Astronomy 330

This class (Lecture 9):

Making N, Molecules, and Star Formation

Next Class:

Exoplanets

HW 3 is due Wednesday!

Music: *Why Does the Sun Really Shine?* – They Might Be Giants

Question

Exam 1 is schedule for Feb 25 (little over 1 week!). It will be multiple choice. How many multiple choice questions do you want on Exam 1?

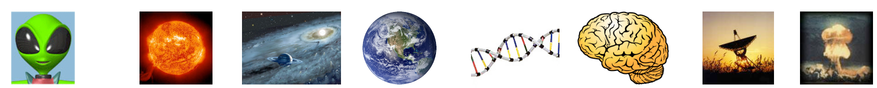
a) 25
b) 30
c) 35
d) 40
e) 45

Outline

- Making N from 2nd generation of stars
- Molecules are good for life.
- A star is born

Drake Equation

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
	9 stars/yr	? systems/star	planets/system	life/planet	intel./life	comm./intel.	yrs/comm.

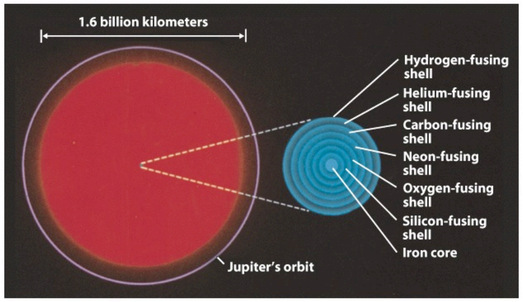
Question

The rocky planets that formed around the first stars would have been?

a) A perfect place to raise a family.
b) Devoid of the molecules necessary for life .
c) Too close to the massive star to have life.
d) Inhabited by truly alien creatures.
e) Trick question. There would not have been any rocky planets.

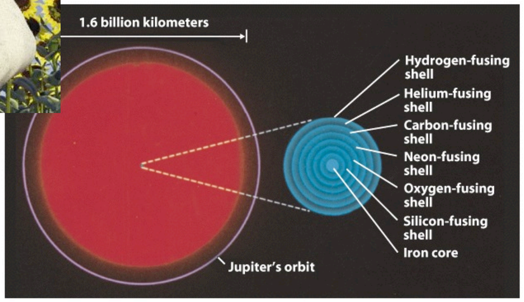
Massive Stars: Cycles of Fusion

- Helium fusion is not the end for massive stars
- Cycles of core contraction, heating, ignition



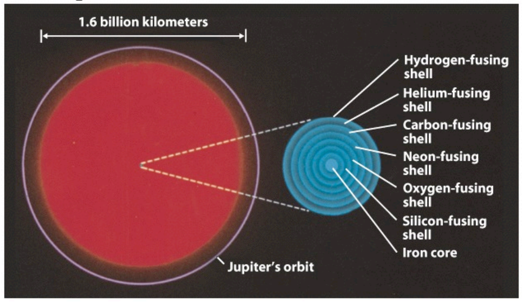
Massive Stars: Cycles of Fusion

- Onion-skin like structure develops in the core
- Has layers…. like an Ogre..



Massive Stars: Cycles of Fusion

- Helium fusion is not the end for massive stars
- Cycles of core contraction, heating, ignition
- Ash of one cycle becomes fuel for the next
  - hydrogen ⇨ helium
  - helium ⇨ carbon & oxygen
  - carbon ⇨ neon, sodium, & magnesium
  - neon ⇨ oxygen & magnesium
  - oxygen ⇨ silicon & sulfur
  - silicon ⇨ iron

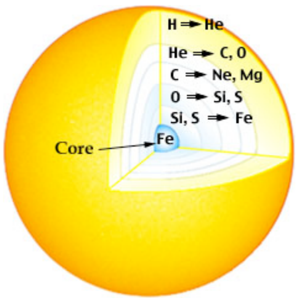


Iron – The End of the Road

- "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

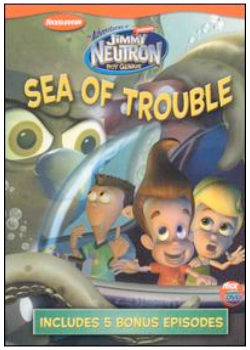
Stage	Temperature	Duration
H fusion	40 million K	7 million yr
He fusion	200 million K	500,000 yr
C fusion	600 million K	600 yr
Ne fusion	1.2 billion K	1 yr
O fusion	1.5 billion K	6 mo
Si fusion	2.7 billion K	1 day

