ASTR 150

- Homework 4 due Monday night
- Night Observing starts next week
- Exam 1 next Friday!
- Last time: The Sun
- Today: The Sun 2

Music: *Here comes the Sun* – Beatles

Hour Exam 1

Hour Exam 1 next Friday, Feb 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

homework questions

iClicker questions

study guid

old exam

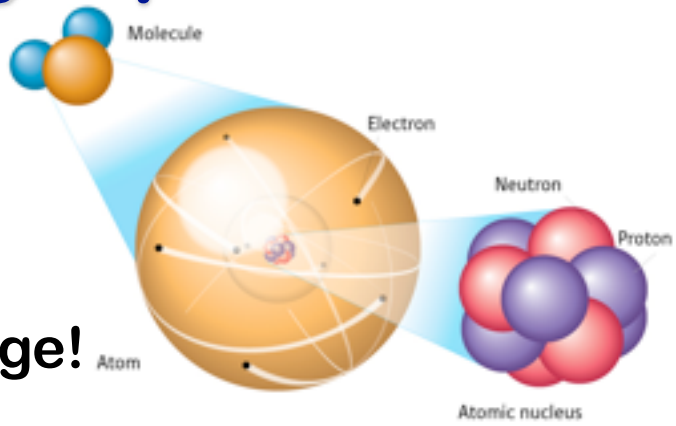
Focus on concepts, main ideas

iClicker Poll: The Sun

The Sun is in hydrostatic equilibrium because

A. it is too big to fail
B. equal forces: gravity vs. fusion
C. equal forces: gravity vs. heat pressure
D. equal forces: gravity vs. electrical repulsion
E. I dunno, something to do with a condom.

Why don't nuclei fly apart?



Nuclei are stable:

- not flying apart
- not accelerating: a = 0
- so no net force: F = 0

But electrical repulsion exists and is huge!

- must be an attractive force to balance

what about gravity?

- Good guess!
- good news protons close -- makes gravity stronger
- bad news protons have tiny mass

Run the numbers:

- compare gravity/electric forces between protons

$$\frac{F_{\text{grav}}}{F_{\text{electric}}} = 10^{-36} = 0.000000000000000000000000000000000001$$

Conclusions:

- gravity feeble in nucleus
- need another force to hold nuclei together!
- new force better be very strong!

The Fantastic 4 Fundamental Forces

All known forces in the Universe trace back to one or more of just four:

Gravity

- acts between all masses
- attractive
- inverse square law

Electromagnetic

- acts between charges
- attractive between unlike charges, repulsive between like charges
- also inverse square law

Strong Nuclear

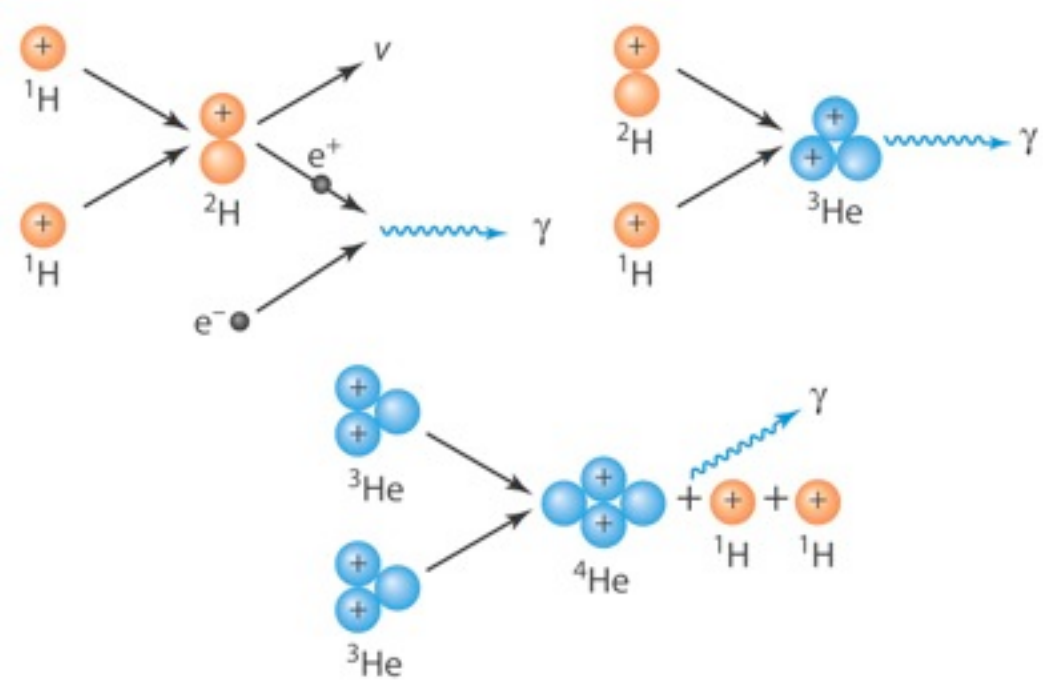
- The strongest of the 4 forces
- Acts between protons and neutrons
  - ultimately, between quarks
  - does not act on electrons
- Attractive: this force holds an atom's nucleus together, overcoming electrical repulsion between the protons.
- Not an inverse square law– very short range.

