ET Life

<u>This class (Lecture 8):</u>

Star Formation

<u>Next Class:</u>

Exoplanets

HW 3 is due Sunday.

First Exam in 2 weeks!

Music: *Sonne* – Rammstein

Presentations

- Good job first presenters!
- Fun and interesting!

- Some people were slow in emailing their presentations.
- Peers (who are grading you) don't want to wait for you to upload new file from flash drive!
- Email it Tuesday night at the latest!
- Or else..

Last Chance

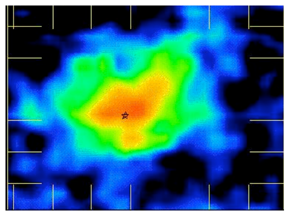
- Check iclicker grades on Compass
- If you do not have grades, then make sure to register it now!
- 4 students are not registered!

Outline

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

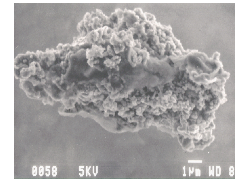
The Importance of being a Molecular Cloud

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



$C^{18}O$ emission from L483

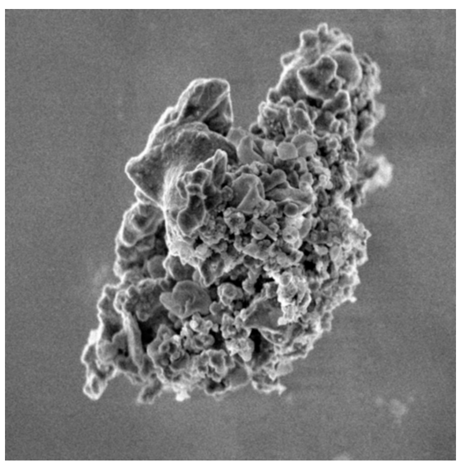
In Dust We Trust



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

Molecule Formation

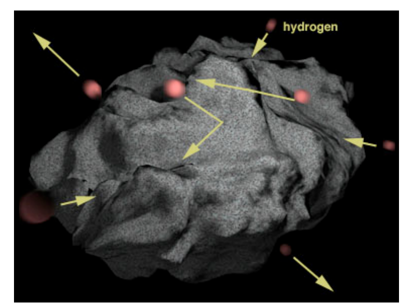
- When molecules form, they must release energy by emitting light or colliding
- Difficult to do in the gas phases, need dust grains as a catalysis.



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

Molecule Formation

- H on dust grain, gets hit by another H, then extra energy ejects the newly formed molecule H_2 from the dust grain.
- For more complicated molecules, they need to be ionized to get easy reaction in space.
- What ionizes the molecules? Ultraviolet light would work, but then the molecules would get destroyed.

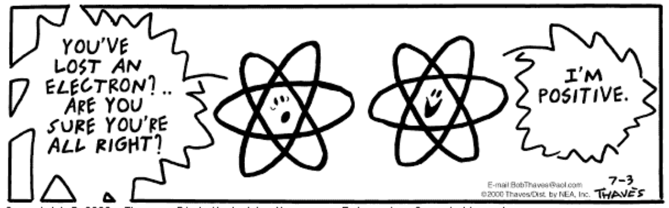


How to Get Complex Molecules

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

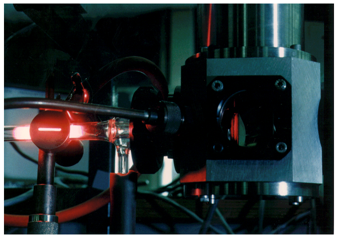
$$H_2^+ + H_2 \rightarrow H_3^+ + H$$
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

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



More to the Story: HONC

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



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

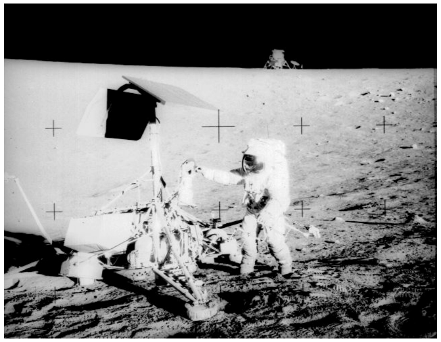
Panspermia

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

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

Panspermia: Case in Point

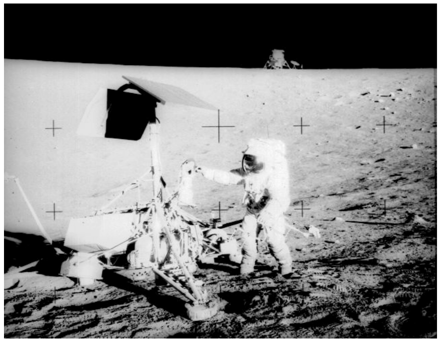
- Surveyor 3: unmanned lunar probe which landed in 1967.
- 2.5 years later, a camera was retrieved by Apollo astronauts.
- The camera had 50 to 100 viable specimens of *Streptococcus mitis*, a harmless bacterium commonly found in the human nose, mouth, and throat.