Values for a $25M_{Sun}$ star



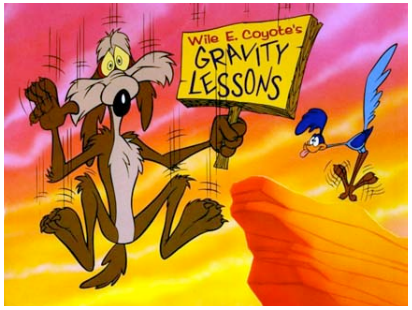
Core Collapse

- **Core collapse!**
  - From 1,000 km across to 50 km in *1/10th of a second*
  - ***Nearly 10% speed of light!***
- The core is transformed into a sea of neutrons
  - Electrons are squeezed into protons, neutrinos released
  - High energy gamma rays produced
  - The core has nuclear density!
  - It Earth has same density, it would be 1000 feet in diameter



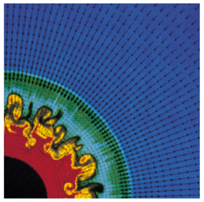
Core Collapse

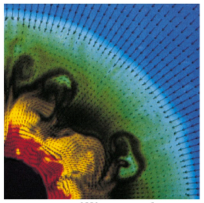
- Core suddenly collapsed
- Envelope has nothing left to stand on
- Envelope falls at significant fraction of the speed of light, slamming into compressed core



Supernova!

- Hitting the compressed core is like hitting a brick wall and the envelope gas reverses direction– blow-back.
  - But, by itself not enough to destroy star.
  - Material is so dense, that it is slightly opaque to the neutrinos produced
  - And 10^{58} neutrinos!
  - Neutrinos give the shock a "kick"
  - Rips the outer layers of the star apart
- Star explodes in a supernova


10 milliseconds


20 milliseconds

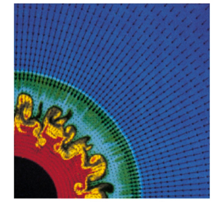
http://www.spacetelescope.org/images/screen/heic0609c.jpg

Supernova!

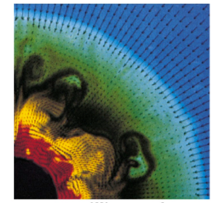
- The lifetime battle against gravity is lost.
- The core collapses under its own weight.
- Much of the mass of the outer region of the star, bounces back into space.

Supernova!

- The energy is enormous! The visible light is around only 1% of the energy output!
  - 99% of the energy in the form of neutrinos
- > 90% of the mass of star is ejected into space!
  - Fast, hot,



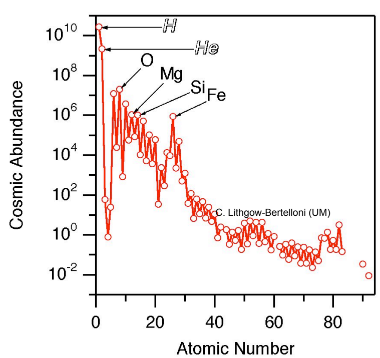
10 milliseconds



20 milliseconds

Making Heavy Elements

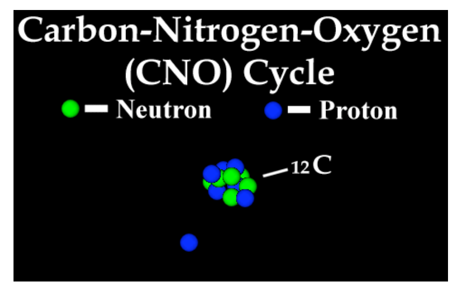
- The star goes **supernova** and explodes. Some of C, O, P, S, Si, and Fe get carried away. At this point, even heavier elements can be made.
- During the explosion, energy-consuming fusion reactions are possible
- These by-products are *blasted* into space (>90% of star)
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**
- **We are Star stuff.**



