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

<u>This Class (Lecture 6):</u>

Star Formation

<u>Next Class:</u>

Planet Formation

Presentation Synopsis due Friday.

Music: *Invisible Sun* – Police

Outline

- 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 huge complexes in space where stars form.
- Molecules, even biologically important ones, can exist in these clouds.

HW1 Result

The class's first estimate (median) is 0.2 Civilizations!!!

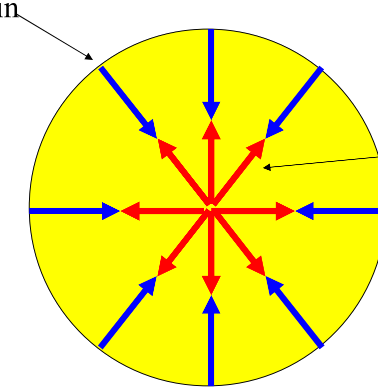
Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

The Battle between Gravity and Pressure

Gravity pushes in

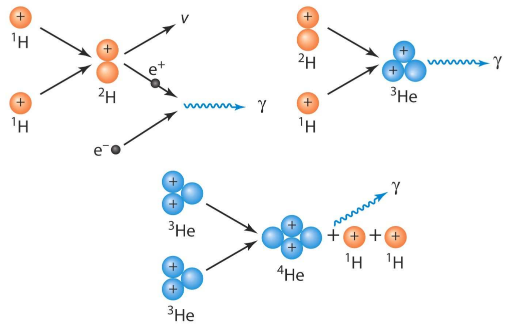


The heat pressure must push out.

Hydrostatic equilibrium

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

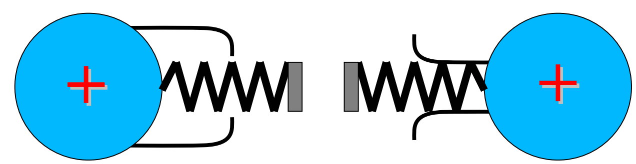
But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

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

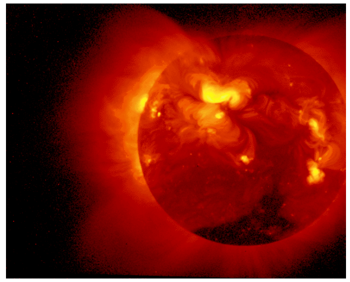
Why Nuclear Fusion Doesn't Occur in Your Coffee

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



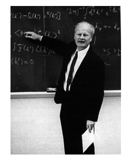
Nuclear Fusion in the First Stars

- 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.

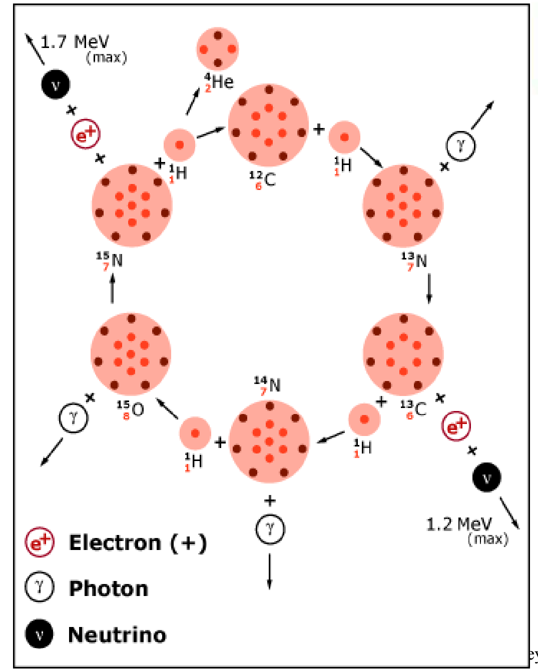


- Thru series (chain) of reactions
- 4 protons ⇒ helium (2p,2n) nucleus + energy
- **Fusion:** light nuclei combine ⇒ heavier nuclei

The CNO Cycle

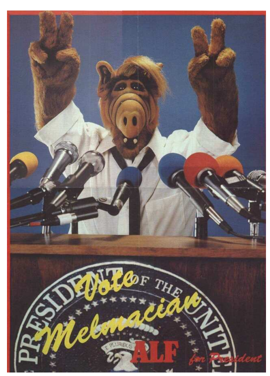


Hans Bethe



Alf Doesn't Care?