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

Panspermia: Case in Point

- The camera was returned under strict sterile conditions.
- The bacteria had survived 31 months in the absence of air or water!
- In SPACE!
- Was subjected to large monthly temperature variations and hard ultraviolet radiation from the Sun.



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

3 Lessons of Interstellar Molecules

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

Question

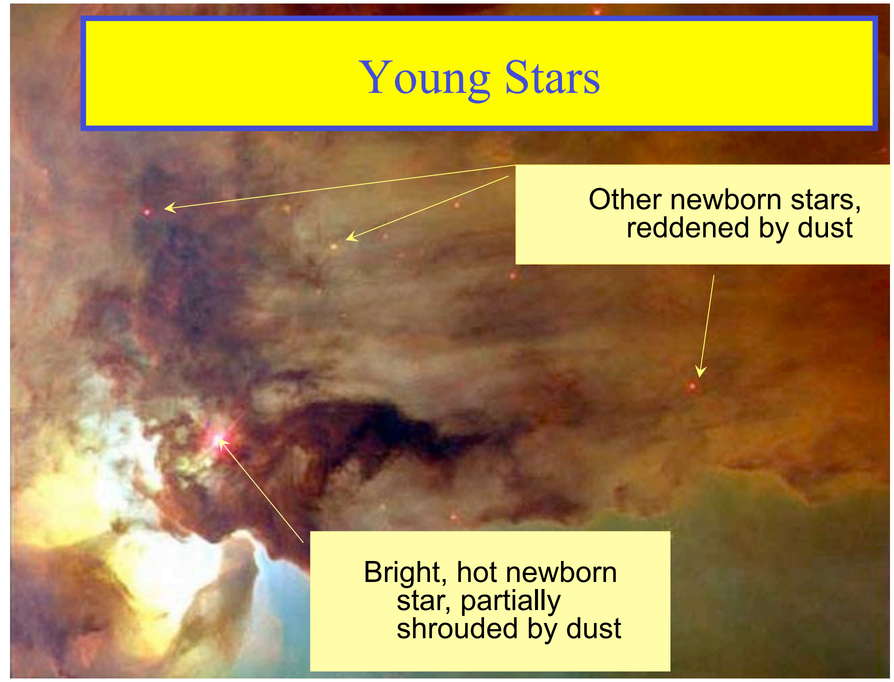
The molecules that life uses on Earth are complex. In space

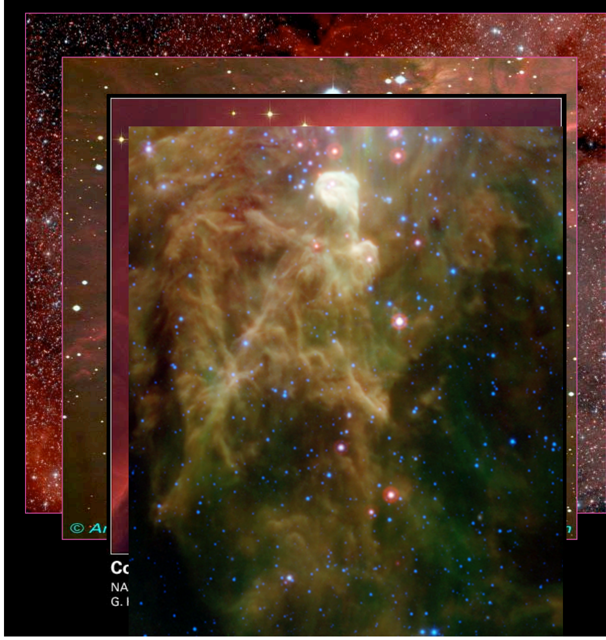
a) no one can hear you scream.
b) complex molecules can not be created. The environment is too harsh.
c) complex molecules, up to 13 atoms, have been detected in large quantities.
d) the only kind of molecules detected are missing C.
e) all molecules are detected.

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.

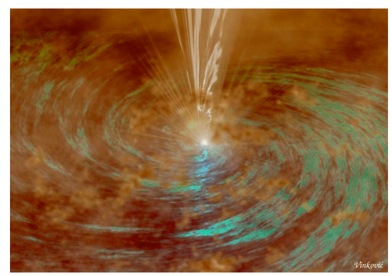
http://antwrp.gsfc.nasa.gov/apod/ap030630.html





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.

