ET: Astronomy 230

Section 1– MWF 1400-1450

134 Astronomy Building

This Class (Lecture 8):

Planet Formation

Next Class:

Nature of Solar Systems

HW #2 is due on Friday

First Presentations on 19th and 23rd

Outline

- From molecular clouds to baby stars– protostars.
- Star formation requires a circumstellar disk that is often seen around young stars.
- The origin of the Solar system also requires a disk of material in which dust clumped, forming planetesimals, then planets.
- Planets are different due to distance away from Sun..

Presentations

- Will be treated like a real scientific talk at a meeting.
- I will keep you to 10 minutes with 5 minutes of questions.
- Any speculative claims *MUST* have a scientific reference source.
  - Can't just claim that monkeys live on the Moon.

Presentations

- Can give presentation in any format you want.
- Last semester:
  - 92% powerpoint
  - 5% talking with pics from webpages
  - 1% dedicated webpage
  - 2% overhead slides
- If presentation is electronic
  - Email me evening before
  - Or, on netfiles, email me URL location BEFORE class
  - Or, bring in burned CD (present to me BEFORE class)

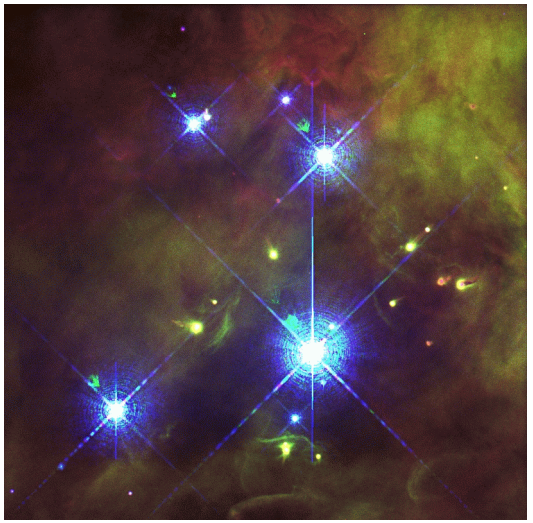
Oral Presentation

1. How relevant is the topic to the search for extraterrestrial life?
2. How interesting is the topic for the general class audience?
3. Rate the extent of the speakers knowledge on the topic?
4. Rate the quality of the overall presentation?
5. Does the research have a solid scientific basis?

These questions are rated 1-10 out of 10 scale by your peers!

The Birthplace of Stars

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



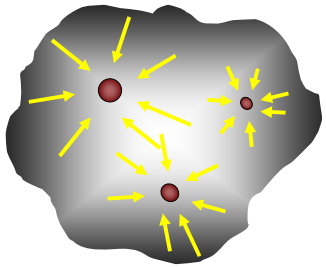
The Trapezium

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.

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.

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

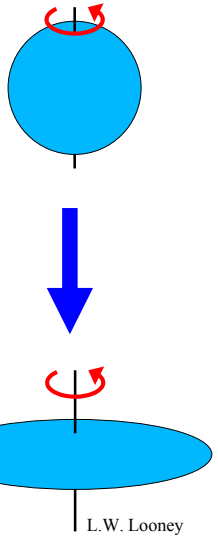
Move closer to axis ➡ speed up!

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

When Doves Cry and Stars Form

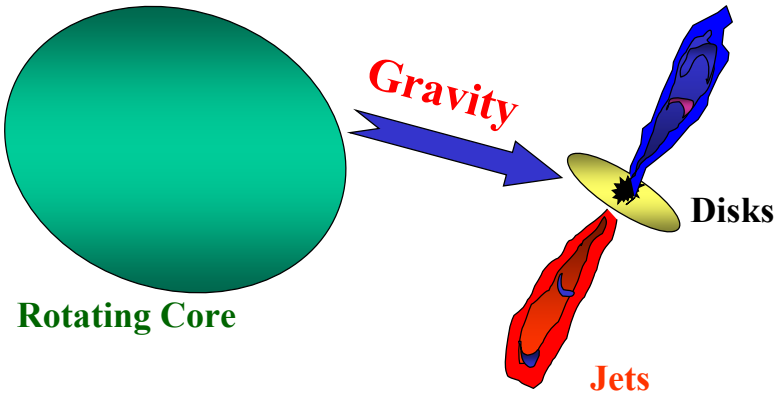
Solar nebula competition:
Gravity vs Angular Momentum

