Astronomy 122

This Class (Lecture 9):

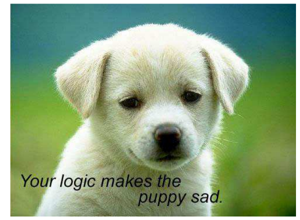
What is a star?

Next Class:

Fusion for you and me

Homework #4 due Sun at 11:59pm!

Music: *Sonne* – Rammstein

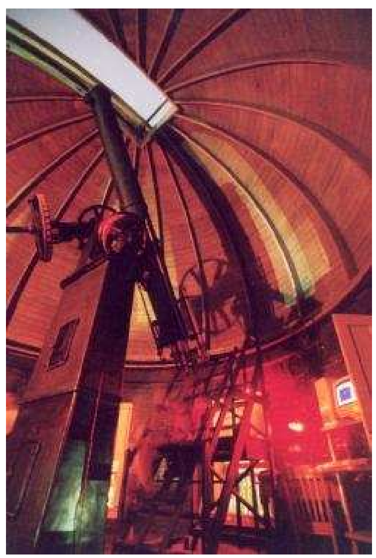


HW

- As I can tell when you look at the HW, I noticed that last Wednesday, the discussion section day, less than 5% of you have even looked at the HW-short.
- Makes discussion sections pointless-- This makes me sad!
- So, I will check this again next week, if it is the same percentage, I will move the HW due to Friday evening.
- If it still does not improve, I will move it to Thursday morning.
- Don't make me sad….

Night Observing

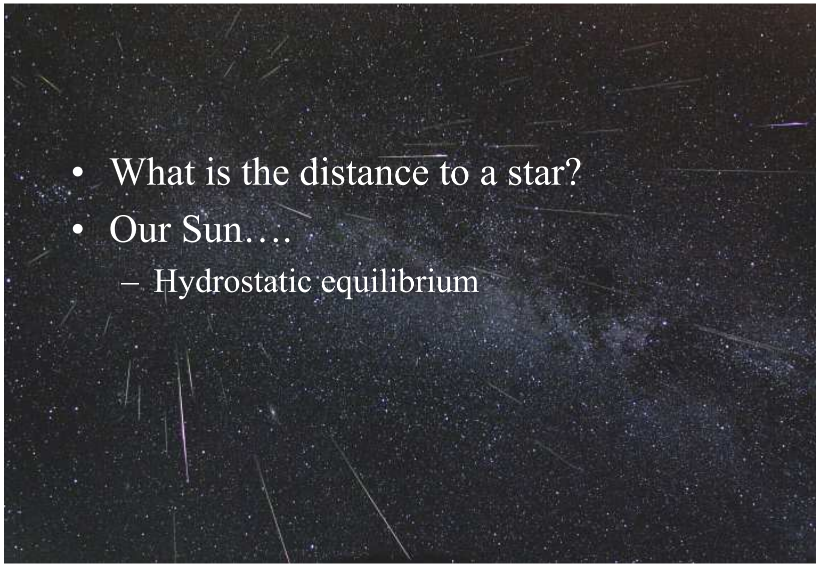
- Night observing started!
  - Feb 11-14th: Monday-Thursday
  - Feb 20th: Wednesday (special Lunar Eclipse!)
  - Feb 25-28th: Monday-Thursday
- Don't wait until last minute (never know about Illinois weather)!
- Observing sessions are from 7:30pm-9:30pm (allow 45 mins to complete)



Night Observing

- Sign up for sessions at http://www.astro.uiuc.edu/classes/nightobs/
- Check weather status before you go at http://www.astro.uiuc.edu/classes/nightobs/status.php
- Download Astro 122 worksheet at http://eeyore.astro.uiuc.edu/~lwl/classes/astro122/spring08/hw.html