Weak Nuclear

Nuclear Fusion in the Sun's Interior

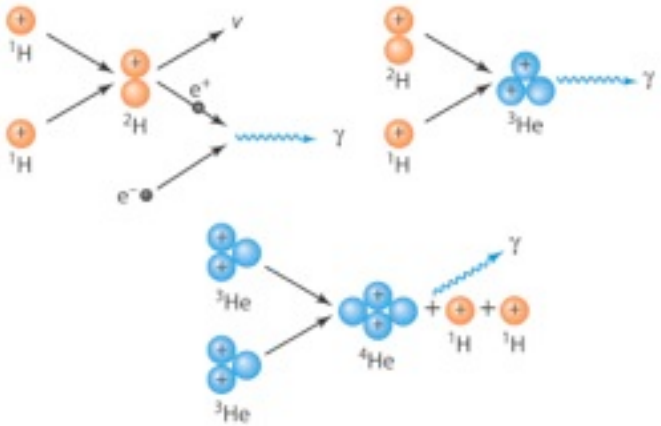
Proton-Proton Chain

- 4 hydrogen atoms fuse to make 1 helium atom
- Nuclear energy released each time a new ^4He is made
- Requires very high density and temperature (at least 7 million K!)



The Proton-Proton (p-p) Chain

Nuclear Fusion in the Sun's Interior



Proton-Proton Chain

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http://www.youtube.com/watch?v=Czbh_sdqX84

Nuclear Reactions in the Sun

Chain: 4 protons ⇒ helium

First step in chain (2 protons combine):

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

Start with 2 particles (protons)

End up with 4 particles (two of which are glued together)

each of products is very interesting in its own right....

Nuclear Reactions in the Sun

$$p + p \rightarrow d + e^{+} + \nu$$

deuterium $d = pn$

1 proton + 1 neutron bound together into nucleus of element… Hydrogen, but has neutron, so 2 times mass of normal H

- "Heavy Hydrogen"
- Simplest composite nucleus

Discovery of D in lab: Nobel Prize

about 0.01% of all H on earth is D

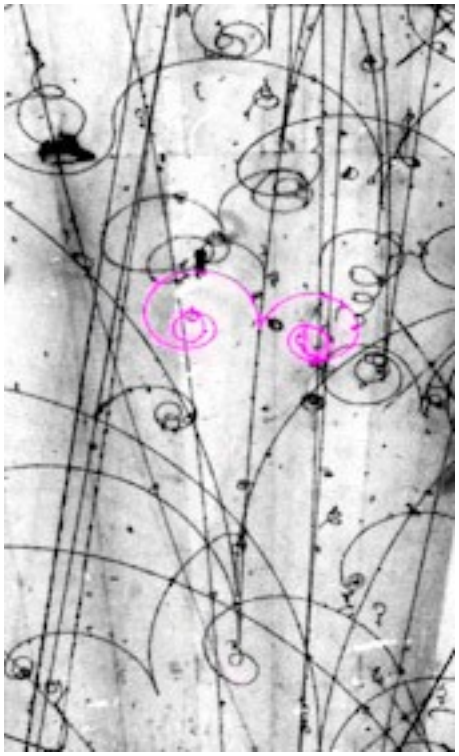
- ✓ including in your body:
  you contain about 10 kilos (20 lbs) of H, and about 2 grams of D
- ✓ Water (normally H_2O) with D is D_2O : "heavy water"

Nuclear Reactions in the Sun

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

positron e^+

- Exactly the same as electron but charge **+1**
- **Antimatter**
- Combines with normal **e-**
  - Both are gone, release of energy
  - **Annihilation**



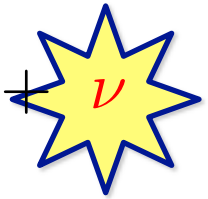
Discovery of positron in lab: **Nobel Prize**

Because of this reaction

- The Sun contains a small amount of antimatter!

Nuclear Reactions in the Sun

$$p + p \rightarrow d + e^{+} + \nu$$



neutrino ν (greek letter "nu")

- Particle produced in nuclear reactions only
- Tiny mass: m(ν) < 10^{-6}m(e) !
- Moves at nearly the speed of light
- very weakly interacting: ghostly!
- only created in nuclear reactions
  - in fact: only feel Weak Nuclear Force
  - created in reactions transforming protons to neutrons or vice versa

Discovery of neutrino in lab: Nobel Prize

10 billion from Sun go through your hand every sec

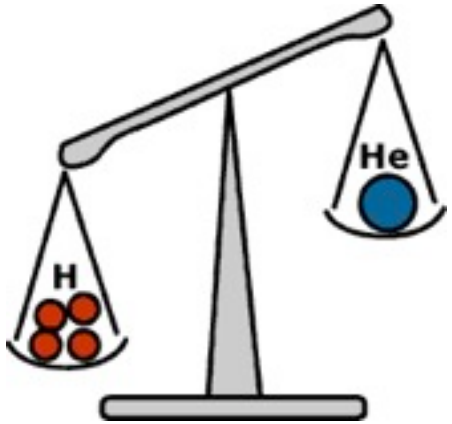
- Reach out!
- Go through your body, Earth, but almost never interact

Why does fusion release energy?