- 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 planet's orbits!
  - Organizes spins along initial spin axis

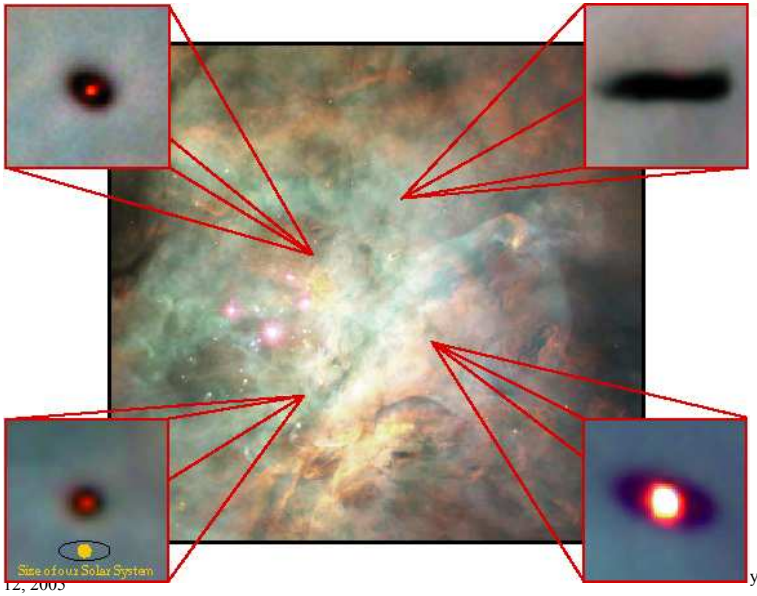


The Protostar Stage

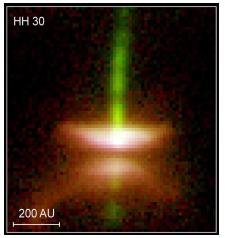
Gravity, Spin, & Magnetic Fields

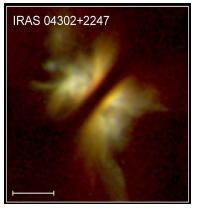


Disks around Young Stars are Common

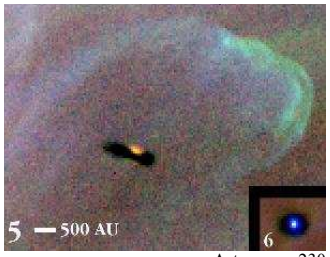


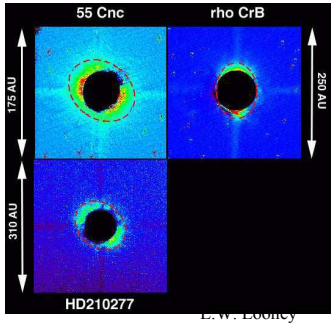
And Disks around Young Stars are Common



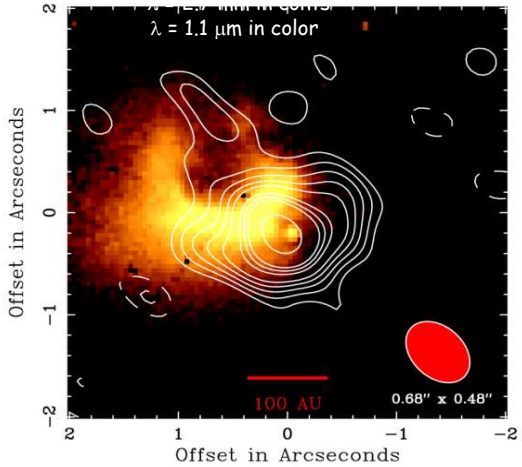


http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm



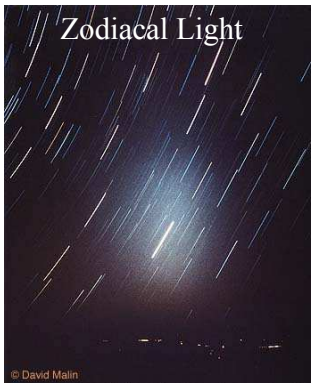


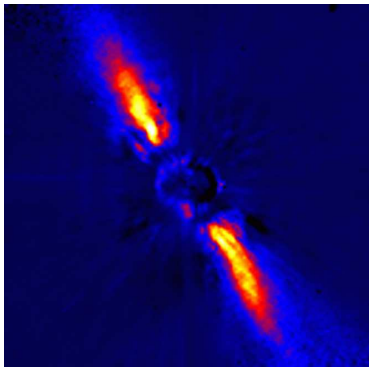
The Circumstellar Disk of HL Tauri



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.