Outline



- What is the distance to a star?
- Our Sun….
  - Hydrostatic equilibrium

Distance

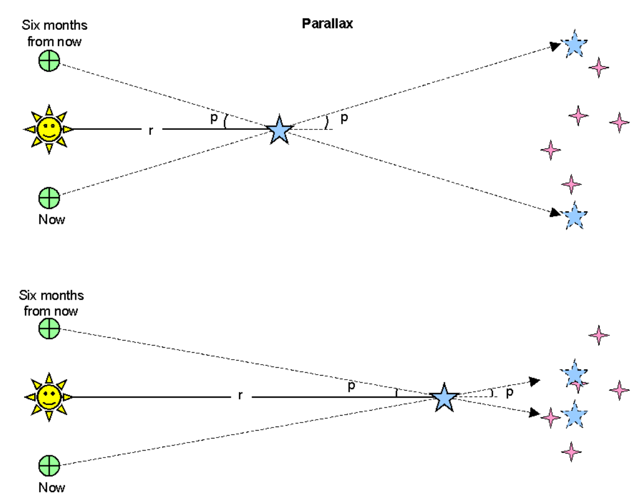
- We know that the stars must be very far away.
  - They don't move much.
- Measuring the distance is a <u>hard</u> problem.
- We've only had the technology to do it for the last 200 yrs or so.

Parallax

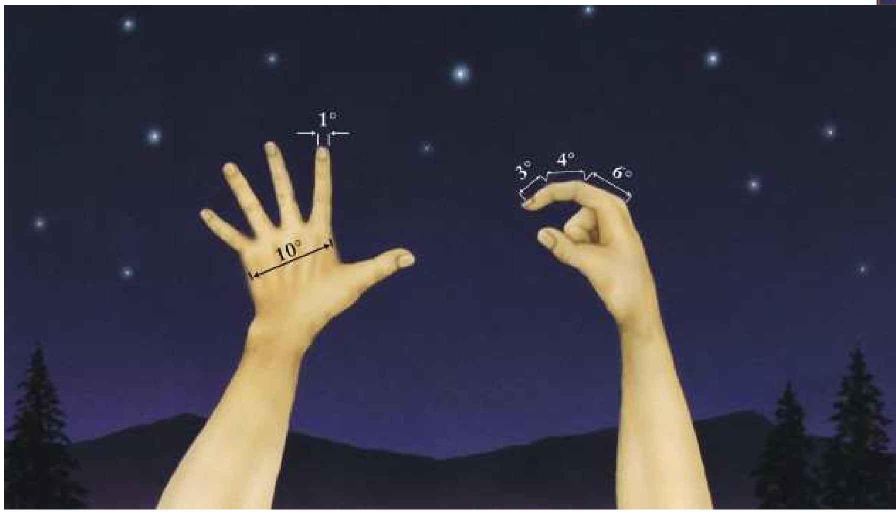
How do astronomers measures distances to nearby stars?

How to Measure Parallax

- Look at a star compared to background stars– and wait 6 months.
- How much, if any, have the stars moved?



Angular Sizes



How far away am I– with parallax?

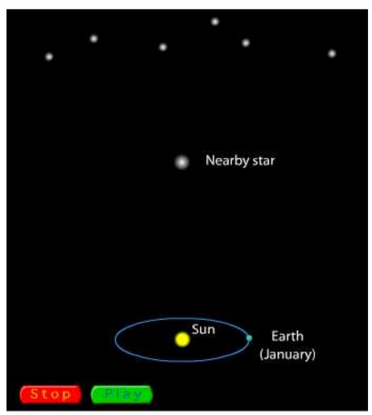
Question

The measured parallax of me (as viewed from the class) against the chalkboard depended upon

a) The distance from me to the chalkboard
b) The distance from your eye to your thumb
c) The distance from me to you
d) The distance from the back of the room to the front of the room.

