ET Life

This class (Lecture 8):

Star Formation

Next Class:

Exoplanets

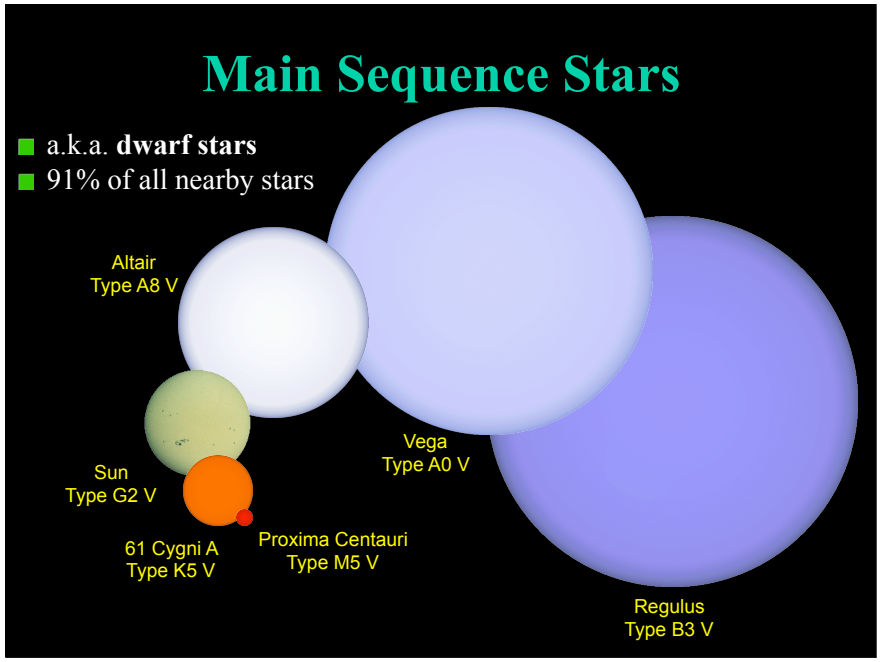
Paige Malec

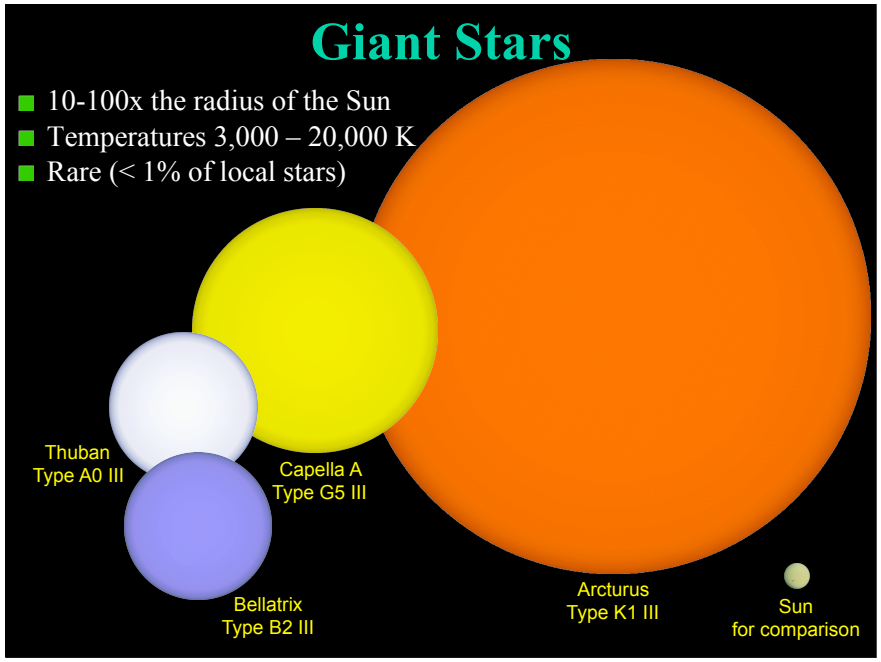
HW 2 is due tonight

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

Outline

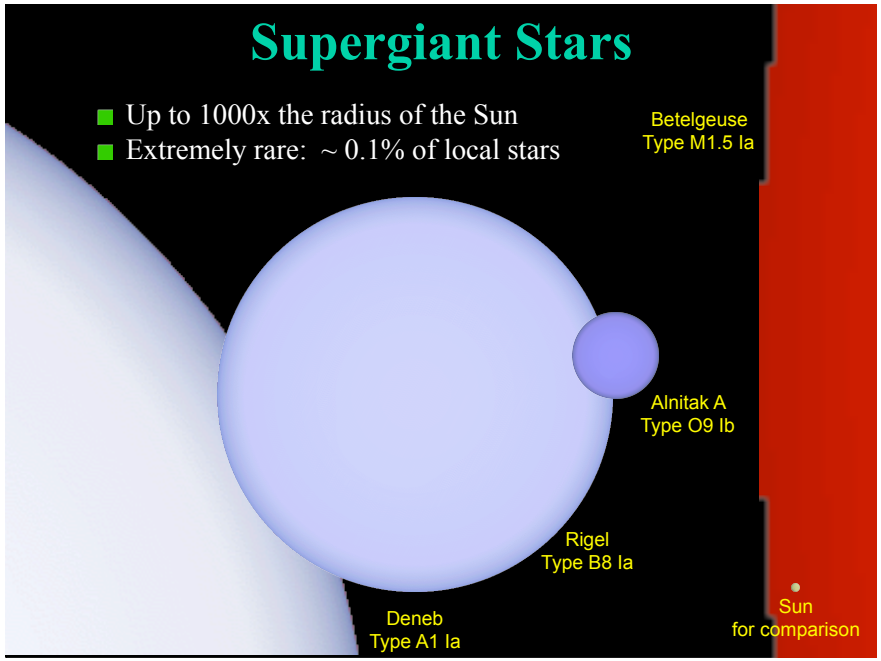
- Molecules are for life.
- From molecular clouds to stars
- How did our solar system form?
- Circumstellar disks are the birth place of planets
- Circumstellar disks are common!





