Astronomy 230
Section 1– MWF 1400-1450
106 B6 Eng Hall

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

Star Formation

Presentation Synopsis due today.

<u>Next Class:</u>

Planet Formation

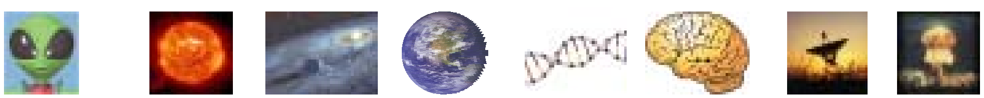
Music: *Invisible Sun* – Police

Outline

- Finish discussion on molecular clouds.
- Star formation is ongoing.
- Stars form in dense molecular clouds.
- The cores collapse, and often fragment, forming multiple young stars.
- The young stars are embedded and enshrouded in dust.
- Protostars have circumstellar disks and jets that influence their environment.

Drake Equation
HW1 Results

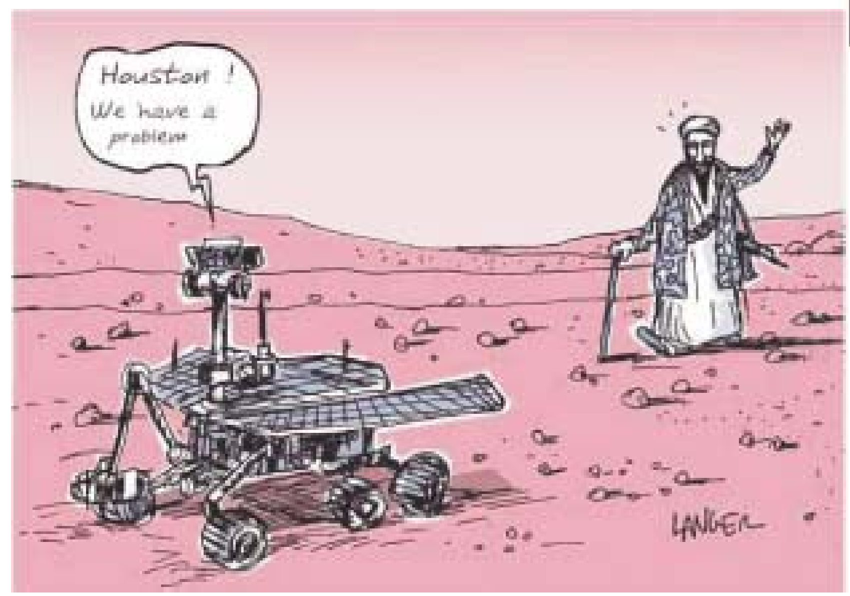
Frank Drake



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

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of star formation	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

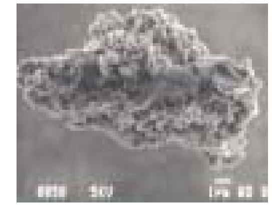
N = 135



Talkin' About a Revolution

- Molecules first showed up in space after enough heavy elements accumulated.
- There is a lot of interstellar molecular gas clouds in space.
- First complicated molecules found in space in 1968, and we have found even more over the last 20 years.
- They emit light in the millimeter regime.

