Astronomy 330

<u>This class (Lecture 7):</u>

Making C,O, and N

<u>Next Class:</u>

Planet Formation
Seth Orr

HW 2 due tonight.

Music: *Sonne*– Rammstein

Outline

- The Death of High Mass Stars
- C and O for the first time (1st gen of stars)
- N for the first time (2nd gen of stars)

Drake Equation

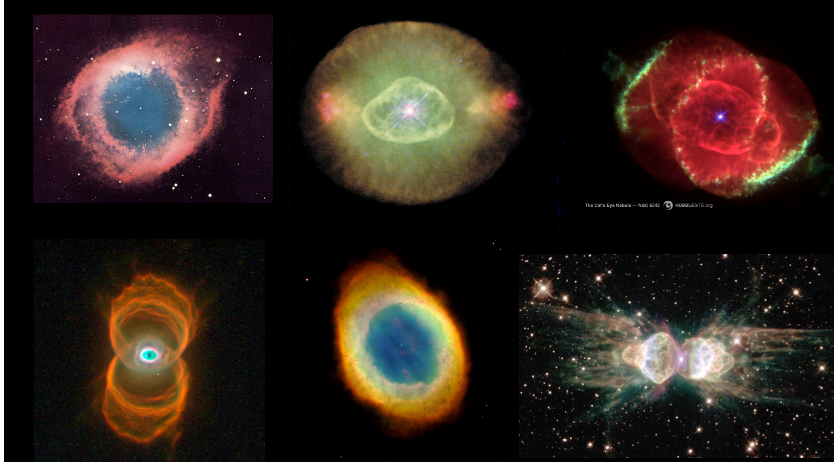
The class's first estimate is


Frank Drake

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

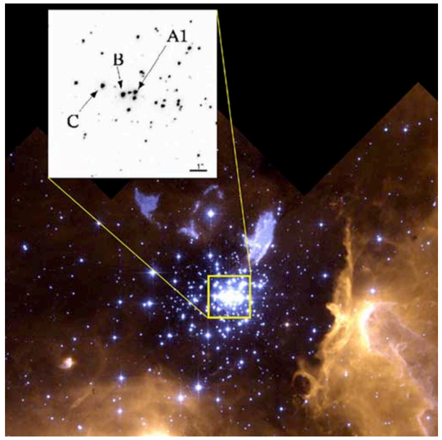
N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations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

Planetary Nebulae



For High Mass Stars

- For stars with an <u>initial mass</u> of more than 10 solar masses
- The final state will no longer be a white dwarf.
- Let's follow more carefully the life path of a high mass star– it's short sweet and ends with a bang!

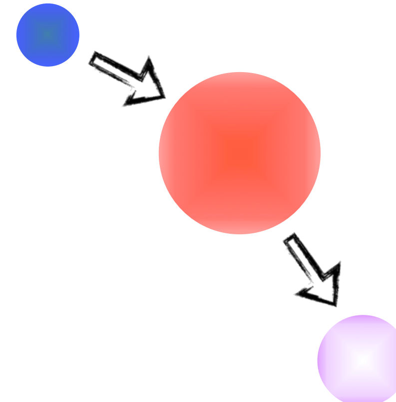


A1: A 150 solar mass star!

The fate of a massive star (First Stars were massive)

– Massive stars have too much mass to die as white dwarfs.

– However, their evolution begins much like that of their lower-mass cousins.

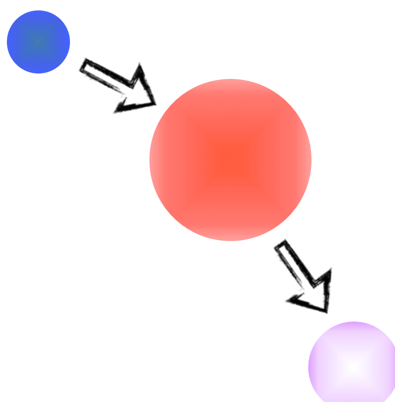


Top - Blue main sequence star.
Middle - Red supergiant,
Bottom - Blue supergiant

The fate of a massive star

– They consume the hydrogen in their cores, ignite hydrogen shells, and become giants or, for the most massive stars, supergiants.

– Their cores contract and fuse helium first in the core and then in a shell, producing a carbon–oxygen core.