Supergiant Stars

- Up to 1000x the radius of the Sun
- Extremely rare: ~ 0.1% of local stars

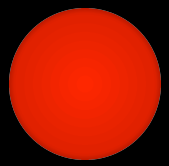


White Dwarf Stars

- About the size of the Earth
- Very hot: 5,000 – 20,000 K
- About 8% of local stars

Kinds of Dwarfs

Red dwarf
Just a very cool main-sequence star



Gliese 229A

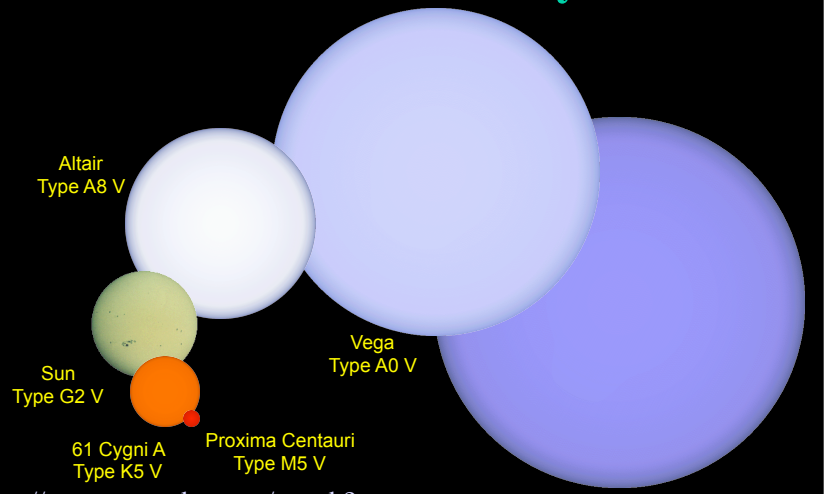
White dwarf
White-hot burned-out core of a star

Sirius B

Black dwarf
A very old cooled white dwarf

Brown dwarf
Not a star at all; wasn't massive enough

Stellar Summary



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

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

Groups

On Tuesday, we discussed the origins of the elements for life. In a few sentences, explain to your non-science major friends how HONC (the elements of life) were created.

Groups

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Drake Equation

The class's first estimate is

Frank Drake





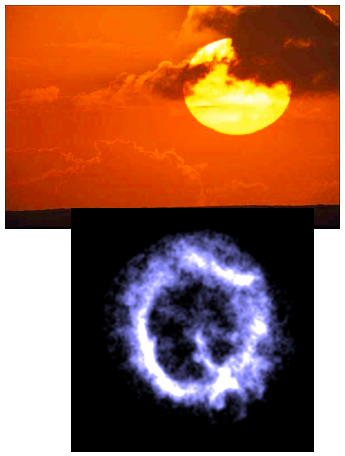



$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

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

Star Stuff

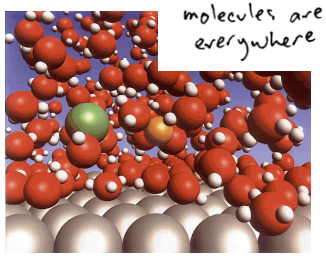
- Now, we have the elements crucial to life in the Galaxy--**HONC**.
- There are about 92 elements found in the Universe and about 20 more elements that have been created in laboratories (but decay quickly).
- The 92 elements were almost all made in the interiors of massive stars or during a supernova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



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

Star Stuff and Earth Stuff

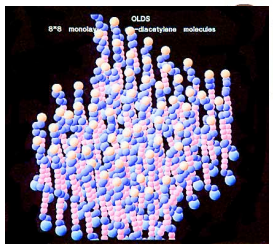
- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, all of the important aspects of life depend on molecules. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.

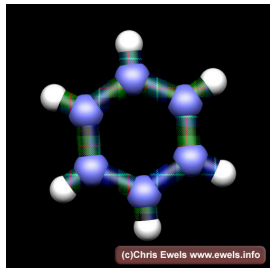


http://nanokids.rice.edu/explore.cfm
http://www.toothpastefordinner.com/archives-sum02.php
http://www.psc.edu/science/Voth/Voth.html

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.

