# Astronomy 230

## Section 1– MWF 1400-1450

## 106 B6 Eng Hall

<u>This Class (Lecture 7):</u>

Planet Formation and

<u>Next Class:</u>

Extrasolar Planets



# 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..



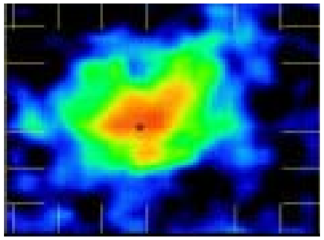
# HW #2: Due Sept 20th

1. Using a web search engine, find a web page about aliens, ET intelligence, or UFOs that interests you (not about your presentation topic). Use at least 2 key words for search. Write down your key words, URL, and print main page (only 1 page necessary).
2. Write a 3-4 sentence summary of web page content.
3. Critique web page in another 3-4 sentences.
   - Does it have a scientific basis?
   - Does it use common sense reasoning?
   - Does it sound reasonable?
4. List one thing good and one thing that sounds crazy (if possible) from the webpage conclusions.
5. Be prepared to discuss in class.



# 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?*



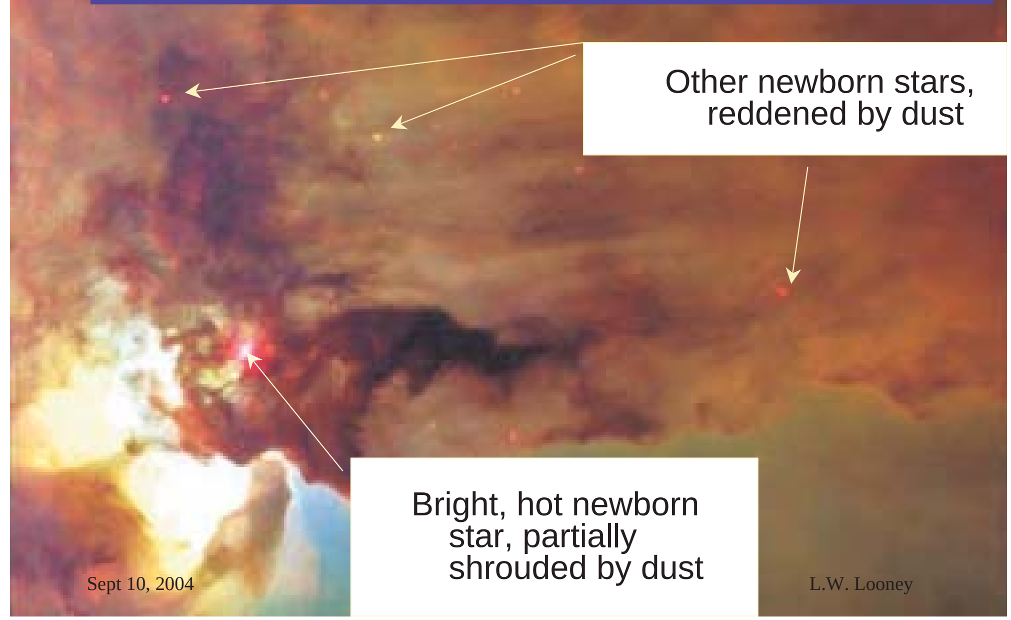
$C^{18}O$ emission from L483

# 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.



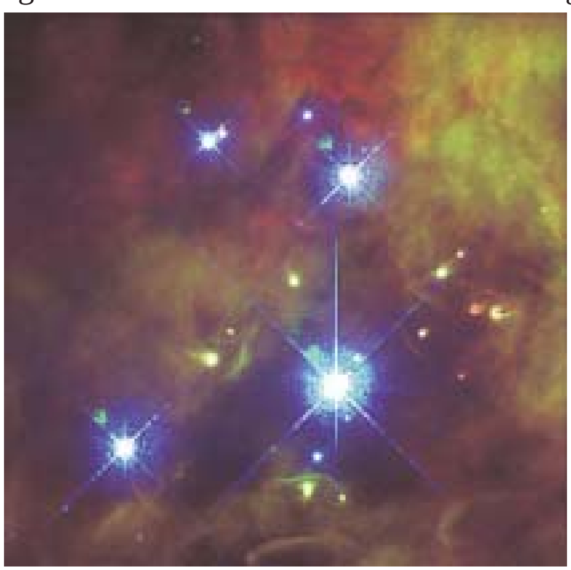
# Young Stars






# 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

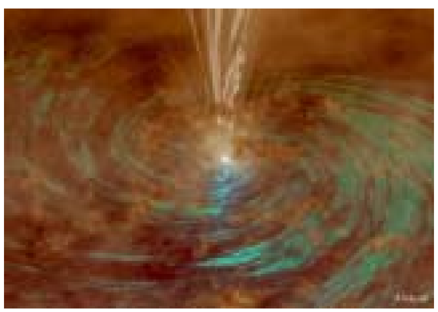


# Stars

- 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

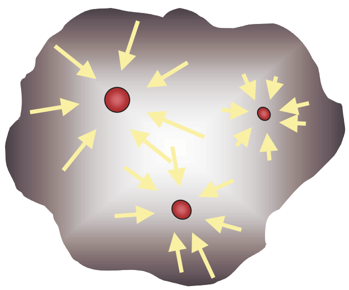
- Cloud turbulence
- Collision with another cloud
- Nearby supernova explosion
- Nearby hot star wind
- Disturbance from the Galaxy



# 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!

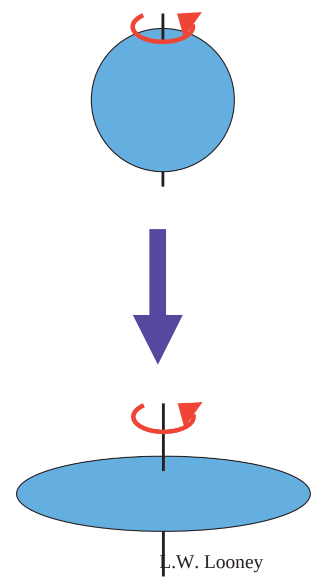
Recall Kepler 2nd law – really due to angular momentum!



# *When Doves Cry and Stars Form*

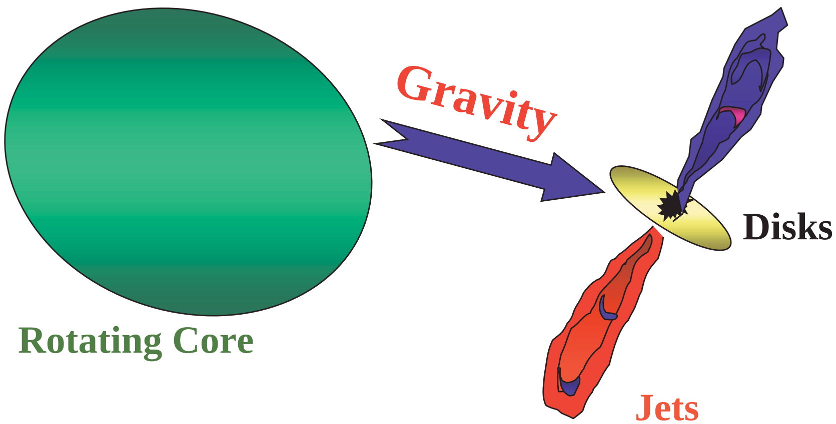
Solar nebula competition:
Gravity vs Angular Momentum

