The History of the Universe in 200 Words or Less

Quantum fluctuation. Inflation. Expansion. Strong nuclear interaction. Particle-antiparticle annihilation. Deuterium and helium production. Density perturbations. Recombination. Blackbody radiation. Local contraction. Cluster formation. Reionization? Violent relaxation. Virialization. Biased galaxy formation? Turbulent fragmentation. Contraction. Ionization. Compression. Opaque hydrogen. Massive star formation. Deuterium ignition. Hydrogen fusion. Hydrogen depletion. Core contraction. Envelope expansion. Helium fusion. Carbon, oxygen, and silicon fusion. Iron production. Implosion. Supernova explosion. Metals injection. Star formation. Supernova explosions. Star formation. Condensation. Planetesimal accretion. Planetary differentiation. Crust solidification. Volatile gas expulsion. Water condensation. Water dissociation. Ozone production. Ultraviolet absorption. Photosynthetic unicellular organisms. Oxidation. Mutation. Natural selection and evolution. Respiration. Cell differentiation. Sexual reproduction. Fossilization. Land exploration. Dinosaur extinction. Mammal expansion. Glaciation. Homo sapiens manifestation. Animal domestication. Food surplus production. Civilization! Innovation. Exploration. Religion. Warring nations. Empire creation and destruction. Exploration. Colonization. Taxation without representation. Revolution. Constitution. Election. Expansion. Industrialization. Rebellion. Emancipation Proclamation. Invention. Mass production. Urbanization. Immigration. World conflagration. League of Nations. Suffrage extension. Depression. World conflagration. Fission explosions. United Nations. Space exploration. Assassinations. Lunar excursions. Resignation. Computerization. World Trade Organization. Terrorism. Internet expansion. Reunification. Dissolution. World-Wide Web creation. Composition. Extrapolation?

Astronomy 230
Section 1– MWF 1400-1450
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This Class (Lecture 4):

The Early Galaxy and the First Stars

Next Class:

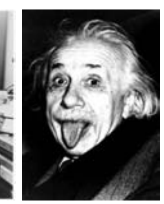
From Atoms to Molecules

Outline

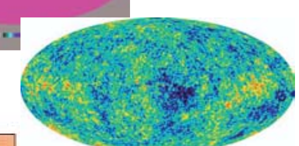
- 3 Reasons we believe in the Big Bang Theory.
- Implications for early life.
- Early Galaxy and the First Stars
- Hydrostatic Equilibrium
- 4 Fundamental Forces
- Nuclear Fusion

From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

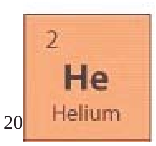
3. Hubble: v=HR
   + Einstein General Relativity
   = Big Bang and expanding Universe
   with age t = 13.7 billion yrs



2. Cosmic microwave background
   Primordial fireball– Big Bang working at
   t = 400,000 yrs
   - Nearly uniform temperature in all directions early Universe was very homogeneous
   - Tiny temperature fluctuations: "seeds" of galaxies



1. Big Bang Nucleosynthesis
   H and (almost all) He come from Big Bang
   Big Bang model working at t = 1 s



What's this mean?

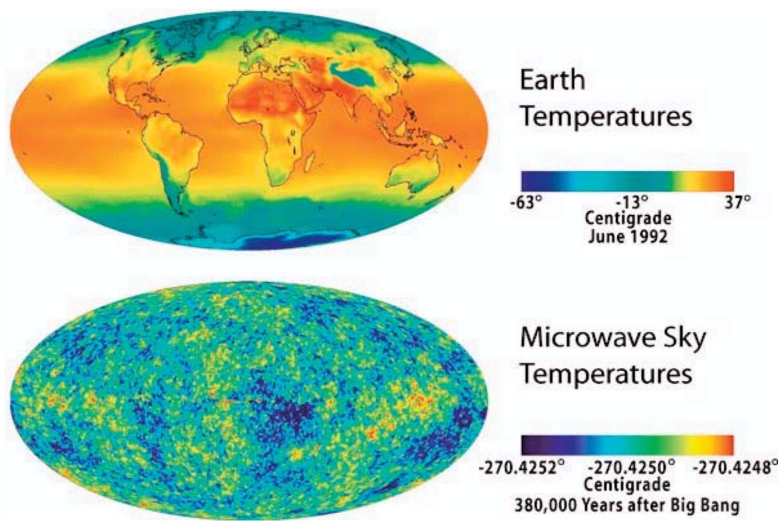
- So, in the early Universe, the first elements formed were mostly Hydrogen (75%) and Helium (25%) by mass. What does that mean for life in the early Universe?
- Globular clusters contain the oldest stars in the Milky Way– about 10 to 13 billion years old. Should we look for life around these stars?

