Astronomy 150:

Killer Skies

This Class (Lecture 6):
More Asteroids

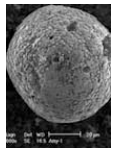
Next Class:
Dino-Killers

HW1 due on Sun. Last day to go to the Nat History Building before deadline.

Music: *The Day Lassie Went to the Moon* – Camper van Beethoven

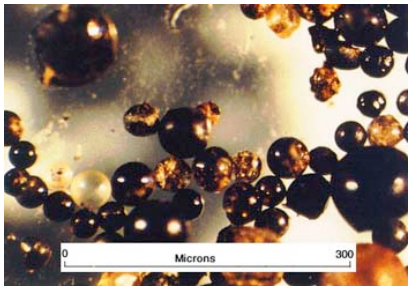
HW2: Micro-Meteorites

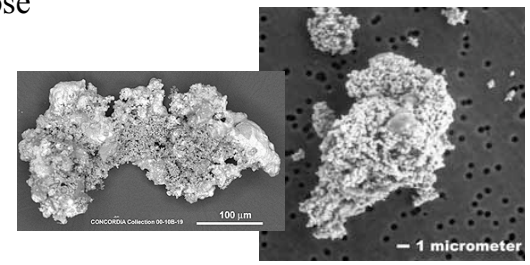
- Group project!
  - Seems like labor weekend is a good time!
- Find a flat container– the bigger surface area the better.
- Fill with water and leave outside (away from buildings and tress), perhaps on a roof if possible, for a few for a few days.
- Strain through a coffee filter or a few or paper towels.



HW2: Micro-Meteorites

- Use a magnet to find the magnetic dust.
- Wrap magnet in plastic for easy removal.
- Probably most of those are from space.
- So small, they fall to Earth unchanged.





How much Credit For Getting iClicker Questions Wrong?

Originally, I said that iClicker questions wrong are only worth 75%. I am willing to change. What do you prefer?

a) 65%
b) 70%
c) 75%
d) 80%
e) 85%

Outline

- Star Formation– where did the rocks come from

Water Power?

- Does a bottle of water have any stored energy? Can it do work?

The water has potential energy. It wants to flow downhill. If I pour it out, the conservation of energy tell us that it must turn that potential energy into kinetic energy (velocity). The water wants to reach the center of the Earth. This is how we get hydro energy from dams.

Gas powered

- Similar to my bottle of water, the initial gas clumps in molecular clouds want to reach the center of their clump-ness.
- The center gets hotter and hotter. The gravitational energy potential turns into heat (same as velocity actually).
- It is a run-away feature (or snowballing), the more mass at the center, the more mass that wants to be at the center.
- The center of these clumps gets hotter and denser.

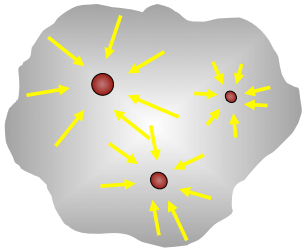
http://www.rob-clarkson.com/duff-brewery/snowball/04.jpg

Gravitational Contraction

- 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.

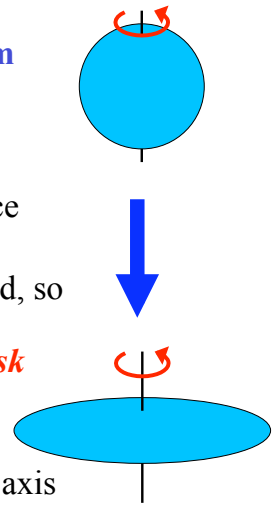
Angular momentum is a single, *constant* number = *conserved*!

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

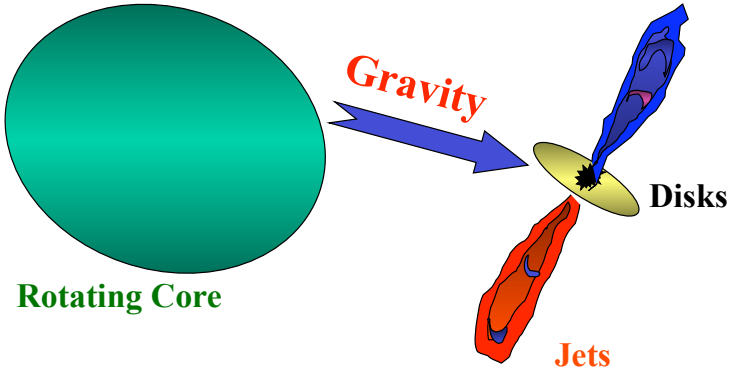
Question

Since a collapsing cloud is spinning, the cloud will form

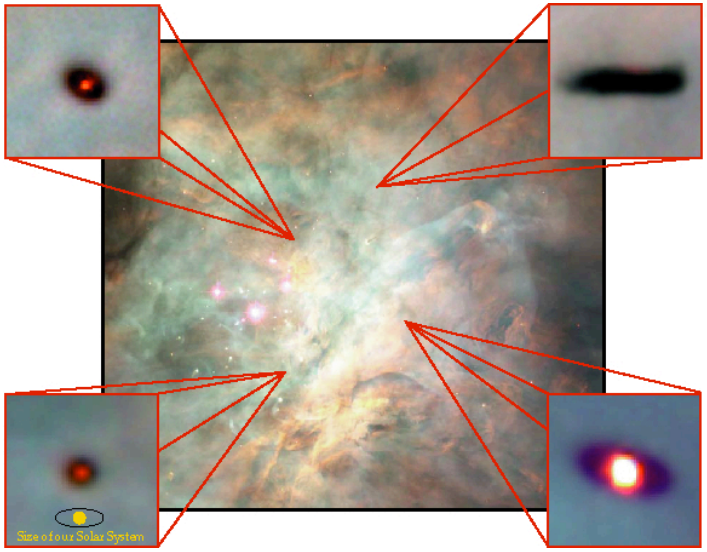
a) a spherical cloud
b) a star
c) a flattened disk
d) a planet
e) a galaxy