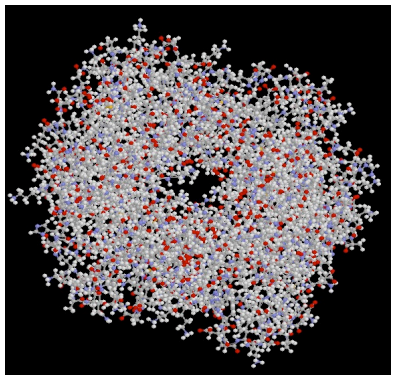




http://www.ph.qmw.ac.uk/research_bk/theory.htm

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.

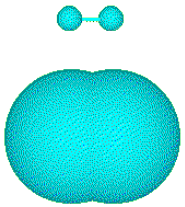


http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

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

Example H_2

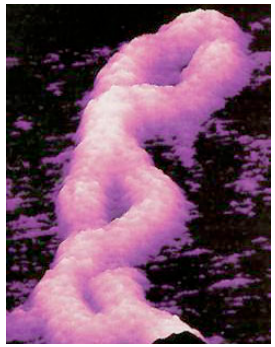
- H_2 is the simplest molecule– two hydrogen atoms.
- What does that mean?
  - There are 4 particles.
    - 2 protons of the 2 nuclei, which repel each other
    - 2 electrons of the 2 atoms, which repel each other
  - But
    - The electron of each atom will attract the other nucleus
- Although not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

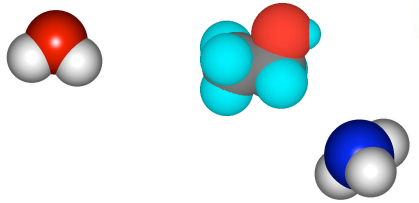
The Interstellar Medium (ISM)

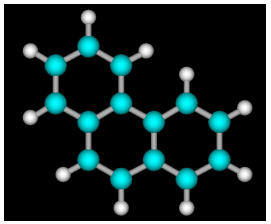
- Stuff between the stars in a galaxy.
- Sounds sort of boring, but
  - Actually very important
  - Features complex physical processes hidden in safe dust clouds
- Every star and planet, and maybe the **molecules** that led to life, were formed in the dust and gas of clouds.
- Exists as either
  - Diffuse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

Keyhole Nebula

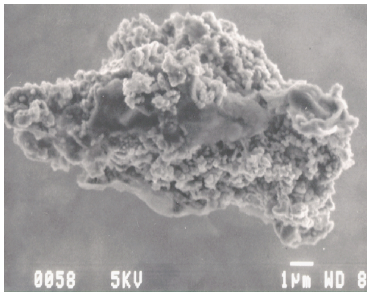
Other Things Besides Hydrogen in Molecular Clouds

- 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

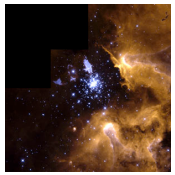




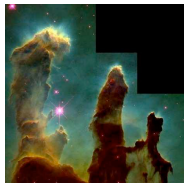
Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)



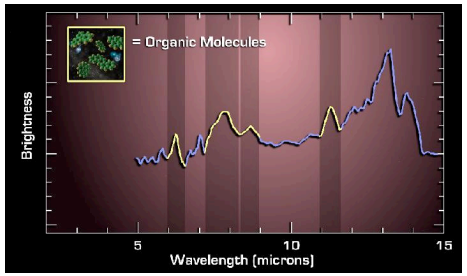
Molecular Clouds

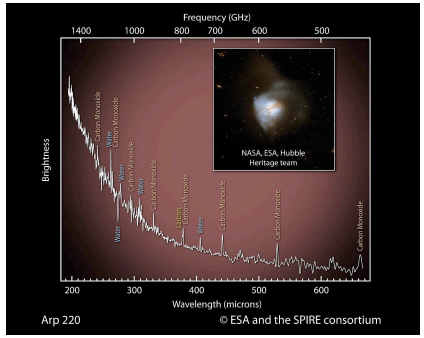


- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- H_2 is not good at emitting photons, so easier to see larger molecules emitting– especially CO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





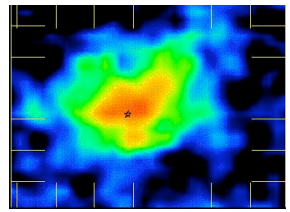
Question

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

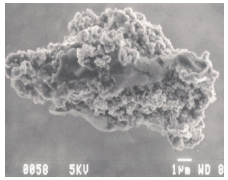
The Importance of being a Molecular Cloud