http://www.shef.ac.uk/physics/research/pa/DM-introduction-0397.html

What is the Earth made of?

- Very little hydrogen and helium. They make up less than 0.1% of the mass of the Earth.
- Life on Earth does not require any helium and only small amounts of non-H_2O hydrogen.
- All of these elements must be formed in stars. That means 2nd or 3rd or nth generation of stars are required before life can really get going. These elements were not originally formed in the Big Bang.
- "We are star stuff!"
- How did that come about?

WMAP took a "baby picture" of the Universe

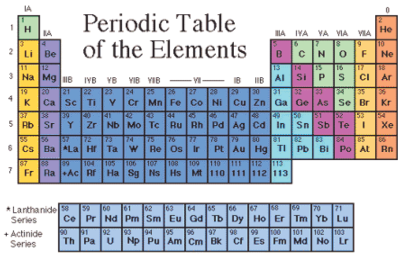


What are Galaxies?

- They are really giant re-cycling plants separated by large distances.
- Stars are born only in galaxies out of dust and gas.
- Stars turn hydrogen into helium, then into heavier elements through fusion for millions or billions of years.
- Stars die and eject material back into the galaxy.
- New stars are formed.
- And so on.
- Crucial to the development of life!

Chemical Basis for Life

- The average human has:
  - 6×10^{27} atoms (some stable some radioactive)
  - During our life, 10^{12} atoms of Carbon 14 (^{14}C) in our bodies decay.
  - Of the 90 stable elements, about 27 are essential for life. (The elements from the Big Bang are not enough!)



http://www.genesismission.org/science/mod2_aei/

Chemical Basis for Life

By Number…

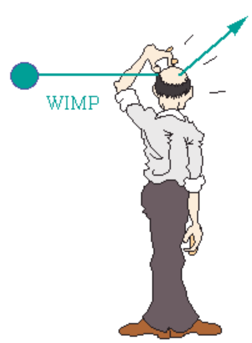
- Life on Earth is mostly:
  - 60% hydrogen
  - 25% oxygen
  - 10% carbon
  - 2% nitrogen
  - With some trace amounts of calcium, phosphorous, and sulfur.
- The Earth's crust is mostly:
  - 47% oxygen
  - 28% silicon

- The Universe and Solar System are mostly:
  - 93% hydrogen
  - 6% helium
  - 0.06% oxygen
  - 0.03% carbon
  - 0.01% nitrogen

The Early Galaxies

- The Universe is dominated by Dark Matter, probably some heavy exotic particle created during the Big Bang. (Weakly Interacting Massive Particle– WIMPs).
- One way that we know this comes from the rotation curves of Galaxies. We can't see dark matter, but we can see the influence of it.
- The normal matter flocks to the dark matter due to gravity. These initial seeds of galaxies and galaxy clusters are the original mix of elements– 75% hydrogen and 25% helium (by mass).

How to search for WIMPs?



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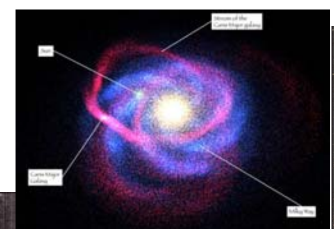
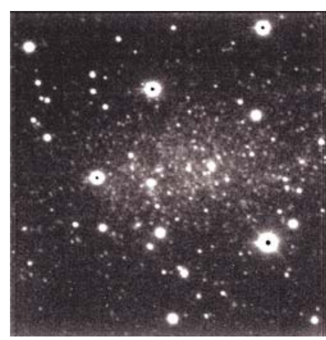
Remember that the Milky Way is Not Alone?

