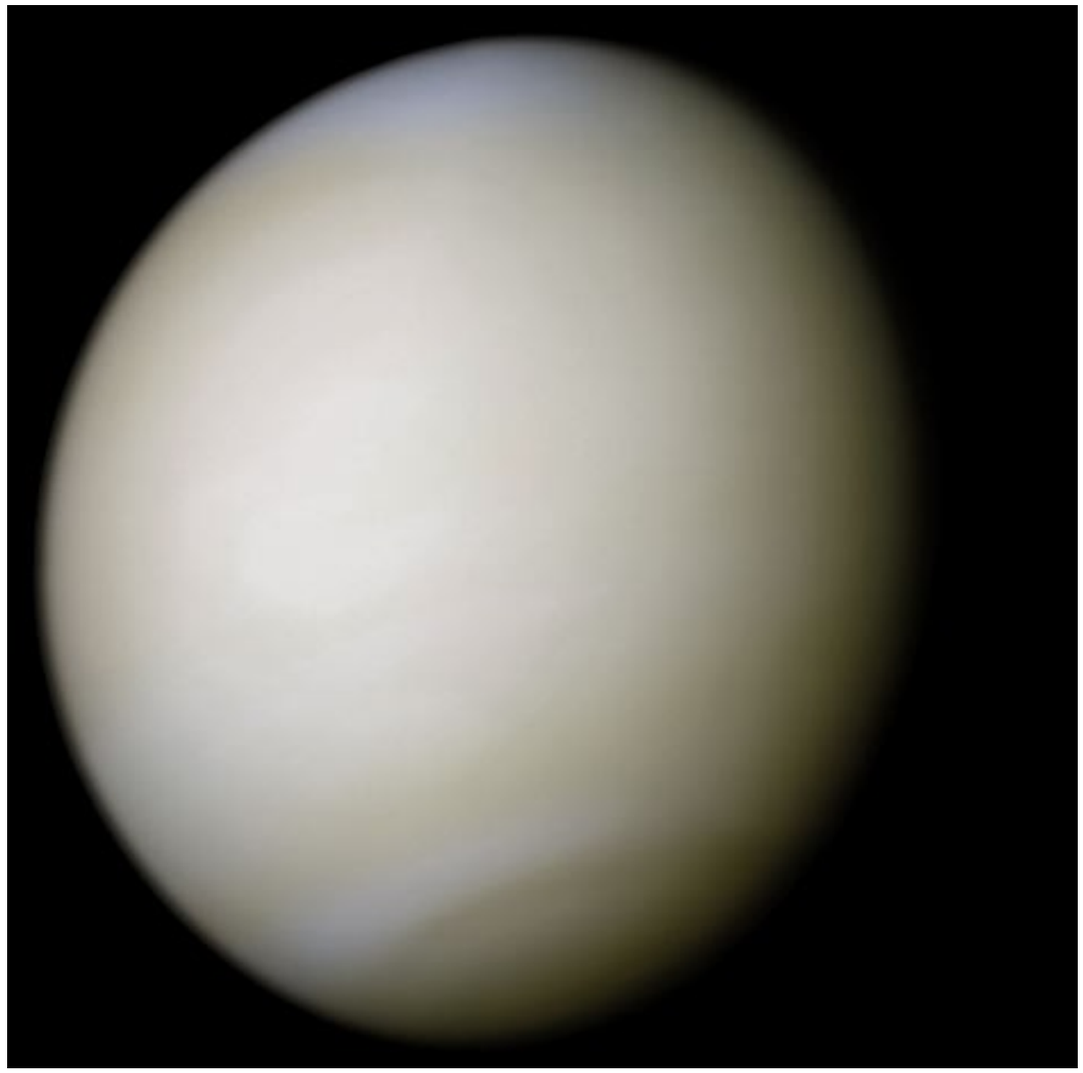
**Venus is almost exactly same size as Earth, but...**