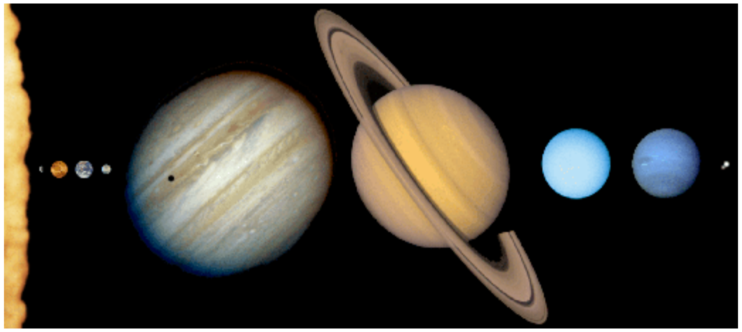
What is the origin of the Solar System?

- 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?

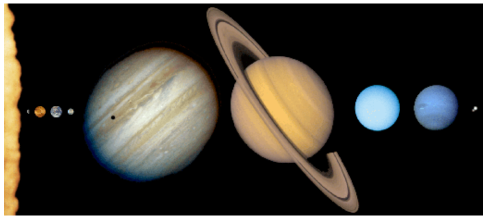
Some Facts of the Solar System

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



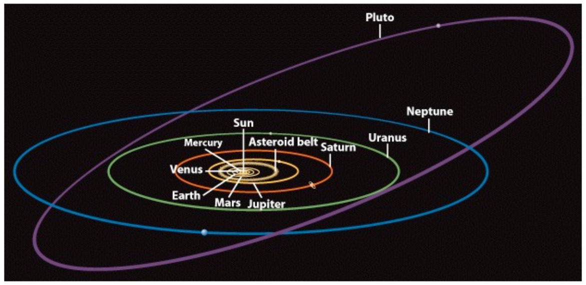
Some Facts of the Solar System

- 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)

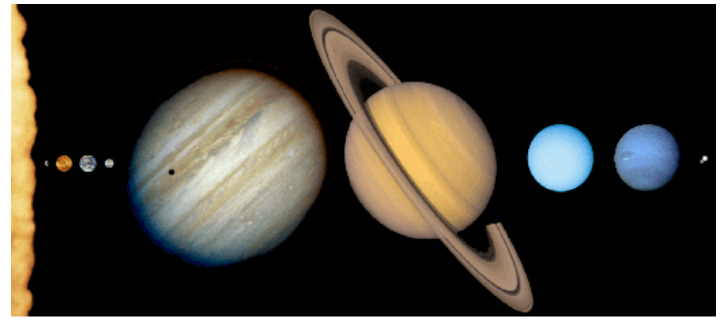


- There are some exceptions
- Venus, Uranus, and Pluto rotate clockwise (orbits are still clockwise)
- Some moons orbit backwards

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

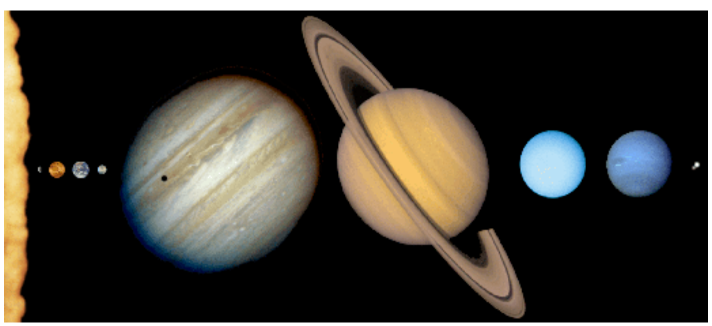
Some Facts of the Solar System

- 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 obit, 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

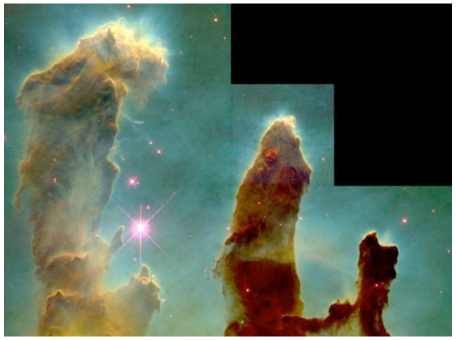
- **Age of Solar System is probably around 4.6 billion years old**

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.