We have a few orbiting galaxies that are gravitationally bound the Milky Way.

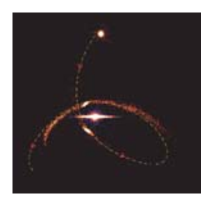


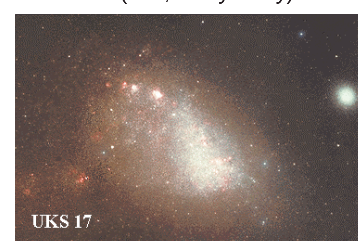
Canis Major
(42,000 ly away)

Large Magellanic Cloud
(180,000 ly away)



Sagittarius Dwarf Elliptical
(80,000 ly away)





Small Magellanic Cloud
(250,000 ly away)

And Many Galaxies in the Local Group

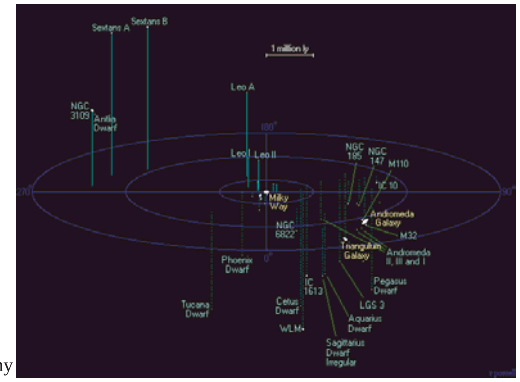

Milky Way

0.7 Mpc


Andromeda (M31)


Triangulum (M33)


Local Group Dwarf galaxies



The First Stars

- From the initial seeds of the Big Bang, our local group of galaxies probably broke into clumps of hydrogen and helium.
- We'll look at star formation in detail latter, but let's think of the first star to form in our Milky Way
- May have formed as early as 200 million years after the Big Bang.
- Probably more massive than stars today, so lived quickly and died quickly.
- What happened? Why did this "raw" gas form anything?

Water Power?

- Does a bottle of water have any stored energy? Can it do work?

Gas powered

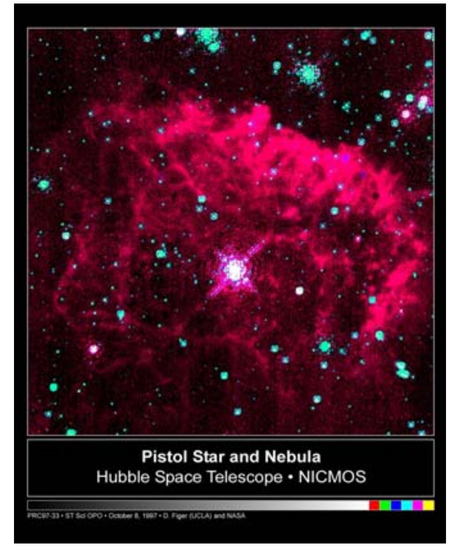
- Similar to my bottle of water, these initial gas clumps want to reach the center of their clump-ness.
- The center gets hotter and hotter. The gravitational energy potential turns into heat (same as velocity actually).
- It is a run-away feature, the more mass at the center, the more mass that wants to be at the center.
- The center of these clumps gets hotter and denser.

Cooking with Gas

- For the first time, since 1-month after the Big Bang, the centers of the clumps get above 10^7 K.
- That is hot enough for nuclear fusion to occur. If that had not happened, life would never have existed.
- But are things different than what we learned in Astro 100? These are the First Stars after all.

The Most Massive Star in the Milky Way?

- The Pistol star near the Galactic center started as massive as 200 solar masses.
- Releases as much energy in 6 seconds as the Sun in a year.
- But it blows off a significant fraction of its outer layers.
- How did the first stars stay so massive?
- Perhaps they are slightly different than this case?

