ET: Astronomy 230
Section 1– MWF 1400-1450
134 Astronomy Building

This Class (Lecture 5):

From Atoms to Molecules to Clouds

Next Class:

Star Formation

HW1 due today!

Music: *Supernova* – Liz Phair

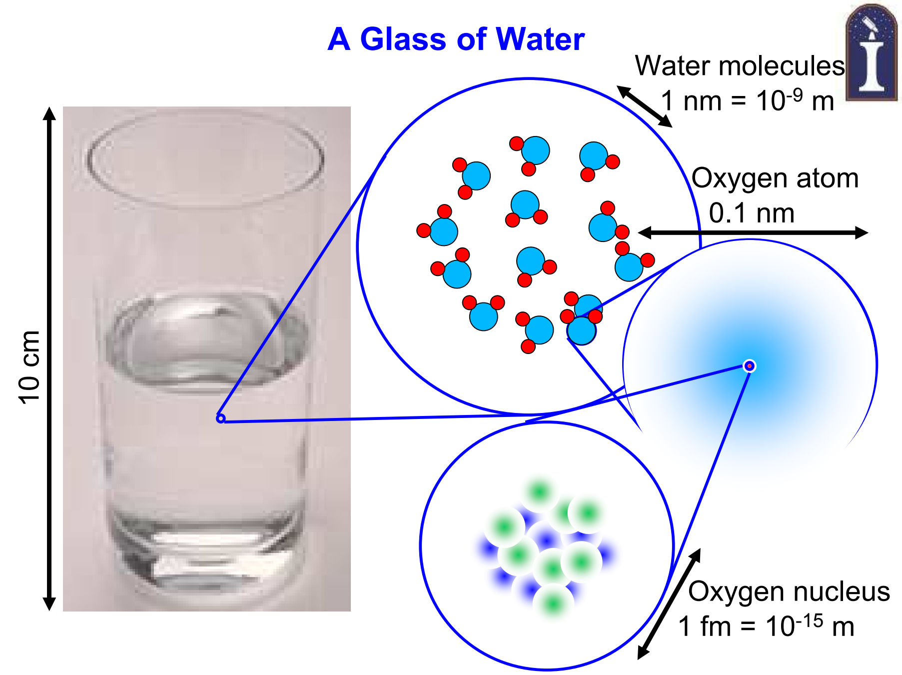
Outline

- What is life made of?
- We are star stuff!
- The first stars.
- Hydrostatic equilibrium of stars.
- Nuclear fusion.

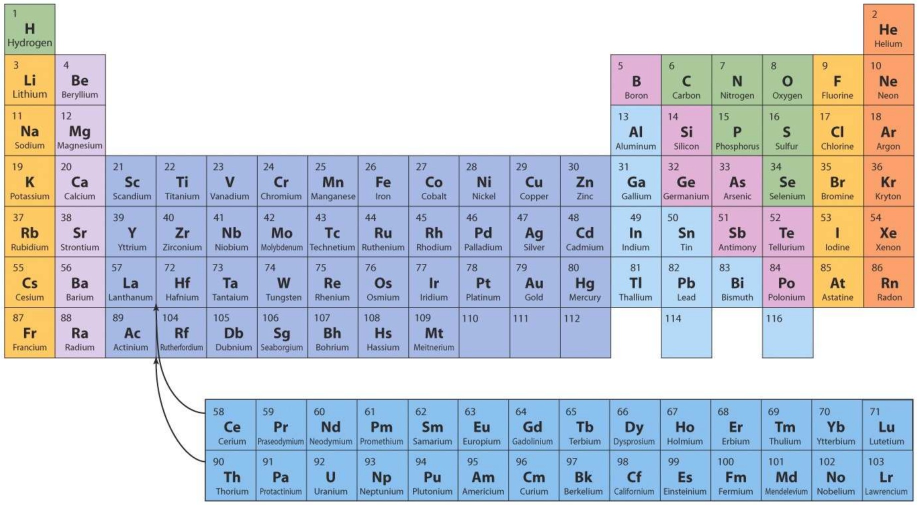
The Early Universe?