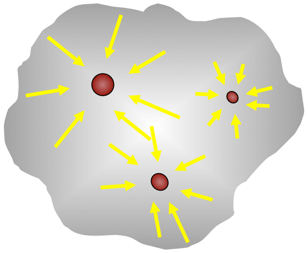


Gravitational Contraction

- 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

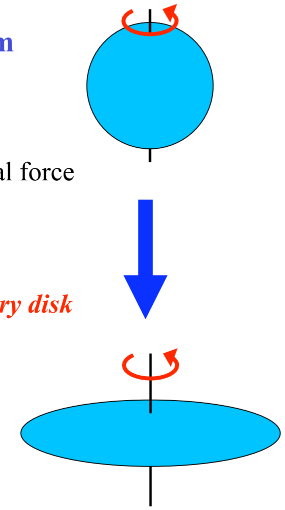
Move closer to axis → speed up!

Kepler's 2nd law – really due to angular momentum!

When Doves Cry and Stars Form

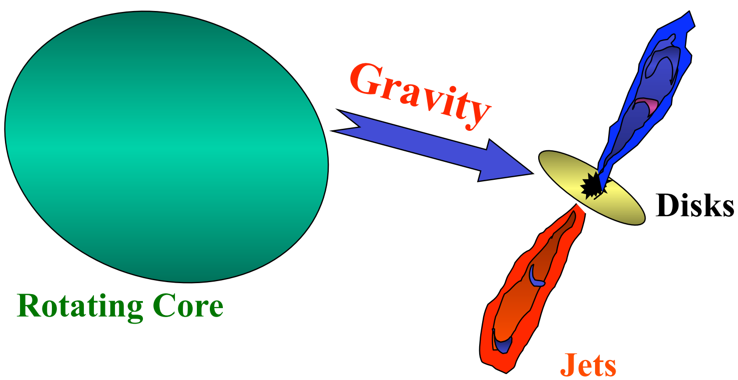
Solar nebula competition:
Gravity vs Angular Momentum

- If fall perpendicular to spin axis
  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