- 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

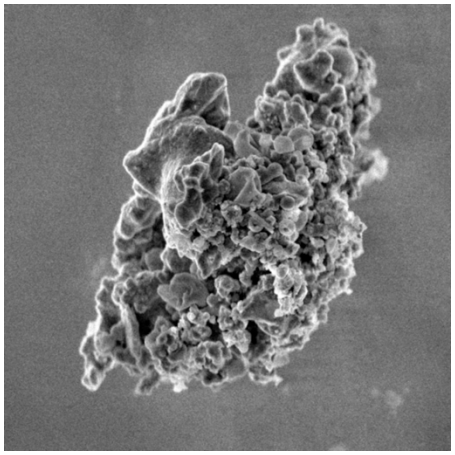
In Dust We Trust



- 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

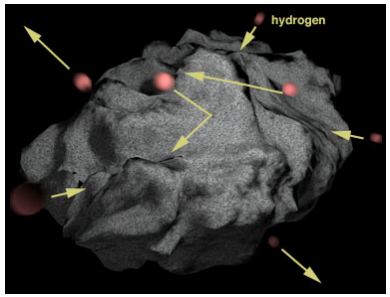
- When molecules form, they must release energy by emitting light or colliding
- Difficult to do in the gas phases, need dust grains as a catalysis.



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.

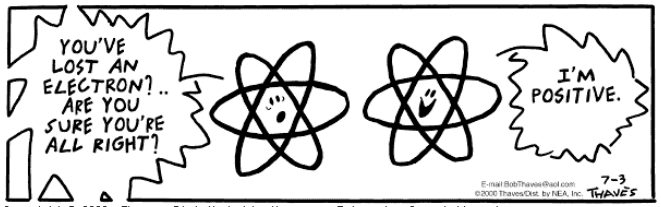


How to Get Complex Molecules

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

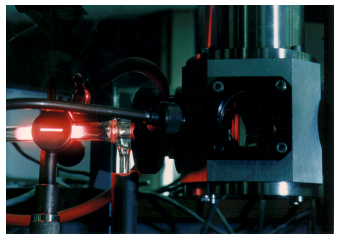
$$H_2^+ + H_2 \rightarrow H_3^+ + H$$
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

- 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/

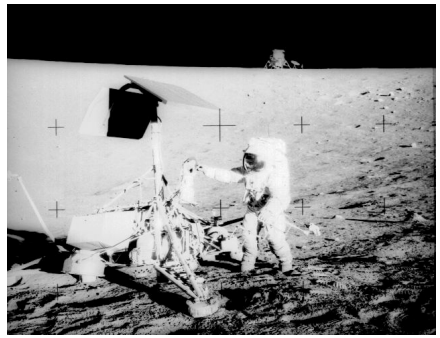
Panspermia

- 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

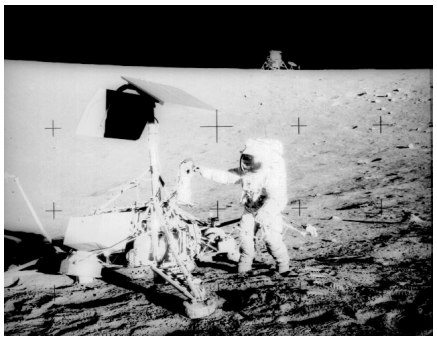
- Surveyor 3: unmanned lunar probe which landed in 1967.
- 2.5 years later, a camera was retrieved by Apollo astronauts.
- The camera had 50 to 100 viable specimens of *Streptococcus mitis*, a harmless bacterium commonly found in the human nose, mouth, and throat.



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

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

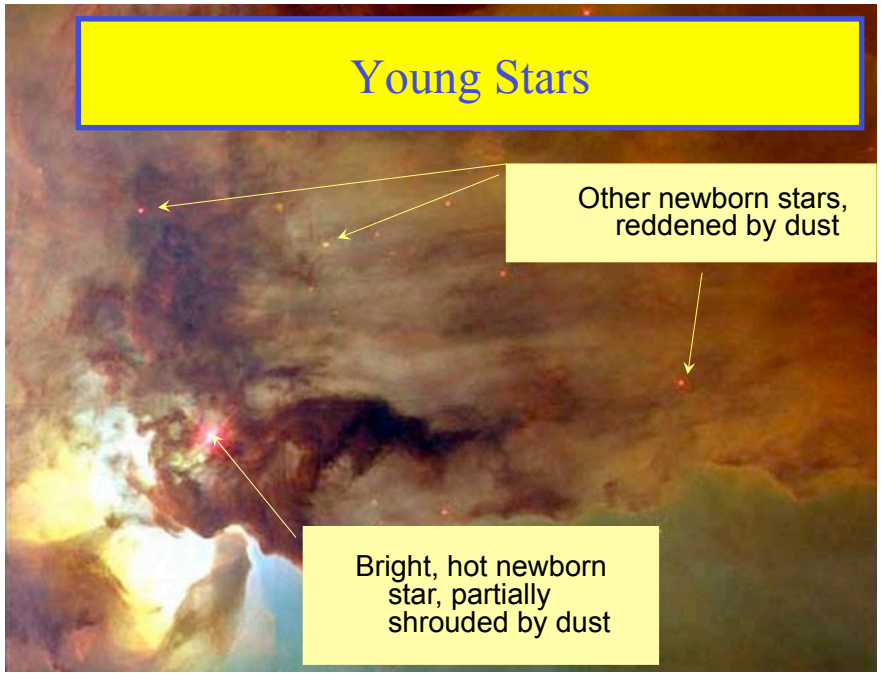
The molecules that life uses on Earth are complex.
In space