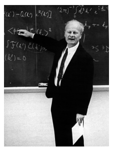
Delenn, B5

CNO-ing

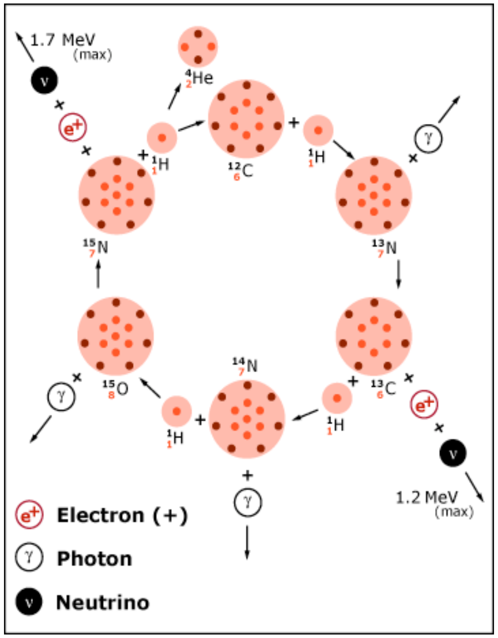
- Now the Universe has some C and O laying around; it can use it.
- In the next generation of stars, the CNO cycle can be used in the fusion process.
- It is more efficient in stars slightly more massive than the Sun.
- Remember the Sun mostly uses proton-proton fusion.



The CNO Cycle

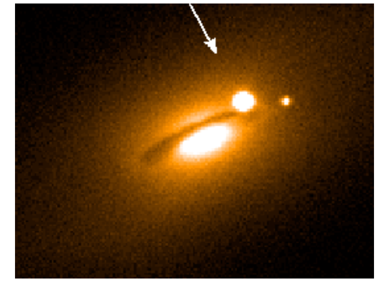


Hans Bethe



The Second Generation

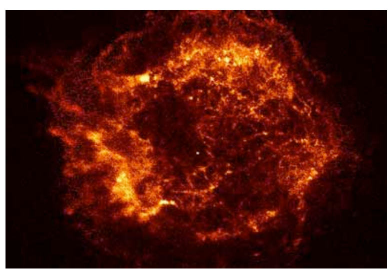
- The first stars blew up, their new elements blown into the proto-galaxy.
- Now, the second stars form in the ashes of the first.
- With C and N, the 2nd generation can form helium through the CNO cycle, in which most of the Universe's nitrogen is created.
- The 2nd generation also eventually explodes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

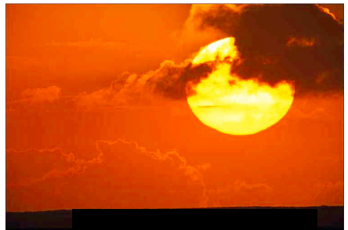
Question

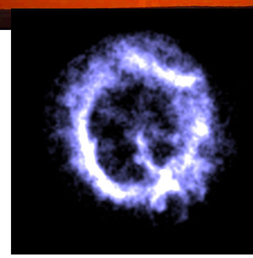
HONC is important for life. In which order did these elements first appear in the Universe?

a) H, O, N, C
b) All at once
c) H, C, O, N
d) N, O, H, C
e) C, O, N, H

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.

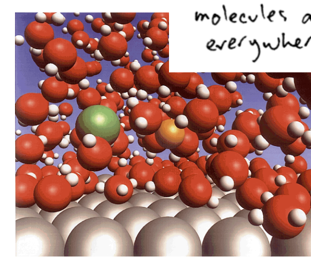


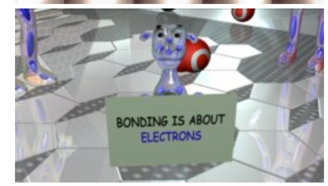


http://www.astronomyinfo.pwp.blueyonder.co.uk/starstuff.htm
http://antwrp.gsfc.nasa.gov/apod/ap991209.html

Star Stuff and Earth Stuff

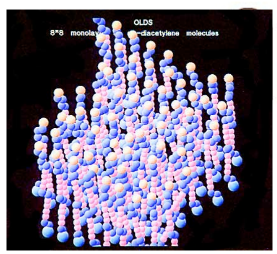
- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, all of the important aspects of life depend on molecules. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.