In Dust We Trust

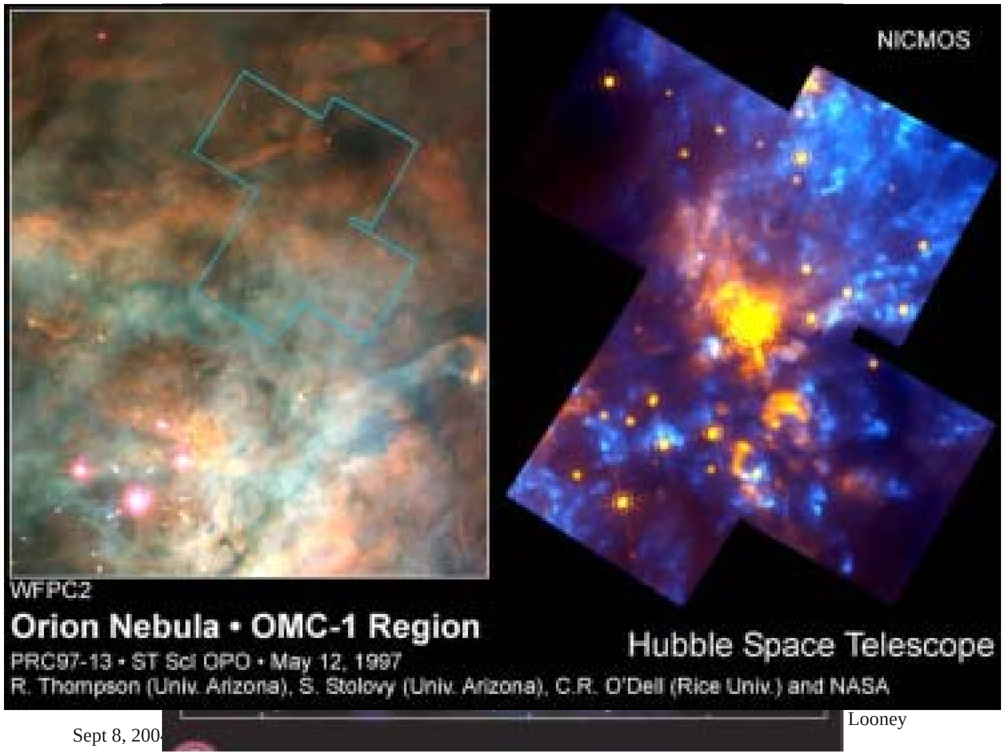


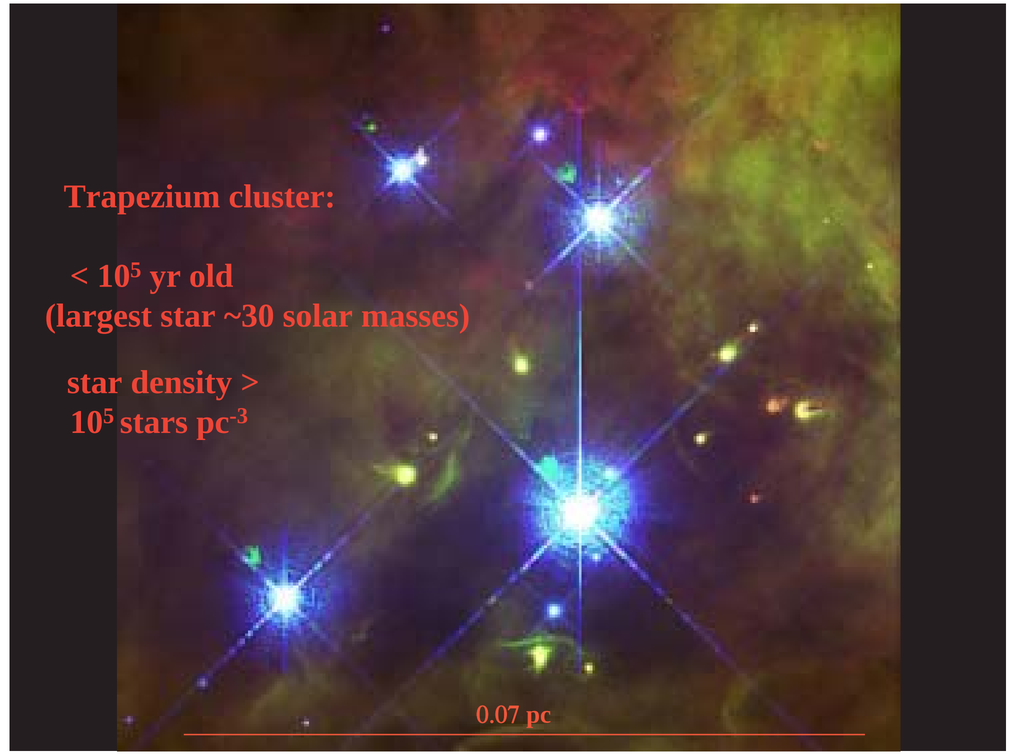
- Small (< 1 micron), solid particles
- Two types:
  - Primarily carbon (sort of like what we call soot)
  - Silicates, minerals of silicon and oxygen (sort of like what we call dust)
- Produced in material flowing from old stars, but mixed in space.
- When concentrated can protect molecules from ultraviolet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