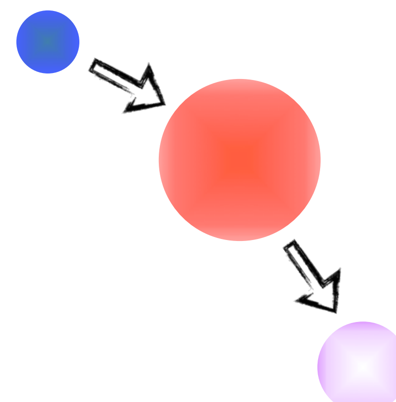


Top - Blue main sequence star.
Middle - Red supergiant,
Bottom - Blue supergiant

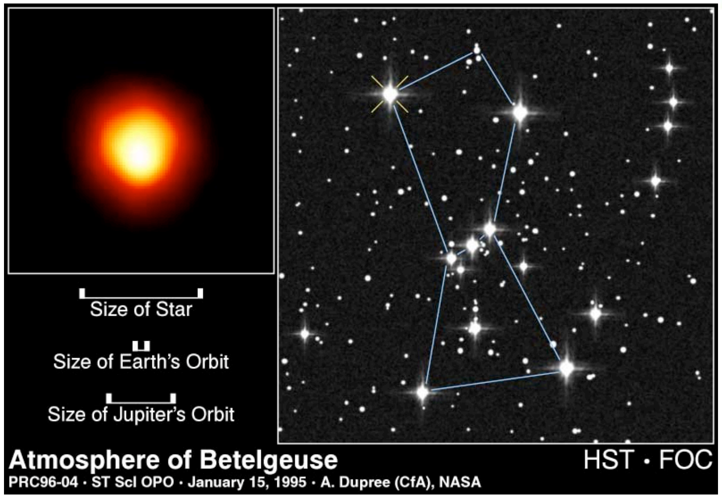
The fate of a massive star

Initial stages are similar to those of Sun-like star:

- Main Sequence: H fuses to He in core
- Red Supergiant: H fuses to He in shell around contracting He core
- Blue Supergiant: He fuses to C in core



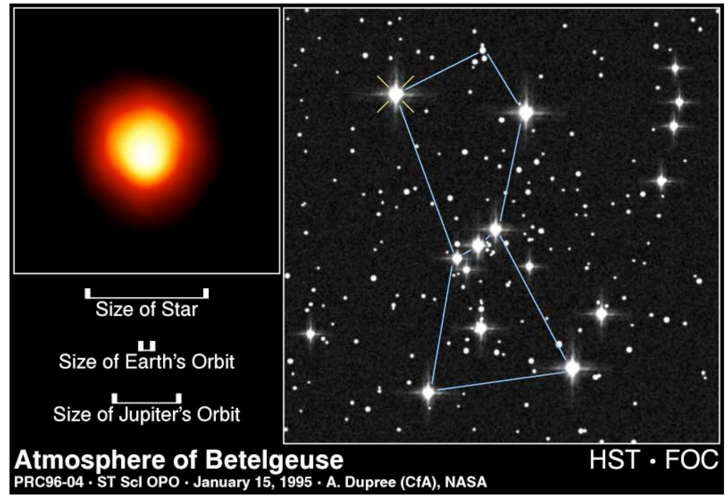
Truly Supergiant Stars...



Andrea Dupree (Harvard-Smithsonian CfA), Ronald Gilliland (STScI), NASA and ESA

Big Betelgeuse! Red Supergiant.

Truly Supergiant Stars...

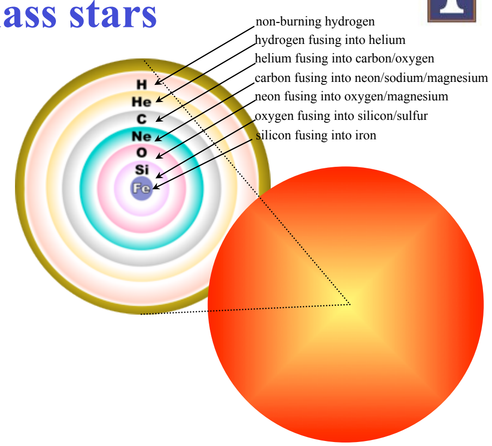


Andrea Dupree (Harvard-Smithsonian CfA), Ronald Gilliland (STScI), NASA and ESA

http://www.youtube.com/watch?v=HEheh1BH34Q

Helium fusion is not the end for high mass stars

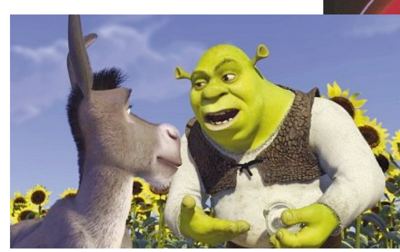
- Massive stars can fuse heavier elements--since they are hotter
- Cycles of core fusion, core contraction
  - Shell fusion occurs in layers around the core
  - Ash of one fusion becomes fuel for the next

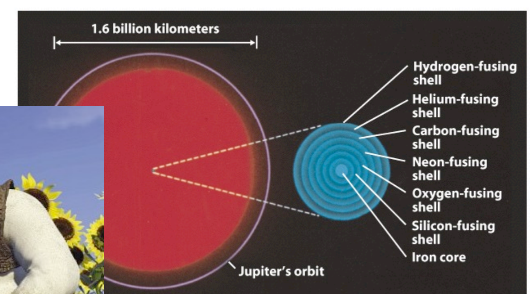


The onion-like layers inside a supergiant star in the final stages of its life

Massive Stars: Cycles of Fusion

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





http://servantsthoughts.blogspot.com/2007/08/onion-theory.html

Each stage of core fusion is shorter than the last...

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

– The fusion of the nuclear fuels goes faster and faster evolving rapidly.

– The amount of energy released per fusion reaction decreases as the mass of the types of atoms involved increases.

Each stage of core fusion is shorter than the last...

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

– To support its weight, a star must fuse oxygen much faster than it fused hydrogen.

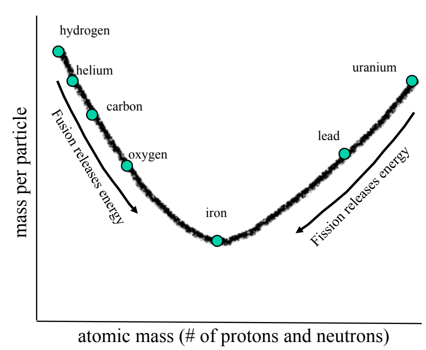
– Hydrogen fusion can last 7 million years in a 25-solar-mass star.

