

ET Life



Website



- The domain uiuc.edu is no longer valid.
- So, the correct class website is:
<http://eeyore.astro.illinois.edu/~lwl/classes/astro330/spring10/>

This class (Lecture 8):

Star Formation

HW 3 is due Wed.

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

Next Class:

Exoplanets

Aaron White

Connor Simmons

Drake Equation

The class's first estimate is

Frank Drake



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

# 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 communicate	Lifetime of advanced civilizations
10	stars/yr	systems/star	planets/system	life/planet	intel./life	comm./intel.	yrs/comm.

Outline

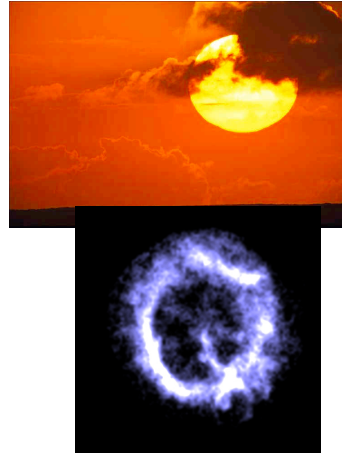


- Molecules are for life.
- From molecular clouds to stars
- How did our solar system form?
- Circumstellar disks are the birth place of planets
- Circumstellar disks are common!

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.



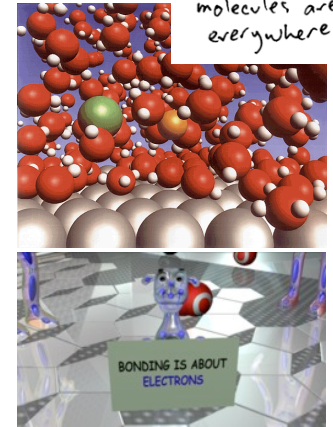
<http://www.astronomyinfo.pwp.blueyonder.co.uk/starstuff.htm>
<http://antwrp.gsfc.nasa.gov/apod/ap991209.html>

Star Stuff and Earth Stuff



molecules are everywhere

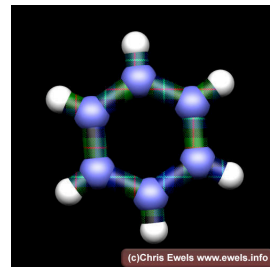
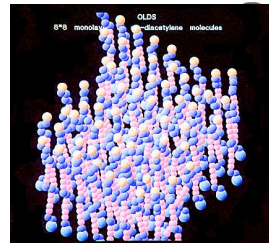
- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, all of the important aspects of life **depend on molecules**. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.



<http://nanokids.rice.edu/explore.cfm>
<http://www.toothpaste4dinner.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 a compound.
- When dividing water, smallest division, before separation of hydrogen and oxygen.

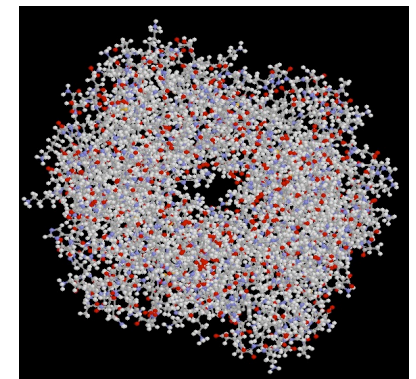


http://www.ph.qmw.ac.uk/research_bk/theory.htm

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.



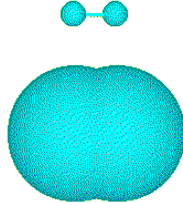
<http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/silymols.htm>

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

Example H₂



- H₂ 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 He₂.

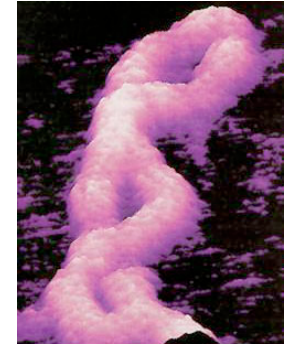


<http://www.historyoftheuniverse.com/h2.html>

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

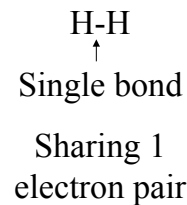
- a) molecules are bigger than atoms.
- b) there are many more molecular options than elements.
- c) molecules survive better at high temperatures.
- d) molecules survive better at low temperatures.
- e) one word— ducks.

How to Write Molecules

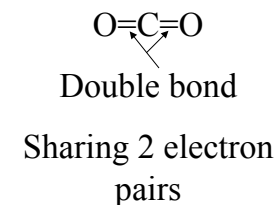


- We'll talk about H₂ or CO₂
- Or

Molecular
Hydrogen



Carbon Dioxide



<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



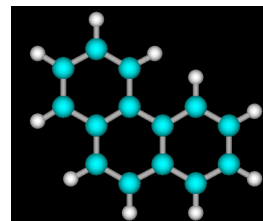
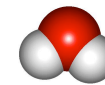
Keyhole Nebula



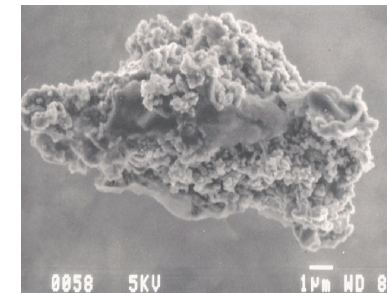
Other Things Besides Hydrogen in Molecular Clouds