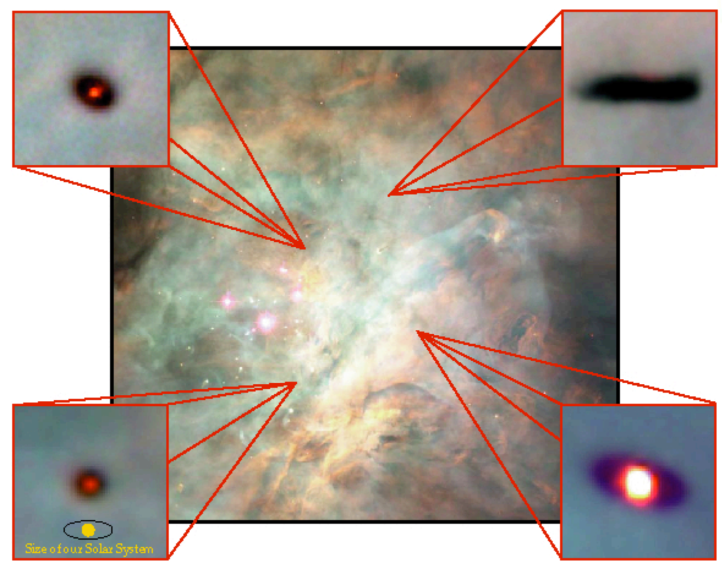


The Protostar Stage

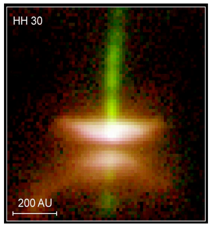
Gravity, Spin, & Magnetic Fields

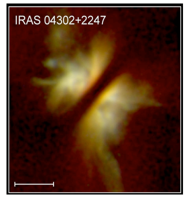


Disks around Young Stars are Common

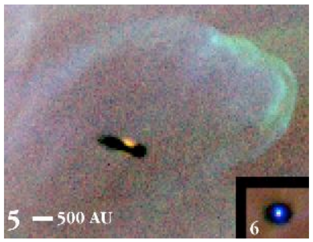


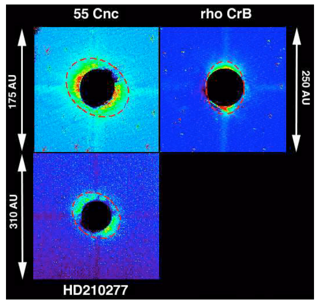
And Disks around Young Stars are Common



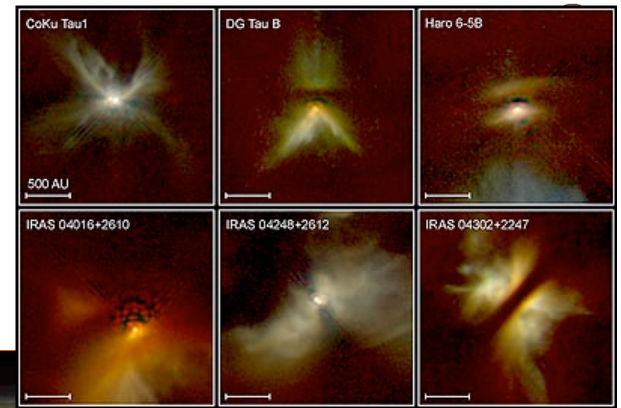


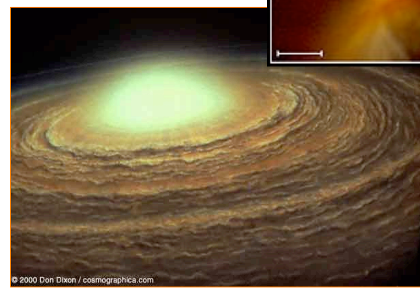
http://
www.ifa.hawaii.edu/
users/tokunaga/SSET/
SSET.htm





Disks have been imaged with HST's infrared camera

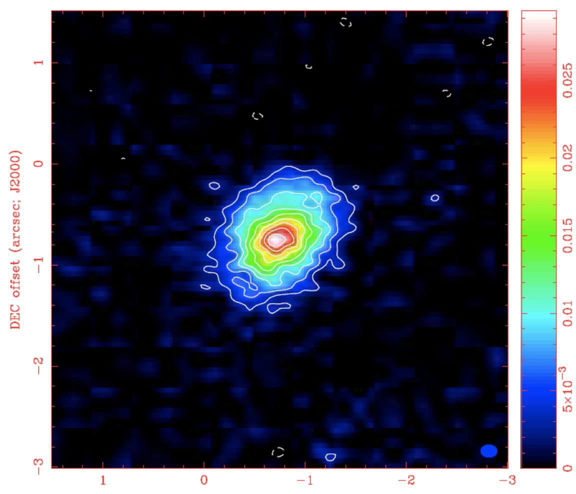




Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material

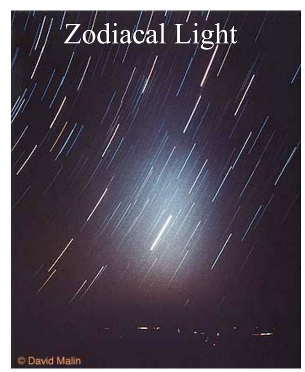
HL Tauri

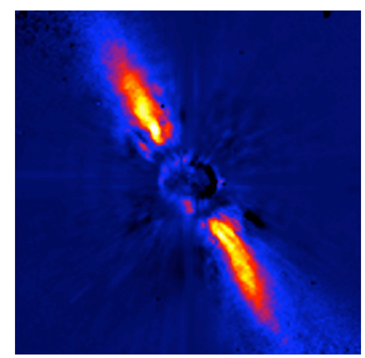


Looney et al. 2009

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.