– The same star will fuse its oxygen in 6 months and its silicon in just one day

A 25 M_{Sun} star will fuse over an entire solar mass of silicon into iron in about 1 day!

Iron - Dead End

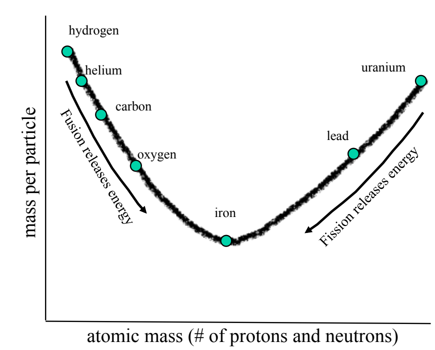
- Final stage of core fusion: Silicon fusion produces iron
- The iron core is a dead end in the evolution of a massive star
- Nuclear reactions involving iron do not release energy
- They consume it!



Neither fusion nor fission releases energy from iron

Iron - Dead End

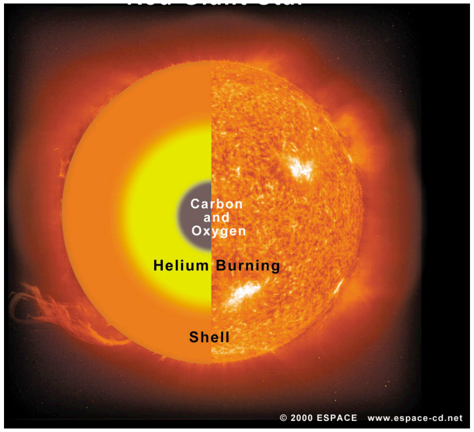
- Once the gas in the core of the star has been converted to iron, there are no further nuclear reactions that can release energy.
- As a star develops an iron core, energy production declines, and the core contracts.
- Iron builds up in core until degeneracy pressure can no longer resist gravity.



Neither fusion nor fission releases energy from iron

Back to 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.



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.

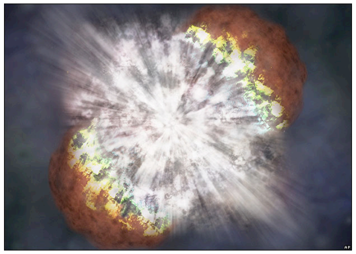
Question

What causes a high-mass star to leave the main sequence?

a) Just gets tired of the main-stream media and lifestyle.
b) Runs out of hydrogen in the core.
c) Runs out of helium in the core.
d) A shell around the core begins to burn helium.
e) A shell around the core begins to burn hydrogen.

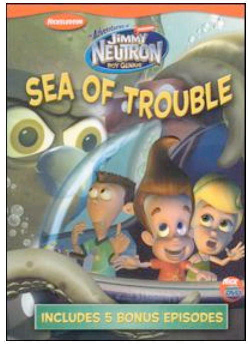
Core Collapse

- Completely out of gas!
- Hydrostatic equilibrium is gone.
- Eventually, gravity wins…



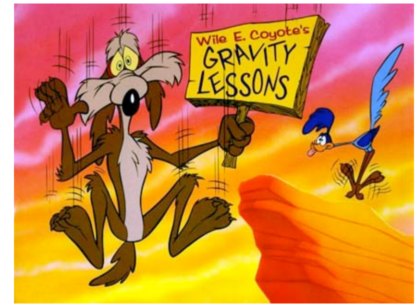
Core Collapse

- 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



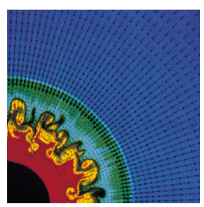
Core Collapse

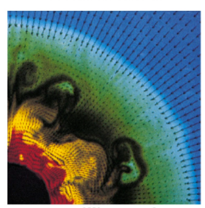
- Core suddenly collapsed
- Envelope has nothing left to stand on
- Envelope falls at significant fraction of the speed of light, slamming into compressed core



Supernova!

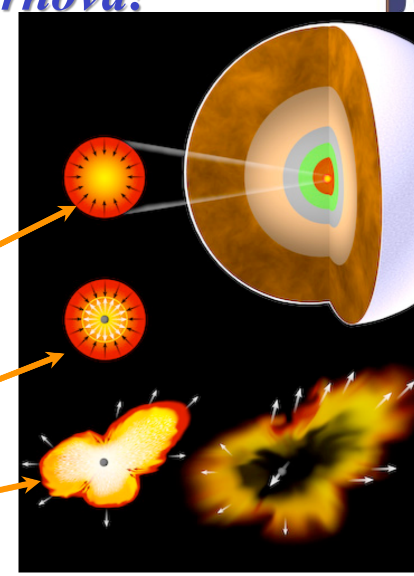
- Hitting the compressed core is like hitting a brick wall and the envelope gas reverses direction– blow-back.
  - But, by itself not enough to destroy star.
  - Material is so dense, that it is slightly opaque to the neutrinos produced
  - And 10^{58} neutrinos!
  - Neutrinos give the shock a "kick"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


10 milliseconds


20 milliseconds

Supernova!