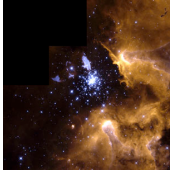
- ▶ Molecules (e.g.)
 - ▶ Carbon monoxide (CO)
 - ▶ Water (H₂O)
 - ▶ Ammonia (NH₃)
 - ▶ Formaldehyde (H₂CO)
 - ▶ Glycine (NH₂CH₂COOH)?
 - ▶ Ethyl alcohol (CH₃CH₂OH)
 - ▶ Acetic Acid (CH₃COOH)
 - ▶ Urea [(NH₂)₂CO]
- ▶ Dust particles
 - ▶ Silicates, sometimes ice-coated
 - ▶ Soot molecules



Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)



Molecular Clouds

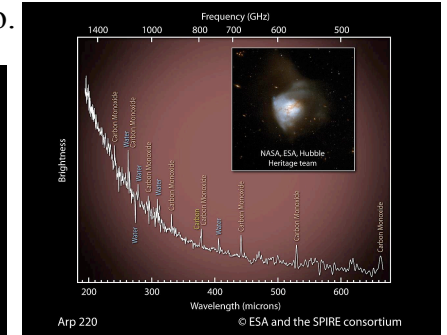
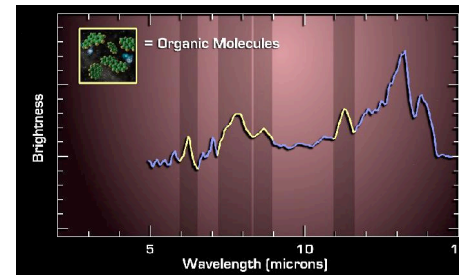


- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- H₂ is not good at emitting photons, so easier to see larger molecules emitting– especially CO (which tells the temperature of these clouds).
- Other molecules (mostly H₂CO, 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



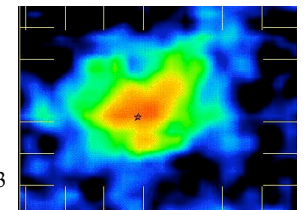
Molecular clouds, where stars form, are mostly made up out of

- dust
- a rich assortment of molecules that range from alcohol to urea
- Hydrogen
- water
- H₂

The Importance of being a Molecular Cloud

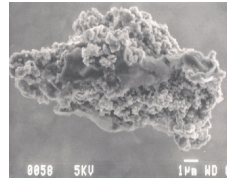


- Different than the clouds that formed the First Stars
- Stars form in cold, dense molecular clouds (normally starless)
 - Colder: molecules and dust easily emit in the radio and infrared, which cools the cloud.
 - Clumpy: clumps more easily, as the material is cold, forming regions of high density.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



C¹⁸O emission from L483

In Dust We Trust

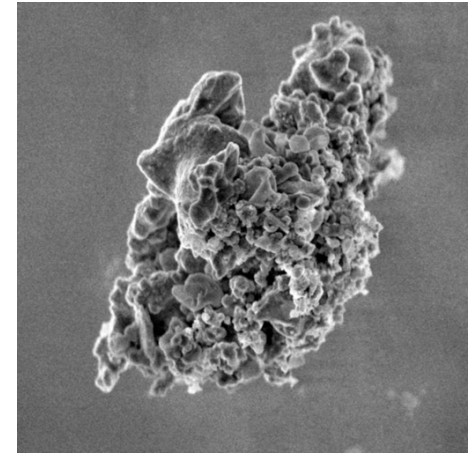


- Small (< 1 micron), solid particles in space
- Two types:
 - Primarily carbon (sort of like what we call soot)
 - Silicates, minerals of silicon and oxygen (sort of like what we call dust)
- Produced in material flowing from old stars, but mixed in space.
- When concentrated can protect molecules from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

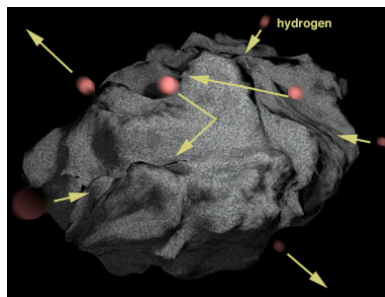


http://spiff.rit.edu/classes/phys230/lectures/sim_dust/sim_dust.html

Molecule Formation



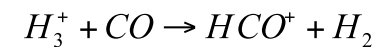
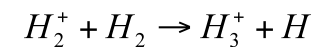
- H on dust grain, gets hit by another H, then extra energy ejects the newly formed molecule H₂ from the dust grain.
- For more complicated molecules, they need to be ionized to get easy reaction in space.
- What ionizes the molecules? Ultraviolet light would work, but then the molecules would get destroyed.