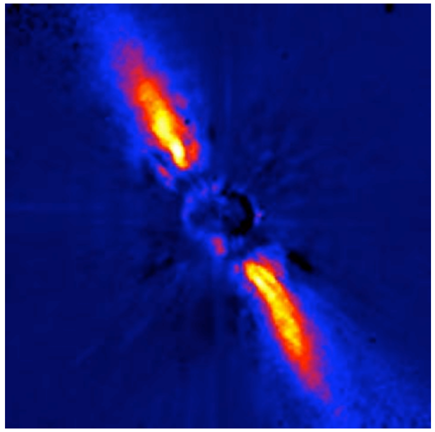


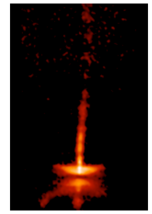


http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

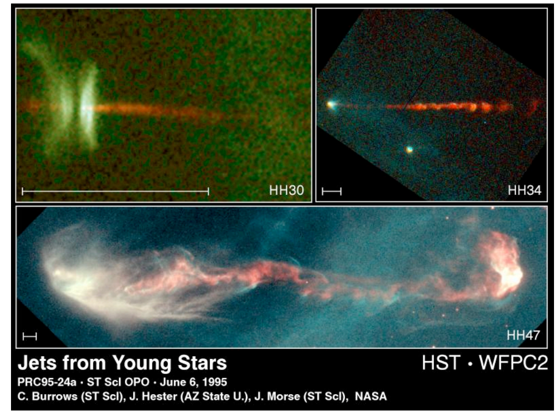
Disks Around Young Stars

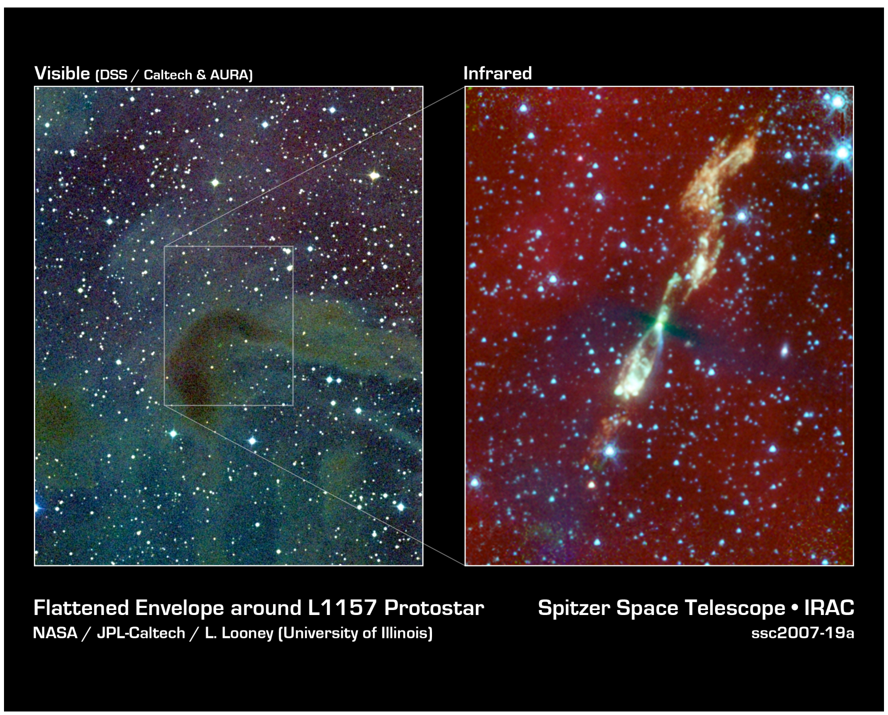
- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!



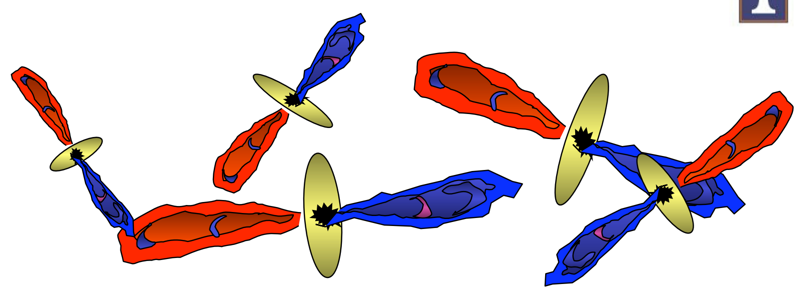


Protostellar Jets



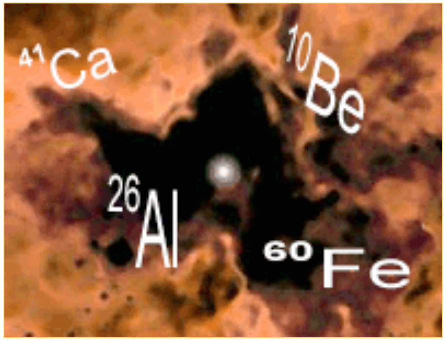


Young Stars in Groups



- 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

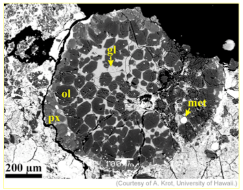
^{26}Aluminum
- 13 protons
- 13 neutrons

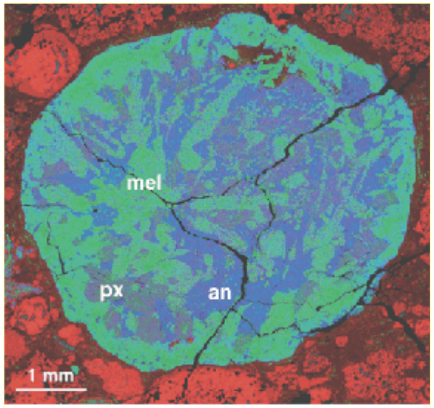
↓

^{26}Magnesium
- 12 protons
- 14 neutrons

The Earliest Pre-Solar Dust Grains

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





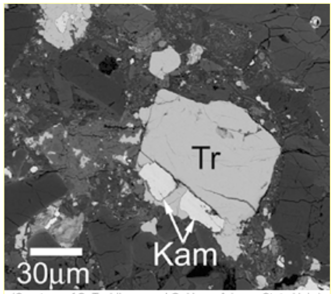
(Courtesy of A. Krot, University of Hawaii.)

Formed 4,700,000,000 years ago

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.)