- 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



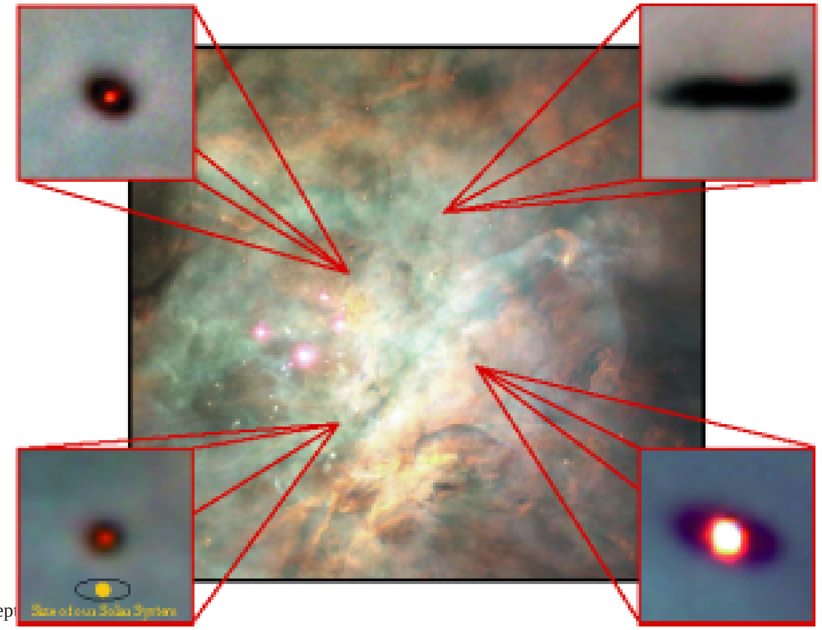
# The Protostar Stage

## Gravity, Spin, & Magnetic Fields



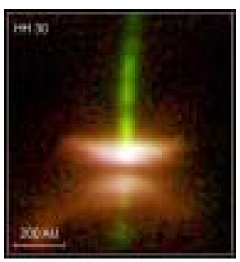


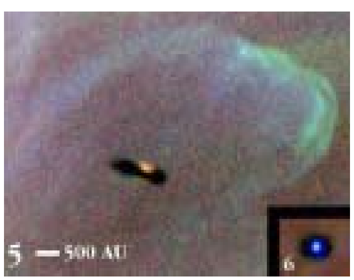

# Disks around Young Stars are Common



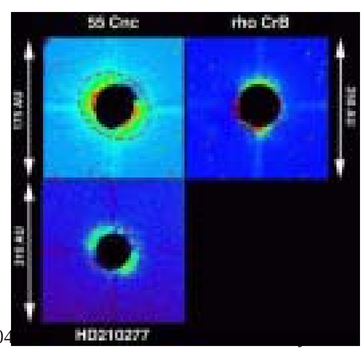


# And Disks around Young Stars are Common



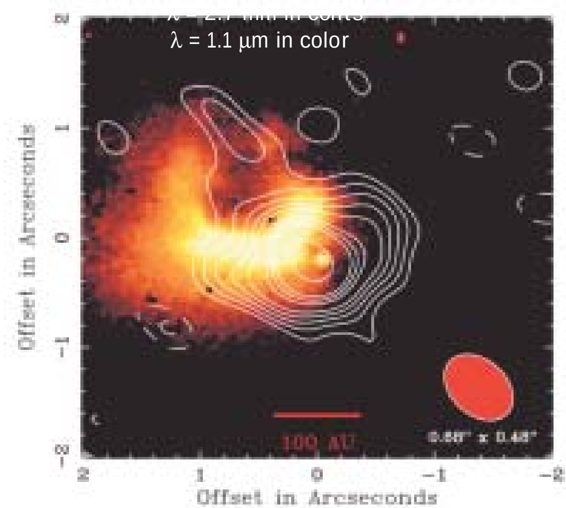




http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm



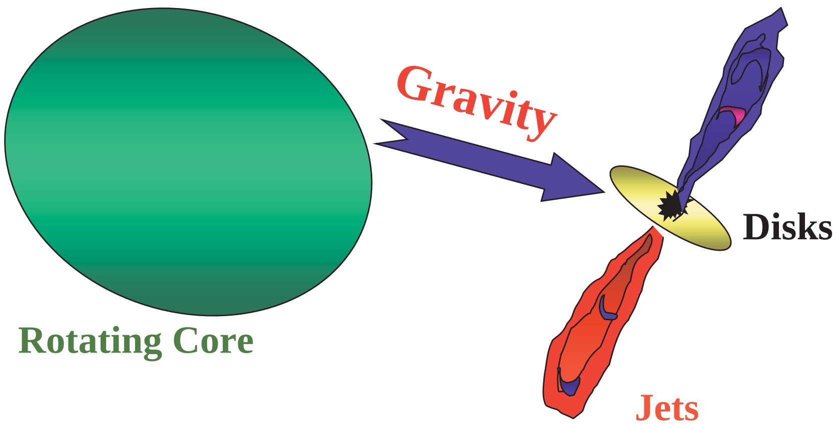



# The Circumstellar Disk of HL Tauri



# The Protostar Stage

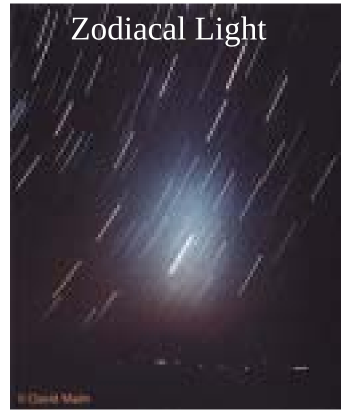
## Gravity, Spin, & Magnetic Fields

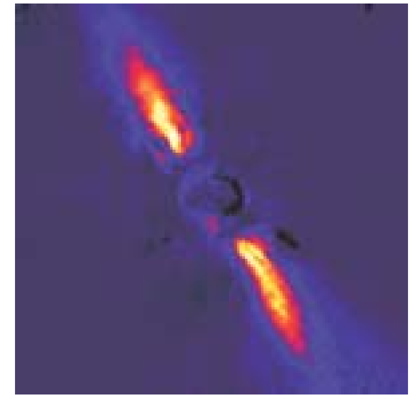