How to Get Complex Molecules



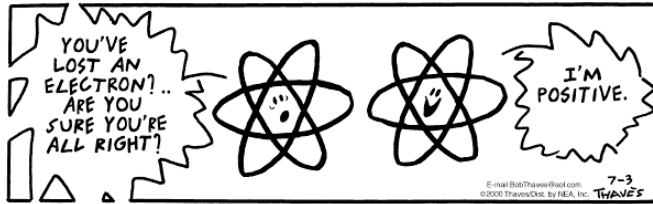
- Best answer is that the rare cosmic rays ionizes molecules inside of a molecular cloud.
- For example:



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

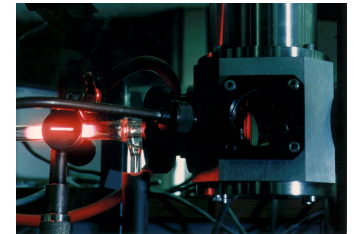


More to the Story: HONC



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- 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/>

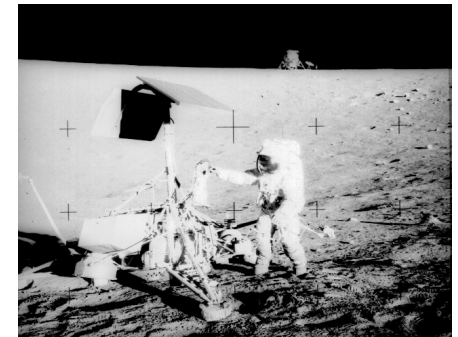


<http://www.daviddarling.info/images/lithopanspermia.jpg>

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.

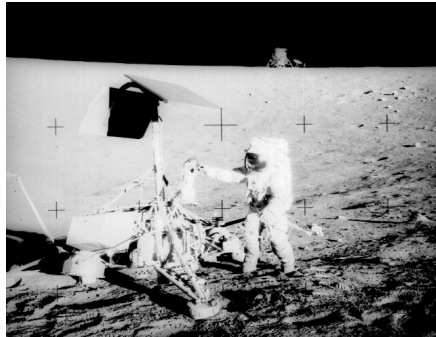


http://nsdc.gsfc.nasa.gov/planetary/news/image/conrad_19990709_c.jpg

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://nsdc.gsfc.nasa.gov/planetary/news/image/conrad_19990709_c.jpg

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 in large quantities.
- d) the only kind of molecules detected are missing C.
- e) all molecules are detected.

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.

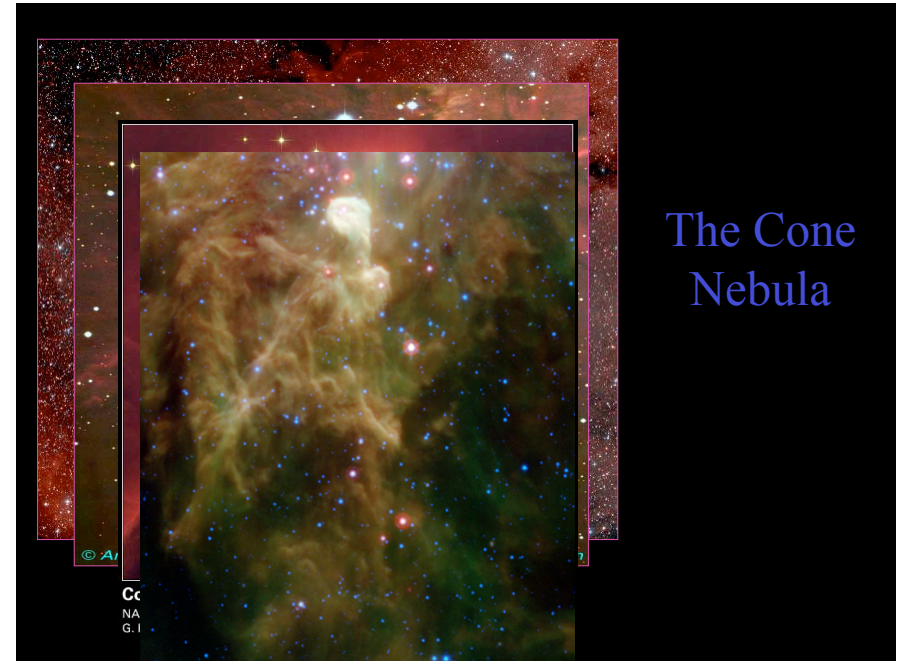
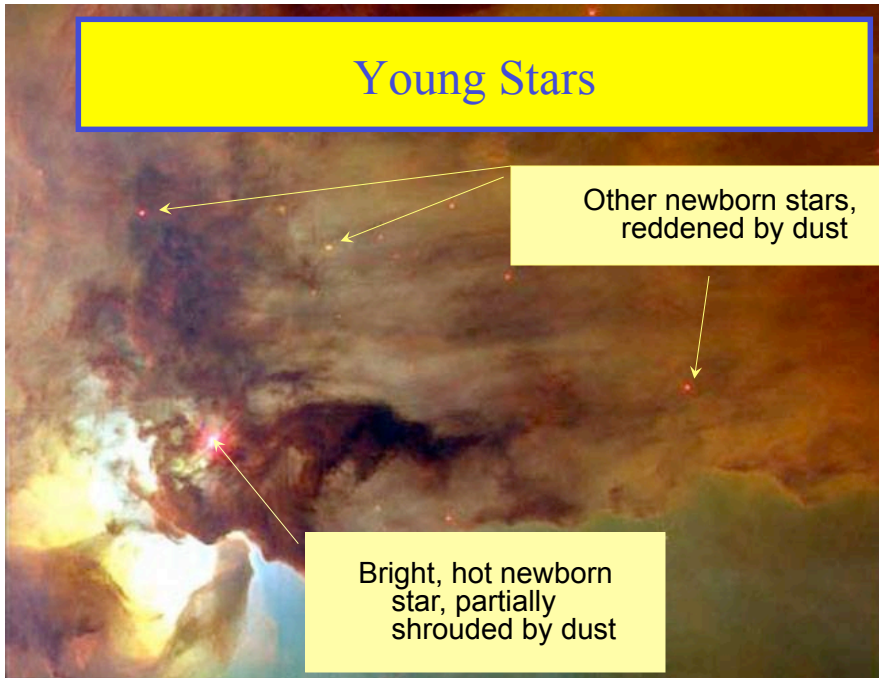
How Do We Know that Stars Form in Molecular Clouds ?