Orion Nebula

(near infrared)

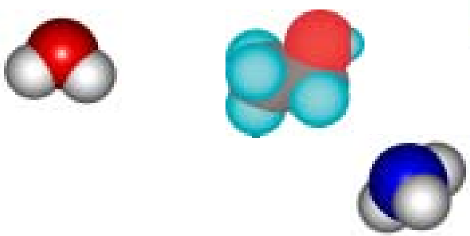
Nearest massive star forming region with a large molecular cloud associated (distance of 1500 lys)

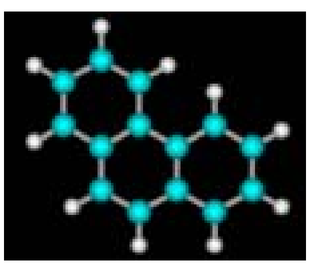




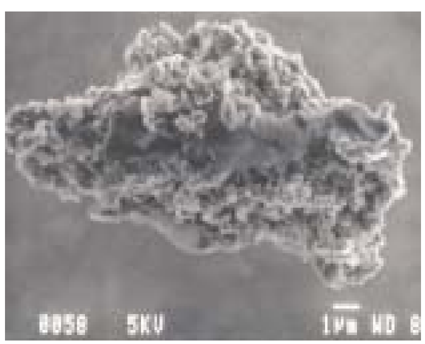
Other Things Besides Hydrogen in Molecular Clouds

- Molecules (e.g.)
  - Carbon monoxide (CO)
  - Water (H_2O)
  - Ammonia (NH_3)
  - Formaldehyde (H_2CO)
  - Glycine (NH_2CH_2COOH)?
  - Ethyl alcohol (CH_3CH_2OH)
  - Acetic Acid (CH_3COOH)
  - Urea [$(NH_2)_2CO$]
- Dust particles
  - Silicates, sometimes ice-coated
  - Soot molecules





Polycyclic aromatic hydrocarbons (PAH)



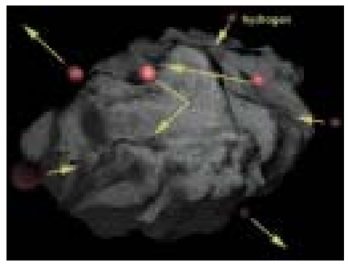
Dust particle (interplanetary)

So?

- Complex molecules (>13 atoms) have evolved in places other than the Earth.
- Maybe there are more? The more complex molecules are harder to detect.
- Seen in other galaxies too.

Molecule Formation

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

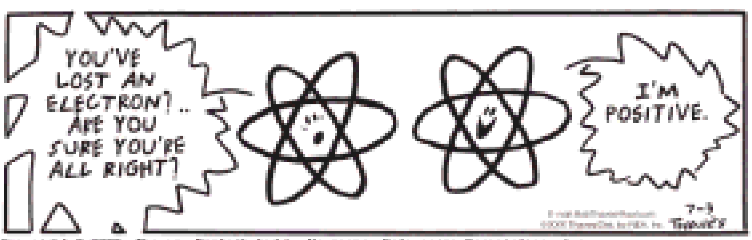


Complex Molecules

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

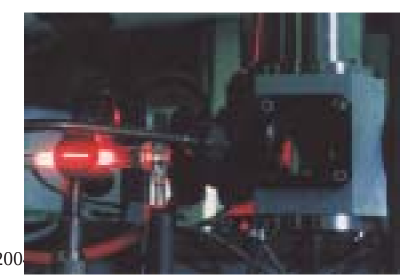
$$H_2^+ + H_2 \rightarrow H_3^+ + H$$
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

