Astronomy 230

Section 1– MWF 1400-1450

106 B1 Eng Hall

<u>This Class (Lecture 5):</u>

From Atoms to Molecules

HW 1 Due today at the start of class today.

<u>Next Class:</u>

Star Formation

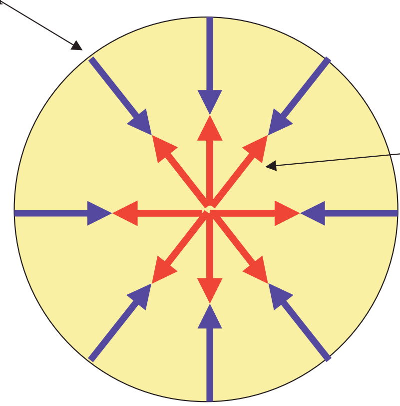
Presentation Synopsis due next Weds.

Music: *Supernova* – Liz Phair

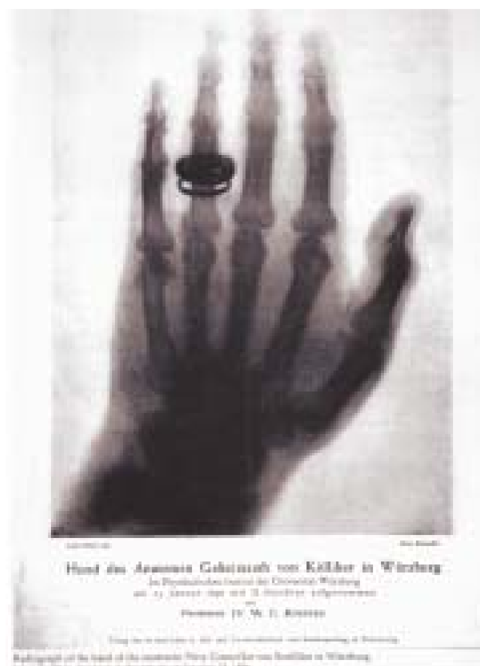
Outline

- Nuclear Reactions
- The atomic elements from the first and second generation of stars are distributed into the galaxy.
- These elements create molecules in areas called molecular clouds.
- Molecular clouds are these huge complexes in space where stars form.
- Molecules, even biologically important ones, can exist in these clouds.

The Battle between Gravity and Pressure



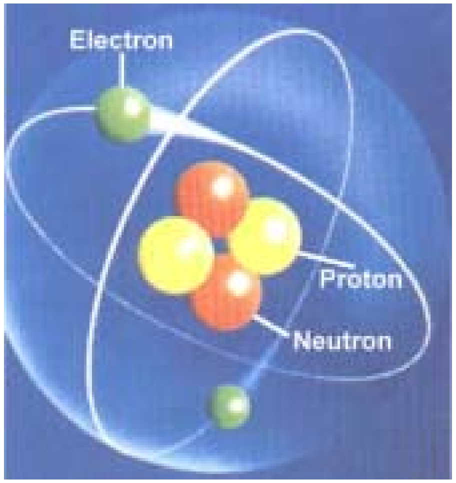
Hydrostatic equilibrium



Eyes began to turn to the nuclear processes of the Atoms

Back to Atoms

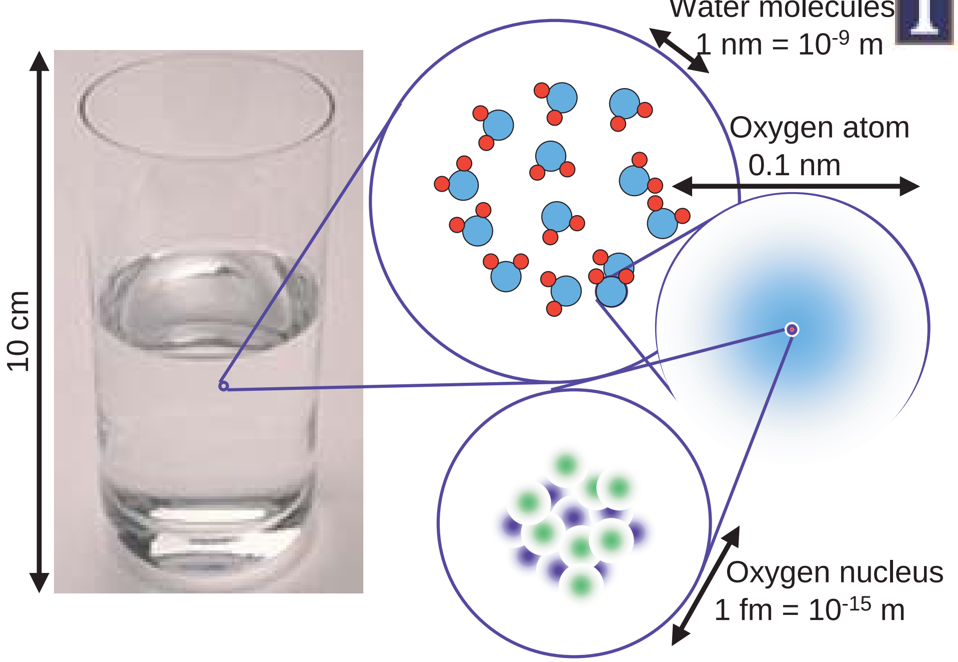
Remember that the atom consists of a nucleus and electrons moving around the nucleus.