# Do Fossil Disks Exist around other Stars?

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



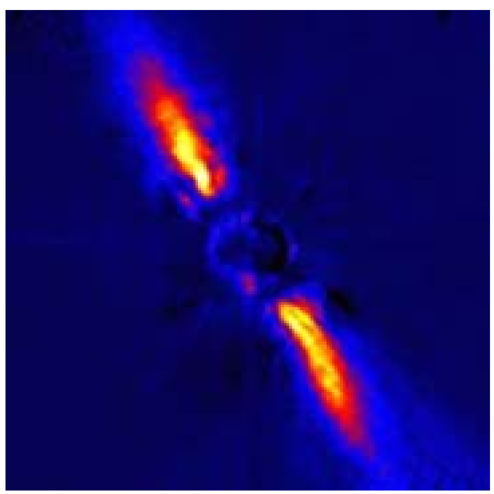



http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html



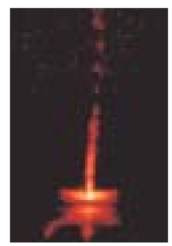
# Disks Around Young Stars

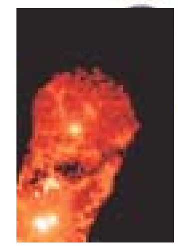
- Many (> 50%) of newborn stars surrounded by a disk of material!
- Disks thick, blocks light
  - Enough material to make planets
  - Agrees with Solar Nebula theory!



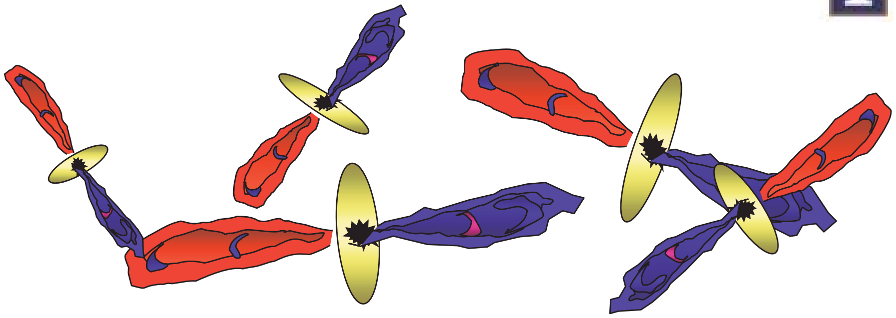


# Protostellar Jets





# 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



way
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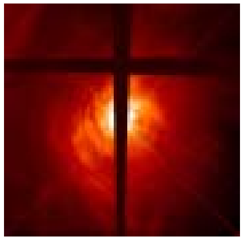
l.