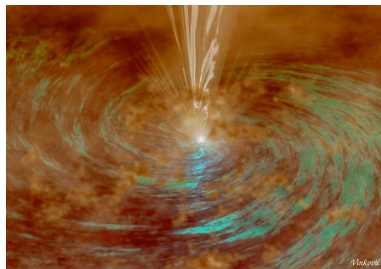
- Young stars are seen near molecular clouds.
- In infrared light, we can see into the deeper regions of clouds, and see clusters of young stars with circumstellar material (dust and gas) surrounding them.
- Stars are continuously being formed in our galaxy.



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



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

- in molecular clouds.
- in supernovae.
- in black holes.
- on Broadway.
- in empty space.

What is the origin of the Solar System?



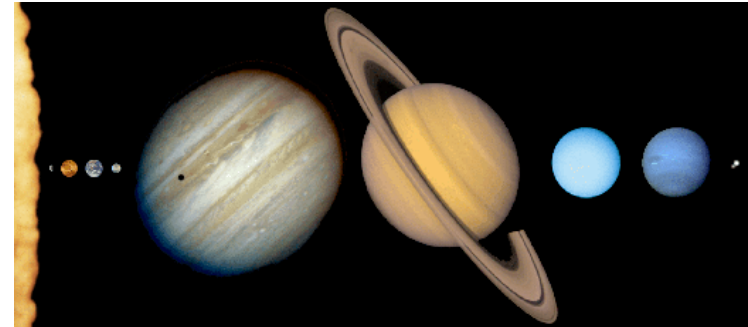
- Explain present-day Solar System data.
- Predict results of new Solar System data.
- Should explain and predict data from other stars!

What are clues to solar system origins?

Some Facts of the Solar System



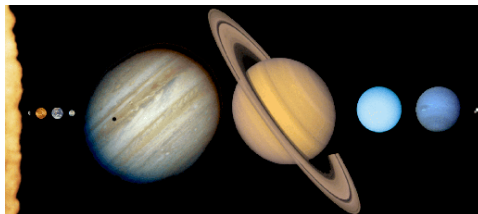
- We have 8 or 9 planets.
- So perhaps the average extrasolar system has about 10 planets (rounded off).



Some Facts of the Solar System



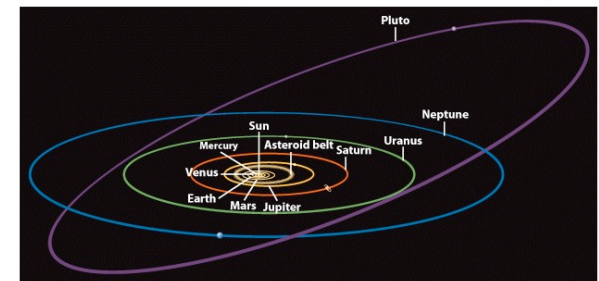
- Mass of solar system
 - 99.85% in the Sun (planets have 98% of ang. mom.)
 - Outer planets more massive than the inner ones
 - Jupiter is more than twice as massive as the rest of the planetary system combined!
- The inner planets are rocky and the outer planets are gaseous



Planetary Orbits



Most of the motions in the Solar System are counter clockwise in a flat system (pancake-like)



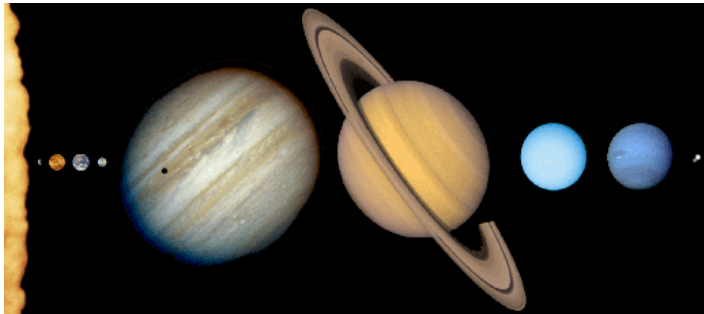
- There are some exceptions
- Venus, Uranus, and Pluto rotate clockwise (orbits are still clockwise)
- Some moons orbit backwards

<http://janus.astro.umd.edu/javadir/orbits/ssv.html>

Some Facts of the Solar System



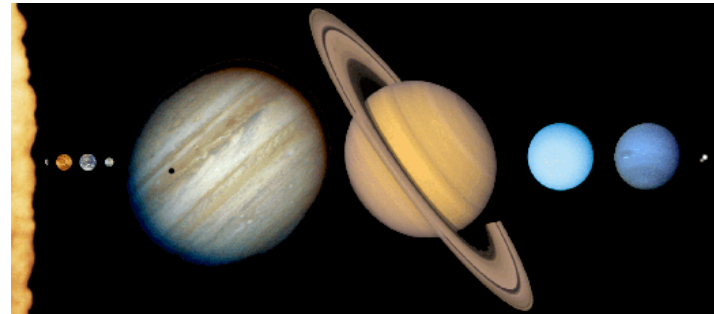
- Outer planets more massive than inner planets.
- The inner planets are rocky and the outer planets are gaseous.