- 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



The Periodic Table of the Elements



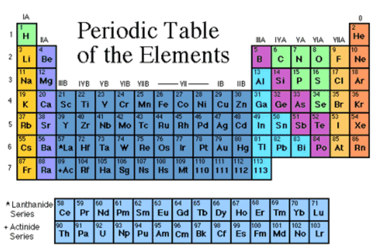
The number of protons in an atom determines the type of element, and the number of protons and neutrons determine the atomic weight.

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 have been formed in stars. That means 2^{nd} or 3^{rd} or n^{th} generation of stars are required before life can really get going.
- **"We are star stuff!"**
- How did that come about?

Chemical Basis for Life

- The average human has:
  - 6 x 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% **H**ydrogen
  - 25% **O**xygen
  - 10% **C**arbon
  - 2% **N**itrogen
  - With some trace amounts of calcium, phosphorous, and sulfur.
- The Earth's crust is mostly:
  - 47% oxygen
  - 28% silicon

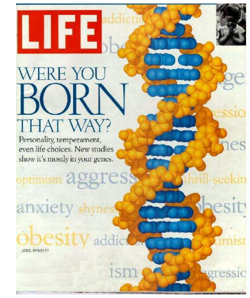
- The Universe and Solar System are mostly:
  - 93% hydrogen
  - 6% helium
  - 0.06% oxygen
  - 0.03% carbon
  - 0.01% nitrogen

What are Galaxies?

- They are really giant re-cycling plants separated by **large** distances.
- Stars are born 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!

Galaxies for you and me

- Life as we know it, needs more elements than the Big Bang could provide.
- Composition of life is unique.
- Does the environment of the Galaxy nourish life?
- At the vary least we need galaxies to process the material from the Big Bang into materials that life can use.
- How did galaxies form?

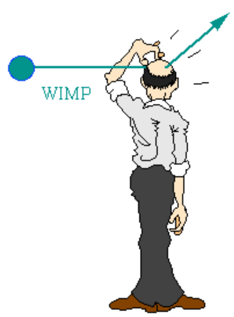


http://www.chromosome.com/lifeDNA.html

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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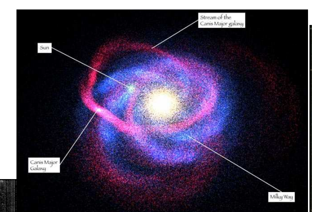
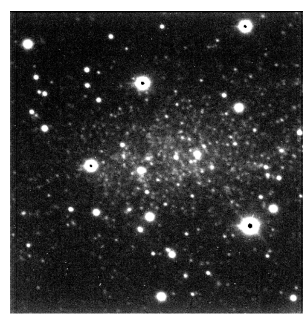
Remember that the Milky Way is Not Alone?

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

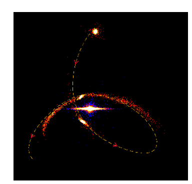


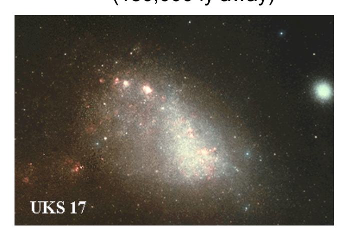
Canis Major (42,000 ly away)

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

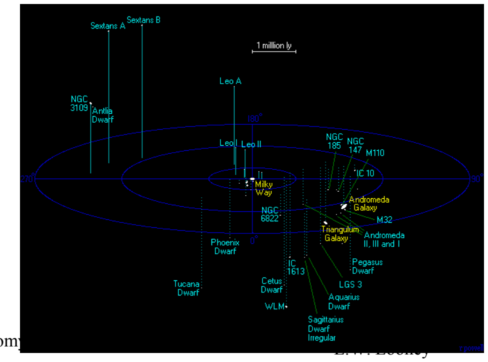
Milky Way

2 MLyrs

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.

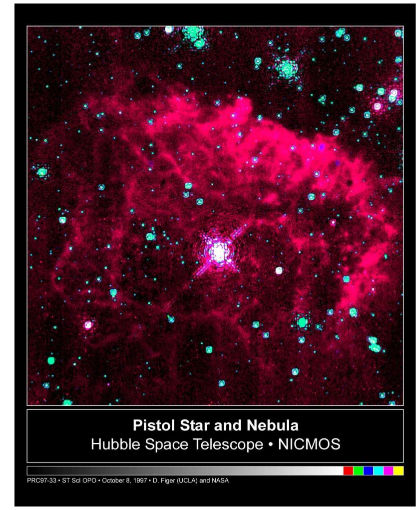
http://www.gemini.edu/

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 Today

- 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?