Parallax and Parsecs

- **1 parsec (1 pc)** – Distance at which the radius of the Earth's orbit would make (subtend) an angle of 1 arcsecond
- 1 pc = 3.09×10^{13} km = 3.26 light-years



Distance to a star in parsecs = $\frac{1}{\text{Star's parallax in arcseconds}}$

Parallax and Parsecs

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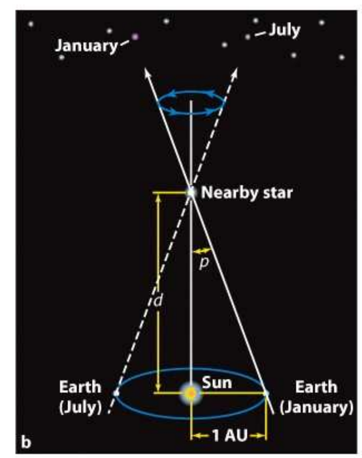
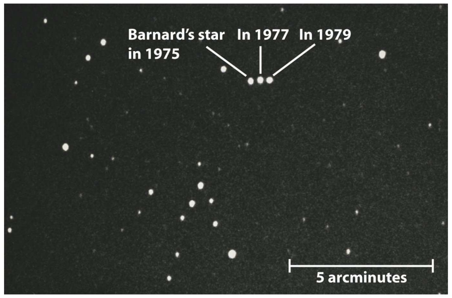


Distance to a star in parsecs = $\frac{1}{\text{Star's parallax in arcseconds}}$

Barnard's Star

Has a measured parallax of 0.547 arcseconds.



$$d = \frac{1}{p} = \frac{1}{0.547} = 1.83 \text{ pc}$$

Because 1 parsec is 3.26 light-years, this can also be expressed as

$$d = 1.83 \text{ pc} \times \frac{3.26 \text{ ly}}{1 \text{ pc}} = 5.96 \text{ ly}$$

Question

If a star has a parallax of 0.25 arcseconds, how far away is it in parsecs?

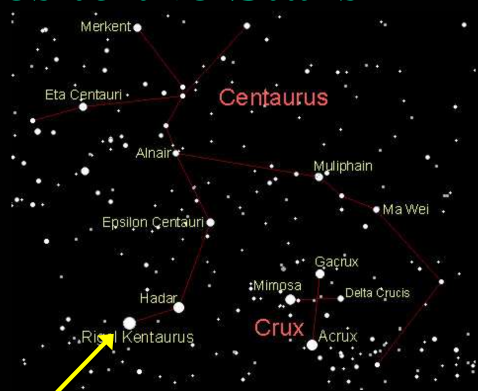
a) 0.25 pc
b) 1 pc
c) 4 pc
d) 0.5 pc
e) 25 pc

The Distances to the Stars

Sun's disk seen from Earth

1/2 degree = 1800 arcsec

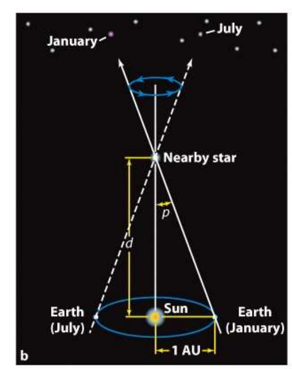
Dime at arm's length



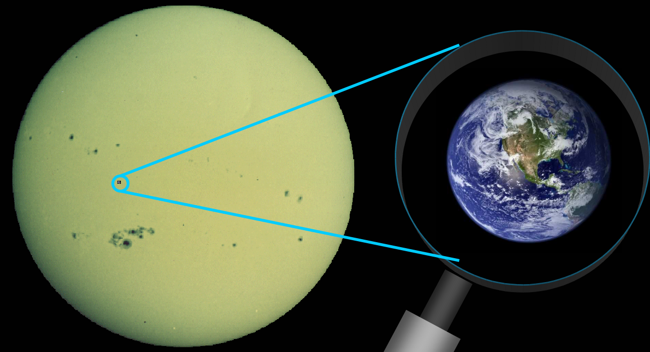
Closest star to Earth:
Proxima Centauri
(part of α Centauri system)
Parallax: 0.77 arcseconds
Distance: 1.3 pc = 4.2 ly
like a dime 2 km away

Parallax Peril

- Drawback: p measurable only for nearest stars
- Angular shift becomes tiny when star very far away
- Immeasurable when star is beyond few 100's of pc
- And Galaxy is 100,000 lyr across, Universe is 10 billion lyr
- What to do? ... stay tuned...