- Nuclear reactions cease at the center of the star's core
  - Gravity > Pressure
- The core collapses in less than 1/10th of a second
- Triggers an intensely energetic rebound
- Shatters the star in a supernova



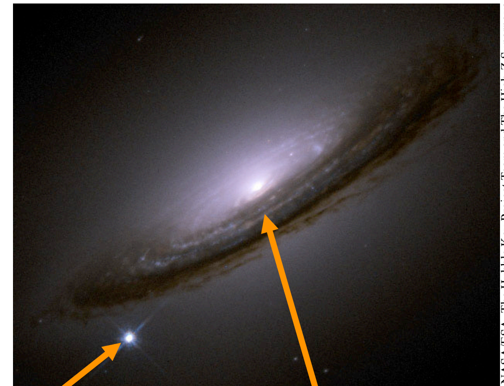
http://www.spacetelescope.org/images/screen/heic0609c.jpg

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.

Luminosity of 1 BILLION SUNS!

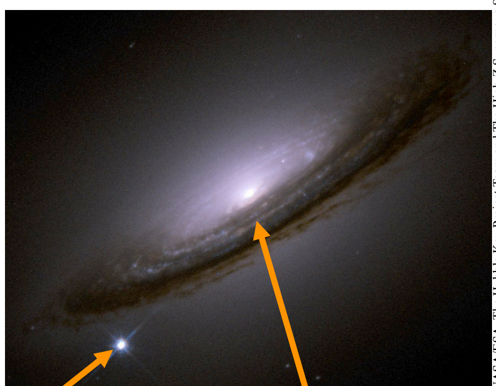
- Supernovae are luminous
- Luminosity increases 10,000 times!
- Rivals that of a moderate-sized galaxy!
- Freaky-bright!



NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

Luminosity of 1 BILLION SUNS!

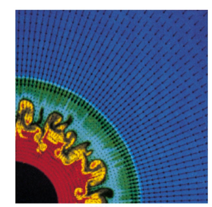
- During the supernova, many elements are forged
- Lots of spare energy so even reactions that require energy can occur



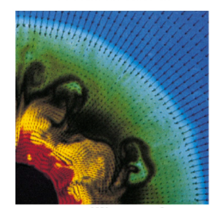
NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

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,

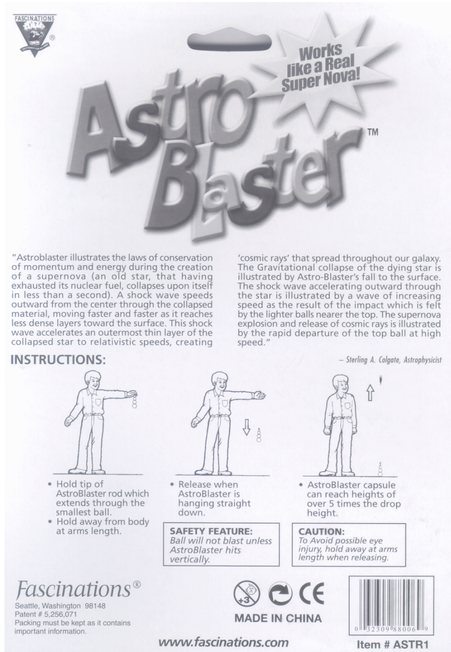


10 milliseconds



20 milliseconds

AstroBlaster!



Question

In the astroblaster demo, what did the little red ball represent?

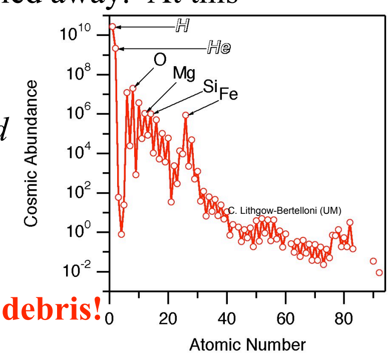
a) The inner core of the massive star
b) The envelope of the massive star
c) A low-mass stellar companion to the high mass star.
d) Iron.

Game Over!

http://www.youtube.com/watch?v=8MHb6_35XJM

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 energy consuming fusion reactions
- 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.**



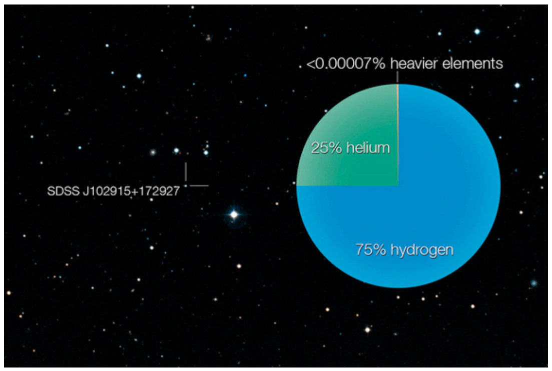
http://www.youtube.com/watch?v=ptwEV0xhTzI&feature=related

2:00 - 3:06

Delenn, B5

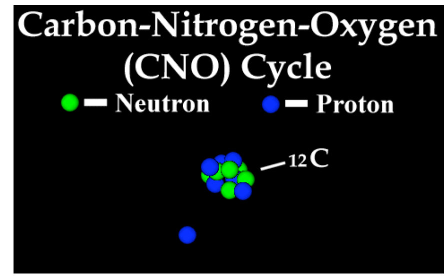
Back to the Second Stars

- Made from the leftovers of the first generation of stars.
- Enriched with new elements (still low numbers though)
- But, note that there is no significant source of nitrogen yet.