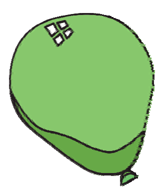


http://www.u.arizona.edu/~justin/images/hubblepics/full/PistolStarandNebula.jpg

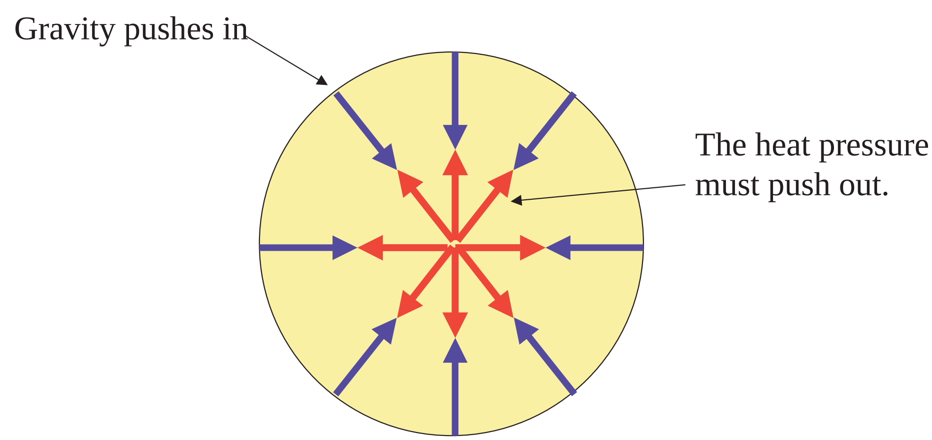
Pressure

- What is pressure?
  - Pressure $= \frac{Force}{Area}$
- Explain blowing up a balloon?
- http://www.phy.ntnu.edu.tw/java/idealGas/idealGas.html

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



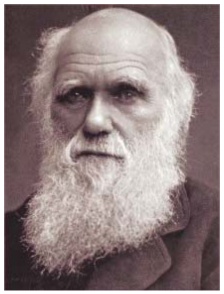
The Battle between Gravity and Pressure



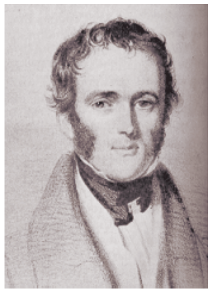
Hydrostatic equilibrium

What Holds Up the Sun?

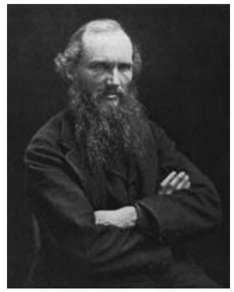
- Without an energy source, the Sun would rapidly cool & contract
- Mid-1800s:
  - Darwin: evolution needs Sun & Earth to be > 10^8 years old
  - Lyell: geological changes also needs > 10^8 years
  - Kelvin: gravitational heating gives only a few million years!
- No physical process then known would work!