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



More to the Story: HONC

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



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

Panspermia

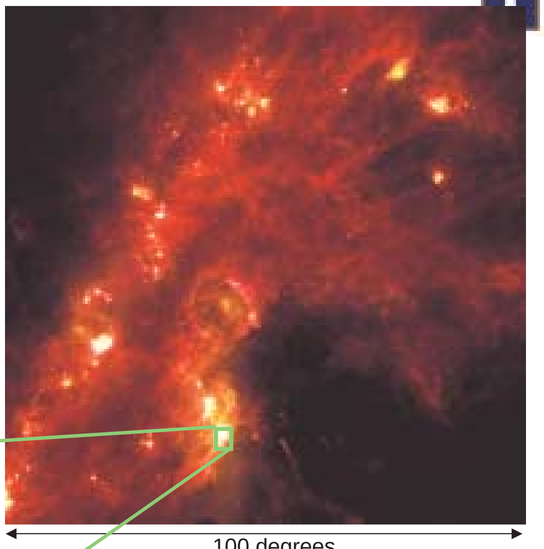
- Some have stated that perhaps life-important molecules formed in these clouds and spread to planets. Infection!
- Comets could have carried molecules to Earth's surface. Or ordinary meteors.
- Maybe epidemic outbreaks on Earth related to comet landings?
  - Incidentally, it has been observed that peaks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

Molecular Clouds

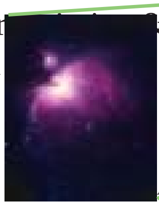
- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules– molecules or dust.
- H_2 is not good at emitting photons, so easier to see molecules emitting– especially CO (which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

Giant Molecular Clouds

- Cool: < 100 K
- Dense: $10^2 – 10^5$ H_2 molecules/cm^3 (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 – 10^6$ solar masses
- CO molecular x dust emission structure



Infrared image from *IRAS*

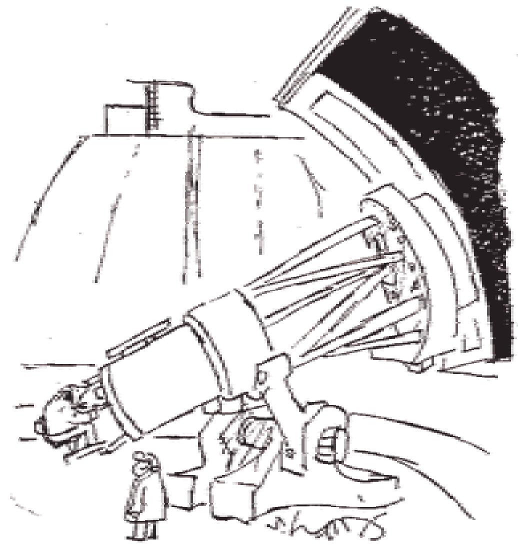


3 Lessons of Interstellar Molecules

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. <u>Dominance of carbon in interstellar chemistry.</u> 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 they were not expected

Estimate of R_*: The Rate of formation of Sun-like stars

- We are about to start the topic of star formation and planet formation, but really the field is not well developed to estimate R_*.
- It is more accurate to just take the total number of stars in the galaxy and divide by how long it took those stars to form.
- Later we will correct for the stars that are too big, too small, or too variable.



"Let's see, now ... picking up where we left off ... one billion, sixty-two million, thirty thousand, four hundred and thirteen ... one billion, sixty-two million, thirty thousand, four hundred and fourteen ... "

Counting Stars

Estimate of R_*: The Rate of star formation

Take the total number of stars in the galaxy and divide by how long it took those stars to form.

Sounds easy, but it isn't. We can't see all of the stars, interstellar dust blocks our view of most of them.