- 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

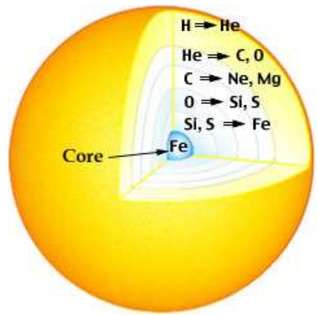
- In the cores of the first stars, it gets hot enough for nuclear fusion.
- In the internal furnace of these first stars is where carbon and oxygen are created for the first time in the Universe.
- Higher density and temperature of the red giant phase allows for the creation of sulfur, phosphorous, silicon, and finally iron.
- Iron has the lowest nuclear potential energy, it cannot produce energy by fusion.

Iron – The End of the Road

- “Burning” heavier and heavier atoms in the fusion process
- Each stage faster than the last
- After iron - no fuel left!
  - It requires energy to produce heavier atoms

Stage	Temperature	Duration
H fusion	40 million K	7 million yr
He fusion	200 million K	500,000 yr
C fusion	600 million K	600 yr
Ne fusion	1.2 billion K	1 yr
O fusion	1.5 billion K	6 mo
Si fusion	2.7 billion K	1 day

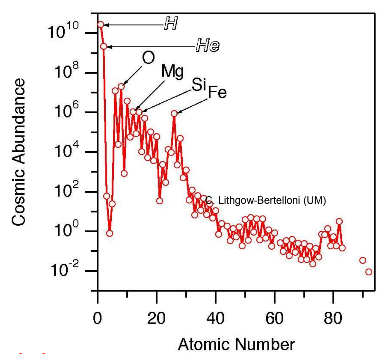
Values for a 25M_{Sun} star



Supernova!

Making Heavy Elements

- 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.
- During the explosion, energy-consuming fusion reactions are possible
- These by-products are *blasted* into space (>90% of star)
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**
- **We are Star stuff.**



Delenn, B5

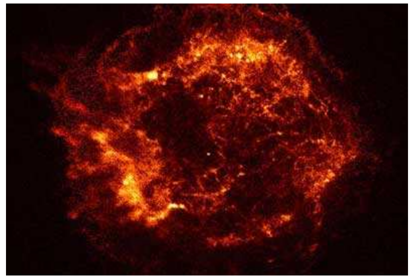
The Second Generation

- 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

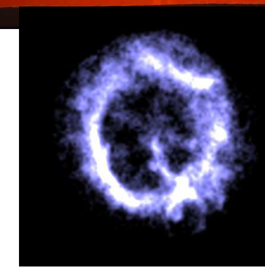
- The new atomic elements from the 1st and 2nd stars are spread out into the galaxy.
- The Sun must be at least a 3rd generation star as we have **nitrogen** in abundance.
- Indeed, the percentage of heavier elements is larger toward the center of the galaxy, where the first generation of stars probably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

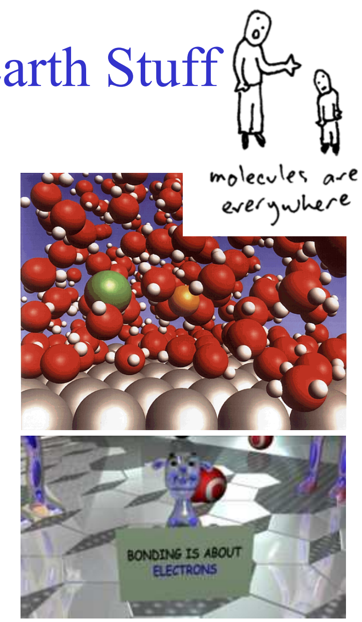
- Now, we have the elements crucial to life in the Galaxy-- **HONC**.
- There are about 92 elements found in the Universe and about 20 more elements that have been created in laboratories (but decay quickly).
- The 92 elements were almost all made in the interiors of massive stars or during a supernova explosion.



http://www.astronomyinfo.pwp.blueyonder.co.uk/starstuff.htm
http://antwrp.gsfc.nasa.gov/apod/ap991209.html

Star Stuff and Earth Stuff

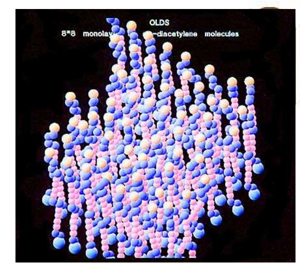
- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, most of the important aspects of life depend on molecules. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.