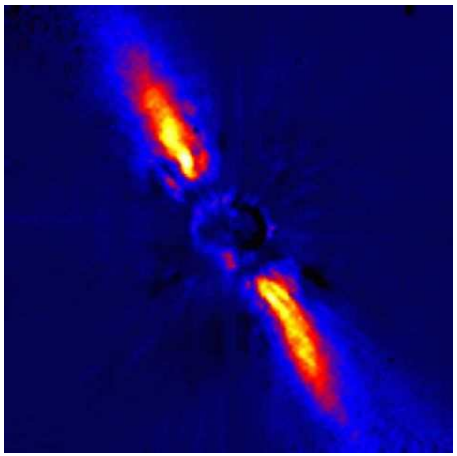




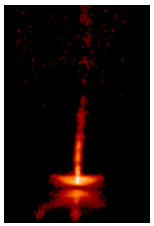
http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

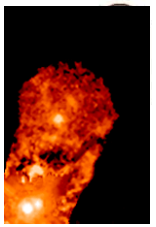
Disks Around Young Stars

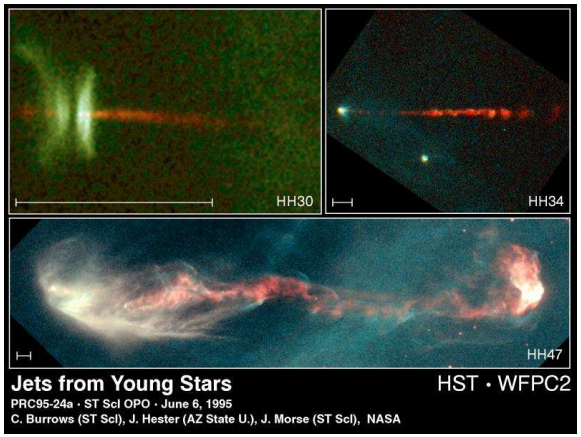
- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!