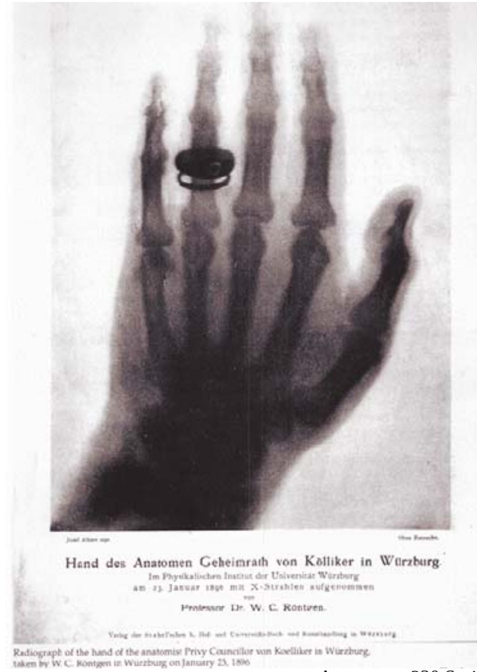
Charles Darwin



Charles Lyell



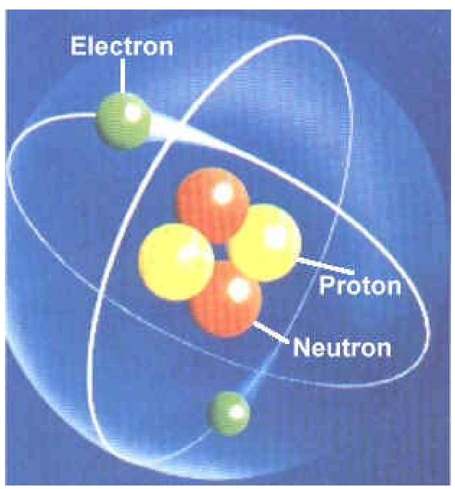
William Thomson, Lord Kelvin



Eyes began to turn to the nuclear processes of the Atoms

Back to Atoms

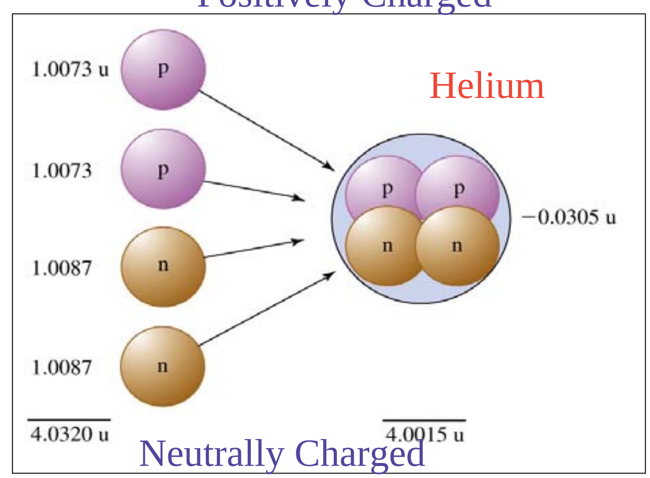
Remember that the atom consists of a nucleus and electrons moving around the nucleus.



The Nucleus

- Okay, so we know that the nucleus can have numerous protons very close.
- Why doesn't the nucleus of the atom fly apart?

Positively Charged



4 Fundamental Forces

- Gravity
- Electromagnetic
- Strong Nuclear
- Weak Nuclear

Gravity

- As described by Newton
- The weakest of the forces, yet it is the dominant force in the universe for shaping the large scale structure of galaxies, stars, etc.
- Only purely attractive force
- Arguably the least understood force
- Infinite range

Electromagnetic

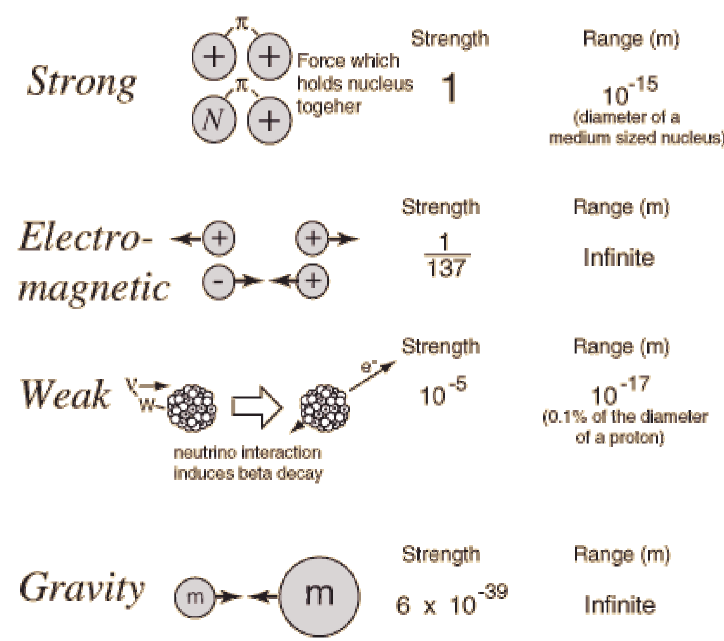
- Similar to the gravitation force (inverse square law)
- Electric and Magnetic fields
- Both attractive and repulsive force
- Only acts on charges particles
- Responsible for all electric and magnetic phenomena we observe— includes light.
- Infinite range

Strong Nuclear

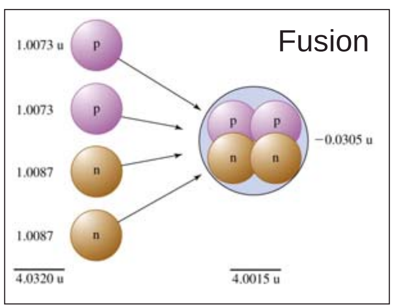
- The strongest of the 4 forces
- The force which holds an atom's nucleus together, in spite of the repulsion between the protons.
- Does not depend on charge
- Not an inverse square law– very short range.