Fusion: $4p \rightarrow {}^4\mathrm{He} = \boxed{2p, 2n}$

Fact: $m(4p) > m({}^4\mathrm{He})$

mass of whole < sum of masses of parts!

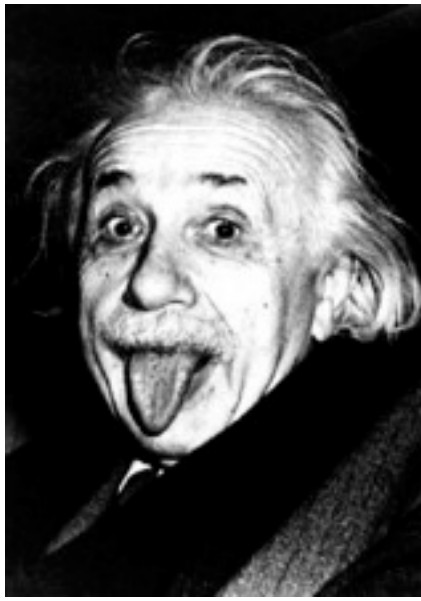


Einstein says $E = mc^2$

Mass is a form of energy!

Each ^{4}He liberates energy:

$$E_{\mathrm{fusion}} = m_{\mathrm{lost}} c^2 = 4m(p)\, c^2 - m({}^4\mathrm{He})\, c^2 > 0 \quad !$$