We can estimate the number of stars based on the total mass of the Galaxy and some corrections.

$$N_* = 5\times10^{10} \; to \; 5\times10^{11} \, stars$$

Estimate of R_*: The Rate of star formation

Age of our galaxy is around 10^{10} years.

$$R_* = \frac{5\times10^{10} \; to \; 5\times10^{11} \, stars}{10^{10} \, years} = 5 \; to \; 50 \, \frac{stars}{year}$$

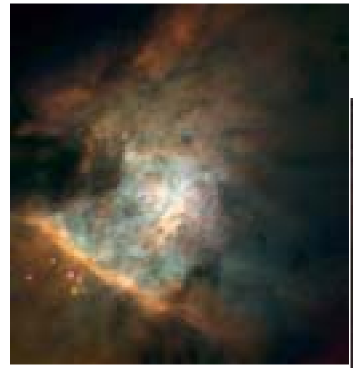
Probably the best estimate for the entire Drake Equation, meaning it can be off my a factor of 10 or so.

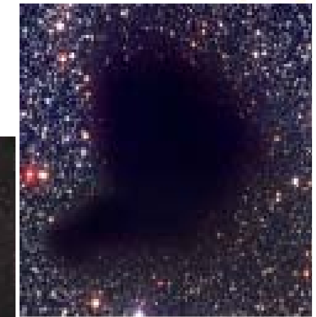
Estimate of R*:
The Rate of star formation

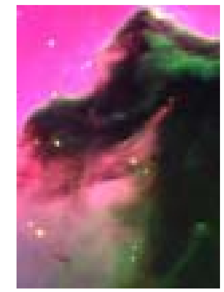
$$R_* = \frac{5\times10^{10} \text{ to } 5\times10^{11}\, stars}{10^{10}\, years} \approx 5 \text{ to } 50 \frac{stars}{year}$$

Choose a lower/higher number if you think that the star formation rate was biased by non-uniform star formation. Did the early galaxy produce more stars? Was there a star burst long ago?

Interstellar Clouds



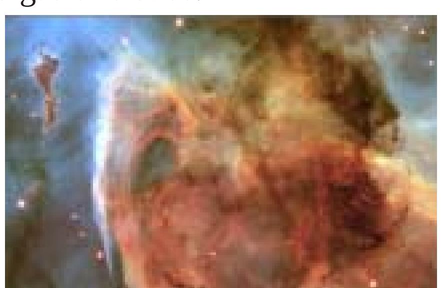




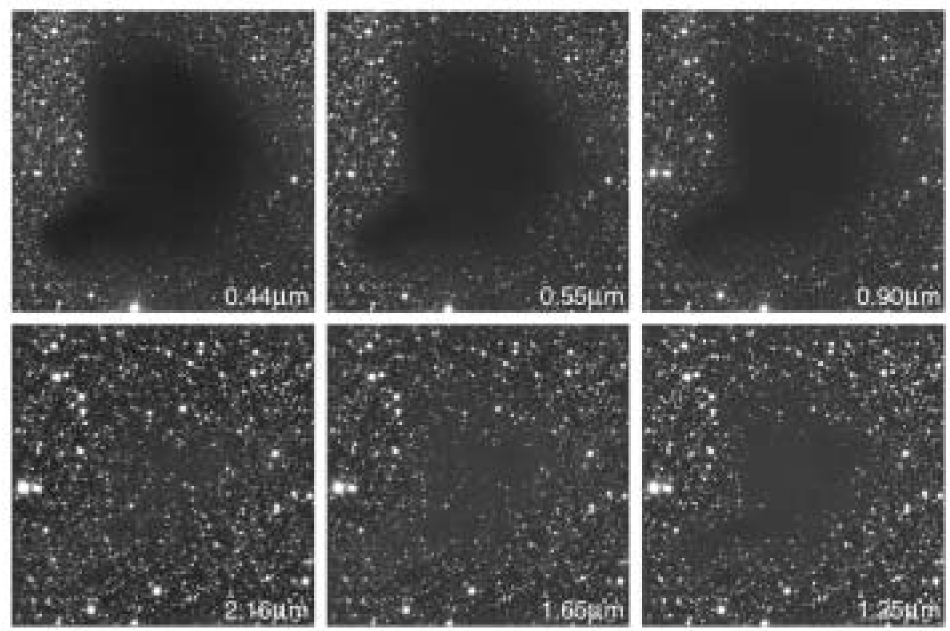
http://www.seds.org/messier/more/oricloud.html