Earth-Sun Comparison

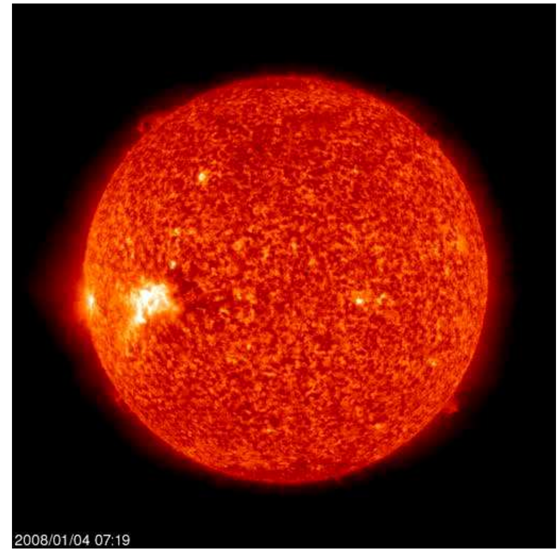


In general, a very typical star. Keep in mind that it is really a ball of gas.

Visual radius	109 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} W
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

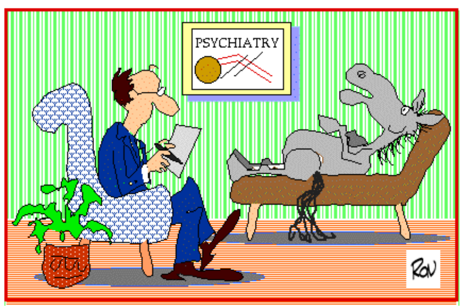
LIVE from the Sun

http://sohowww.nascom.nasa.gov/data/realtime/mpeg/



Question of Stability

- The Sun's size is constant.
- No weatherman says it will be especially hot tomorrow as the Sun's size will be increasing.
- Not expanding or collapsing.
- The Sun is stable! Why?

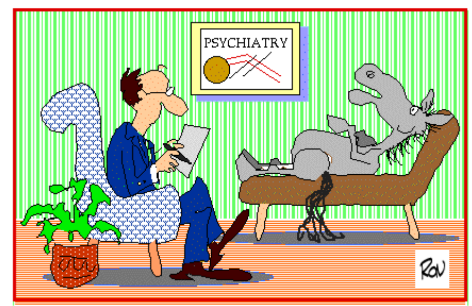


"I just don't feel stable."

http://www.londonstimes.us/toons/index_medical.html

Question of Stability

- Not trivial, could have gone the other way
- Think: Sun is made of gas, yet not like a cloud, for example, which is made of gas but size, shape changes all of the time
- Not a coincidence: really good reason



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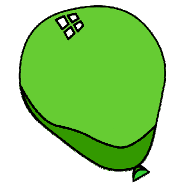
Why is the Sun Stable?

- What keeps gravity from collapsing the Sun?
- What keeps the Sun from exploding?