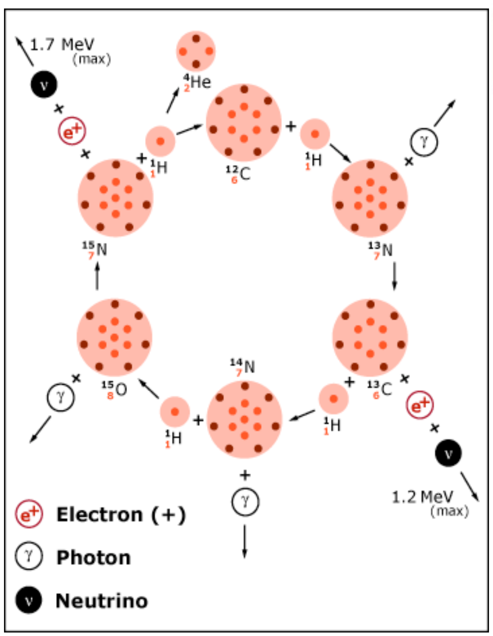


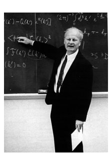
CNO-ing/2nd Gen

- 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 H-He 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

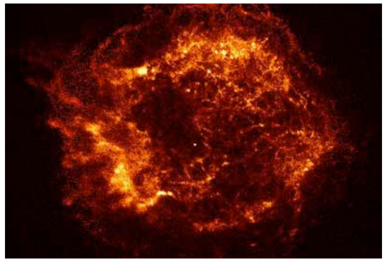
The Second Generation

- The first stars blew up their new elements 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.



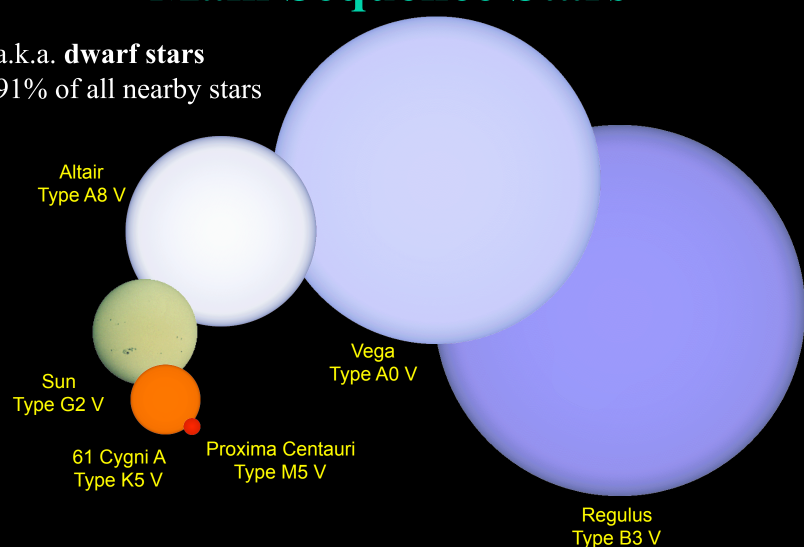
The Chandra x-ray observatory has shown that the CasA supernova has flung calcium, iron, and silicon into space.

Stars Today

- So stars today have many more elements than the first generations of stars did.
- What do today's stars look like?