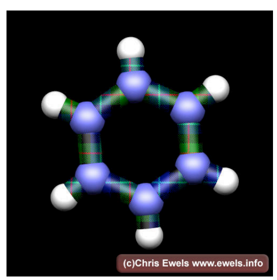


http://nanokids.rice.edu/explore.cfm
http://www.toothpastefordinner.com/archives-sum02.php
http://www.psc.edu/science/Voth/Voth.html

Molecules



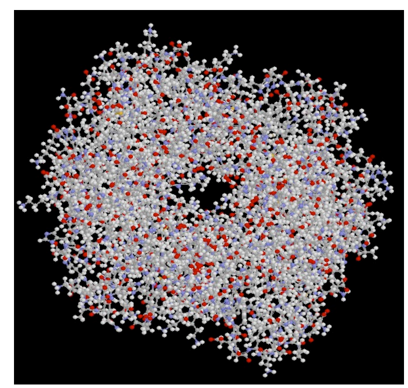
- Combination of 2 or more atoms such that they are bound together without their nuclei merging.
- Just like an atom is the smallest piece of an element, a molecule is the smallest piece of an compound.
- When dividing water, smallest division, before separation of hydrogen and oxygen.



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.

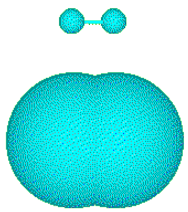


http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

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

Example H_2

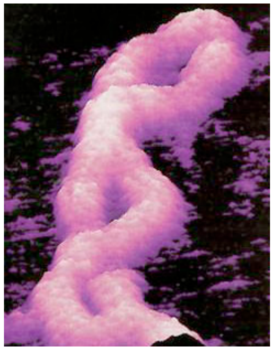
- H_2 is the simplest molecule– two hydrogen atoms.
- What does that mean?
  - There are 4 particles.
    - 2 protons of the 2 nuclei, which repel each other
    - 2 electrons of the 2 atoms, which repel each other
  - But
    - The electron of each atom will attract the other nucleus
- Although not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

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/

Question

Life is based on molecules instead of atoms because

a) molecules are bigger than atoms.
b) there are many more molecular options than elements.
c) molecules survive better at high temperatures.
d) molecules survive better at low temperatures.
e) one word– ducks.

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

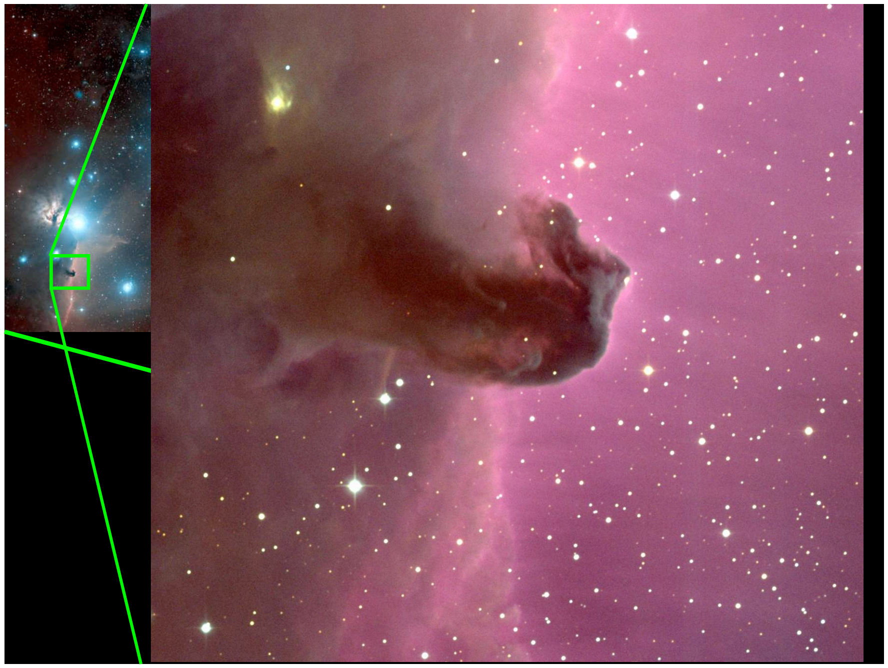
Talkin' About a Revolution

- Molecules first showed up in the Universe 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)