The 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.

A Glass of Water

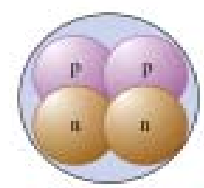


The Nucleus

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

Helium

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

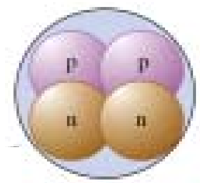


The Nucleus

- **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
- 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

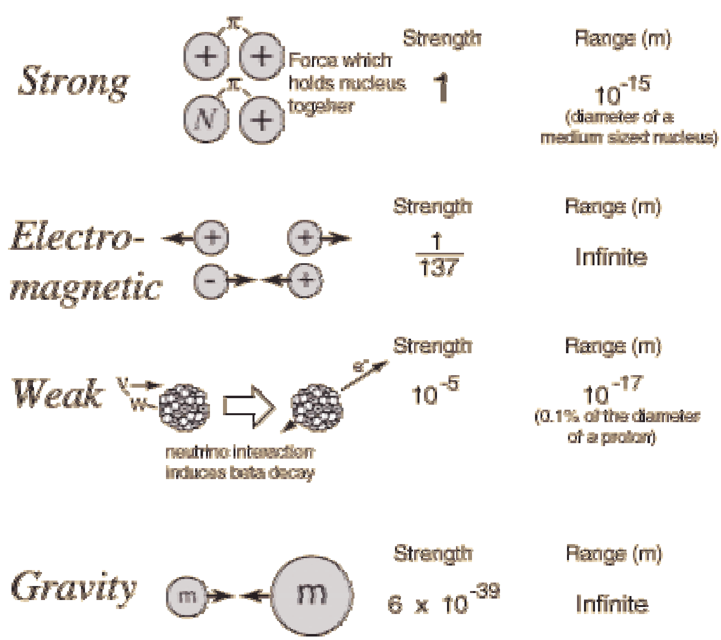
- Similar to the gravitation force (inverse square law)
- Electric and Magnetic fields
- Both attractive and repulsive force
- Only acts on charges particles
- Responsible for all electric and magnetic phenomena we observe— includes light.
- Infinite range

Strong Nuclear

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

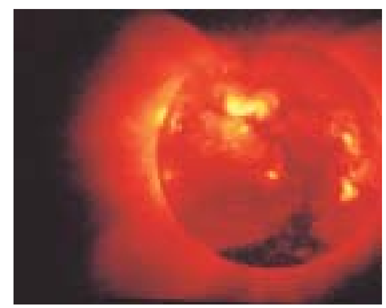
Weak Nuclear

- 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 Fusion in the First Stars

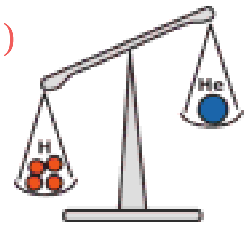
- Core *T* > 10 million K
  - Violent collisions
  - e^- stripped from atoms (ionized)
  - Nuclei collide, react
    - They get close enough that the strong force takes over.



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

Why does fusion release energy?