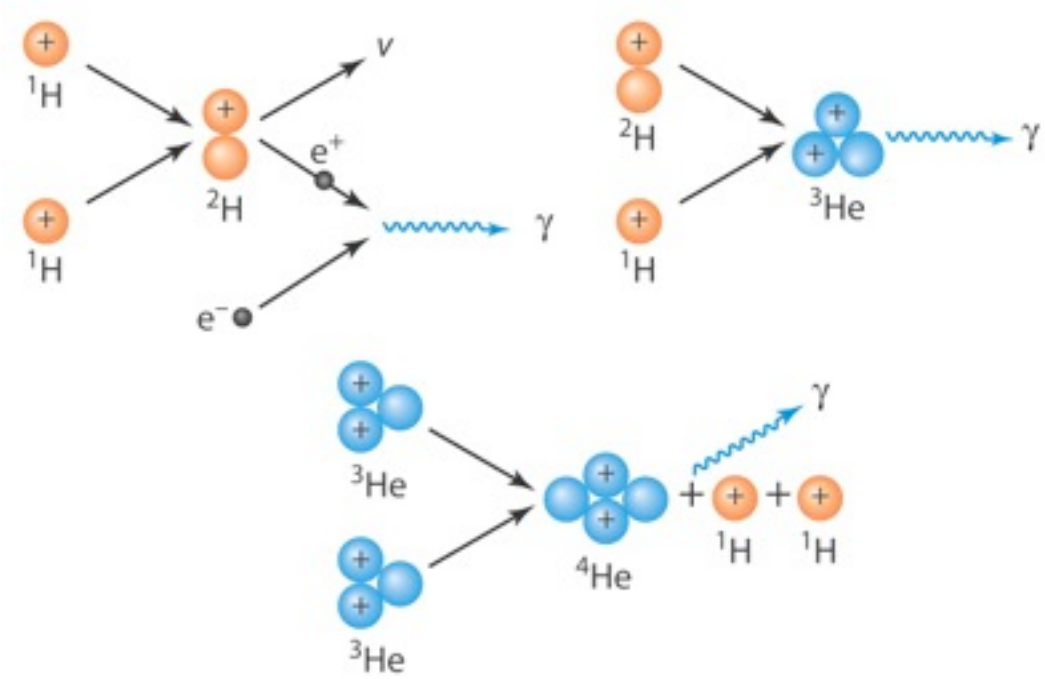


Nuclear Fusion in the Sun's Interior

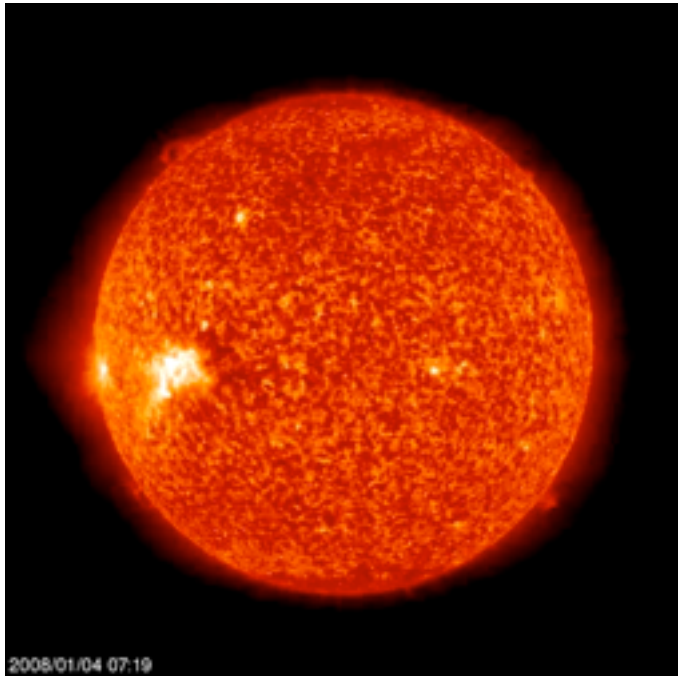
The Sun is a nuclear reactor

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**



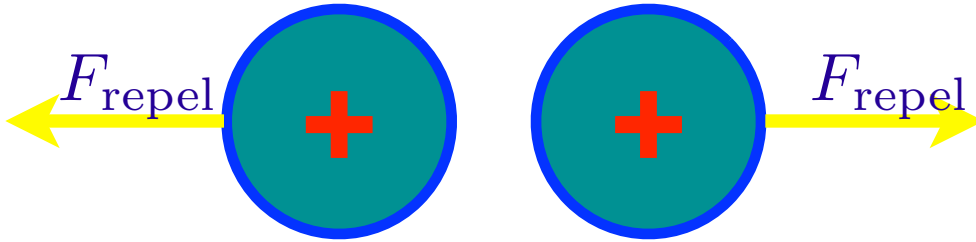
The Proton-Proton Cycle



Why Nuclear Fusion Doesn't Occur in Your Coffee

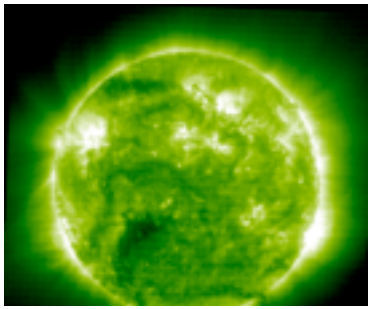
- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time

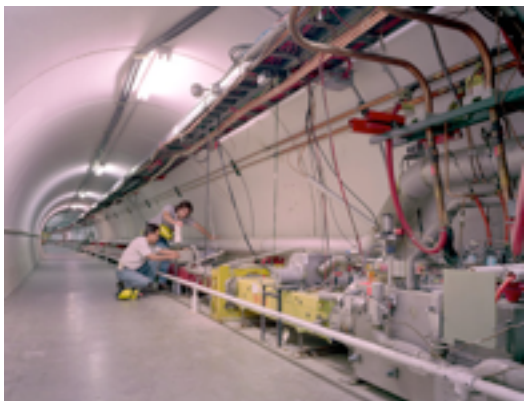
Nuclear collisions must be very violent to overcome proton repulsion



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

- centers of stars
- big bang





They Might Be Giants
Why Does The Sun Shine

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is far away... About 93,000,000 miles away
And that's why it looks so small

But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own Sun's atomic energy

Scientists have found that the Sun is a huge atom smashing machine
The heat and light of the sun are caused by nuclear reactions between Hydrogen, Nitrogen, Carbon, and helium

The Sun is a mass of incandescent gas
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The Sun is large... If the sun were hollow, a million Earth's would fit inside
And yet, it is only a middle sized star

The Sun is hot, the Sun is not
A place where we could live
But here on Earth there'd be no life
Without the light it gives

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The Sun is not that everything on it is a gas: Aluminum, Copper, Iron, and many others

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The Sun is so hot that everything on it is a gas: Aluminum, Copper, Iron, and many others

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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

$$p + p \rightarrow d + e^{+} + \nu$$

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

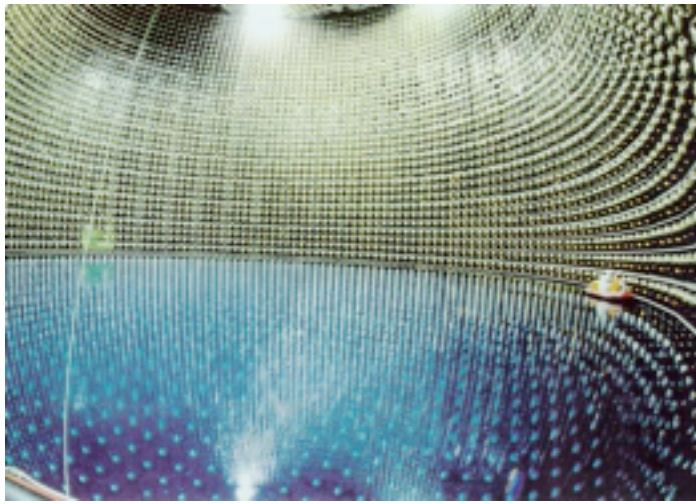
It would take a block of lead over a quarter of a light-year long to stop one

The Evidence!
Solar Neutrinos

Neutrino Experiments:

huge vats of ultrapure water

- collisions:
- "kicked" electrons emit light flashes $\nu + e^- \rightarrow \nu + e^- + \text{light}$
- 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!