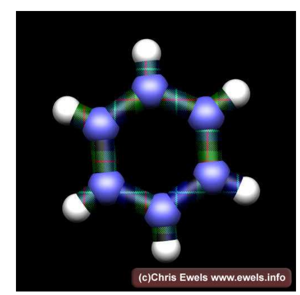


http://nanokids.rice.edu/explore.cfm
http://www.toothpastefordinner.com/archives-sum02.php
http://www.psc.edu/science/Voth/Voth.html

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.

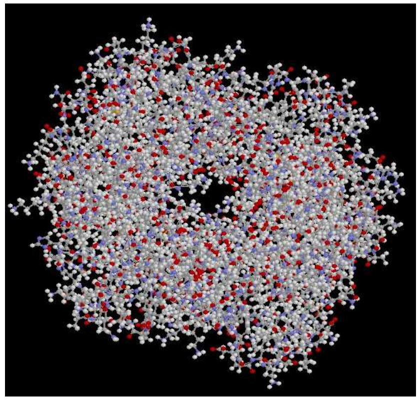




http://www.ph.qmw.ac.uk/research_bk/theory.htm

Molecules

- 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.

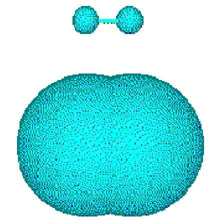


http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

http://www.steve.gb.com/science/molecules.html

Example H_2

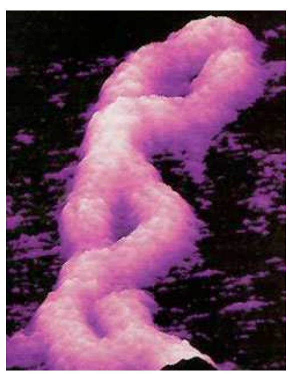
- H_2 is the simplest molecule– two hydrogen atoms.
- What does that mean?
  - There are 4 particles.
    - 2 protons of the 2 nuclei, which repel each other
    - 2 electrons of the 2 atoms, which repel each other
  - But
    - The electron of each atom will attract the other nucleus
- Although not 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

Molecular 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

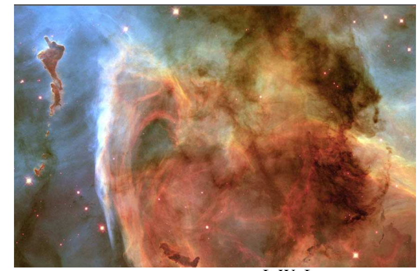
http://www.gristmagazine.com/dogood/connections.asp

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 often emit light in the millimeter regime.

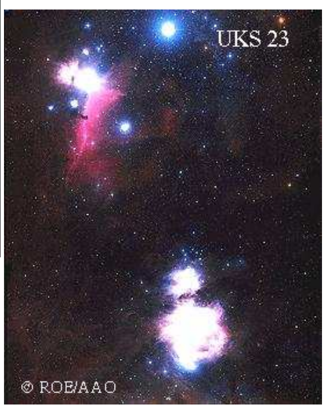
The Interstellar Medium (ISM)

- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds
- Every star and planet, and maybe the molecules that led to life, were formed in the dust and gas of clouds.
- Exists as either
  - Diffuse Interstellar Clouds
  - Molecular Clouds