**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 $H_2O$**

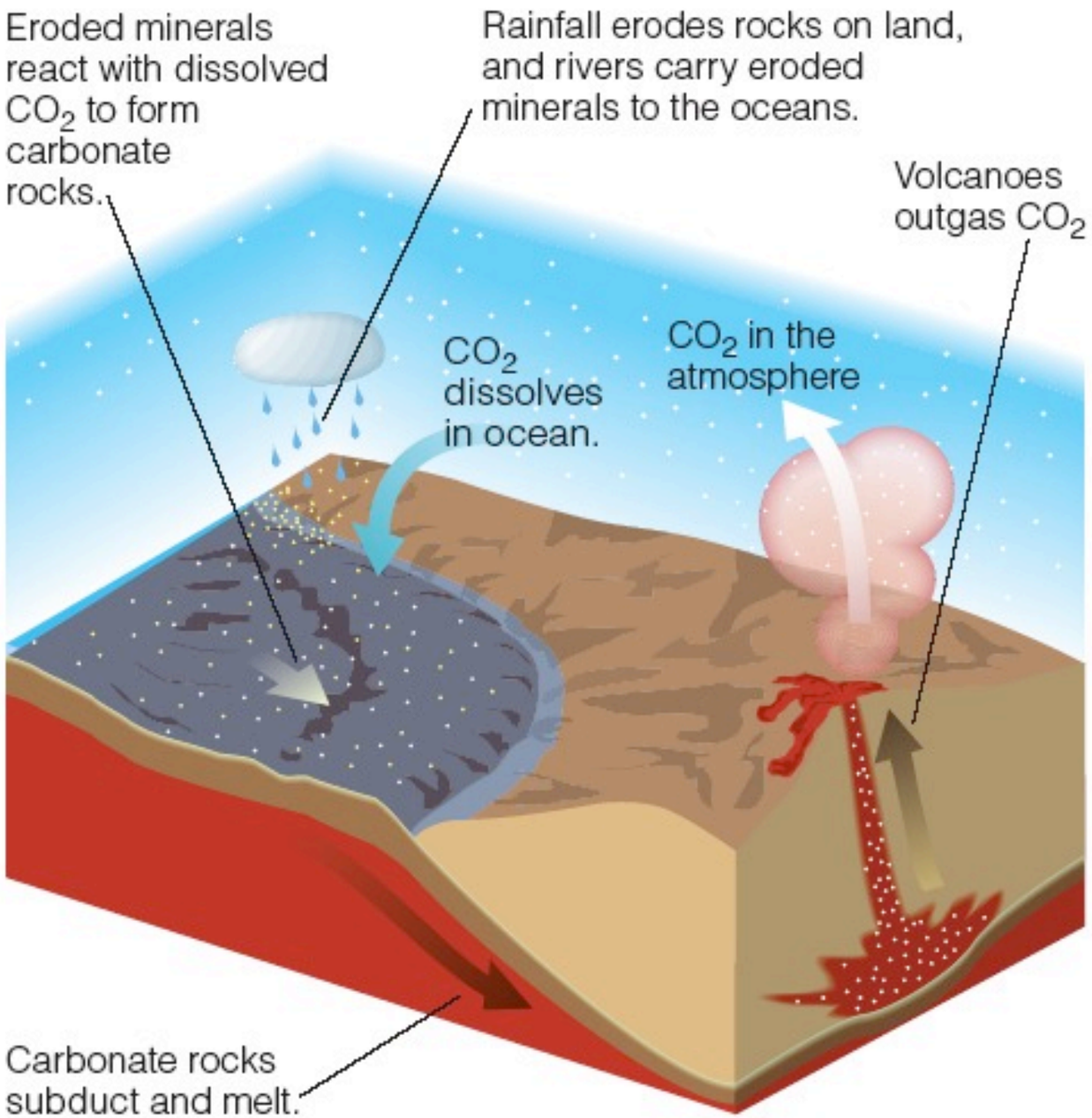
**Earth's atmosphere is only 0.03% $CO_2$ and the surface is covered by $H_2O$**