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



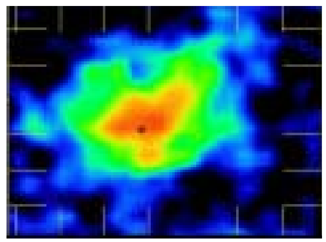
The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

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

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, as molecules and dust easily emit in the radio and infrared.
  - Thus, 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?*

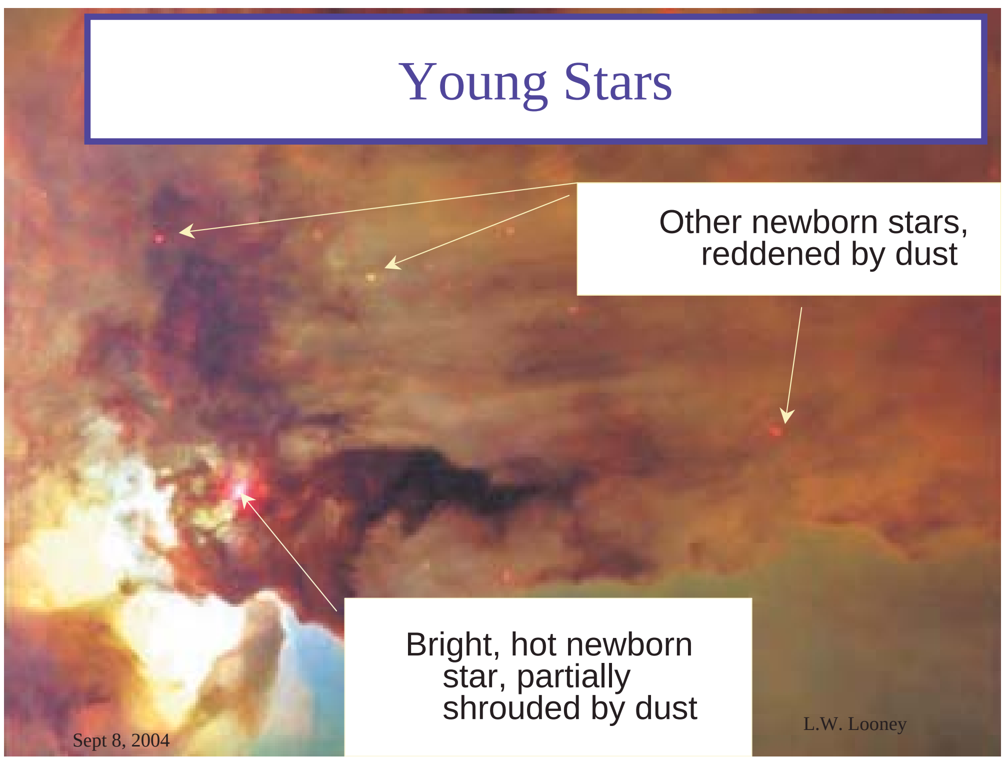
$C^{18}O$ emission from L483



How do we know?

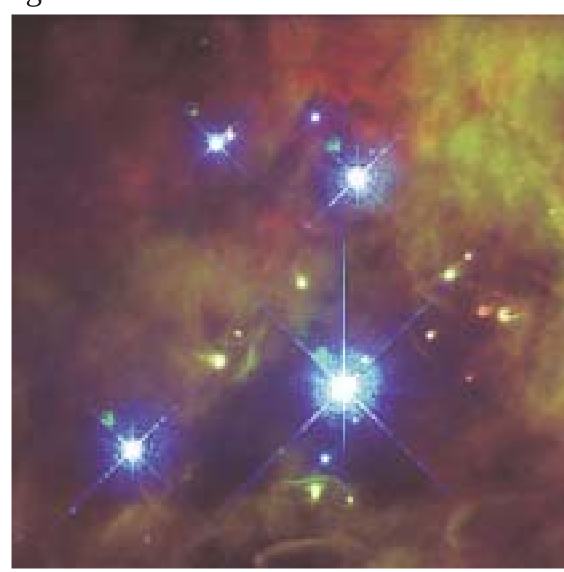
- Young stars are seen near molecular clouds.
- In infrared light, we can see into the deeper regions of clouds, and see clusters of young stars with circumstellar material (dust and gas) surrounding them.
- Stars are continuously being formed in our galaxy.