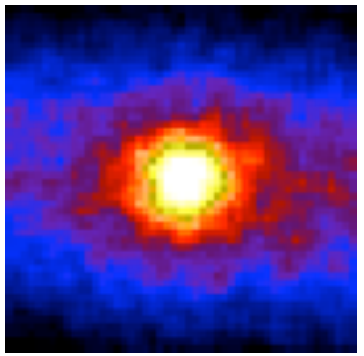


Image of the Sun taken with neutrinos!

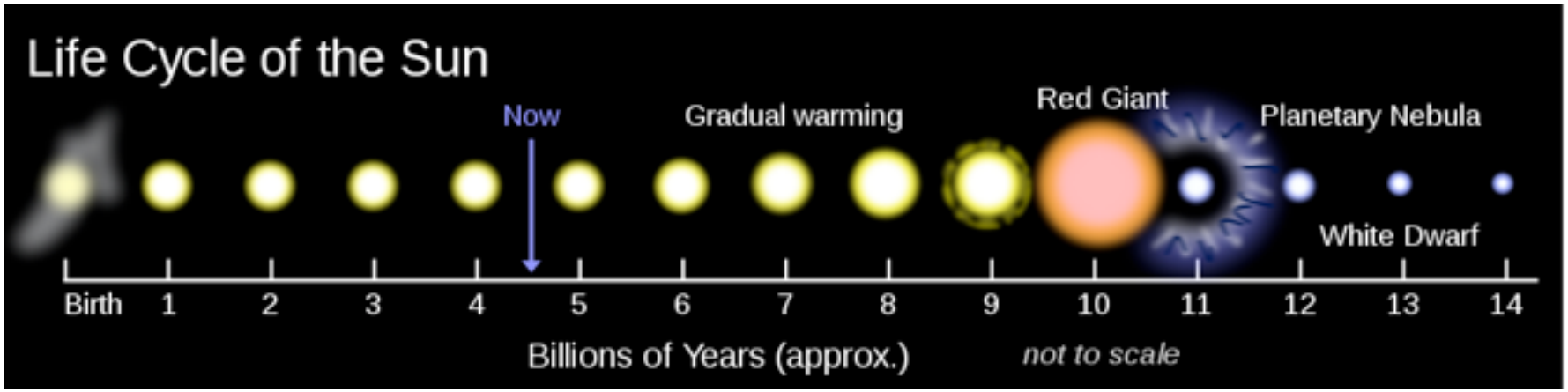
The Future History of the Sun Part I

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



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

Why is the Sun getting brighter?

Each fusion reaction reduces the number of particles in the Sun

- 4 H become 1 He!

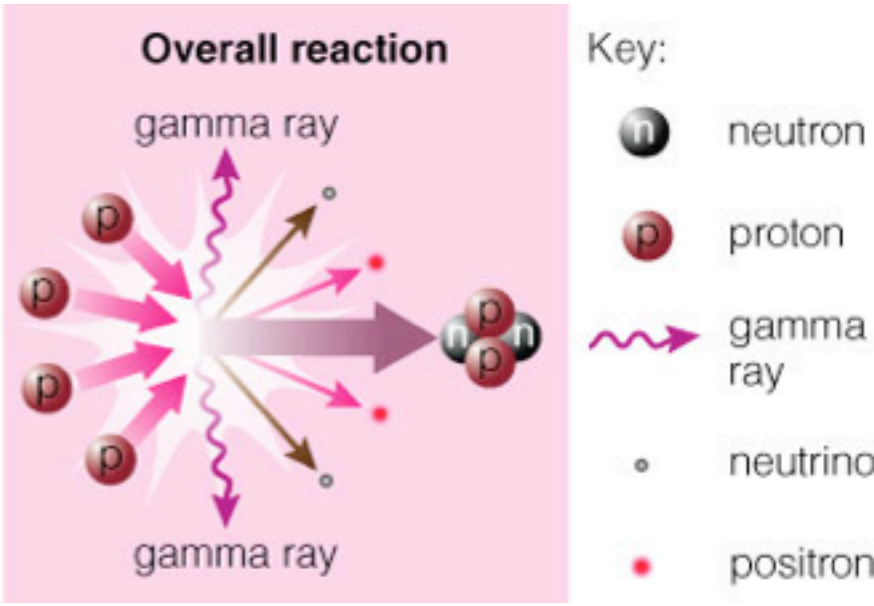
Gas pressure is based on the number of particles and their average temperature