# 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**

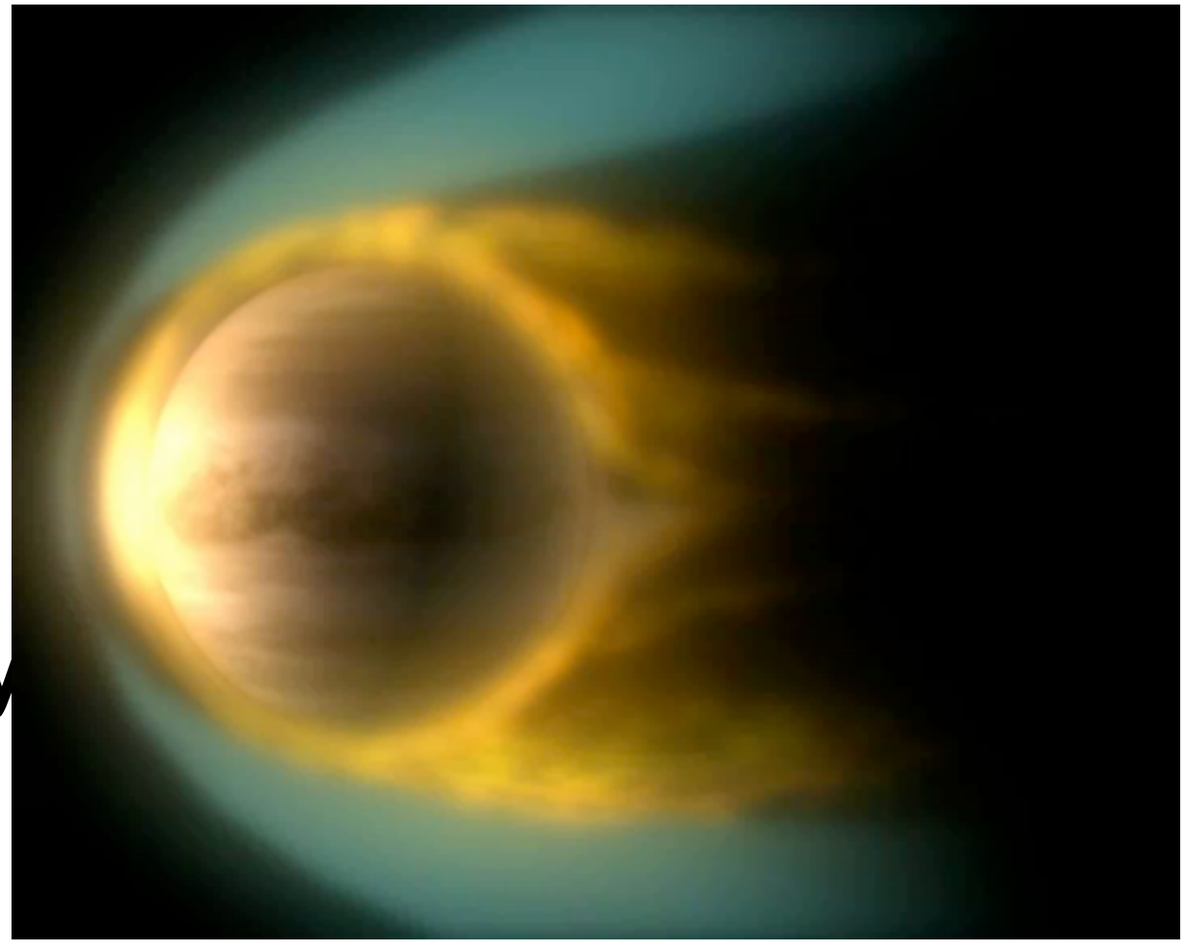
- **note that heating from future sun releases this $CO_2$ into atmosphere, also adds to increase in greenhouse effect**




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

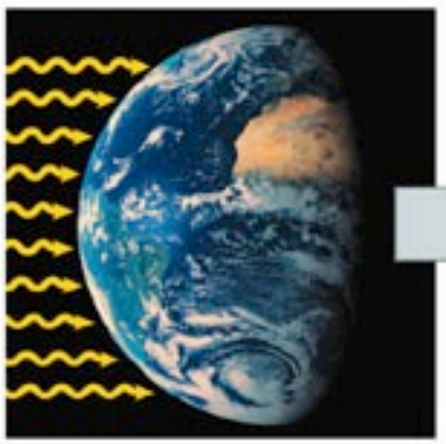
# Where did Venus' water go?