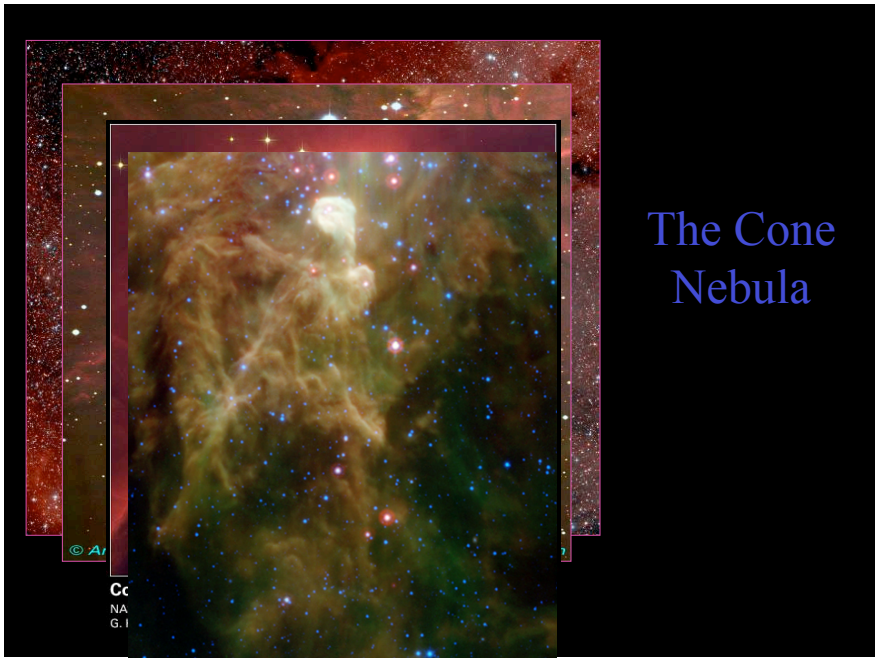
a) no one can hear you scream.
b) complex molecules can not be created. The environment is too harsh.
c) complex molecules, up to 13 atoms, have been detected in large quantities.
d) the only kind of molecules detected are missing C.
e) all molecules are detected.

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.

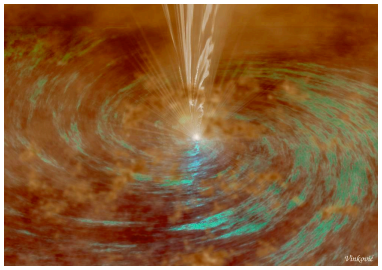
http://antwrp.gsfc.nasa.gov/apod/ap030630.html





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.

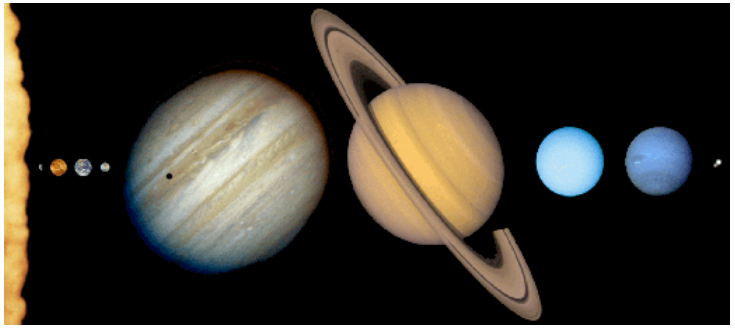
What is the origin of the Solar System?

- 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?

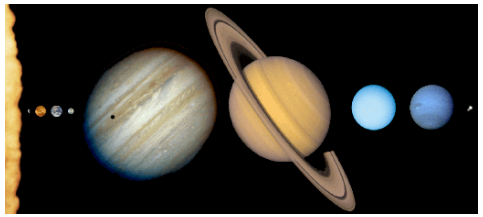
Some Facts of the Solar System

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



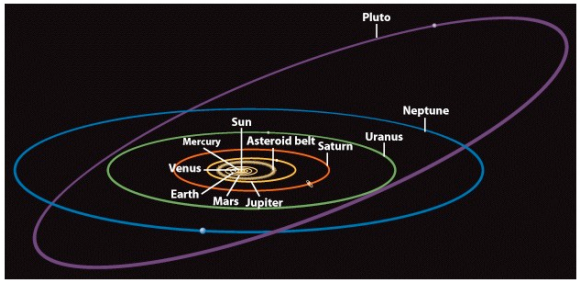
Some Facts of the Solar System

- 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)