Weak Nuclear

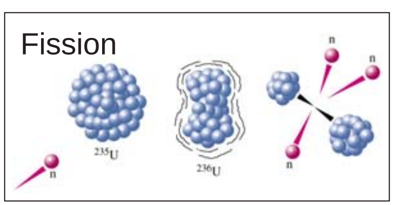
- Moderates certain kinds of nuclear decays such as the neutron decay
- The most common particle which interacts only via the Weak Force is the *neutrino*
- Very short range

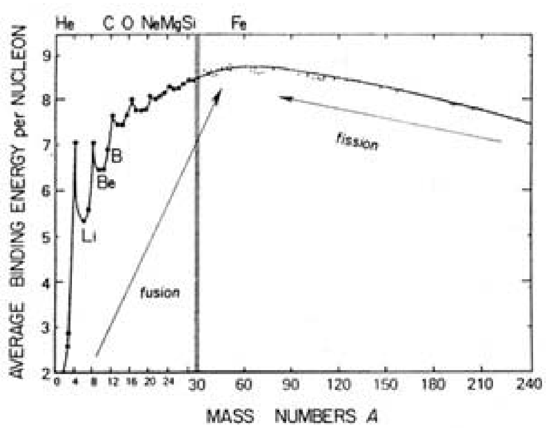


Nuclear Reactions



- Atomic nuclei can combine or split
- Release energy in process ($E = mc^2$)
- Light nuclei: fusion
- Heavy nuclei: fission





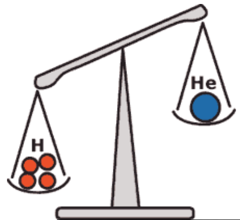
Nuclear Fusion in the First Stars

- Core T > 10 million K
  - collisions violent:
  - e stripped from atoms (ionized)
  - nuclei collide, react
- thru series (chain) of reactions
- 4 protons ⟹ helium (2p,2n) nucleus + energy
- **Fusion:** light nuclei combine ⟹ heavier nuclei

Why does fusion release energy?

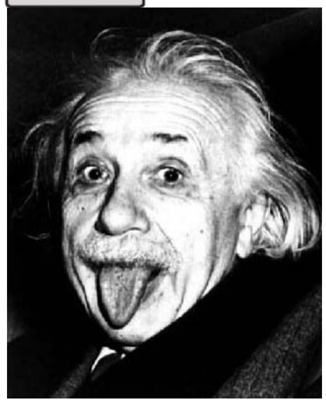
Fusion: $4\,p \rightarrow {}^4\mathrm{He} \quad (2\,p, 2\,n)$

fact: **$4m(p) > m({}^4\mathrm{He})$** !
mass of whole < mass of parts!



Einstein says ***E = mc***^{2}:
- mass is a form of energy!
- each ^{4}He liberates energy:

$$E_{1\,\mathrm{fusion}} = m_{\mathrm{lost}}c^2 = 4m(p)c^2 - m({}^4\mathrm{He})c^2 > 0!$$



Nuclear Reactions in the Sun

- Chain: 4 protons → helium
- first step in chain:

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

- start with 2 particles (protons)
- end up with 4 (two of which are glued together)
- each of products is very interesting in its own right....