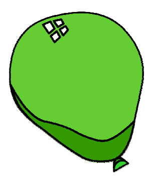
http://www.u.arizona.edu/~justin/images/hubblepics/full/PistolStarandNebula.jpg

Pressure

- What is pressure?
  - $\text{Pressure} = \frac{Force}{Area}$

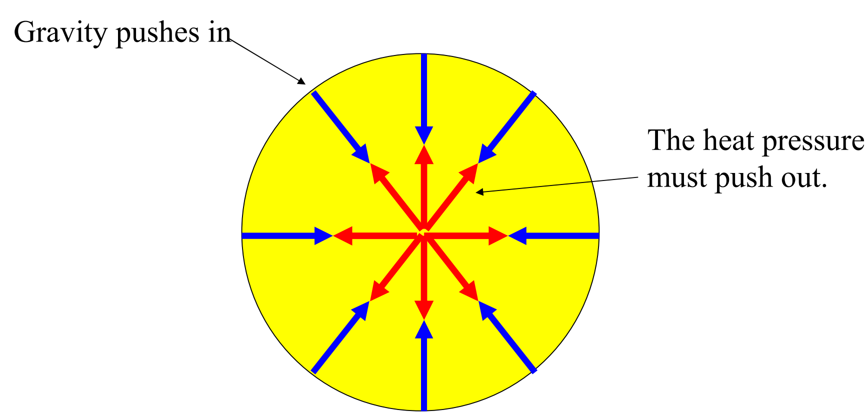
Pressure of Earth's atmosphere is 14.7 pounds per square inch

- Explain blowing up a balloon?



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

The Battle between Gravity and Pressure



Hydrostatic equilibrium

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 2000: 3.8 trillion kWh…

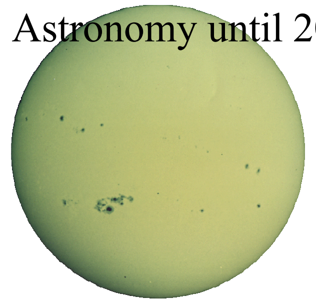
… Sun = 3 x 10^7 times this *every second*

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

… Sun = 4 million times this *every second*

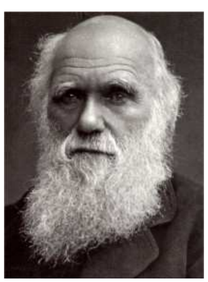
So, What Powers the Sun?

- Sun shines by its own power.
- But what is the power source?
- What keeps the Sun hot? It doesn't cool like a hot coffee cup. Biggest mystery in Astronomy until 20th century.

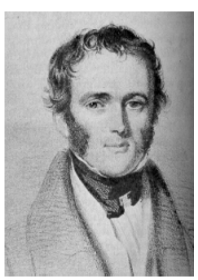


What Holds Up the Sun?

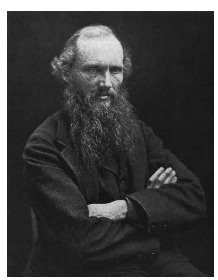
- Without an energy source, the Sun would rapidly cool & contract
- Mid-1800s:
  - Darwin: evolution needs Sun & Earth to be > 10^8 years old
  - Lyell: geological changes also needs > 10^8 years
  - Kelvin: gravitational heating gives only a few million years!
- No physical process then known would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