Pressure Stable

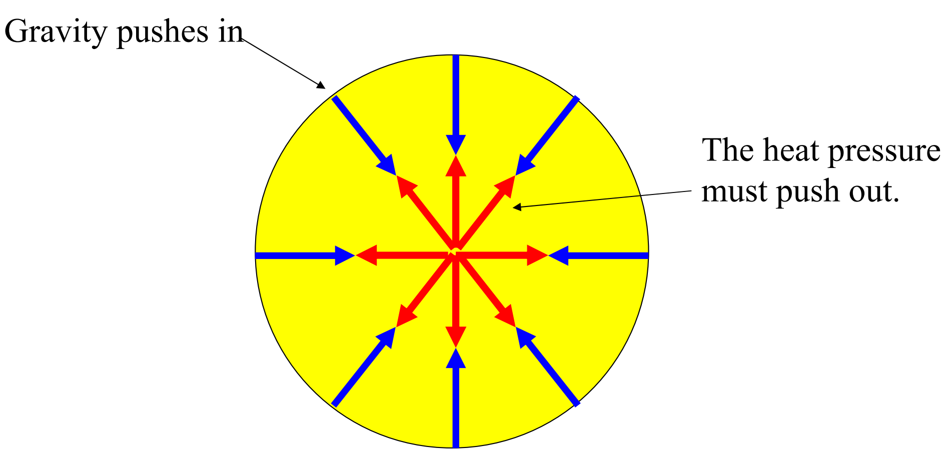
- What is pressure?
  - Pressure $= \frac{Force}{Area}$
- Explain blowing up a balloon?

Pressure of Earth's atmosphere is 14.7 pounds per square inch



- http://www.phy.ntnu.edu.tw/java/idealGas/idealGas.html

The Battle between Gravity and Pressure



Hydrostatic equilibrium: Balanced forces

Question

What was the point of that experiment?

a) Showed that the Sun is burning H into He.
b) Showed that liquid nitrogen is fun.
c) Showed the adverse effects of cold on veggies.
d) Showed that a stable Sun must have an internal outward force.
e) Showed that an unstable Sun is from nitrogen.

The Sun's Energy Output

3.85 x 10^{26} Watts, but how much is that?

A 100W light bulb…

…the Sun could supply 4 x 10^{24} light bulbs!

U.S. electricity production in 2006: 4.1 trillion kWh…

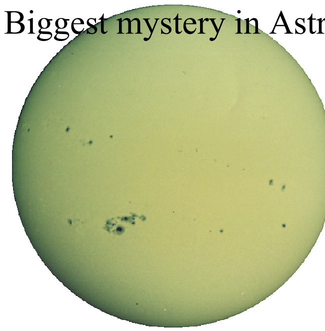
… Sun = 3 x 10^{7} times this *every second*

World's nuclear weapons: 3 x 10^{4} megatons…

… Sun = 4 million times this *every second*

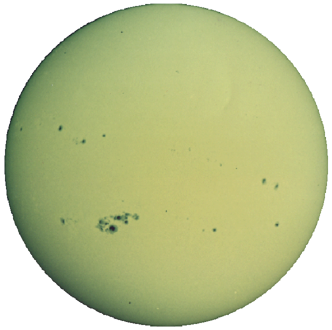
So, What Powers the Sun?

- The Sun does not collapse nor even change it's radius.
- Gravity pushes in, but what pushes out?
- What is its power source?
- What keeps the Sun hot? It doesn't cool like a hot coffee cup.
- Biggest mystery in Astronomy up until 20^{th} century.



So, What Powers the Sun?

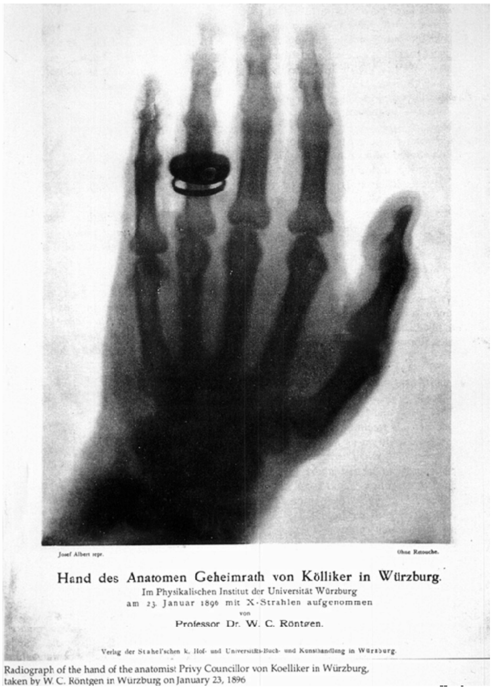
Discuss with neighbors possible heating possibilities. List at least 2 possibilities, even if you know the correct one. List all feasible ideas.