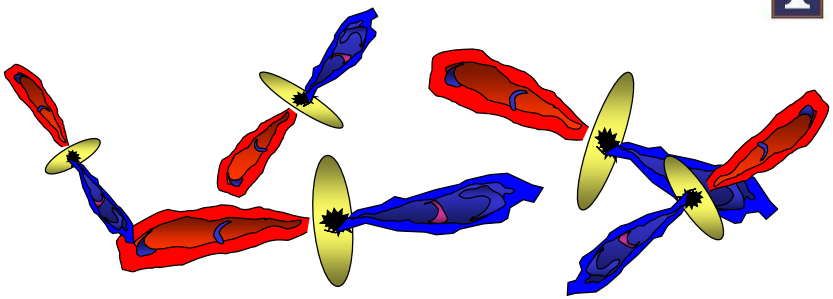
Protostellar Jets







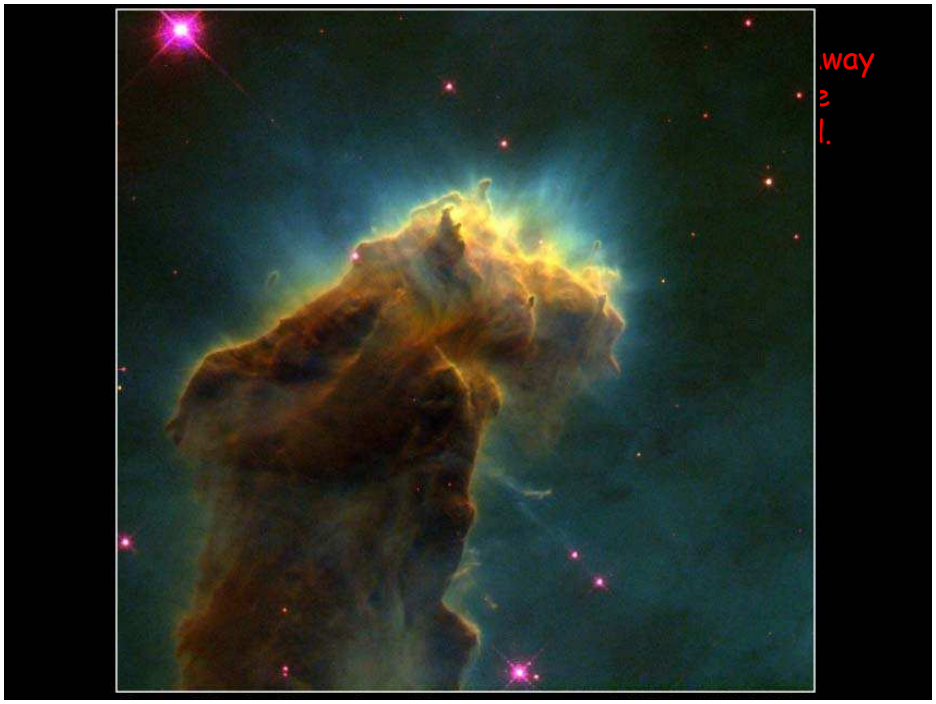
Young Stars in Groups



- Most stars are in multiple systems.
- How does this effect the protostars?
- How does this effect their planet formation?
- How does this effect the possibility of life on the *average* star?

The Cone Nebula

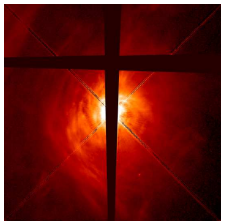
A Star Forming Region

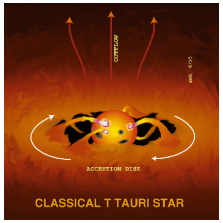


The Protostar Archetype: T Tauri

http://www.astrosurf.com/jwest/ttauri.htm

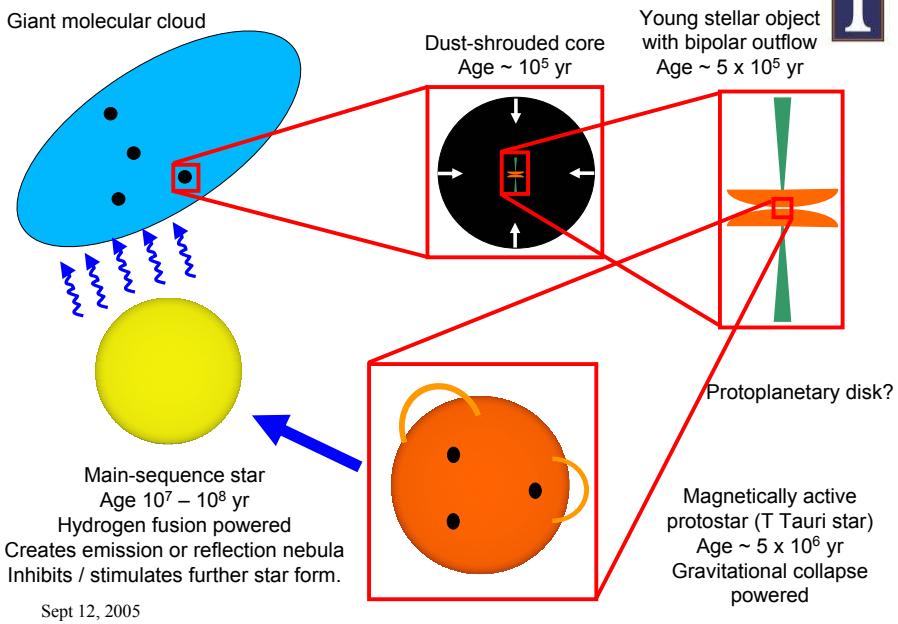
On to the Main Sequence: A Star is Born!