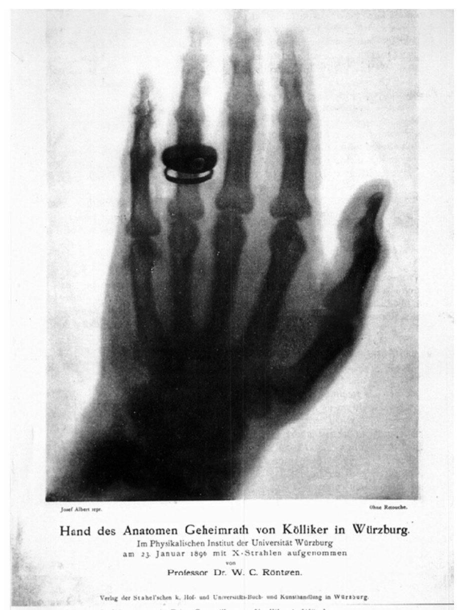
Charles Darwin



Charles Lyell



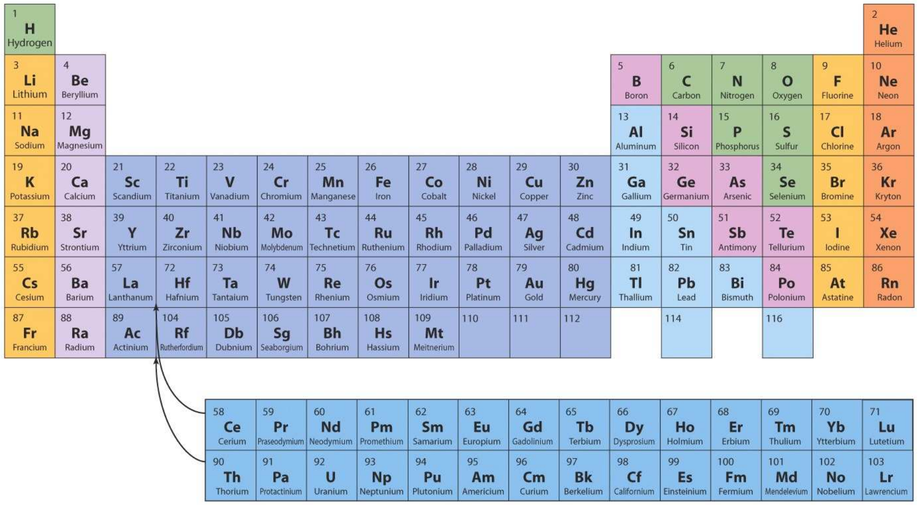
William Thomson, Lord Kelvin



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

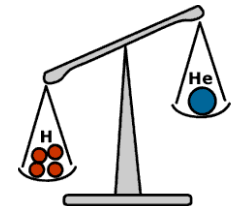
The Periodic Table of the Elements



The number of protons in an atom determines the type of element, and the number of protons and neutrons determine the atomic weight.

How does fusion release energy?

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

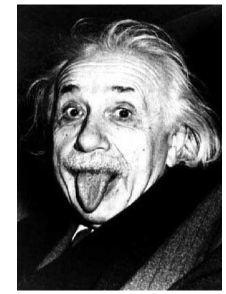


Fact: **$4m(p) > m(^4He)$** !

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

Einstein says ***$E = mc^2$***:

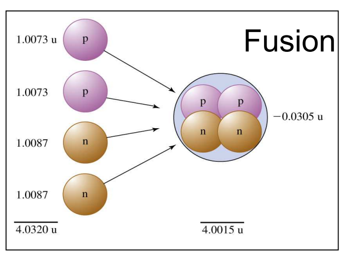
- Mass is a form of energy!
- Each ^{4}He liberates energy:

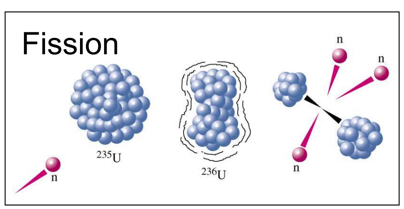


$$E_{fusion} = m_{lost}c^2 = 4m(p)c^2 - m(^4He)c^2 > 0!$$

Fusion vs. Fission

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



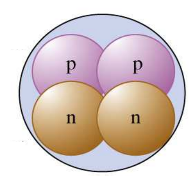


The Nucleus

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

Helium

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

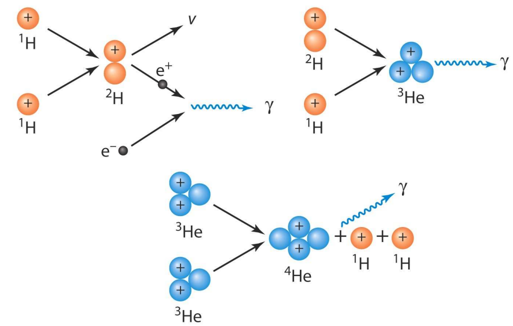


4 Fundamental Forces

- 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 Fusion in the Sun's Interior