Some Facts of the Solar System



- Numerous collisions occurred in the early Solar System
 - Origin of Moon, Lunar craters, Uranus's orbit, and Pluto
- Planets are not evenly spaced– factors of 1.5 to 2.
 - Sun/Saturn distance is 2x Sun/Jupiter distance
 - Sun/Mars distance is 1.5x Sun/Earth distance



What is the Age of the Solar System?



- Earth: oldest rocks are 4.4 billion yrs
- Moon: oldest rocks are 4.5 billion yrs
- Mars: oldest rocks are 4.5 billion yrs
- Meteorites: oldest are 4.6 billion yrs
- Sun: models estimate an age of 4.5 billion yrs
- **Age of Solar System is probably around 4.6 billion years old**

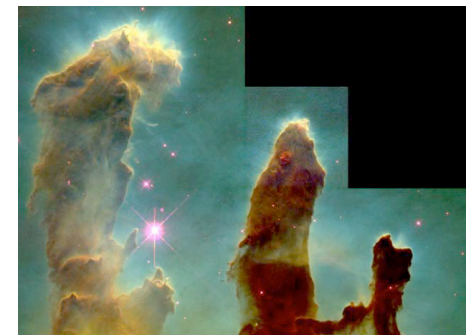
Origin of Solar System: Solar Nebula Theory



Gravitational Collapse

- The basic idea was put forth by Immanuel Kant (the philosopher)– Solar System came from a Gas Nebula.
- 4.6 billion years ago: a slowly spinning ball of gas, dust, and ice with a composition of mostly hydrogen and helium formed the early Solar System.
- This matches nearly exactly with the modern idea of star formation.

“*nebula*” = cloud



Gravitational Contraction

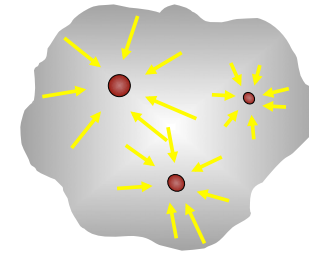


- As we discussed for the first stars, the gravity of the gas and dust clumps push the clumps together, but there is some resistance from pressure and magnetic fields to collapse.
- Probably as the cloud core collapses, it fragments into blobs that collapse into individual stars.
- Cloud becomes denser and denser until gravity wins, and the clumps collapse under their own mass— a protostar.



<http://www.birthingthefuture.com/AllAboutBirth/americanway.php>

Cloud Contraction



But..



- Not all mass falls in directly (radially). Why?
- All gas has a small spin that preferentially causes the formation of a flattened structure
– time for an interlude.



<http://homepages.igrin.co.nz/moerewa/Pages/>

Interlude: Angular Momentum



Spinning or orbiting objects in closed system have angular momentum.



Angular momentum is a single, *constant* number = *conserved!*

Keep same dist. to axis → velocity same

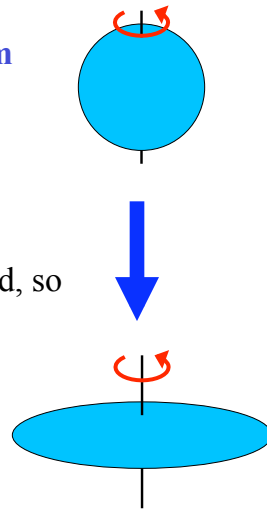
Move closer to axis → speed up!

When Doves Cry and Stars Form



Solar nebula competition: Gravity vs Angular Momentum

- If fall perpendicular to spin axis
Needs to speed up
→ resistance centrifugal force
- If fall parallel to spin axis same speed, so
no resistance
→ forms *protoplanetary disk*
 - Origin of planet's orbits!
 - Organizes spins along initial spin axis



Question



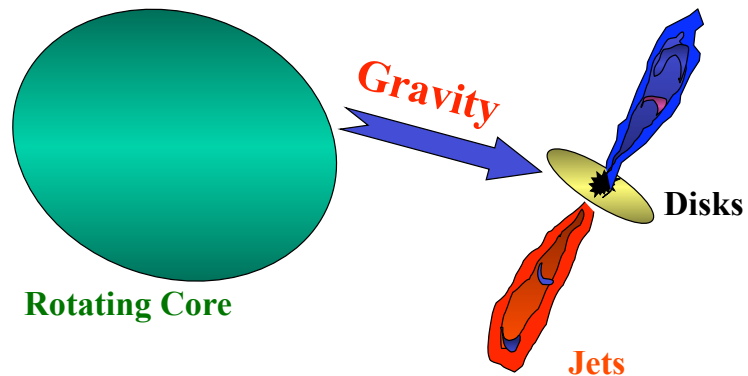
Since a collapsing cloud is spinning, the cloud will form

- a) a spherical cloud
- b) a star
- c) a flattened disk
- d) a planet
- e) a galaxy