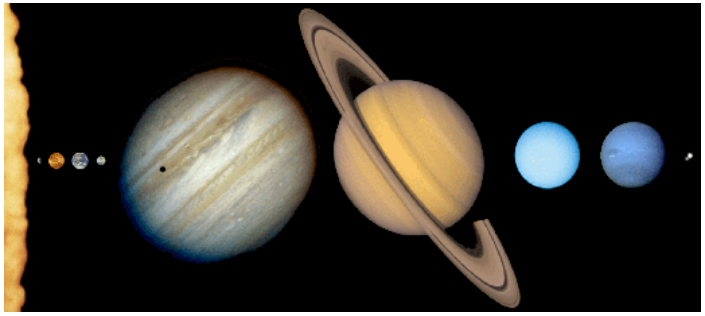


- There are some exceptions
- Venus, Uranus, and Pluto rotate clockwise (orbits are still clockwise)
- Some moons orbit backwards

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

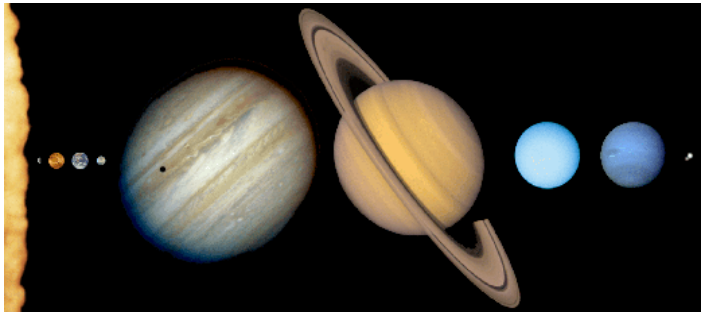
Some Facts of the Solar System

- 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

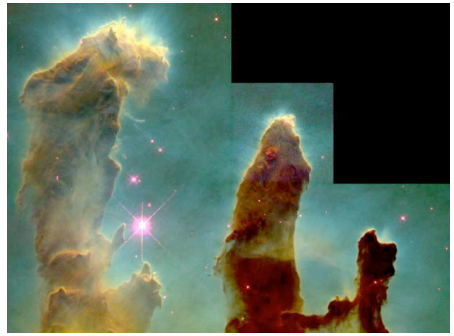
- **Age of Solar System is probably around 4.6 billion years old**

Origin of Solar System: Solar Nebula Theory

"*nebula*" = cloud

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.

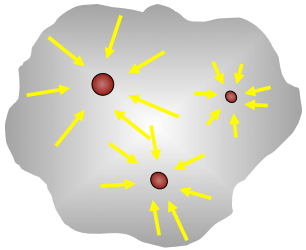


Gravitational Contraction

- 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.

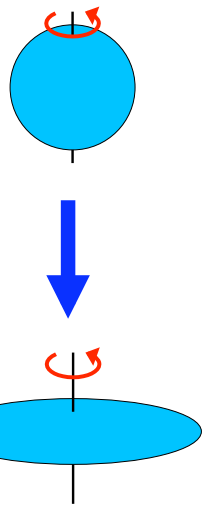
Angular momentum is a single, *constant* number = *conserved*!

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

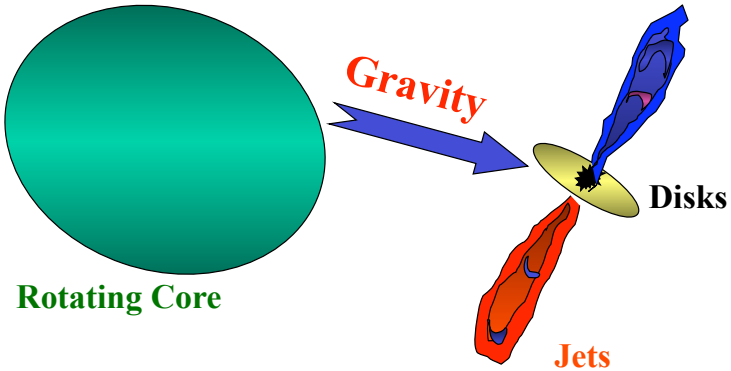
Question

Since a collapsing cloud is spinning, the cloud will form

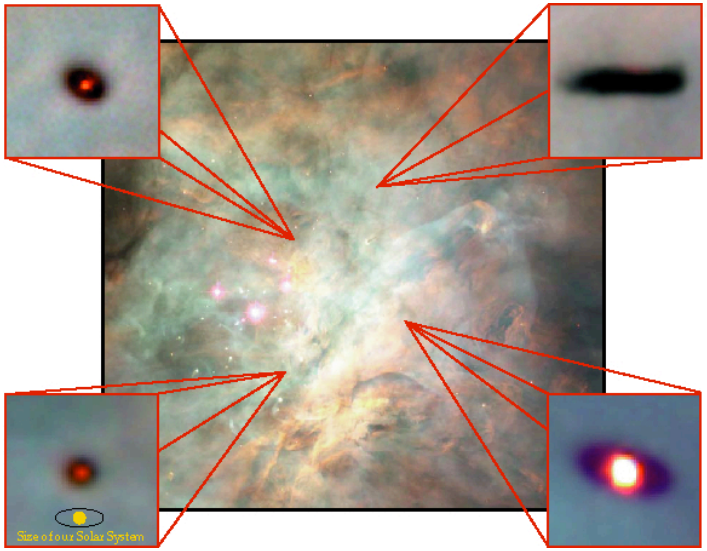
a) a spherical cloud
b) a star
c) a flattened disk
d) a planet
e) a galaxy