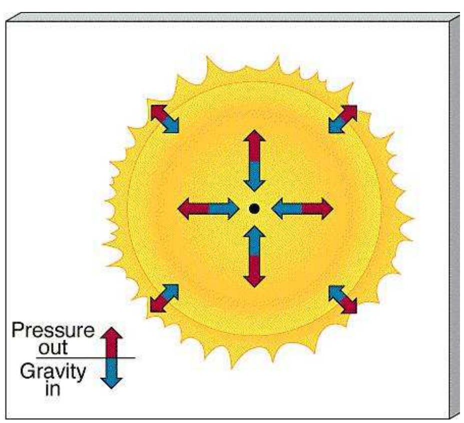
- Proton-Proton Chain
  - 4 Hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)



The Proton-Proton (p-p) Chain

Why Doesn't The Sun Shrink?

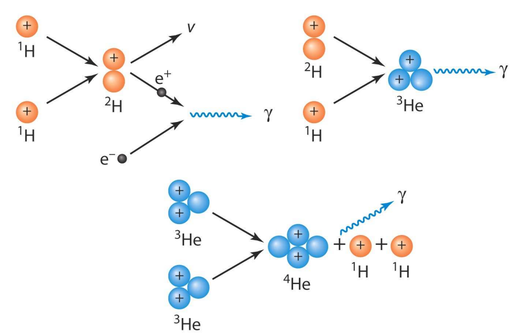
- Sun is currently stable
- Pressure from the radiation created by fusion balances the force of gravity.



- There has to be some pressure. The pressure is 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

They Might Be Giants
Why Does The Sun Shine

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 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-sized star

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

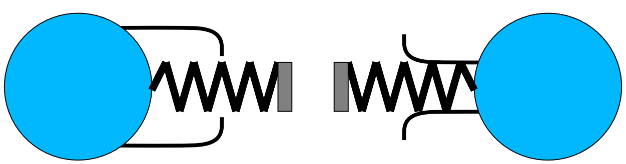
But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

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

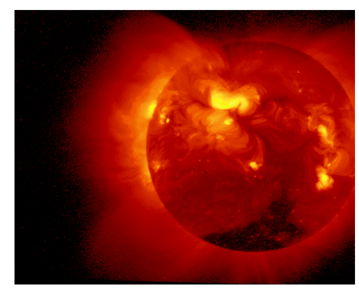
Why Nuclear Fusion Doesn't Occur in Your Coffee

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



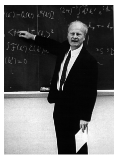
Nuclear Fusion in the First Stars

- Core $T > 10$ million K
  - Violent collisions
  - e^- stripped from atoms (ionized)
  - Nuclei collide, react
    - They get close enough that the nuclear strong force takes over.

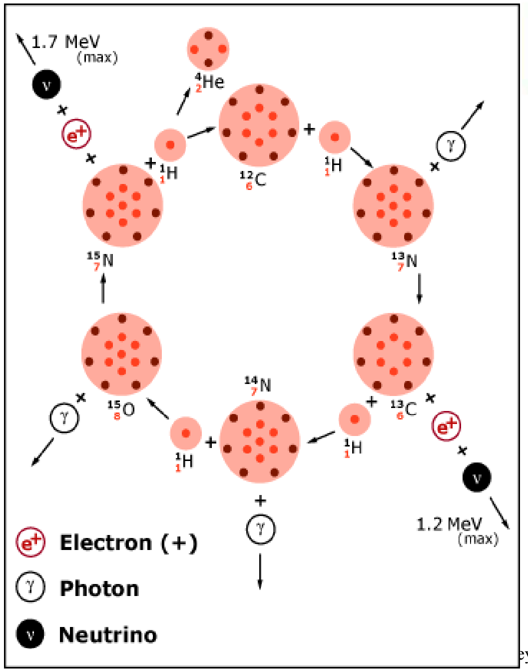


- Thru series (chain) of reactions
- 4 protons ⇒ helium (2p,2n) nucleus + energy
- **Fusion:** light nuclei combine ⇒ heavier nuclei

The CNO Cycle

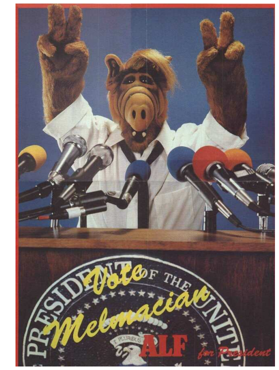


Hans Bethe



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