Young Stars



The Birthplace of Stars

- Young stars often are seen in clusters
- Very young stars are also associated with clouds of gas (nebulae)



The Trapezium

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^6 years.
- Main sequence life (depends on mass!)
  - Few x 10^6 years to more than age of Universe
  - Thermonuclear burning of H to He
- Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes

Stellar Middle Age

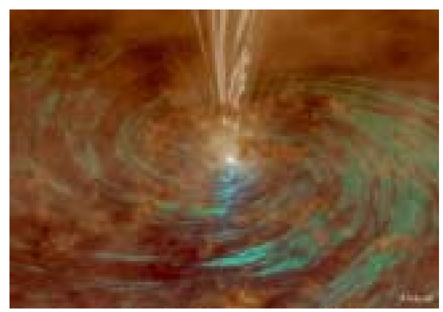
Stars like the Sun

Massive stars

Stars

- The fundamental building blocks of the Universe.
- High mass stars are 8 to 100 solar masses
  - Short lived: 10^6 to 10^7 years
  - Luminous: 10^3 to 10^6 L_{sun}
  - Power the interstellar medium– input of energy
- Intermediate Stars are 2 to 8 solar masses
- Low mass stars are 0.4 to 2 solar masses
  - Long Lived: >10^9 years
  - Good for planets, good for life.
  - Not so luminous: 0.001 to 10 L_{sun}

Star Formation



Stars are born in cold, dense interstellar clouds

- Cold gas
- Dust grains

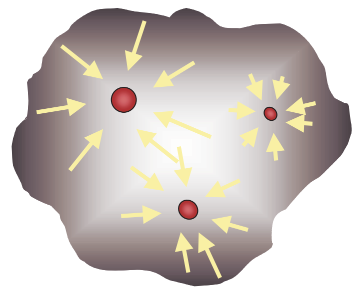
Star formation is probably triggered by

- Cloud turbulence
- Collision with another cloud
- Nearby supernova explosion
- Nearby hot star wind
- Disturbance from the Galaxy

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.
- This process is slower than for the first stars where the clumps were much more massive.
- As the collapse proceeds the molecules and dust emit light, keeping the temperature of the core low.

Cloud Contraction



But..

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

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

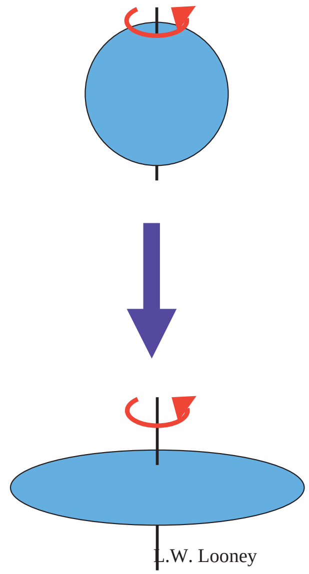
Move closer to axis → speed up!

Recall Kepler 2nd law – really due to angular momentum!