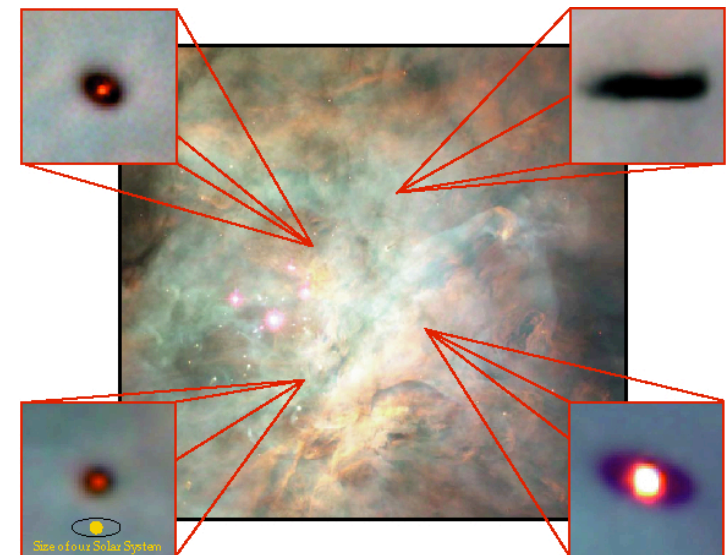
The Protostar Stage



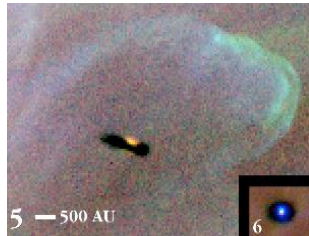
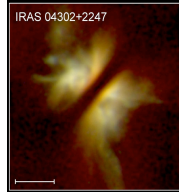
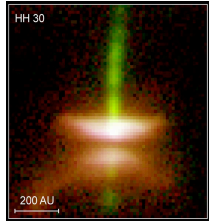
Gravity, Spin, & Magnetic Fields



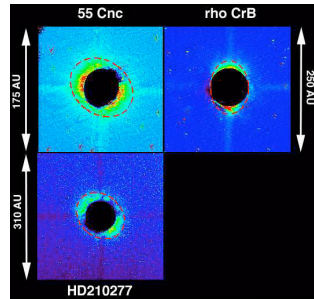
Disks around Young Stars are Common



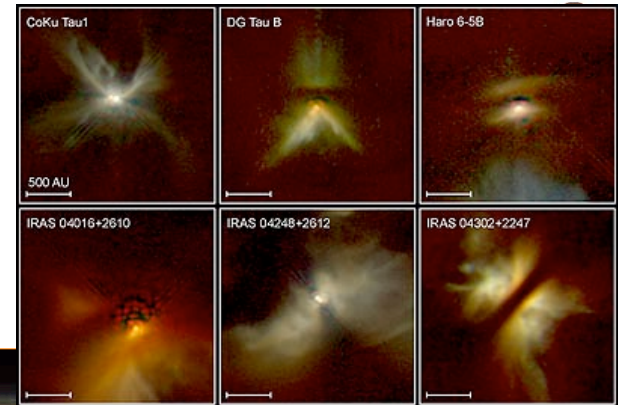
And Disks around Young Stars are Common



<http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm>



Disks have been imaged with HST's infrared camera

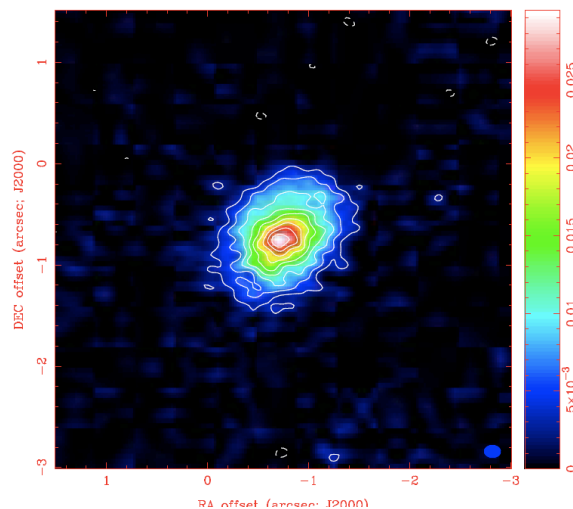


Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material



HL Tauri



Looney et al. 2009

Interesting Question



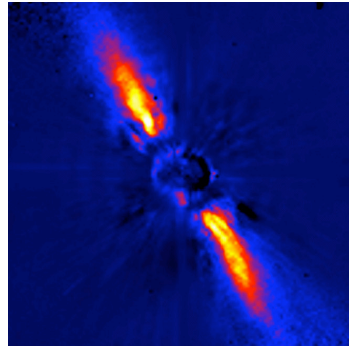
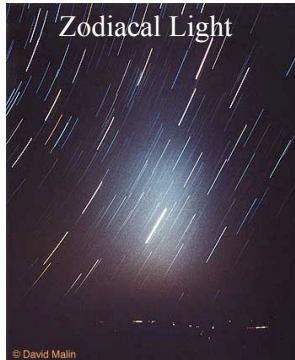
Leslie studies circumstellar disks. What is he actually observing?

- a) The disks of Galaxies.
- b) The disks around Black Holes.
- c) The disks around protostars.
- d) The disks around planets like Saturn.
- e) The disks under nice beverages.

Do Fossil Disks Exist around other Stars?



- We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.

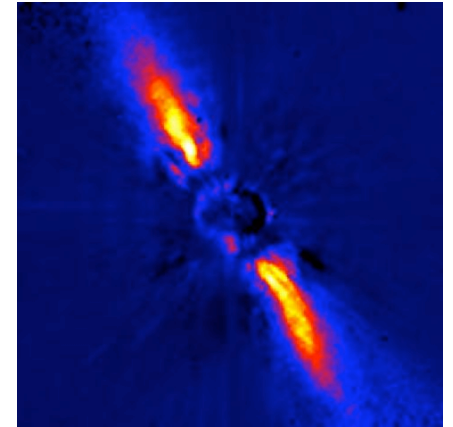


<http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html>
<http://antwrp.gsfc.nasa.gov/apod/ap970826.html>

Disks Around Young Stars



- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
 - Enough material to make planets
 - Agrees with Solar Nebula theory!