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

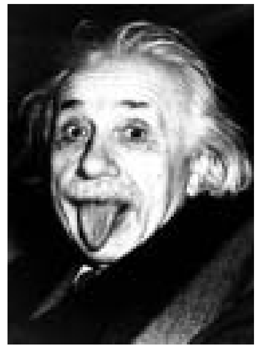


Fact: **4m(*p*) > m(^{4}He)** !

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

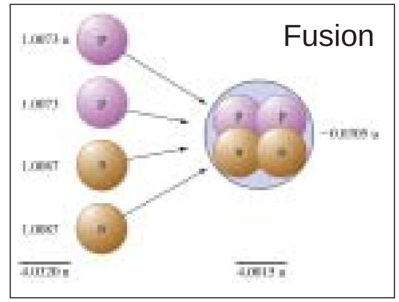
Einstein says ***E = mc***^{2}:

- Mass is a form of energy!
- Each He liberates energy:

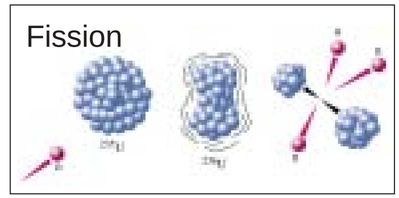


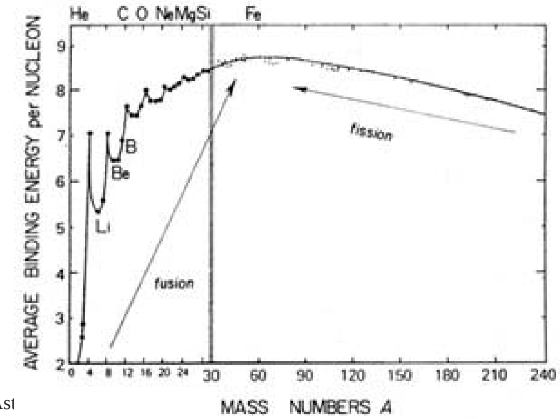
$$E_{\text{fusion}} = m_{\text{lost}} c^2 = 4m(p)c^2 - m(\text{He})c^2 > 0!$$

Nuclear Reactions



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





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

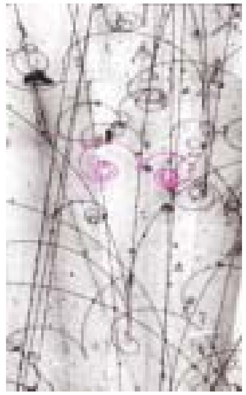
✓ Water (normally H_2O) with D is D_2O : “heavy water"

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

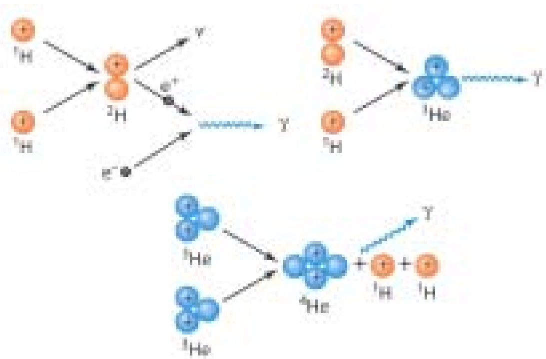
➢ Reach out!

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

Sept 3, 2004 Astronomy 230 Fall 2004 L.W. Looney

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!!)



The Proton-Proton Cycle

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
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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

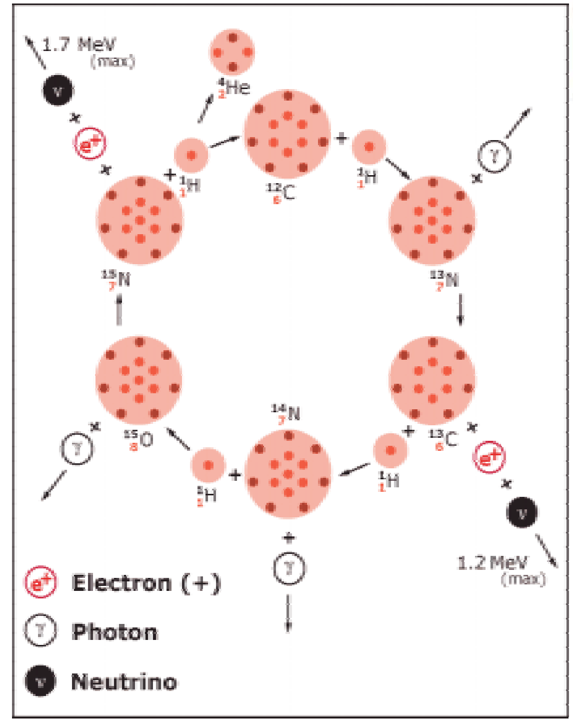
But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