- 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



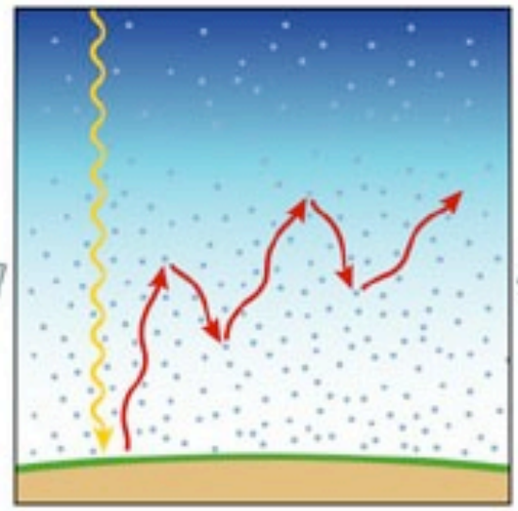
**Interaction between Venus and the solar wind**

# What happens to Earth as the Sun increases in luminosity?



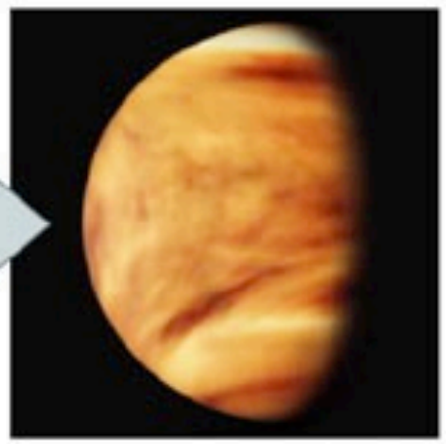
More intense sunlight immediately raises Earth's surface temperature by about 30°C.

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.

# Yikes!
# So what is to be done?

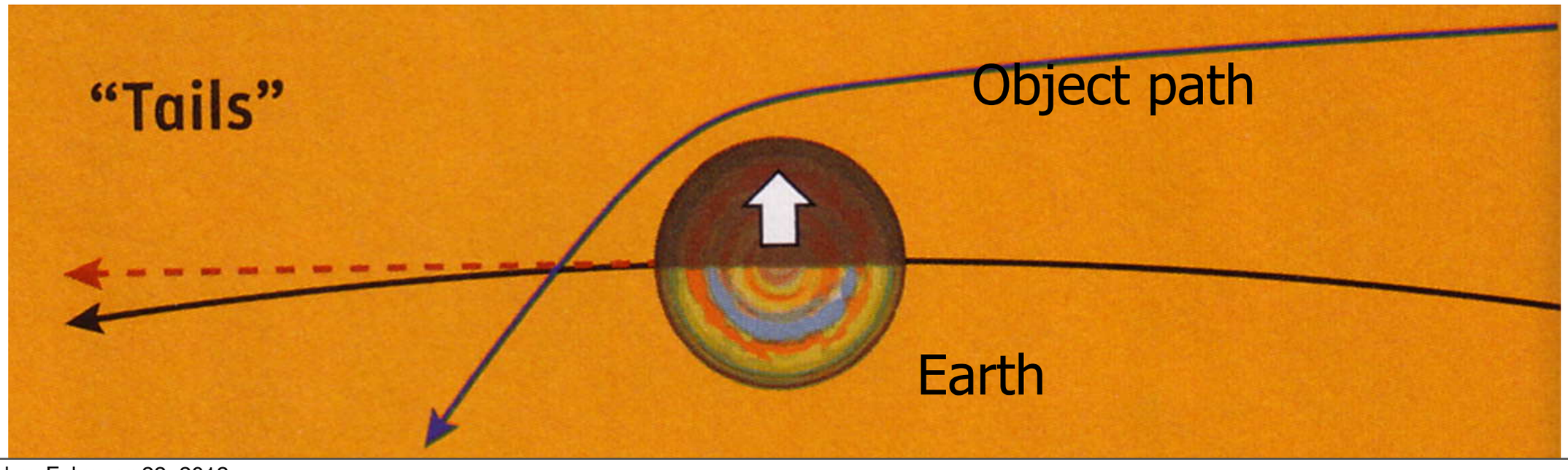
# Mitigation: Astronomical Engineering!