The Protostar Stage

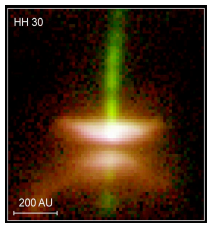
Gravity, Spin, & Magnetic Fields

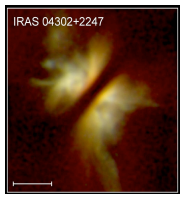


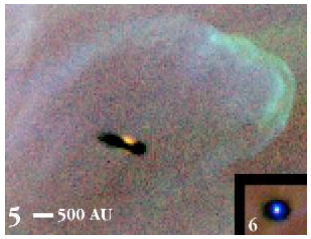
Disks around Young Stars are Common

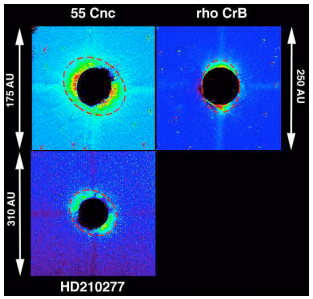


And Disks around Young Stars are Common



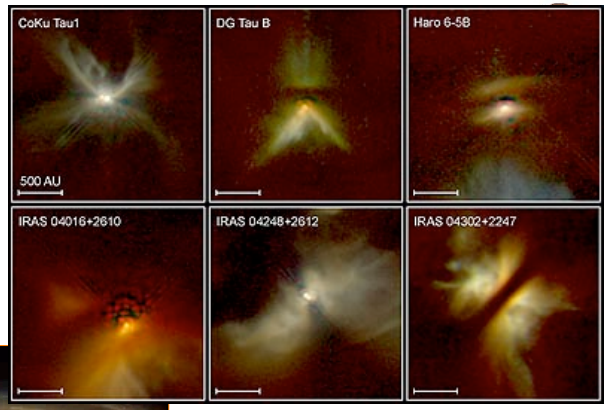






http://
www.ifa.hawaii.edu/
users/tokunaga/SSET/
SSET.htm

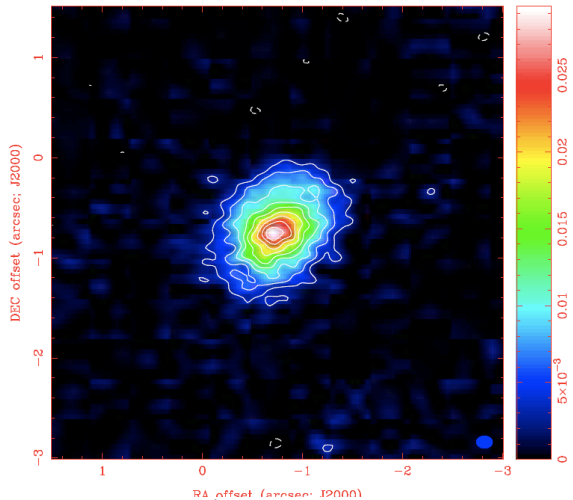
Disks have been imaged with HST's infrared camera



Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material

HL Tauri



Kwon, Looney, & Mundy 2011

Interesting Question

Leslie studies circumstellar disks. What is he actually observing?

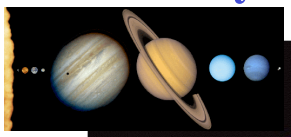
a) The disks of Galaxies.
b) The disks around Black Holes.
c) The disks around protostars.
d) The disks around planets like Saturn.
e) The disks under nice beverages.

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

Planetary Orbits



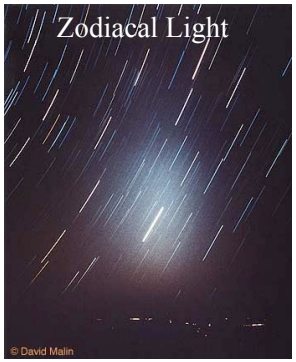
Most of the motions in the Solar System are counter clockwise in a flat system (pancake-like)

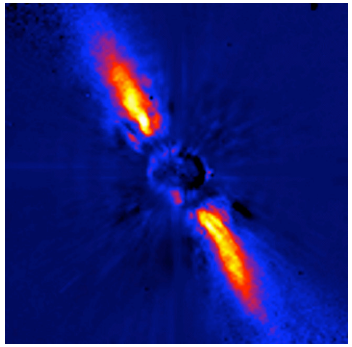
- There are some exceptions
- Venus, Uranus, and Pluto rotate clockwise (orbits are still clockwise)
- Some moons orbit backwards

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

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.