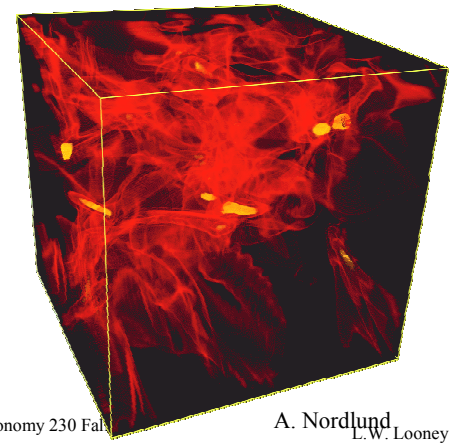
- Density increase, temperature increases until fusion can occur.
  - Blows away most of its natal circumstellar material.
  - Becomes a star on the main sequence of the HR diagram,
  - For low mass stars, this whole process can take 10^6 years.
  - Expect to see a large number of embedded protostars.

Star Formation - Summary



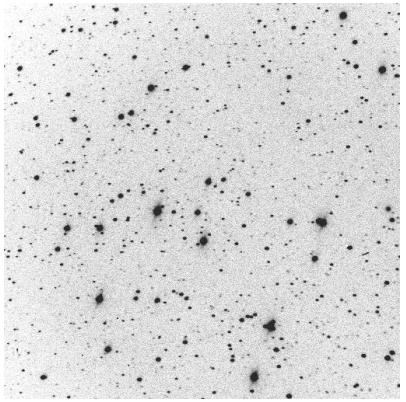
Some outstanding Star Formation Issues

- Why do the cores collapse, but not the entire molecular cloud?
- What sets the sizes of cores, and hence masses of stars?
- What determines how stars cluster, group together, or form multiple systems?



A. Nordlund

Stars Ages and ETs



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

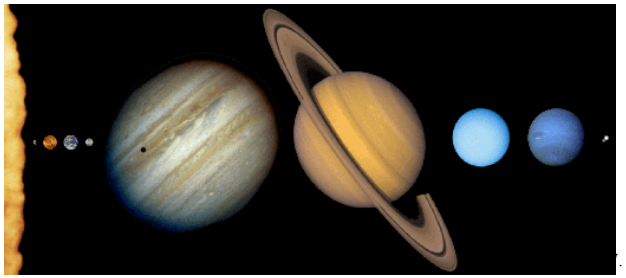
What is the origin of the Solar System?

- 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?

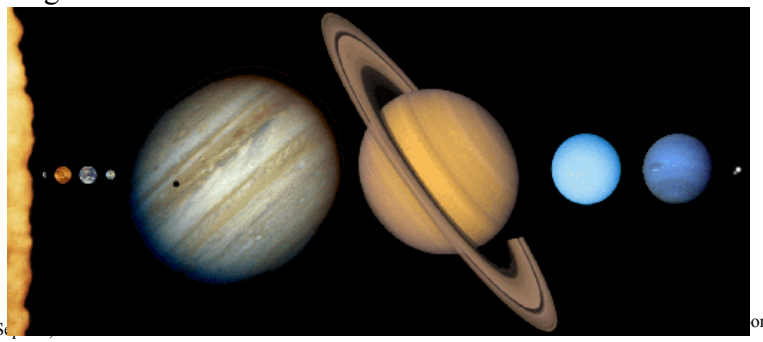
Some Facts of the Solar System

- We have 8 or 9 planets.
  - Pluto, an anomaly in many ways, probably a Kuiper object or moon of Neptune. Other Kuiper objects are being found.
- So perhaps the average extrasolar system has about 10 planets (rounded off).
- The Sun has 99.9% of the mass, but the planets have 98% of the angular momentum (energy stored in orbits)



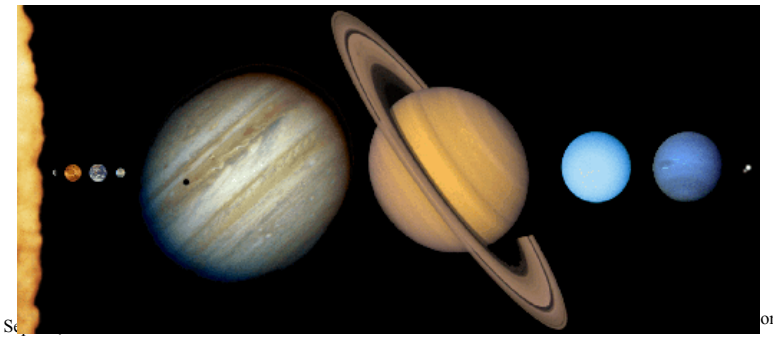
Some Facts of the Solar System

- Outer planets more massive than inner planets.
- Most of the motions in the Solar System are counter clockwise (problems with Venus, Uranus, or Pluto) in a flat system (pancake-like).
- 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