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

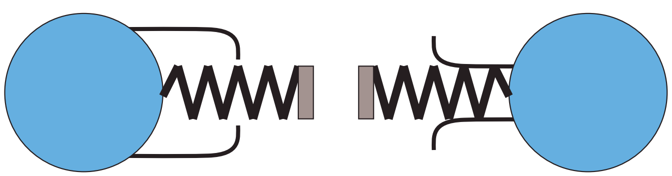
The CNO Cycle


Hans Bethe



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

The First Stars

- In the cores of the first stars, it gets hot enough for nuclear fusion.
- In the internal furnace of these first stars is where carbon and oxygen are created for the first time in the Universe.
- Higher density and temperature of the red giant phase allows for the creation of sulfur, phosphorous, silicon, and finally iron.
- Iron has the lowest nuclear potential energy, it cannot produce energy by fusion.
- The star goes supernova and explodes. Some of C, O, P, S, Si, and Fe get carried away. At this point, even heavier elements can be made.

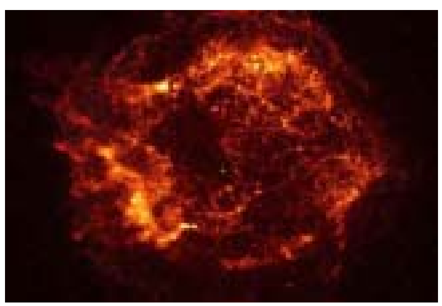
The Second Generation

- The first stars blew up their new elements into the proto-galaxy.
- Now, the second stars form in the ashes of the first.
- With C and N, the 2nd generation can form helium through the CNO cycle, in which most of the Universe's nitrogen is created.
- The 2nd generation also eventually explodes blowing nitrogen and the other elements into the galaxy.

A supernova in a nearby galaxy. A single star exploding can be brighter than millions of stars in the nucleus.

The Next Stars

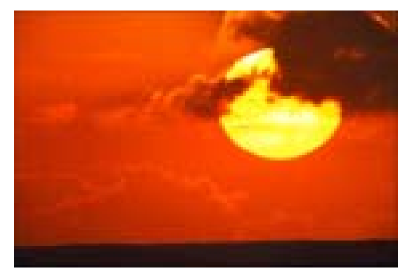
- The new atomic elements from the 1st and 2nd stars are spread out into the galaxy.
- The Sun must be at least a 3rd generation star as we have nitrogen in abundance.
- Indeed, the percentage of heavier elements is larger toward the center of the galaxy, where the first generation of stars probably formed. (Seen in ours and other galaxies.)
- **Again, we are star stuff.**
- Keep in mind that this is all from the nuclear strong force– fusion.



The Chandra x-ray observatory has shown that the CasA supernova has flung calcium, iron, and silicon into space.

Star Stuff

- Now, we have the elements crucial to life in the Galaxy.
- There are about 92 elements found in the Universe and about 20 more elements that have been created in laboratories (but decay quickly).
- The 92 elements were almost all made in the interiors of massive stars or during a supernova explosion.
- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, most of the important aspects of life depend on molecules. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.



http://www.astronomyinfo.pwp.blueyonder.co.uk/starstuff.htm

Molecules

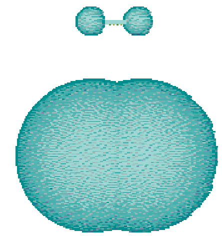
- Combination of 2 or more atoms such that they are bound together without their nuclei merging.
- Just like an atom is the smallest piece of an element, a molecule is the smallest piece of an compound.
- When dividing water, smallest division, before separation of hydrogen and oxygen.
- Wow! An enormous jump in complexity. There are only about 115 elements, but there are millions of known molecules and nearly infinite number of possibilities.
- Some of the key life molecules contain billions of atoms.