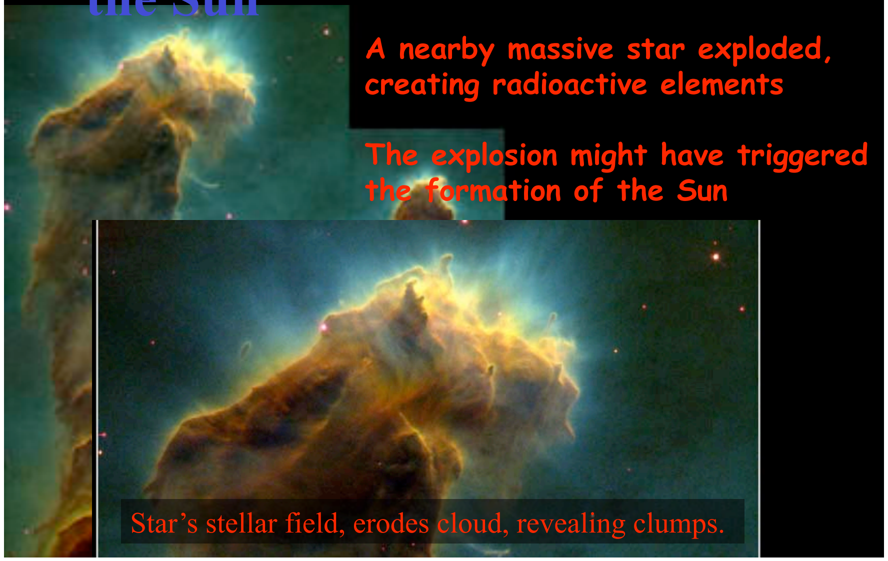
Half life 1.5 million years

The Birth of the Sun

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

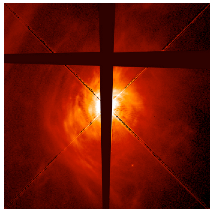
A nearby massive star exploded, creating radioactive elements

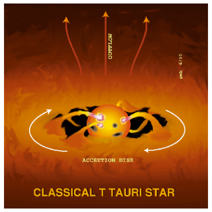
The explosion might have triggered the formation of the Sun



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

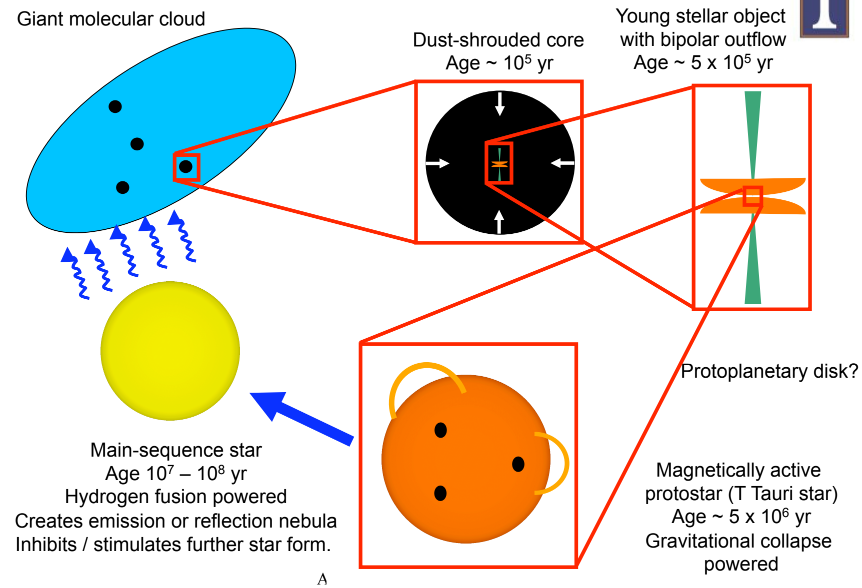
On to the Main Sequence: A Star is Born!





- 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



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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

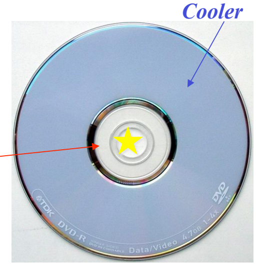
The Early Solar System

- 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.