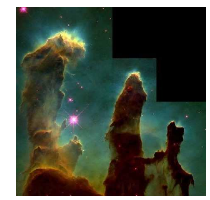
Keyhole Nebula

Interstellar Clouds



http://www.seds.org/messier/more/oricloud.html

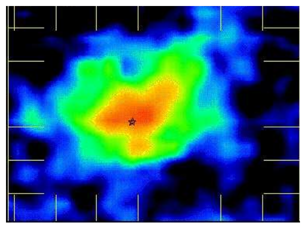
Molecular Clouds



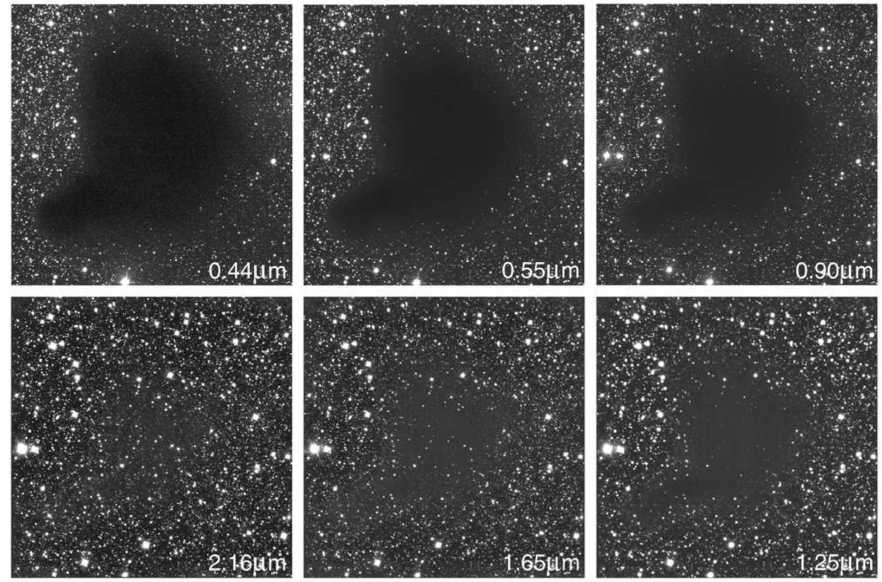
- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- H_2 is not good at emitting photons, so easier to see larger molecules emitting– especially CO (which tells the temperature of these clouds).
- Other molecules (mostly H_2CO, HCN, or CS) are used to derive estimates of density.

The Importance of being a Molecular Cloud

- Different than the clouds that formed the First Stars
- Stars form in cold, dense molecular clouds (normally starless)
  - Colder: molecules and dust easily emit in the radio and infrared, which cools the cloud.
  - Clumpy: clumps more easily, as the material is cold, forming regions of high density.
- Formation of more complex molecules
  - Density allows for more collisions, interactions, formation of molecules
  - *Maybe formed biological compounds?*



$C^{18}O$ emission from L483



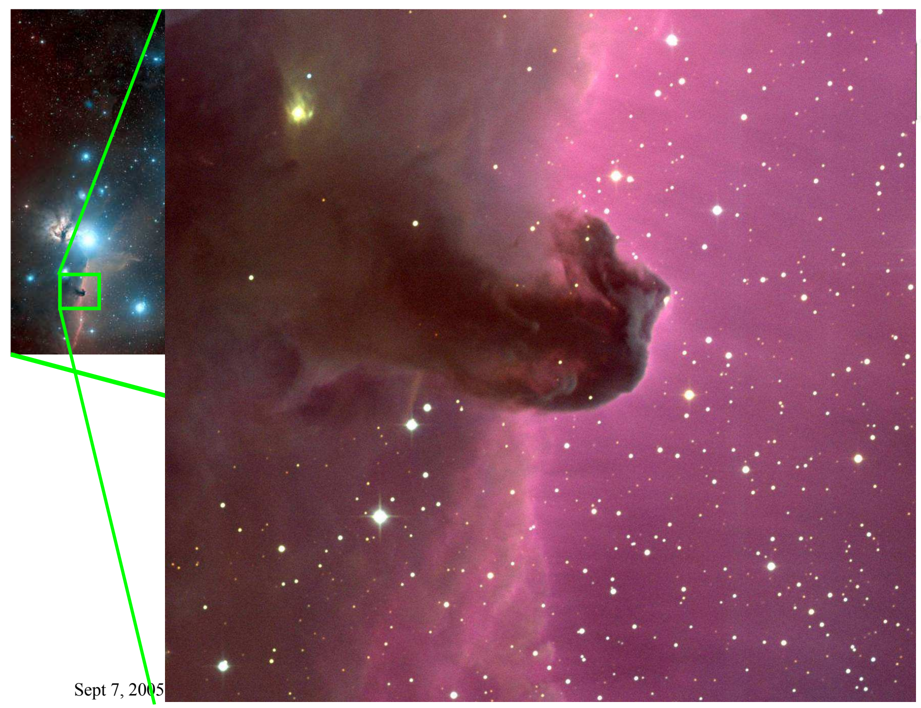
The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