http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

http://www.ph.qmw.ac.uk/research_bk/theory.htm

Example H_2

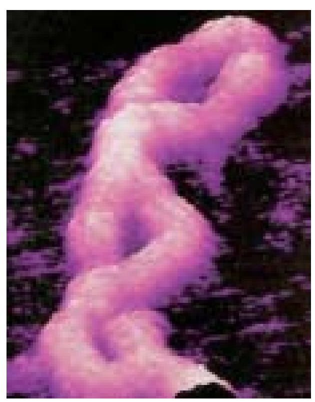
- H_2 is the simplest molecule– two hydrogen atoms.
- What does that mean?
  - There are 4 particles.
    - 2 protons of the 2 nuclei, which repel each other
    - 2 electrons of the 2 atoms, which repel each other
  - But
    - The electron of each atom will attract the other nucleus
- Although not obvious, the 2 attractive forces and 2 repulsion forces equal out.
- The electromagnetic force works for hydrogen, but there is no He_2.



http://www.historyoftheuniverse.com/h2.html

Molecule Benefits for Life

- Molecules can easily be broken apart, but are also stable.
- Flexibility in arrangement.
- Plethora of molecules.
- Electromagnetic force is much weaker than strong nuclear force, lower energies– lower temperatures.
- Perfect for life.