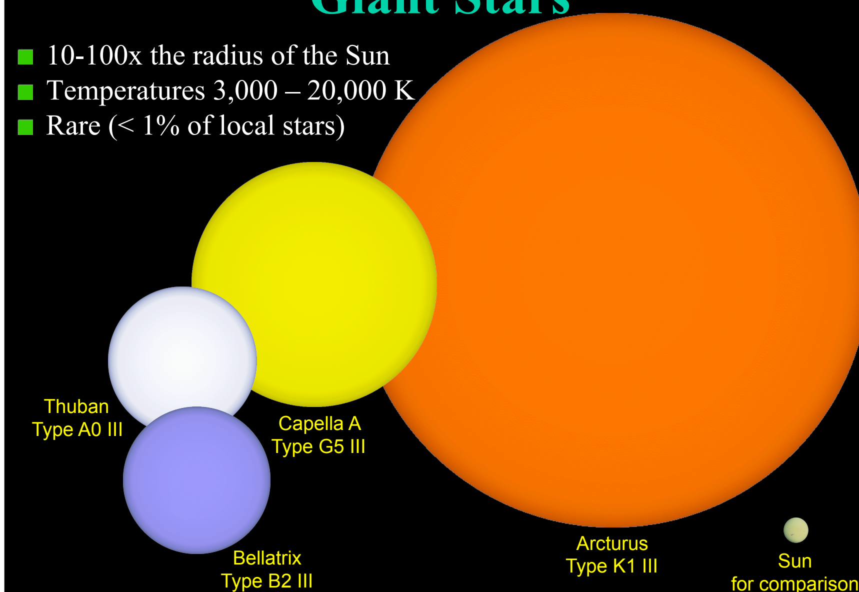
Main Sequence Stars

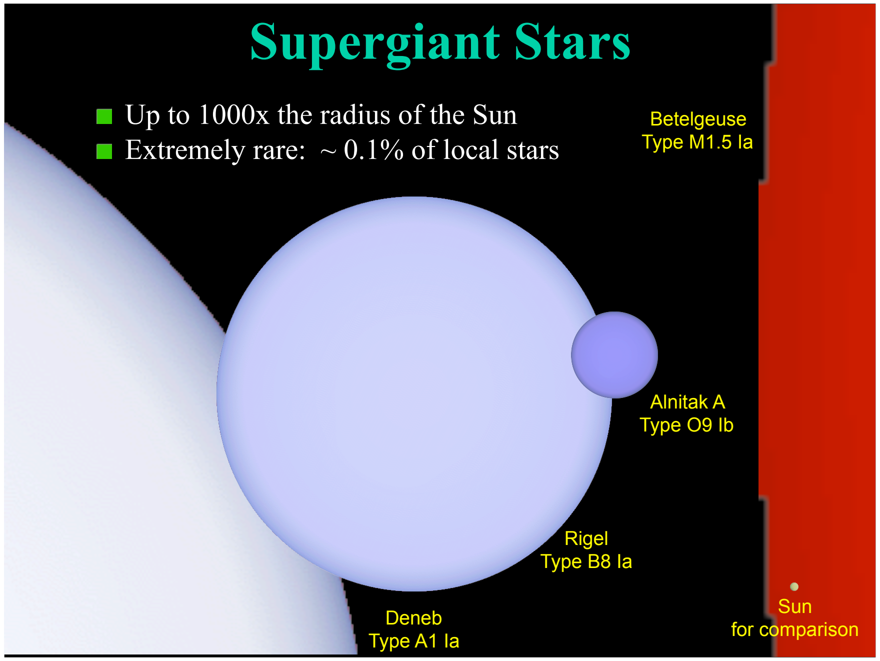
- a.k.a. **dwarf stars**
- 91% of all nearby stars



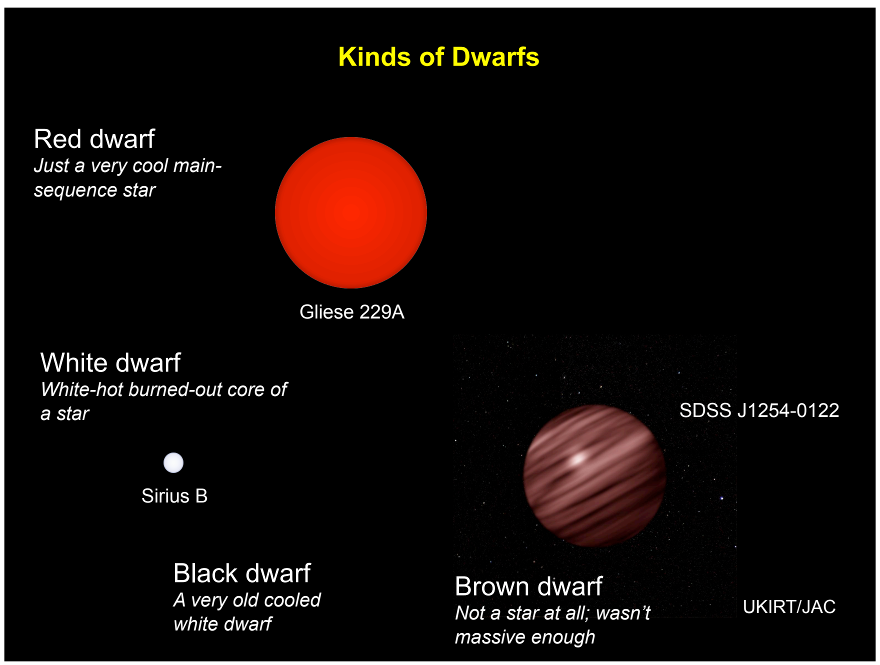
Giant Stars

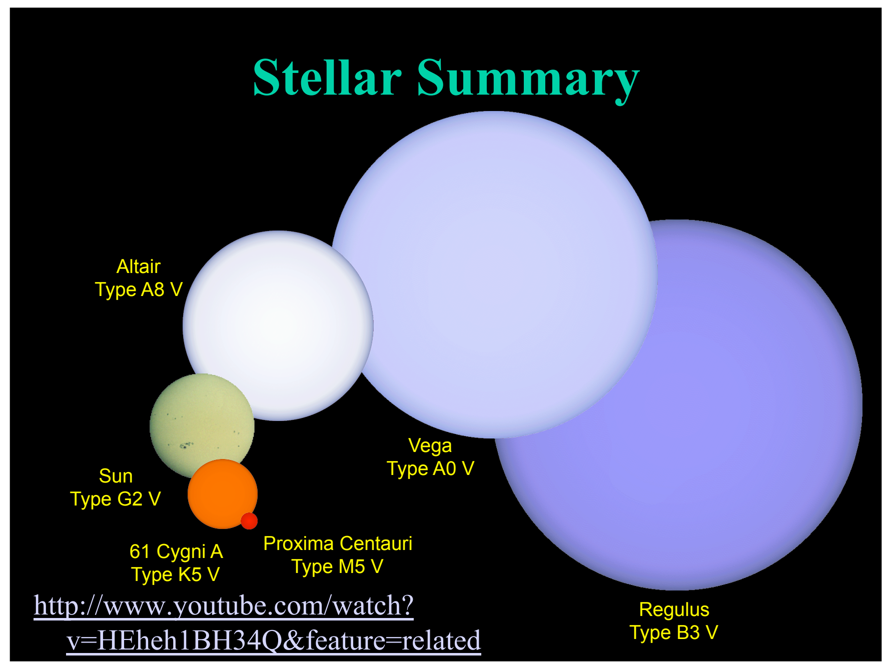
- 10-100x the radius of the Sun
- Temperatures 3,000 – 20,000 K
- Rare (< 1% of local stars)