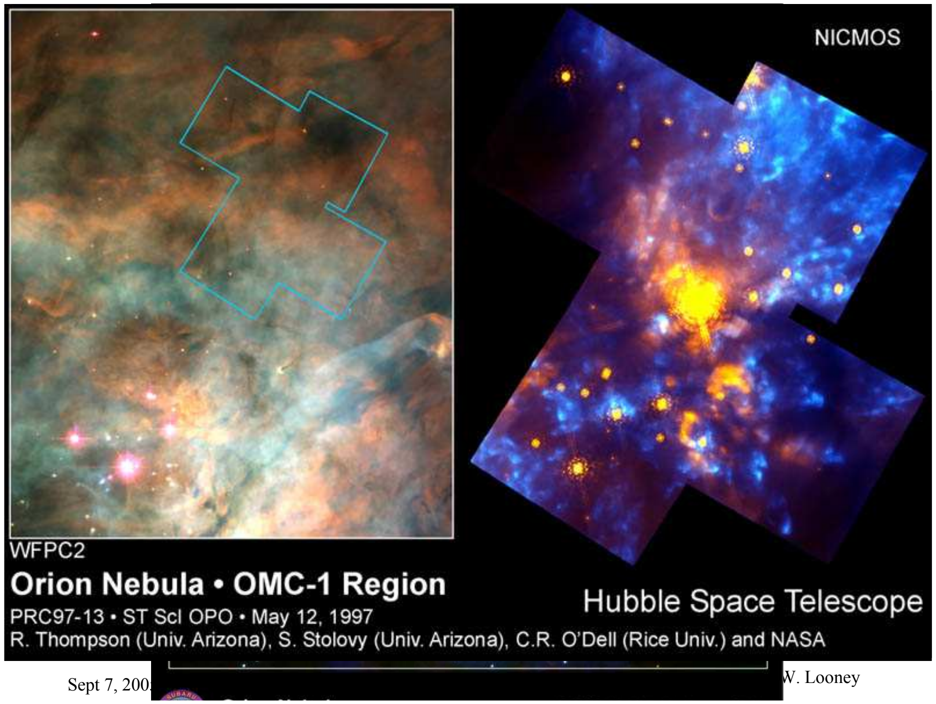
ESO PR Photo 29b/99 (2 July 1999)

Orion Nebula

(near infrared)

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

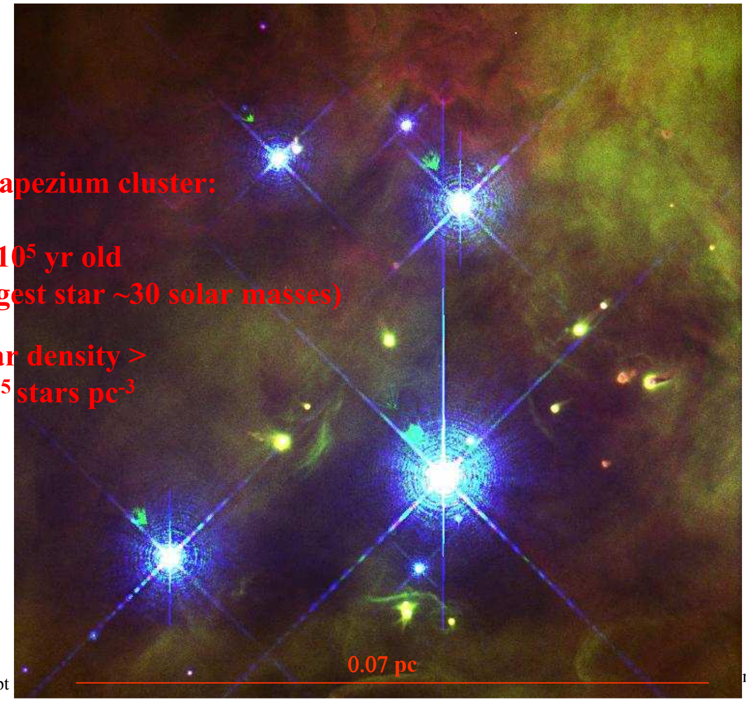




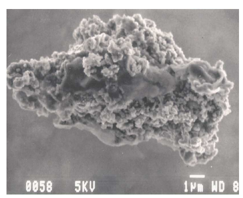
Trapezium cluster:

< 10^5 yr old
(largest star ~30 solar masses)

star density >
10^5 stars pc^{-3}



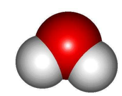
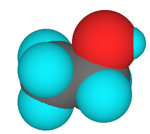
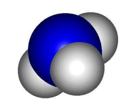
In Dust We Trust