http://www.time.com/time/daily/special/genetics/

How to Write Molecules

- We'll talk about H_2 or CO_2
- Or

Molecular Hydrogen

H-H

Single bond

Sharing 1 electron pair

Carbon Dioxide

O=C=O

Double bond

Sharing 2 electron pairs

http://www.gristmagazine.com/dogood/connections.asp

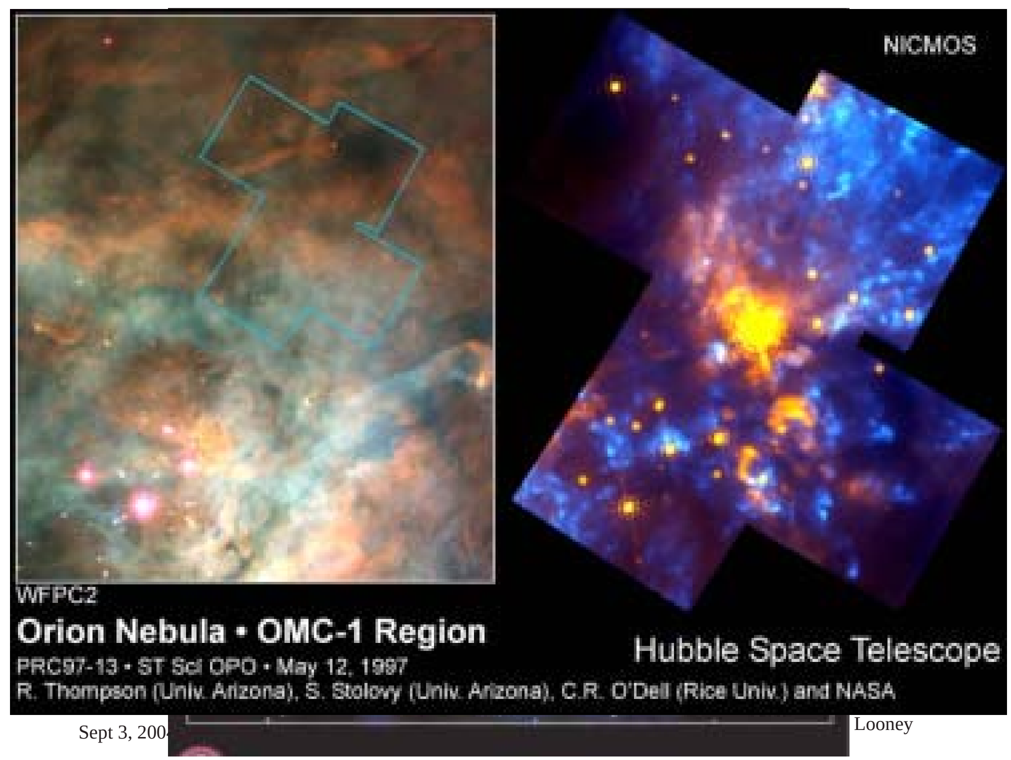
Talkin' About a Revolution

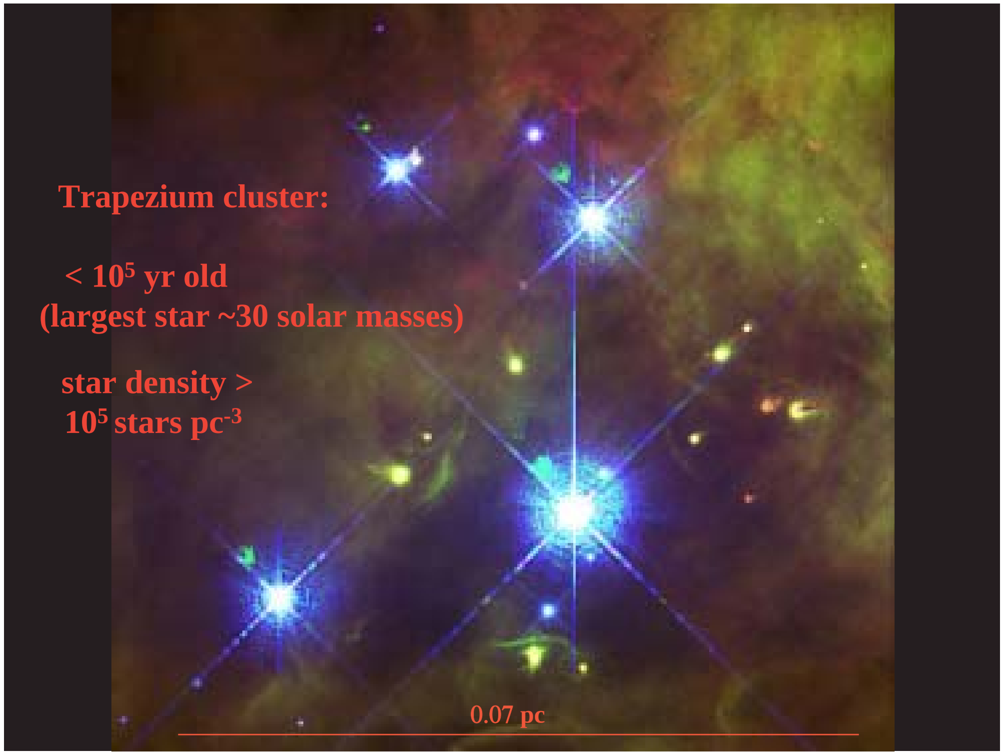
- Molecules first showed up in space after enough heavy elements accumulated.
- There is a lot of interstellar molecular gas clouds in space.
- First complicated molecules found in space in 1968, and we have found even more over the last 20 years.
- They emit light in the millimeter regime.

Orion Nebula

(near infrared)

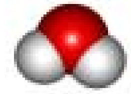
Nearest massive star forming region with a large molecular cloud associated (distance of 1500 lys)

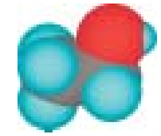


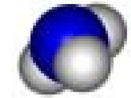


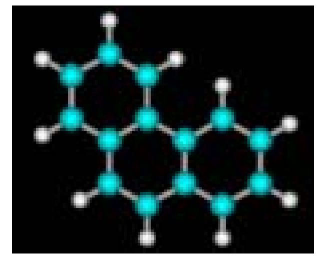
Other Things Besides Hydrogen in Molecular Clouds

- Molecules (e.g.)
  - Carbon monoxide (CO)
  - Water (H_2O)
  - Ammonia (NH_3)
  - Formaldehyde (H_2CO)
  - Glycine (NH_2CH_2COOH)?
  - Ethyl alcohol (CH_3CH_2OH)
  - Acetic Acid (CH_3COOH)
  - Urea [$(NH_2)_2CO$]
- Dust particles
  - Silicates, sometimes ice-coated
  - Soot molecules

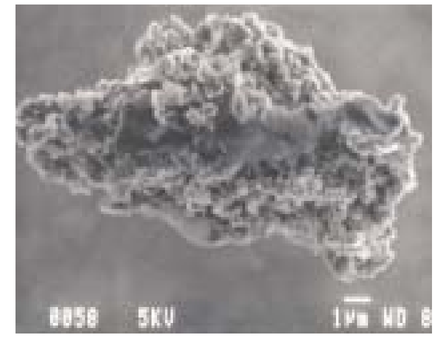








Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)

So?

- Complex molecules (>13 atoms) have evolved in places other than the Earth.
- Maybe there are more? The more complex molecules are harder to detect.
- Seen in other galaxies too.