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

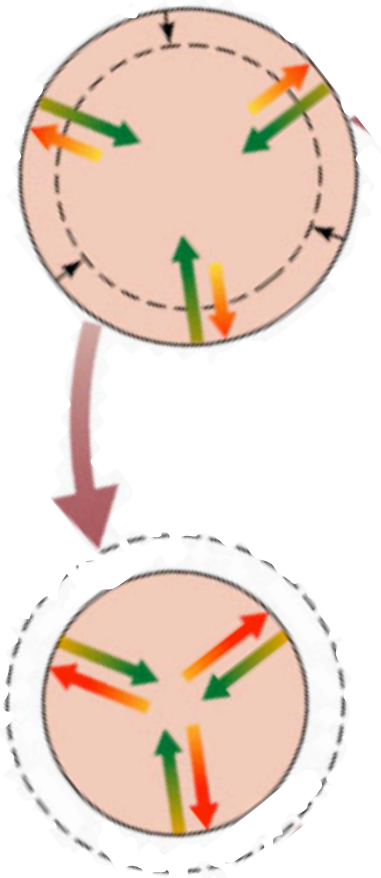
Contraction compresses gas in Sun

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

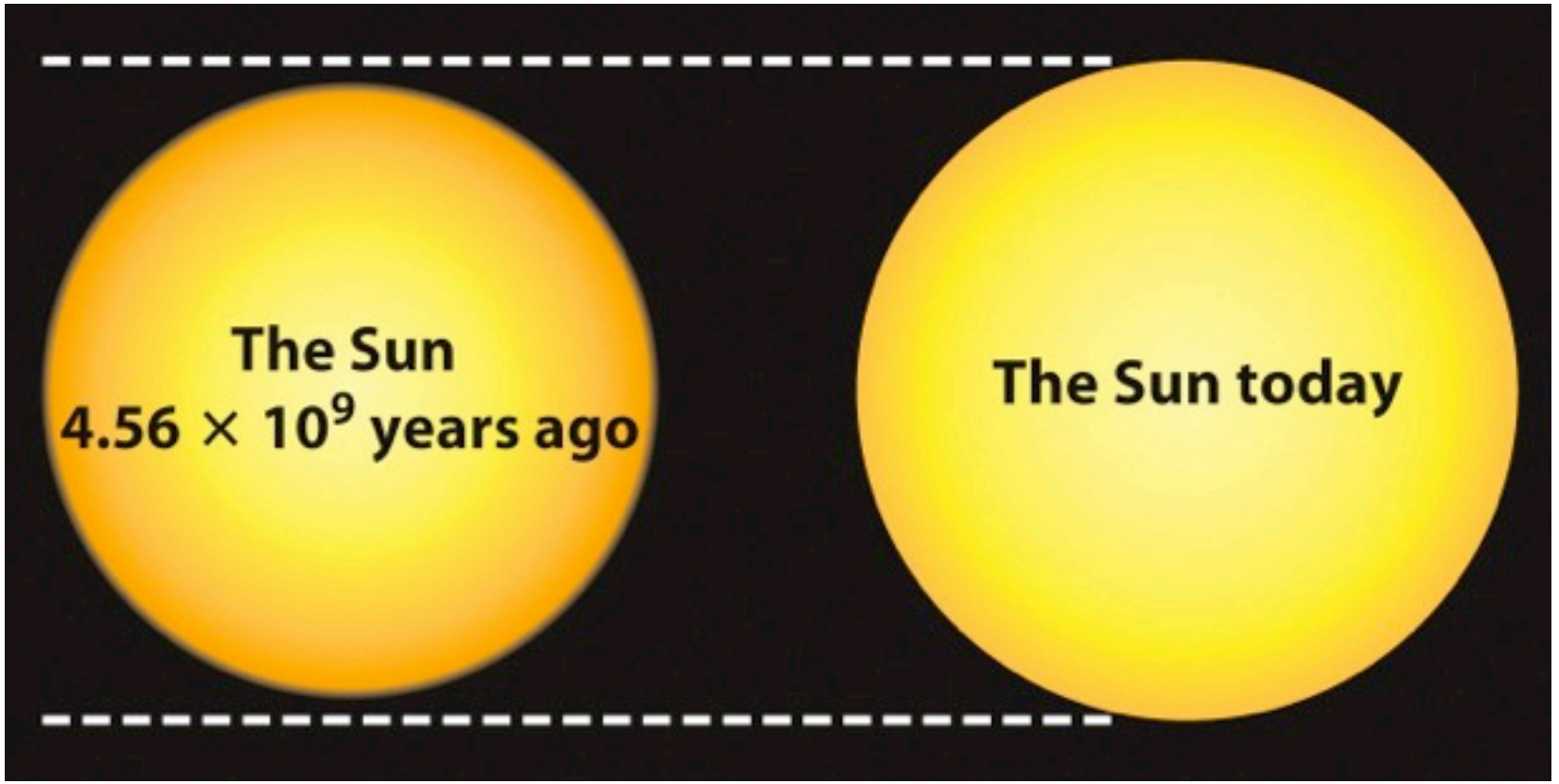
Nuke reactions faster when temperature higher