# The Protostar Archetype: T Tauri


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

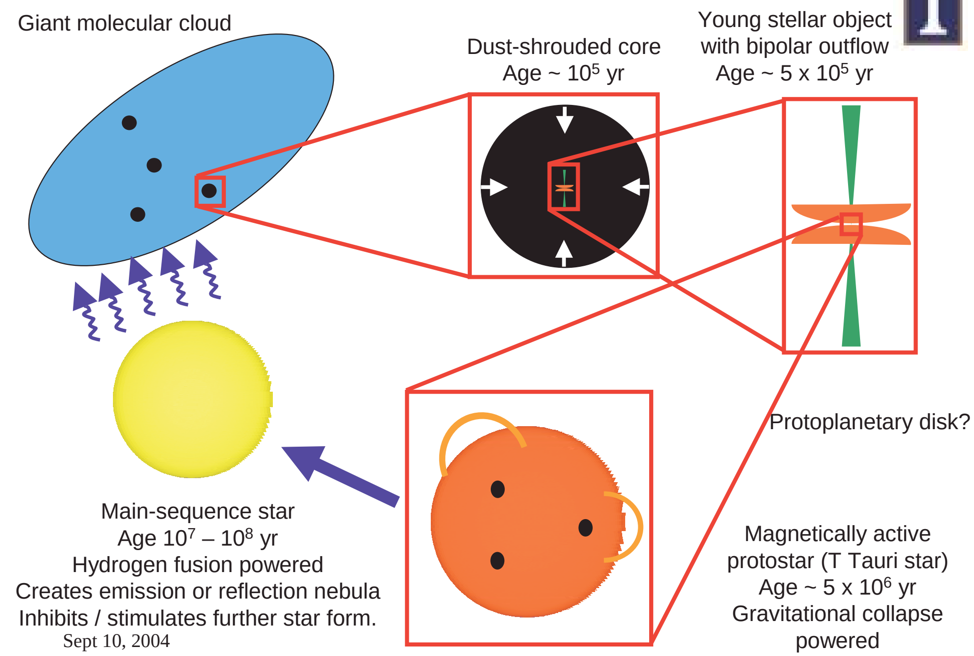
# On to the Main Sequence: A Star is Born!




- 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





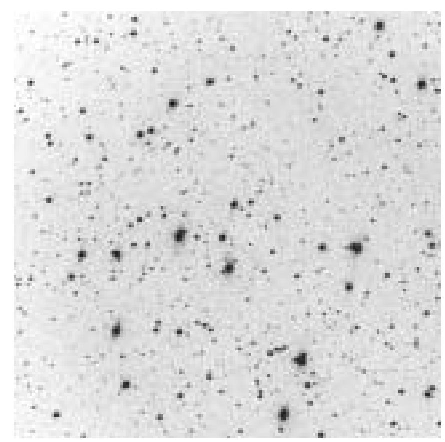

## Stellar Formation

Stars like the Sun

Massive stars

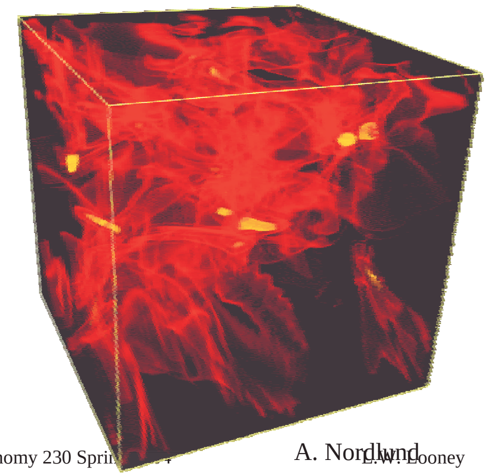


# Stars Ages and ETs



## 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



## 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?*

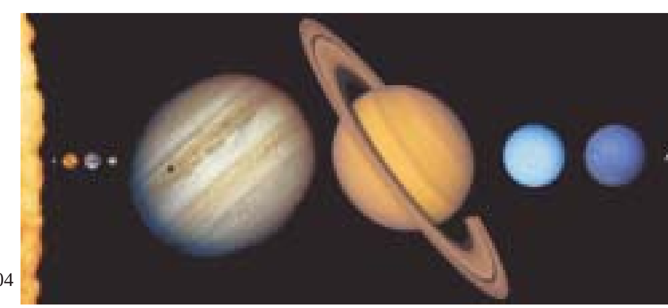
- Explain present-day Solar System data.
- Predict results of new Solar System data.
- Should explain and predict data from other stars!