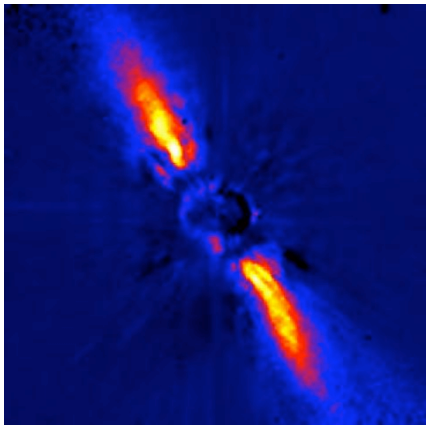


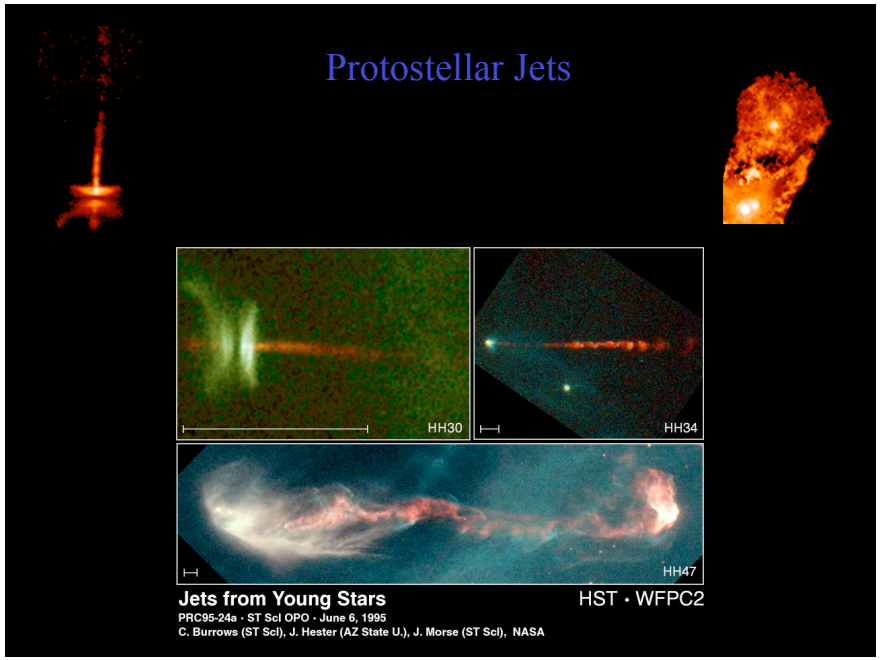
http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html

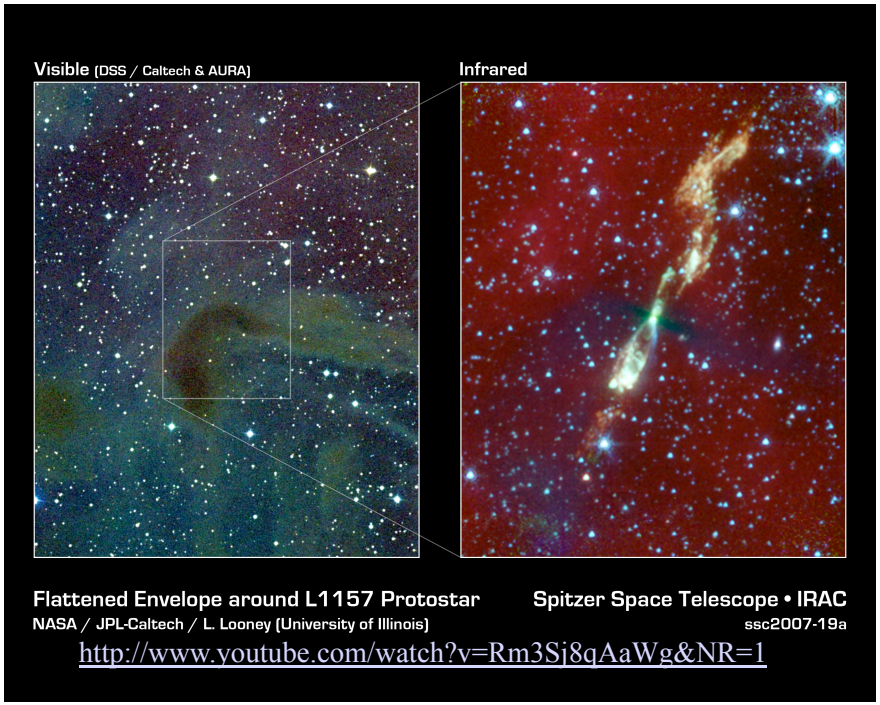
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

Disks Around Young Stars

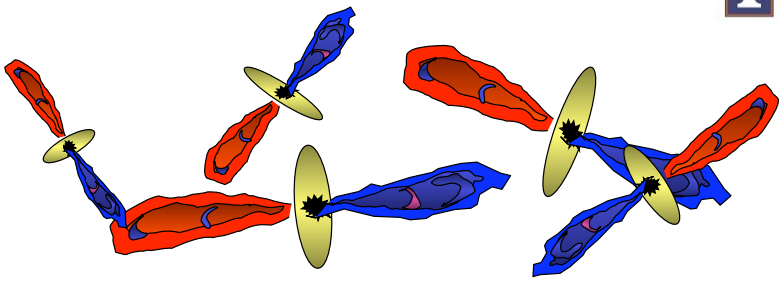
- Many (> 60%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!







Young Stars in Groups



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