More reactions:

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



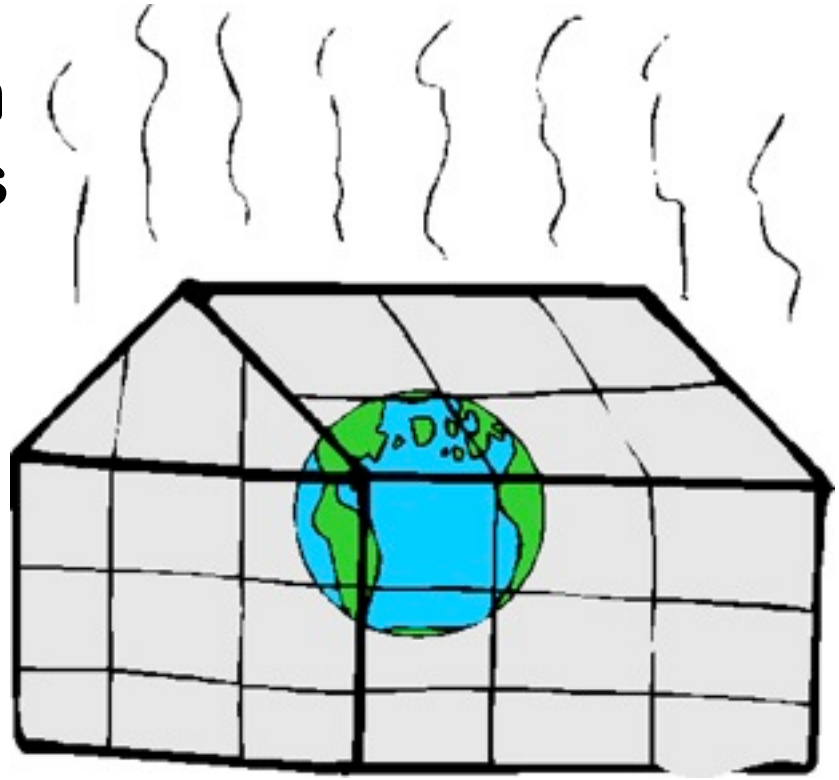
The Sun was less luminous in the past



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 will have major impacts
- Adds 5℃ (10℉) to the average temps
- Leads to increase in greenhouse effect



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

Interlude: the Glow of Heat

Crucial fact for astronomy and for life

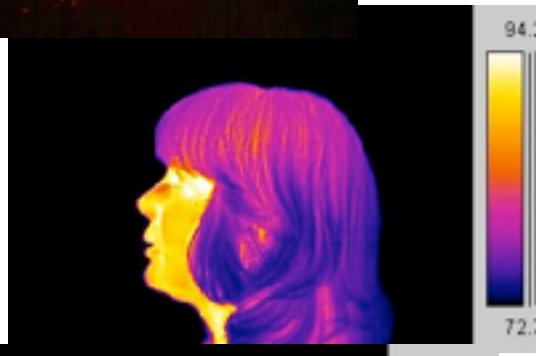
- Hot objects glow!
- temperature -- light connection!
  - "blackbody radiation" -- more on this later

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!

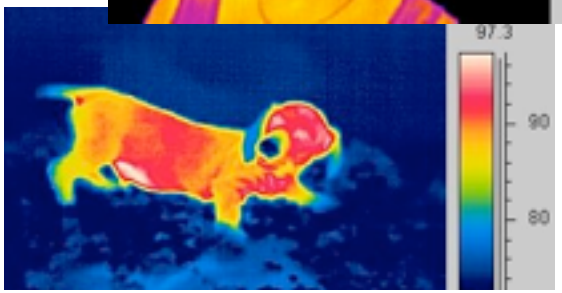
- "infrared" light (IR)



IR humans

Experiments:

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



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

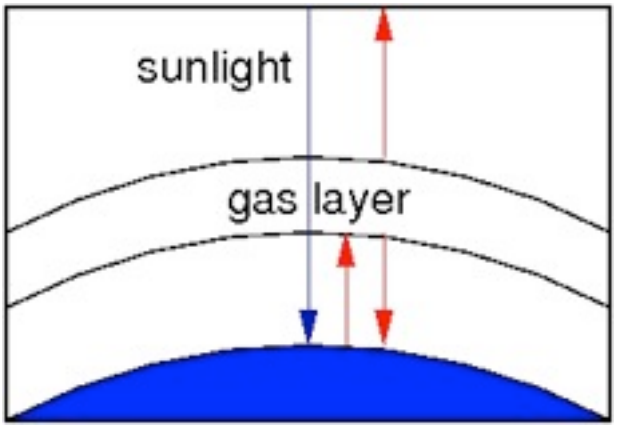
But greenhouse gasses in atmosphere absorb some of the IR from Earth