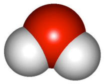
- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds
- Every star and planet, and maybe the **molecules** that led to life, were formed in the dust and gas of clouds.
- Exists as either
  - Diffuse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

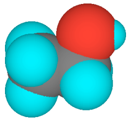
Keyhole Nebula

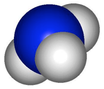


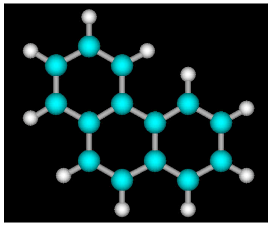
Other Things Besides Hydrogen in Molecular Clouds

- 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

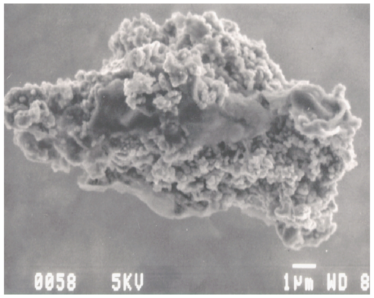






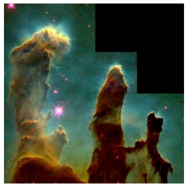


Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)

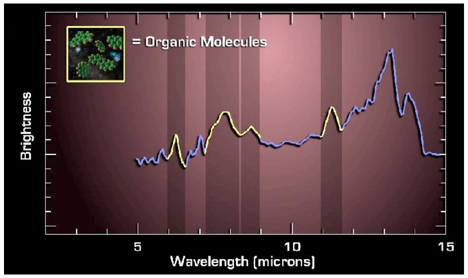
Molecular Clouds

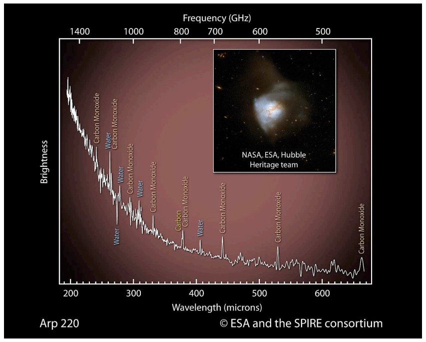


- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- H_2 is not good at emitting photons, so easier to see larger molecules emitting– especially CO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

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.





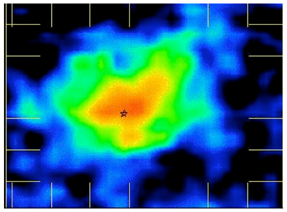
Question

Molecular clouds, where stars form, are mostly made up out of

a) dust
b) a rich assortment of molecules that range from alcohol to urea
c) Hydrogen
d) water
e) H_2

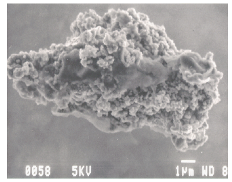
The Importance of being a Molecular Cloud

- 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

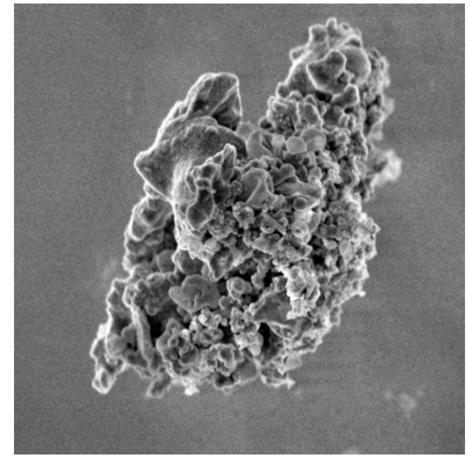
In Dust We Trust



- 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.

Molecule Formation

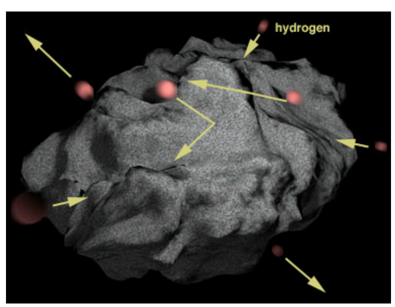
- When molecules form, they must release energy by emitting light or colliding
- Difficult to do in the gas phases, need dust grains as a catalysis.



http://spiff.rit.edu/classes/phys230/lectures/ism_dust/ism_dust.html

Molecule Formation

- 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.