What are clues to solar system origins?



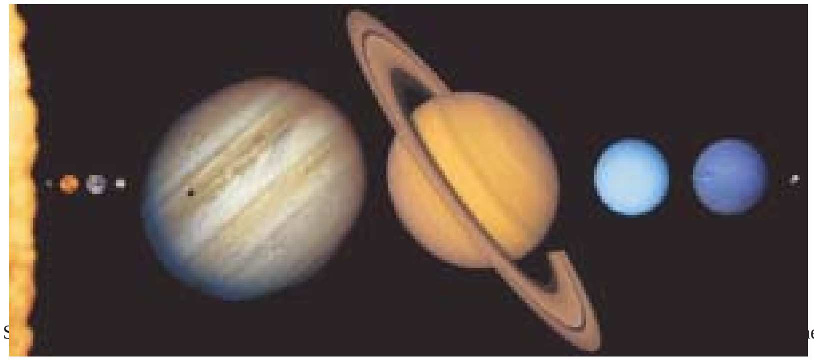
## Some Facts of the Solar System

- 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

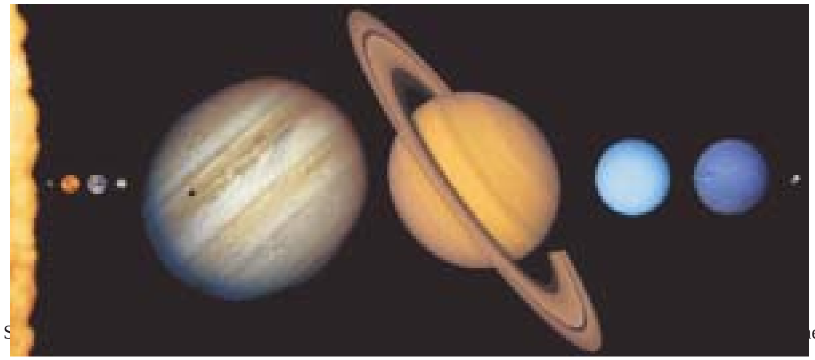
- Outer planets more massive than inner planets.
- Most of the motions in the Solar System are counter clockwise (problems with Venus, Uranus, or Pluto) in a flat system (pancake-like).
- The inner planets are rocky and the outer planets are gaseous.





# 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



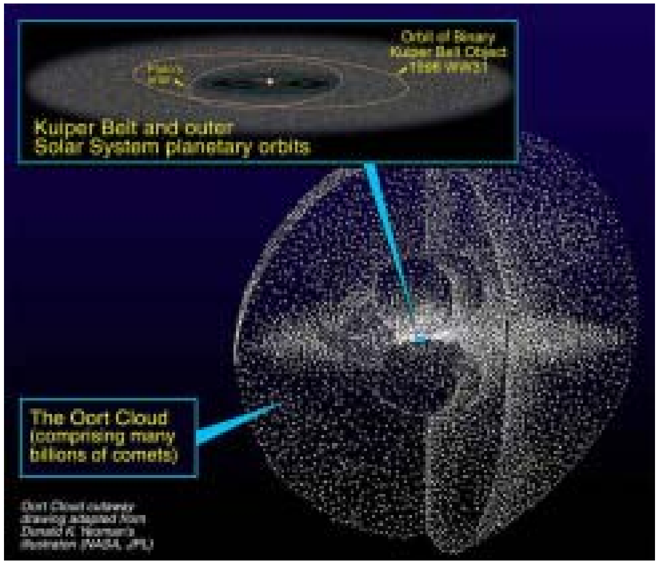
# Data: The Structure of the Solar System

- 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.



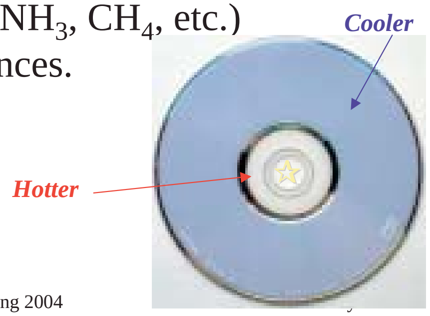
# The Early Solar System

- 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