When Doves Cry and Stars Form

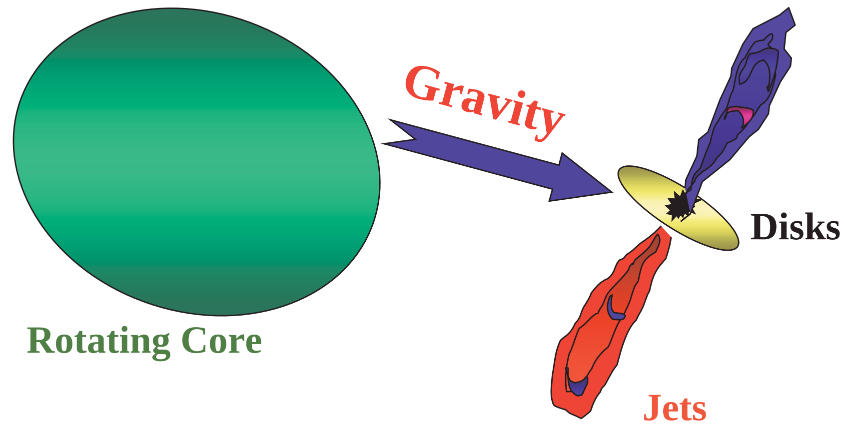
Solar nebula competition:
Gravity vs Angular Momentum

- If fall perpendicular to spin axis
  speed up → resistance
  centrifugal force
- If fall parallel to spin axis
  same speed, so no resistance
  → form ***protoplanetary disk***
  - Origin of ecliptic!
  - Organizes orbits in same direction
  - Organizes spins along initial spin axis

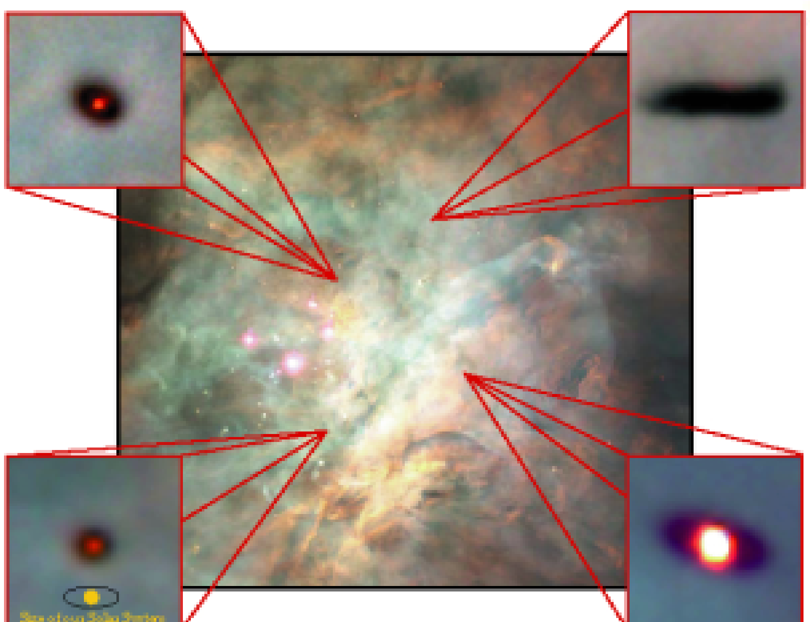


The Protostar Stage

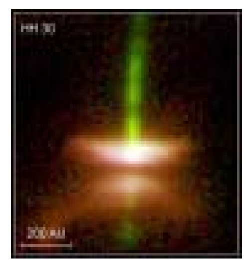
Gravity, Spin, & Magnetic Fields



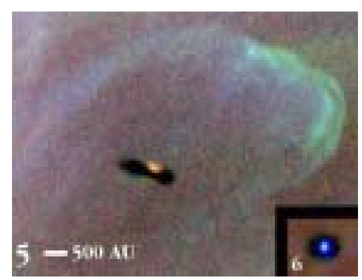
Disks around Young Stars are Common

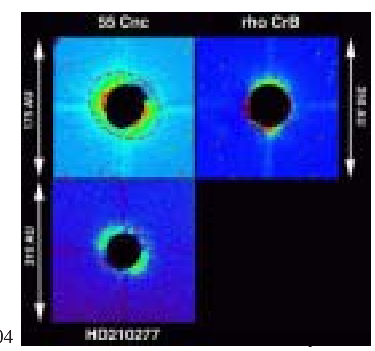


And Disks around Young Stars are Common



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





The Circumstellar Disk of HL Tauri