Data: Planet's Dance

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

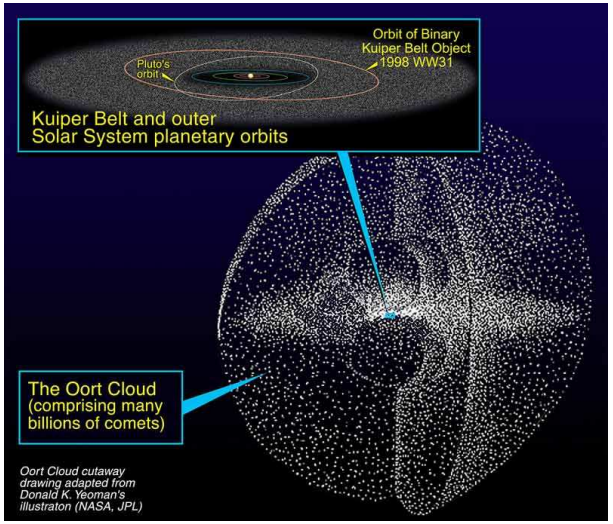
Data:
The Structure of the Solar System

- What are the furthermost solar system objects from the sun and what is their distribution?

Icy objects or long period comets

Furthermost objects form the Oort cloud!
So…Spherical Geometry.

Data: Kuiper Belt



Data:
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

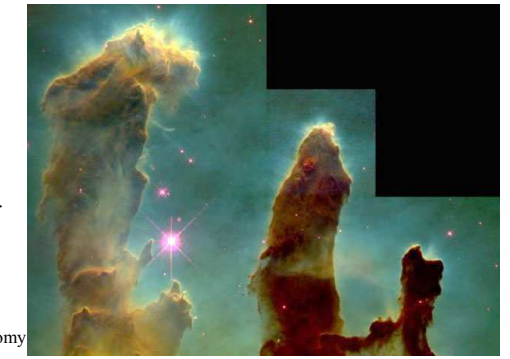
Age of Solar System is probably around 4.6 billion years old

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 idea of star formation developed last class.



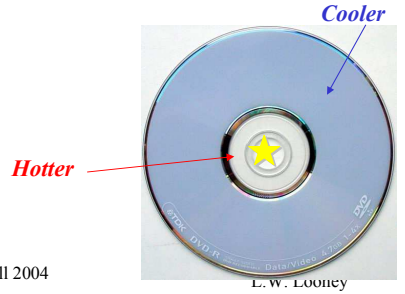
The Early Solar System

- 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.



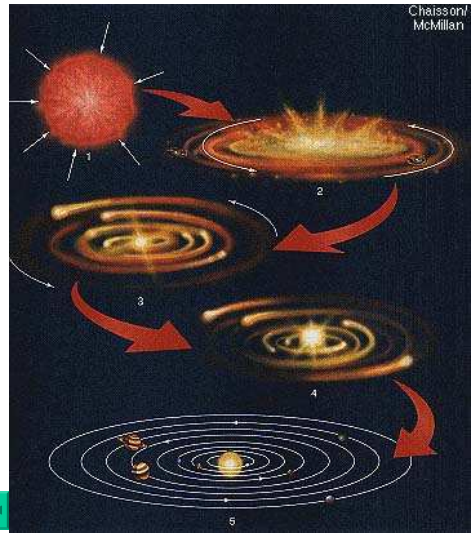
Planet Formation in the Disk

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

What it might have looked like.

http://eeyore.astro.uiuc.edu/~lwl/classes/astro100/fall03/Lectures/solarsystemform.mov



What Are We Looking For?

General Predictions of Solar Nebula Theory

- ☺ Are interstellar dust clouds common? ***Yes!***
- ☺ Do young stars have disks? ***Yes!***
- ? Are the smaller planets near the star?
- ? Are massive planets farther away?

Drake Equation

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 communicate	Lifetime of advanced civilizations

?

Test of Exoplanets

Planets around other stars

= extrasolar planets = "***exoplanets***"

Would our solar system nebula formation theory account for other solar systems around other stars?