How to Test?

- Without an energy source, the Sun would rapidly cool & contract
  - Darwin: evolution needs Sun & Earth to be > 10^{8} years old
  - Lyell: geological changes also needs > 10^{8} years
- Process must be able to power Sun for a long time! At least 4.5 Byrs.

- Gravity:
  - Seems like a good idea. Remember Jupiter gives off heat.
  - A contracting Sun releases gravitational energy.
  - But only enough for 20 million years
- Chemical:
  - If the Sun was made from TNT, something that burns very well, then it would last for 20,000 years



Radiograph of the hand of the anatomist Privy Councillor von Koelliker in Würzburg, taken by W. C. Röntgen in Würzburg on January 23, 1896

Eyes began to turn to the nuclear processes of the Atoms

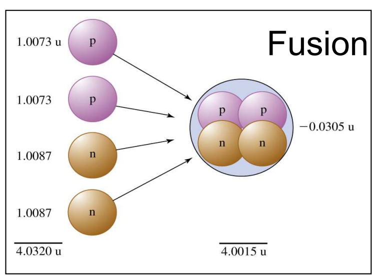
What is Fusion?

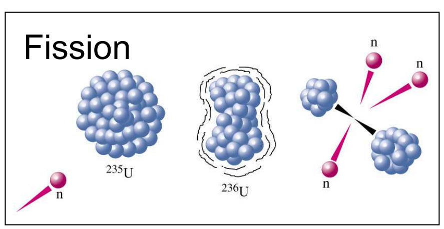
$$4\,p \rightarrow {}^{4}\mathrm{He} \quad (2\,p, 2\,n)$$

Basic idea is to take 4 protons (ionized hydrogen atoms) and slam them together to make an ionized helium atom.

Fusion vs. Fission

- Light nuclei: fusion
  - Happens in the Sun
  - H-Bomb
- Heavy nuclei: fission
  - Used in power plants
  - A-Bomb





Nuclear Fusion in the Sun's Interior

- Proton-Proton Chain
  - 4 Hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)

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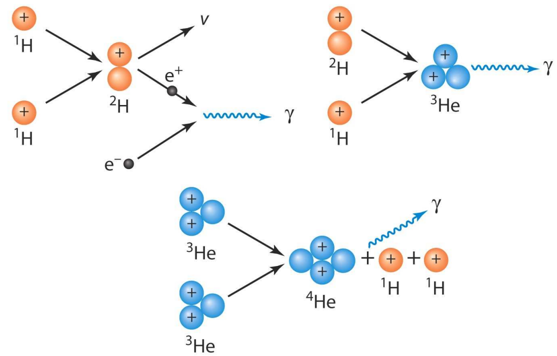


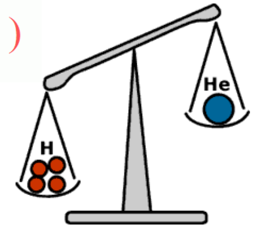
The Proton-Proton (p-p) Chain

Why does fusion release energy?

Fusion: $4\,p \to {}^4\mathrm{He}\ \ (2\,p\,, 2\,n)$

Fact: **4m(*p*) > m(^{4}He)** !

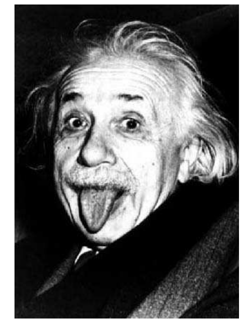
<u>mass of whole < mass of parts</u>!



Einstein says ***E = mc*²**:

- Mass is a form of energy!
- Each ^{4}He liberates energy:

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

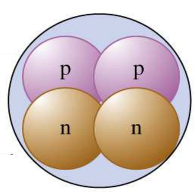


The Nucleus

- Okay, so we know that the nucleus can have numerous protons (+'s) very close.