Protostellar Jets

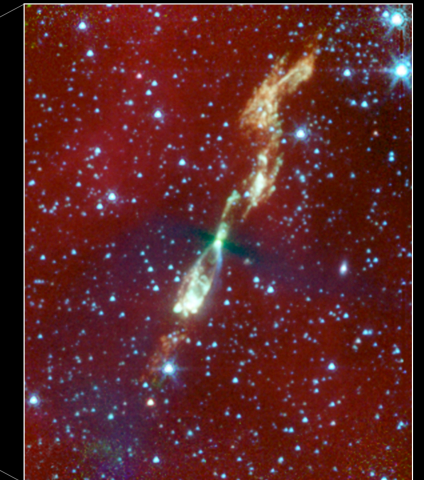
Jets from Young Stars
 PRC95-24a - ST Sci OPO - June 6, 1995
 C. Burrows (ST Sci), J. Hester (AZ State U.), J. Morse (ST Sci), NASA

HST · WFPC2

Visible (DSS / Caltech & AURA)



Infrared

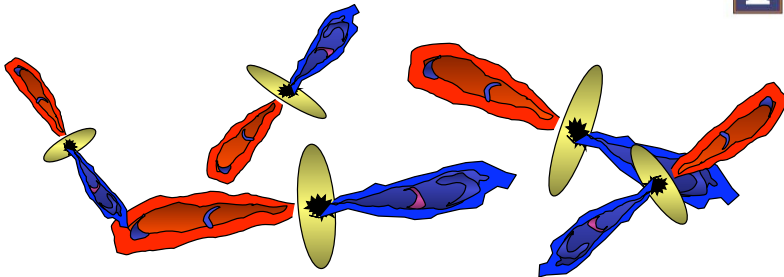


Flattened Envelope around L1157 Protostar
 NASA / JPL-Caltech / L. Looney (University of Illinois)

Spitzer Space Telescope • IRAC
 ssc2007-19a

<http://www.youtube.com/watch?v=Rm3Sj8qAaWg&NR=1>

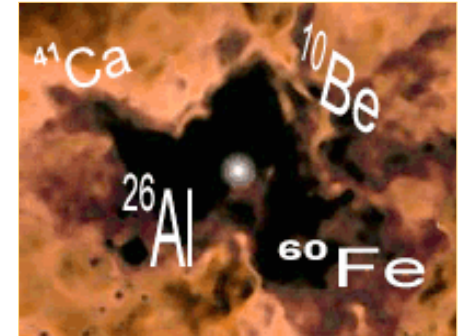
Young Stars in Groups



- Most stars are in multiple systems and clusters
- What about us?

Isotopes in the Pre-Solar Nebula

- The Solar nebula had short-lived radioactive material (e.g. ^{26}Al or ^{60}Fe)
- Small mineral grains in meteorites contain evidence of this decayed material.
- The radioactive material decayed, and left rare forms of some elements in the rock



$^{26}\text{Aluminum}$
 • 13 protons
 • 13 neutrons

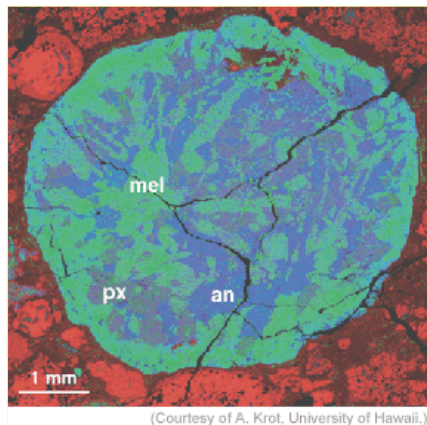


$^{26}\text{Magnesium}$
 • 12 protons
 • 14 neutrons

The Earliest Pre-Solar Dust Grains

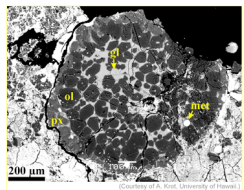


- Calcium-aluminum-rich inclusions (CAIs)
- Chondrules (grains found in primitive meteorites).



(Courtesy of A. Krot, University of Hawaii.)

Formed 4,700,000,000 years ago

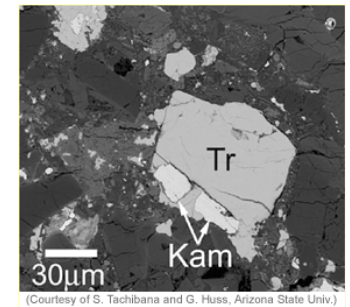


(Courtesy of A. Krot, University of Hawaii.)

CAIs Once Contained ^{60}Fe



- Contain decay products of ^{26}Al and ^{60}Fe
- As seen by an excess of nickel
- Can only be produced by nearby supernova explosion!
- Can use the ensemble of all radioactive elements to estimate distance to the supernova
 – 0.1 to 1.6 pc away



(Courtesy of S. Tachibana and G. Huss, Arizona State Univ.)