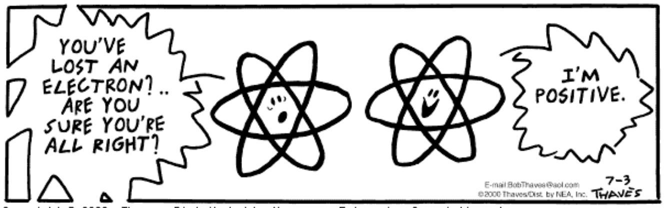
How to Get Complex Molecules

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

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

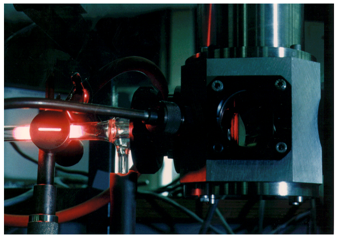
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

- 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 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/

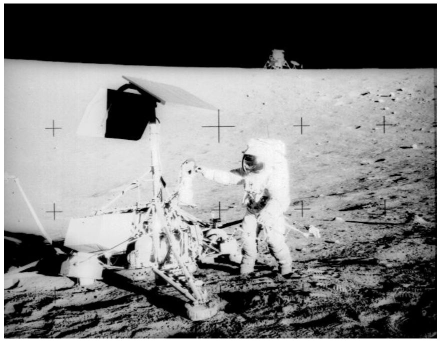
Panspermia

- 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 kinda 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

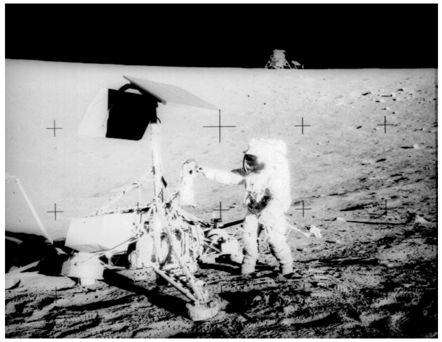
- Surveyor 3: unmanned lunar probe which landed in 1967.
- 2.5 years later, a camera was retrieved by Apollo astronauts.
- The camera had 50 to 100 viable specimens of *Streptococcus mitis*, a harmless bacterium commonly found in the human nose, mouth, and throat.



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

Panspermia: Case in Point

- The camera was returned under strict sterile conditions.
- The bacteria had survived 31 months in the absence of air or water!
- In SPACE!
- 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

3 Lessons of Interstellar Molecules

1. Molecules with as many as 13 atoms have evolved in places other than Earth.
   - In our Galaxy and beyond.
   - Hard thing is getting the lab data for searching for more complicated molecules.
   - Evidence for polycyclic aromatic hydrocarbons (PAHs) links of carbon atoms with hydrogen on the outside is found in space.
   - Also found in the exhaust of cars and may play a role in early life.
2. Dominance of carbon in interstellar chemistry. So perhaps carbon based life forms is not just Earth chauvinism.
3. Study of these in space illustrates the problems of molecules getting more and more complex and not being destroyed by UV light. That's why it wasn't expected.

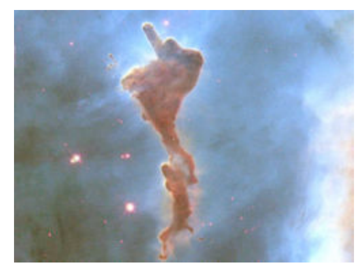
Question

The molecules that life uses on Earth are complex. In space

a) no one can hear you scream.
b) complex molecules can not be created. The environment is too harsh.
c) complex molecules, up to 13 atoms, have been detected.
d) the only kind of molecules detected are missing carbon.
e) all molecules are detected.