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

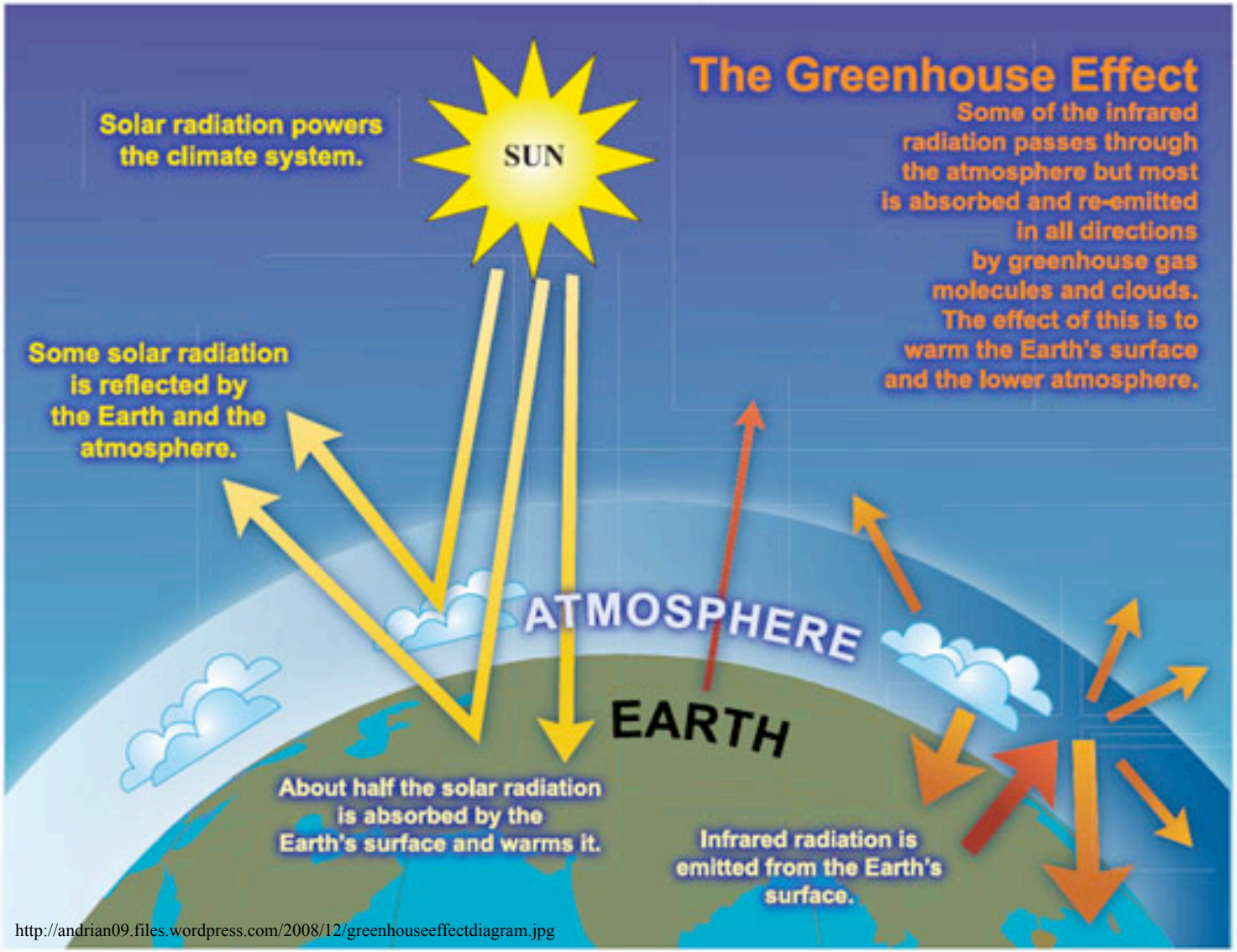
Happens naturally!

- 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

Greenhouse gases (water, CO2, etc.) trap heat, release heat back to Earth, so less heat lost to space
Without greenhouse gases in our atmosphere, Earth average temperature would only be -14C (0F), instead of 14C (57F)
But, humans are putting extra greenhouse gases into atmosphere, so Earth is getting warmer
In aging Sun case, the Sun is adding heat directly!

Greenhouse Effect Explained

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/

Too Much Water

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

iClicker Question

If there was no greenhouse effect today, Earth:

A. Would be safer than it is today
B. There would be no human presence, since humans make the greenhouse effect
C. The Earth's average temperature would be colder than freezing
D. We would be in danger from ultraviolet radiation

Answer C