Helium

- **Something is odd here!**
- **What is it?**

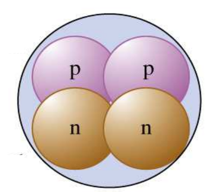


The Nucleus

- **Why doesn't the nucleus of the atom fly apart?**

Helium

- **Something is odd here!**
- **What is it?**



4 Fundamental Forces

- Gravity
- Electromagnetic
- **Strong Nuclear**
  - **The strongest of the 4 forces**
  - **The force which holds an atom's nucleus together, in spite of the repulsion between the protons.**
  - **Does not depend on charge**
  - **Not an inverse square law– very short range.**
- Weak Nuclear

Nuclear Reactions in the Sun

- Chain: 4 protons → helium
- First step in chain (2 protons combine):

$$p + p \rightarrow [np] + e^{+} + \nu$$

- 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

$$p + p \rightarrow [np] + e^{+} + \nu$$

$[np]$ = **deuterium**

- 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

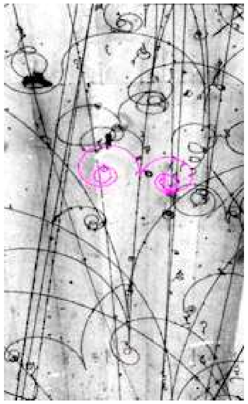
Discovery of D in lab: *Nobel Prize*
about 0.01% of all H on earth is D
✓ including in your body:
you contain about 10 kilos (20 lbs) of H, and about 2 grams of D
✓ Water (normally H_2O) with D is D_2O : "heavy water"

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

e^{+} = **positron**

- 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

$$p + p \rightarrow [np] + e^{+} + \nu$$

ν (Greek letter "nu") = **neutrino**

- Particle produced in nuclear reactions ***only***
- Tiny mass: $m(\nu) < 10^{-6} m(e)$!
- Moves at nearly the speed of light
- ***Very*** weakly interacting

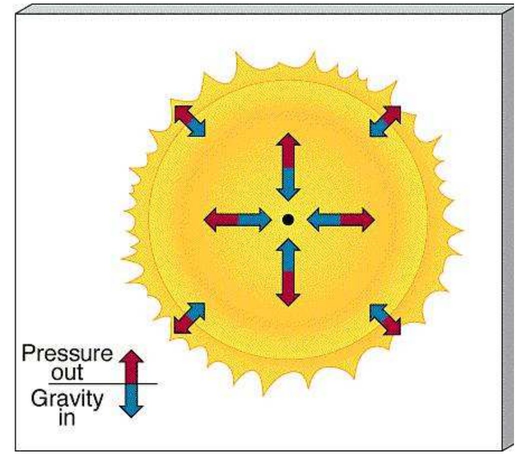
Discovery of neutrino in lab: *Nobel Prize*

10 billion from Sun go through hand every sec

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

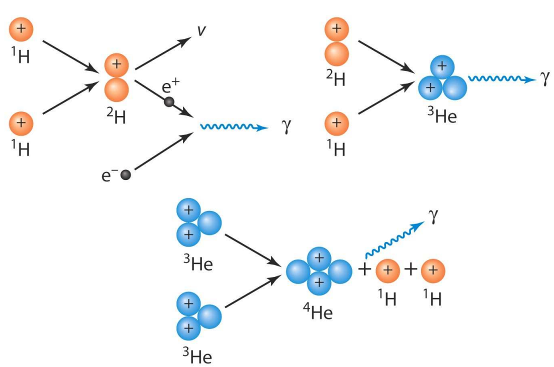
Why Doesn't The Sun Shrink?

- Sun is currently stable
- Pressure from the radiation created by fusion balances the force of gravity.
- Gravity is balanced by pressure from fusion!



Nuclear Fusion in the Sun's Interior

- Proton-proton in stars like the Sun
  - Hydrogen fused to make helium
  - 0.7% of mass converted to energy



The Proton-Proton Cycle