They Might Be Giants
Why Does The Sun Shine

http://eeyore.astro.uiuc.edu/~lwl/classes/astro100/fall03/Lectures/The%20Sun%20Is%20A%20Mass%20Of%20Incandescent%20Gas.mp3

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 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

We need its light
We need its heat
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

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 hot

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

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

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
A gigantic nuclear furnace
Where Hydrogen is built into Helium
At a temperature of millions of degrees

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 n, 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

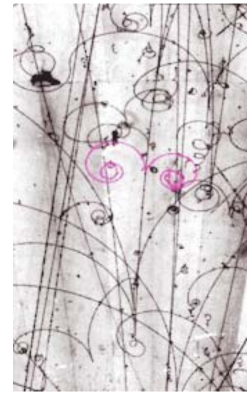
✓ Water (normally H_2O) with D is D_2O : "heavy water"

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 gone, release 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*

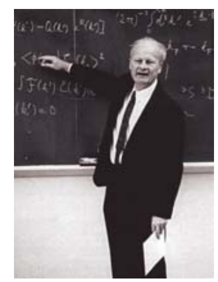
10 billion from Sun go through hand every sec

➢ reach out!

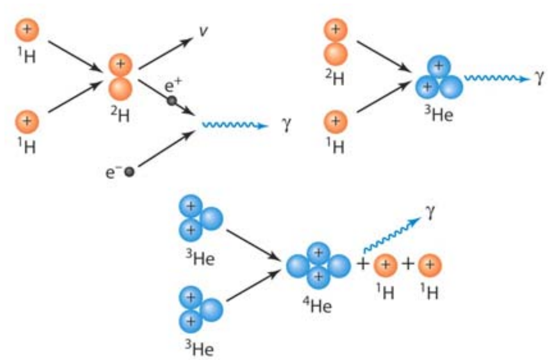
➢ go through your body, Earth, but almost never interact

Nuclear Fusion in the Sun's Interior

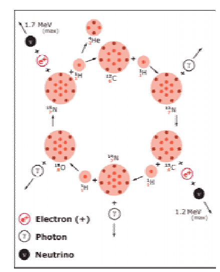
- Proton-proton in stars like the Sun
  - Hydrogen fused to make helium
  - 0.7% of mass converted to energy
- CNO cycle in more massive stars (BUT not the first stars!!)



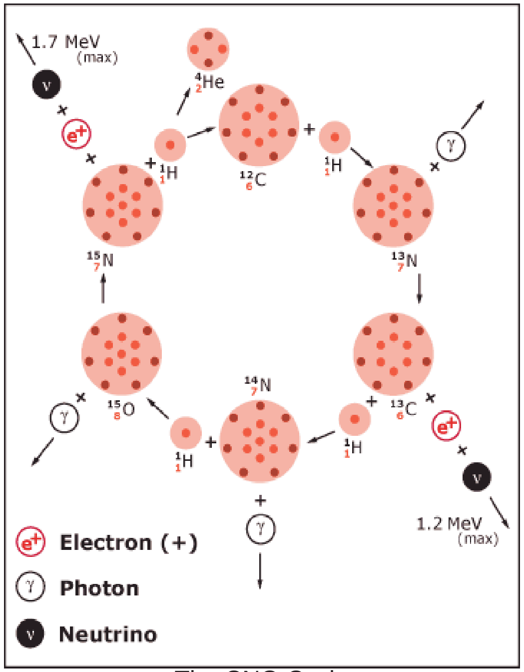
Hans Bethe



The Proton-Proton Cycle



The CNO Cycle



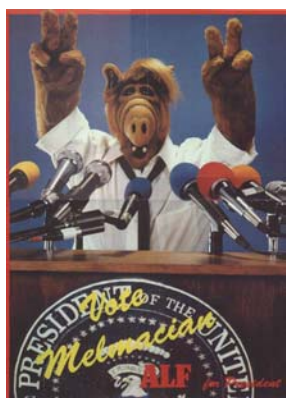
The CNO Cycle

Why Nuclear Fusion Doesn't Occur in Your Coffee

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

So, Why is this Important to Alf?

- A star in hydrostatic equilibrium will not shrink or swell.
- It will maintain constant size, density, and temperature for more than a million years!
- At this point, the star is called a main sequence star.
- If stars were not constant, what effect would that have on life on orbiting planets. Ultraviolet light variations?



http://alf.disim.com/photos/photoposter.htm