Supergiant Stars
Up to 1000x the radius of the Sun
Extremely rare: ~ 0.1% of local stars
Betelgeuse
Type M1.5 Ia
Alnitak A
Type O9 Ib
Rigel
Type B8 Ia
Deneb
Type A1 Ia
Sun
for comparison


White Dwarf Stars
About the size of the Earth
Very hot: 5,000 – 20,000 K
About 8% of local stars
Sunspot
Sirius B
Earth for
comparison
Sun for
comparison


Kinds of Dwarfs
Red dwarf
Just a very cool main-
sequence star
Gliese 229A
White dwarf
White-hot burned-out core of
a star
Sirius B
SDSS J1254-0122
Black dwarf
A very old cooled
white dwarf
Brown dwarf
Not a star at all; wasn't
massive enough
UKIRT/JAC


Stellar Summary
Altair
Type A8 V
Vega
Type A0 V
Sun
Type G2 V
61 Cygni A
Type K5 V
Proxima Centauri
Type M5 V
http://www.youtube.com/watch?
v=HEheh1BH34Q&feature=related
Regulus
Type B3 V

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

Drake Equation

Frank Drake

The class's first estimate is

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

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

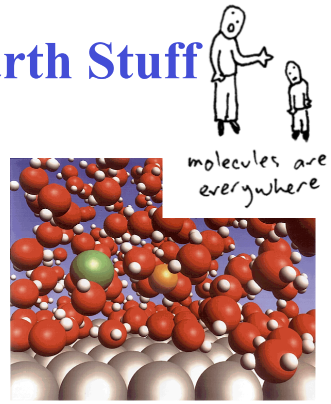
Star Stuff

- 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

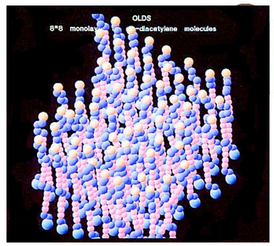
Star Stuff and Earth Stuff

- 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.

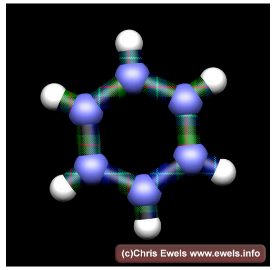


http://nanokids.rice.edu/explore.cfm
http://www.toothpastefordinner.com/archives-sum02.php
http://www.psc.edu/science/Voth/Voth.html

Molecules



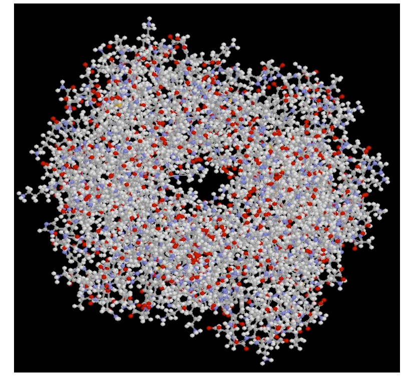
- Combination of 2 or more atoms such that they are bound together without their nuclei merging.
- Just like an atom is the smallest piece of an element, a molecule is the smallest piece of an compound.
- When dividing water, smallest division, before separation of hydrogen and oxygen.



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.

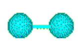


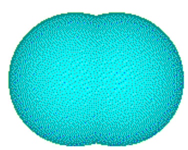
http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

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.
- This electromagnetic force balance works for hydrogen, but there is no He_2.

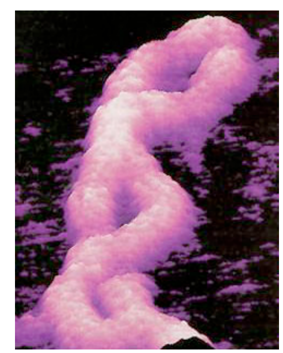




http://www.historyoftheuniverse.com/h2.html

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.

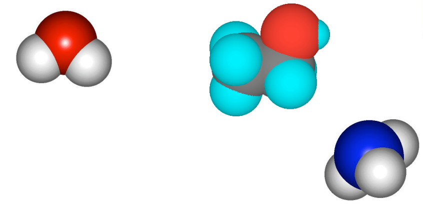
The Interstellar Medium (ISM)

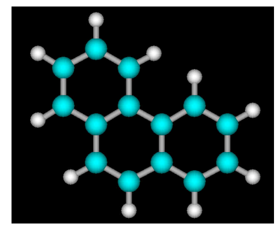
- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds
- Every star and planet, and maybe the **molecules** that led to life, were formed in the dust and gas of clouds.
- Exists as either
  - Diffuse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

Keyhole Nebula

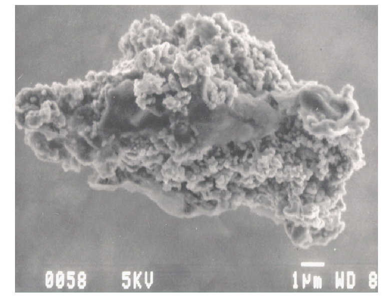
Other Things Besides Hydrogen in Molecular Clouds

- 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



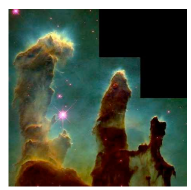


Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)