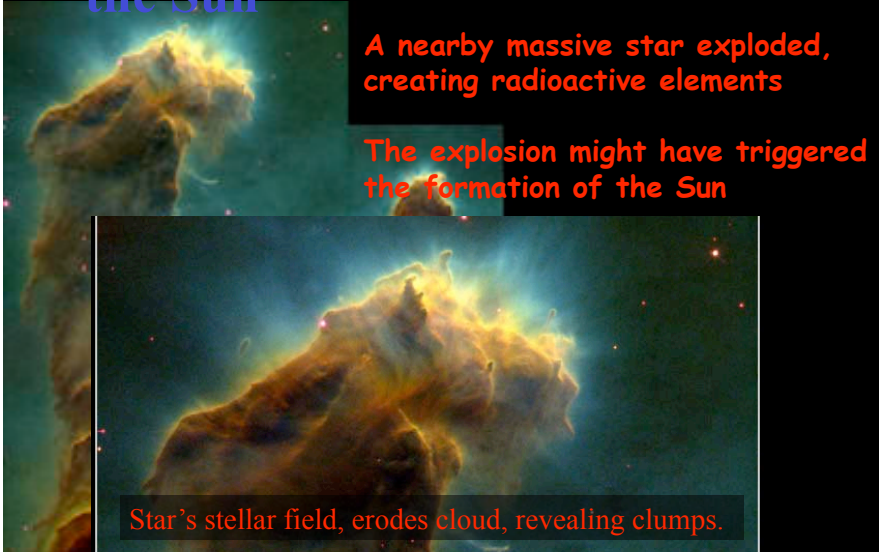
Half life 1.5 million years

The Birth of the Sun

The Sun formed as part of a modest-sized cluster of stars

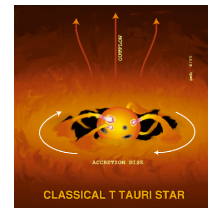
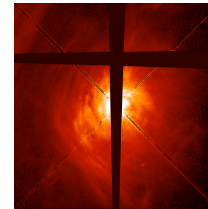
A nearby massive star exploded, creating radioactive elements

The explosion might have triggered the formation of the Sun



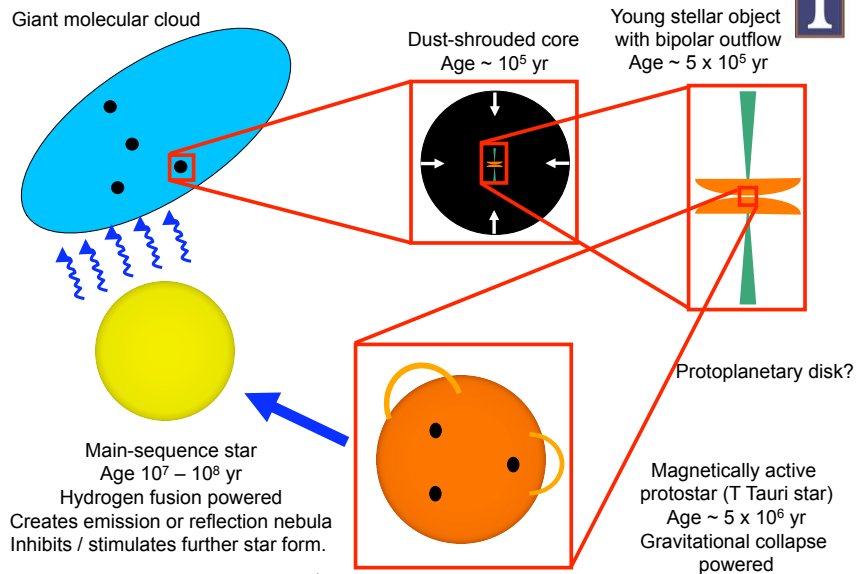
Star's stellar field, erodes cloud, revealing clumps.

On to the Main Sequence: A Star is Born!



- Density increase, temperature increases until fusion can occur.
 - Blows away most of its natal circumstellar material.
 - Becomes a star on the main sequence of the HR diagram,
 - For low mass stars, this whole process can take a few 10^6 years.
 - Expect to see a large number of embedded protostars.

Star Formation - Summary



So, Why would Spock Care?



- If we are to suppose that ET life will be based on a planet orbiting a star, then we need to know
 - How did our solar system form?
 - How rare is it?
 - Is our solar system unusual?



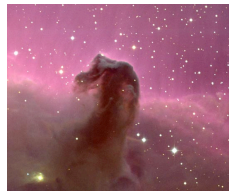
http://homepage.smc.edu/balm_simon/images/astro%205/spock.jpg

The Early Solar System



- A massive cloud of gas and dust
 - Seeded with elements from
 - Big Bang (hydrogen, helium, etc.)
 - Elements from planetary nebula pushed into space by red giant.
 - Elements blown from across galaxy by supernovae.

The cloud collapsed under its gravity and formed the circumstellar disk from which our solar system formed. Most theories for solar system formation require disks with masses of 0.01 to 1 solar masses.



Planet Formation in the Disk



Heavy elements clump

1. *Dust grains* collide, stick, and form planetesimals— about 10^{12} of them, sort of like asteroids! All orbit in the same direction and in the same plane.
2. Gravity Effects: Big planetesimals attract the smaller planetesimals. So, fewer and fewer of large objects (100's). Collisions build-up inner planets and outer planet cores.
3. Collisions can also account for odd motions of Venus (backwards), Uranus (rotates on its side), and Pluto (high inclination of orbit). Proof of period of high collision evident on moon