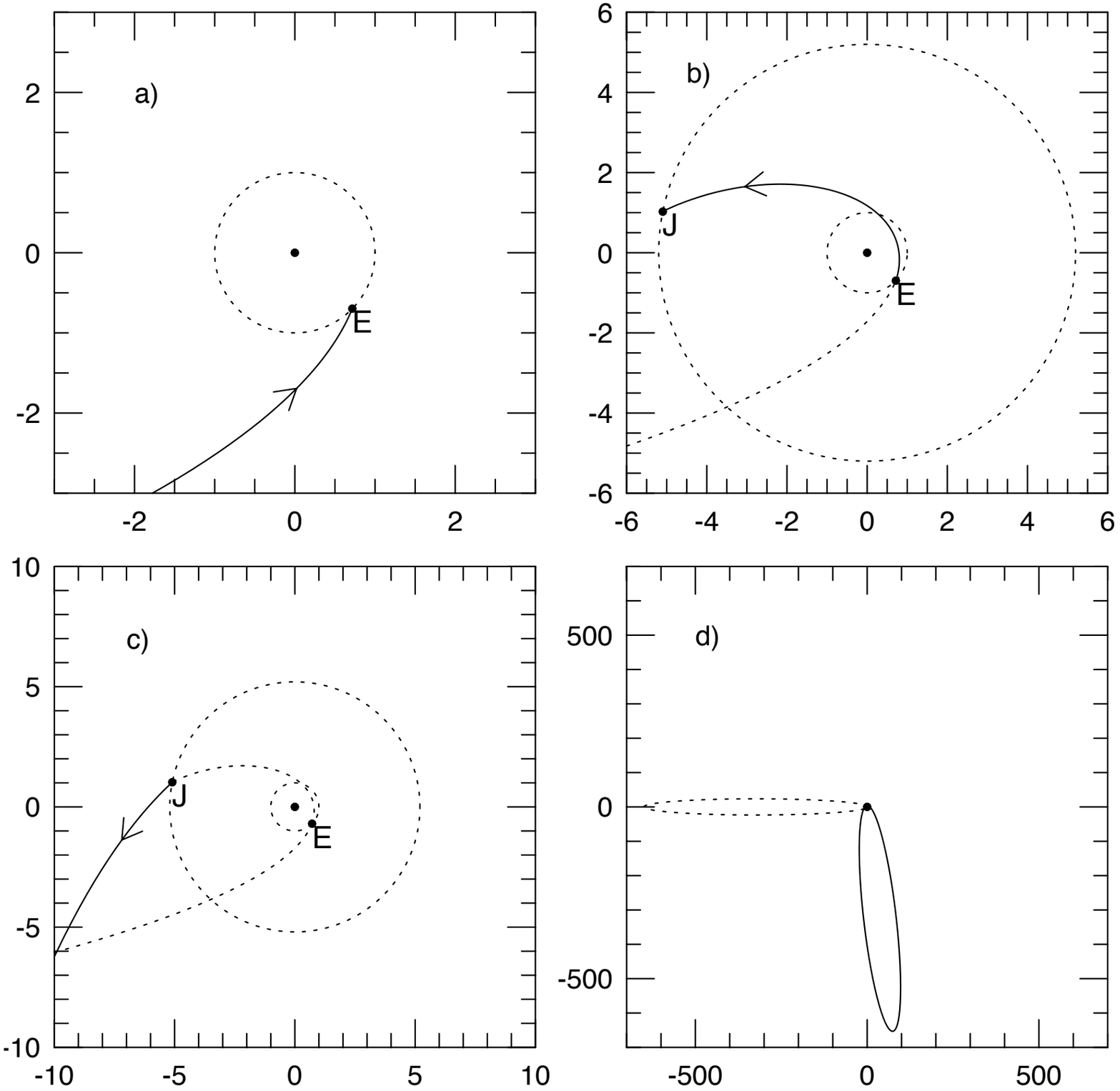
Move a large asteroid to encounter the Earth

Sends object toward the Sun, Earth outward

Need to do this every 6,000 years to keep Earth habitable for ~5 billion years

But, not enough large asteroids - could we recycle one asteroid for many passes?






# Layout of successive encounters for the Earth-Jupiter scheme