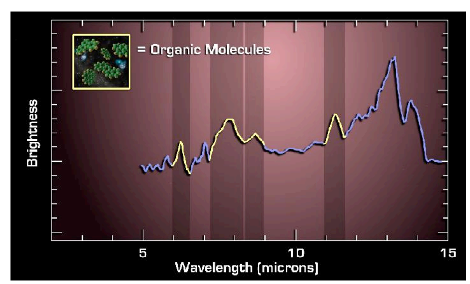
Molecular Clouds

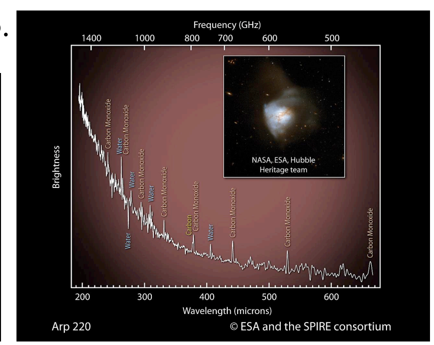


- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- H_2 is not good at emitting photons, so easier to see larger molecules emitting– especially CO (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.





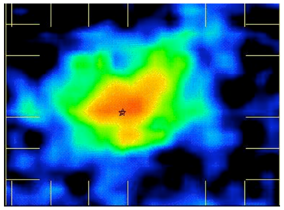
Question

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

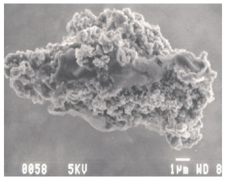
The Importance of being a Molecular Cloud

- 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

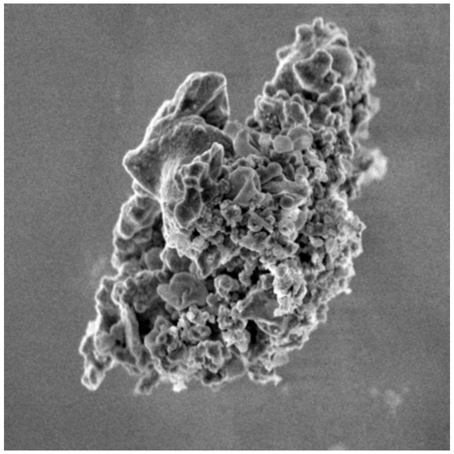
In Dust We Trust



- 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

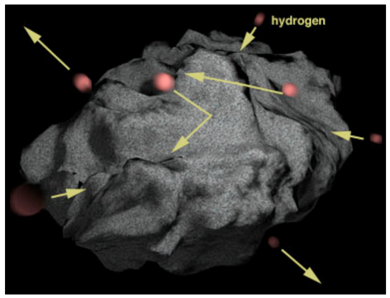
- When molecules form, they must release energy by emitting light or colliding
- Difficult to do in the gas phases, need dust grains as a catalysis.



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.

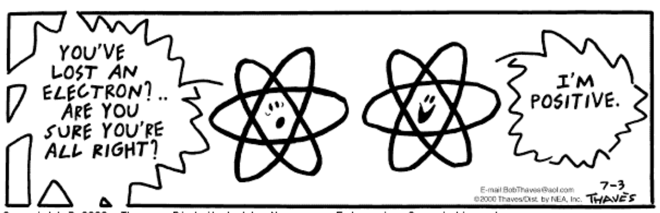


How to Get Complex Molecules

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

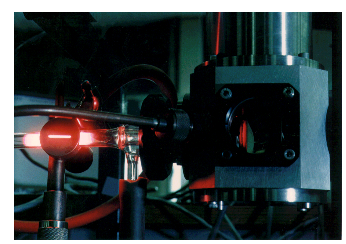
$$H_2^+ + H_2 \rightarrow H_3^+ + H$$
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

- 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/

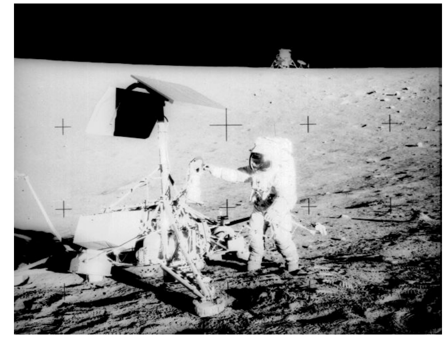
Panspermia

- 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)
  - Still not strong evidence.
  - Earth pathogens had to evolve with hosts to survive.
- http://www.panspermia.org/

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

Panspermia: Case in Point

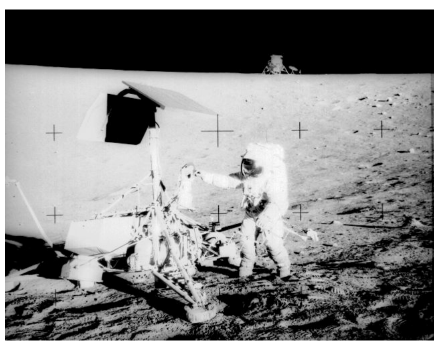
- Surveyor 3: unmanned lunar probe which landed in 1967.
- 2.5 years later, a camera was retrieved by Apollo astronauts.
- The camera had 50 to 100 viable specimens of *Streptococcus mitis*, a harmless bacterium commonly found in the human nose, mouth, and throat.



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