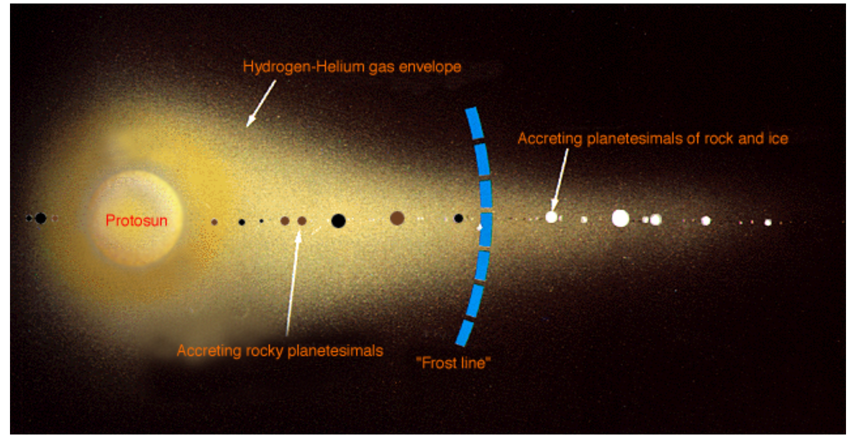
The cloud collapsed under its gravity and formed the circumstellar disk from which our solar system formed. Most theories for solar system formation require disks with masses of 0.01 to 1 solar masses.

Everyone Loves Disks

- As the star forms, the inner region of the disk gets much hotter than the outer regions, creating a temperature gradient.
- The inner part of the disk had a higher density than the outer regions.
- Icy mantles of dust grains (NH_3, CH_4, etc.) evaporated at varying distances.



Why are the Planets so Different?

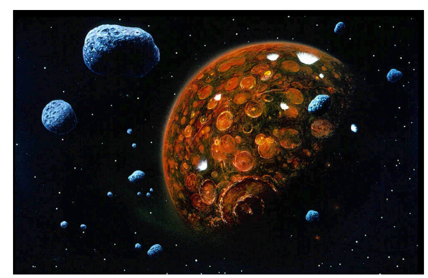


Temperature is the key factor!

Why are the Planets so Different?

- Temperature is the key factor
- Inner Solar System: Hot
  - Light gasses (H, He) and "ices" vaporized
  - Blown out of the inner solar system by the solar wind
  - Only heavy elements (iron & rock) left
- Outer Solar System: Cold
  - Too cold to evaporate ices to space
  - Rock & ice "seeds" grew large enough to pull gasses (H, He) onto themselves

Heavy Bombardment



- There were billions of planetesimals in the early solar system
- Many collided with the young planets
  - Look at the Moon & Mercury!
  - Period of **heavy bombardment**
  - Lasted for about the first 800 million years of the Solar System
- Others were ejected from the solar system…

Fates of the Planetesimals

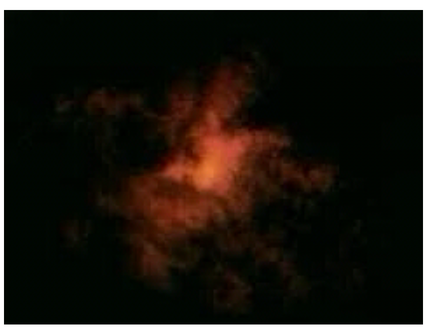
- Between Mars and Jupiter
  - Remain as the asteroids
- Near Jupiter & Saturn
  - Ejected from the solar system
- Near Uranus & Neptune
  - Ejected to the Oort Cloud
- Beyond Neptune
  - Remain in the Kuiper Belt

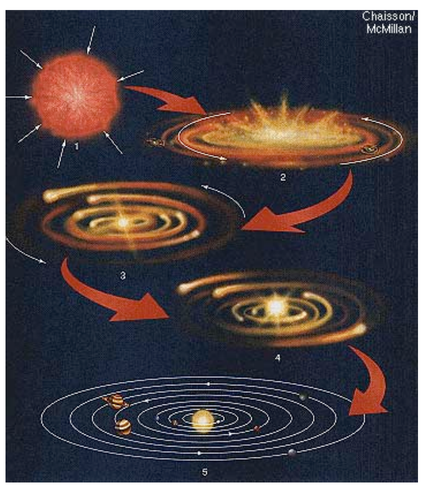
Planet Formation in the Disk

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

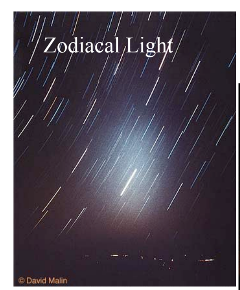
Formation of the Solar System 4.6 billion years ago

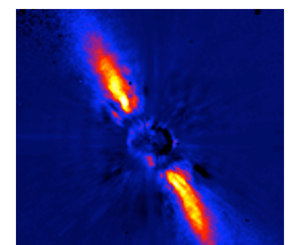




Fossil Disks Exist around other Stars?

- We see old disks around other stars (e.g. Vega and Beta Pictoris) as well as our own.
- Many (more than half!) of newborn stars surrounded by a disk of material!
- Disks are thick and dusty
  - Enough material to make planets
  - Agrees with the Solar Nebula theory!





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