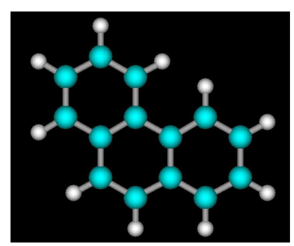


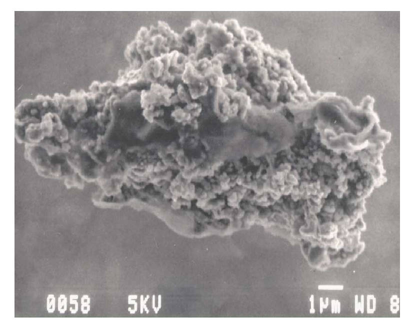
- Small (< 1 micron), solid particles in space
- Two types:
  - Primarily carbon (sort of like what we call soot)
  - Silicates, minerals of silicon and oxygen (sort of like what we call dust)
- Produced in material flowing from old stars, but mixed in space.
- When concentrated can protect molecules from ultraviolet light, which destroy molecules.
- Dust plays a role in formation of molecules.

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)

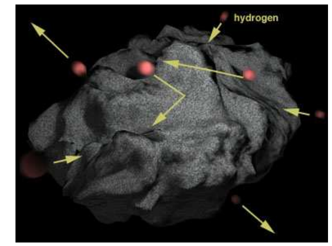

Dust particle (interplanetary)

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.

Molecule Formation

- When molecules form, they must release energy by emitting light or colliding
- Difficult to do in the gas phases, need dust grains as a catalysis.
- H on dust grain, gets hit by another H, then extra energy ejects the newly formed molecule H_2 from the dust grain.
- For more complicated molecules, they need to be ionized to get easy reaction in space.
- What ionizes the molecules? Ultraviolet light would work, but then the molecules would get destroyed.



How to Get Complex Molecules

- Best answer is that the rare cosmic rays ionizes molecules inside of a molecular cloud.
- For example:

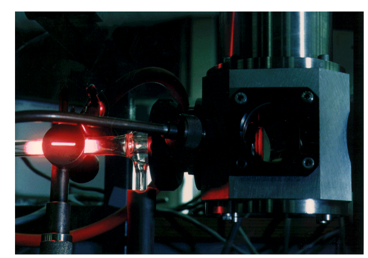
$$H_2^+ + H_2 \rightarrow H_3^+ + H$$

$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

- HCO^+ can then be involved in other reactions, building bigger and bigger molecules.
- These ion molecules can form more complex molecules.

More to the Story: HONC

- But if H_2 can stick to the dust grains, shouldn't larger molecules stick too? In fact, we see water (H_2O), ammonia (NH_3), methane (CH_4), and methanol (CH_3OH) frozen to the dust grains.
- **Hey, that's the most important bioelements (H, O, N, and C) on the dust grains.**
- Mayo Greenberg and co-workers studied these ices in the lab and by adding a little of ultraviolet light, would get what he called "Yellow Stuff" on the dust grains. This stuff is similar to products from experiments designed to study the origin of life.
- Others have taken this a step farther, postulating that life originated on these dust grains, and even today new life is raining down on the earth.



http://www.strw.leidenuniv.nl/~greenber/

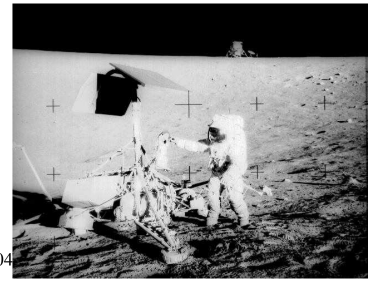
Panspermia

- Some have stated that perhaps life-important molecules formed in these clouds and spread to planets. **Infection!**
- Comets could have carried molecules to Earth's surface. Or ordinary meteors.
- Maybe epidemic outbreaks on Earth related to comet landings?
  - Incidentally, it has been observed that peaks in the influenza cycle matches the 11 year solar cycle (see William Corliss' work)
- http://www.panspermia.org/

http://www.daviddarling.info/images/lithopanspermia.jpg

Panspermia: Case in Point

- Surveyor 3: unmanned lunar probe which landed in 1967.
- 2.5 years later, a camera was retrieved by Apollo astronauts.
- The camera had 50 to 100 viable specimens of *Streptococcus mitis*, a harmless bacterium commonly found in the human nose, mouth, and throat.
- The camera has been returned under strict sterile conditions.
- Those bacteria had survived 31 months in the absence of air or water!
- Was subjected to large monthly temperature variations and hard ultraviolet radiation from the Sun.



http://nssdc.gsfc.nasa.gov/planetary/news/image/conrad_19990709_c.jpg