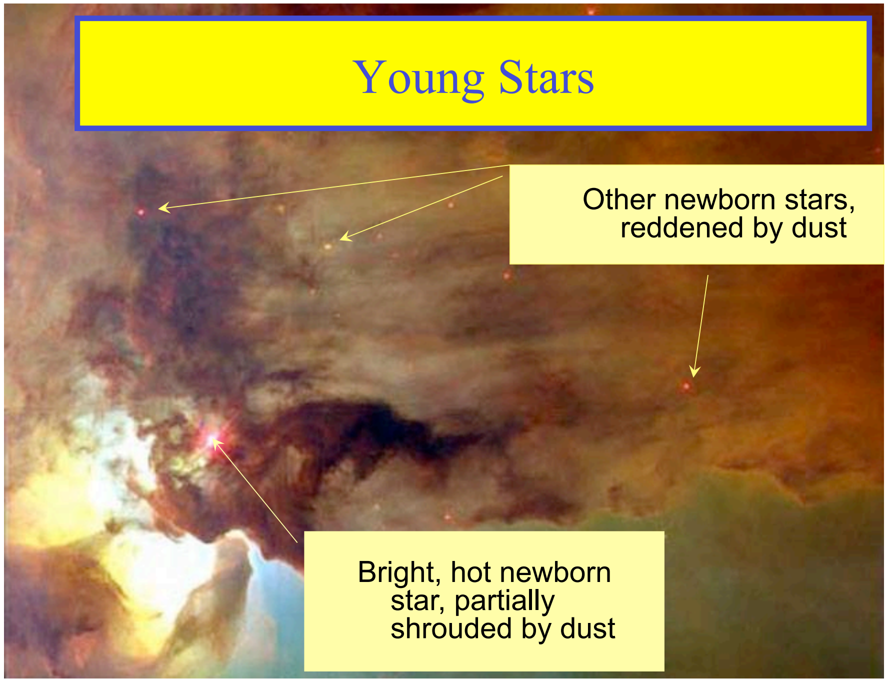
How Do We Know that Stars Form in Molecular Clouds ?

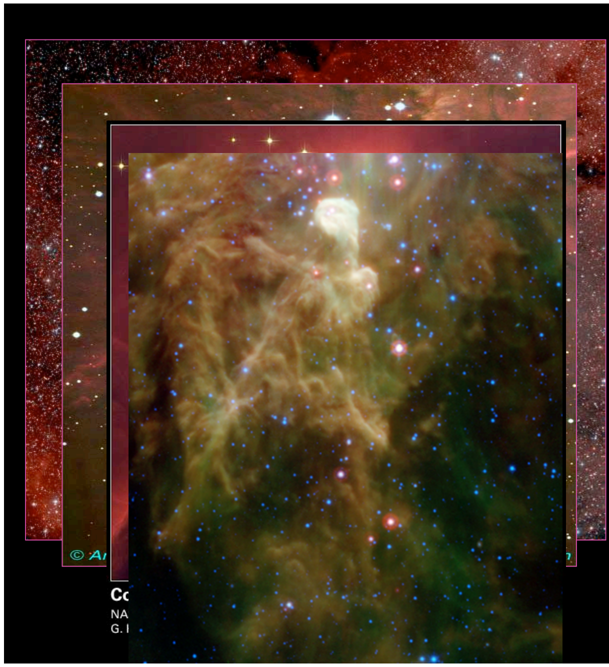
- Young stars are seen near molecular clouds.
- In infrared light, we can see into the deeper regions of clouds, and see clusters of young stars with circumstellar material (dust and gas) surrounding them.
- Stars are continuously being formed in our galaxy.



http://antwrp.gsfc.nasa.gov/apod/ap030630.html

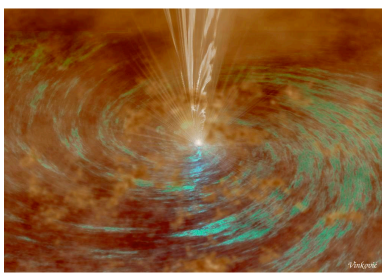
Young Stars





The Cone Nebula

Star Formation



Stars are born in cold, dense interstellar clouds
- Cold gas
- Dust grains

Star formation is probably triggered by
- Cloud turbulence
- Collision with another cloud
- Nearby supernova explosion
- Nearby hot star wind
- Disturbance from the Galaxy

Question

Stars are born

a) in molecular clouds.
b) in supernovae.
c) in black holes.
d) on Broadway.
e) in empty space.