The Protostar Stage

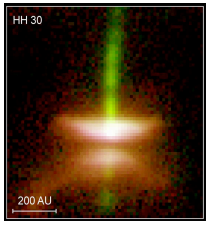
Gravity, Spin, & Magnetic Fields

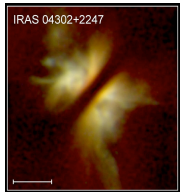


Disks around Young Stars are Common

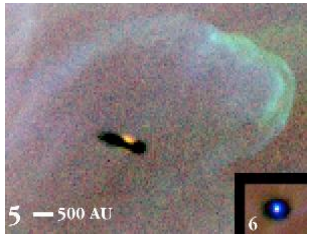


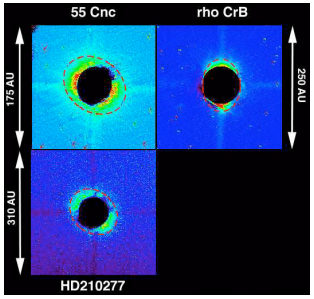
And Disks around Young Stars are Common



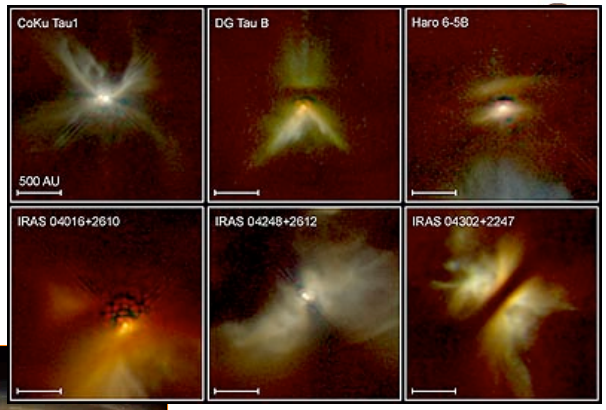


http://
www.ifa.hawaii.edu/
users/tokunaga/SSET/
SSET.htm





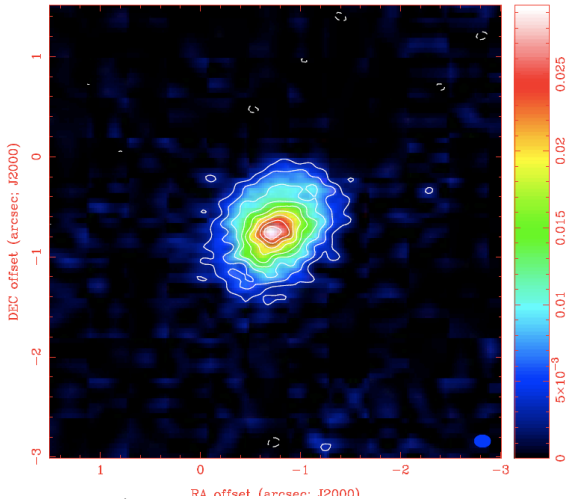
Disks have been imaged with HST's infrared camera



Young stars are surrounded by dense disks of gas and dust

Tracing the Bulk Material

HL Tauri



Looney et al. 2009

Interesting Question

Leslie studies circumstellar disks. What is he actually observing?

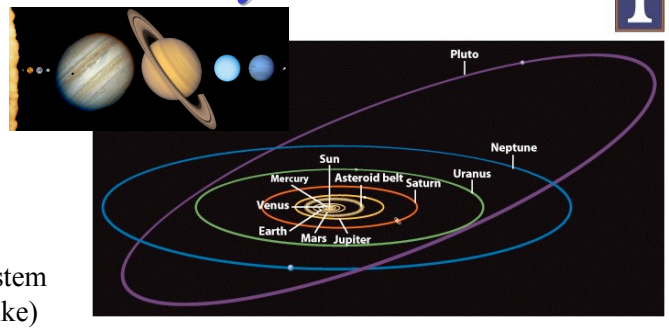
a) The disks of Galaxies.
b) The disks around Black Holes.
c) The disks around protostars.
d) The disks around planets like Saturn.
e) The disks under nice beverages.

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



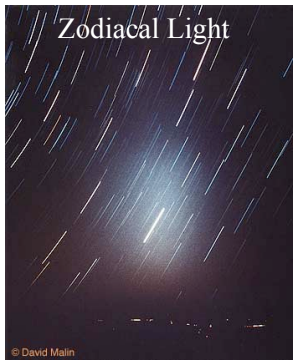
Most of the motions in the Solar System are counter clockwise in a flat system (pancake-like)

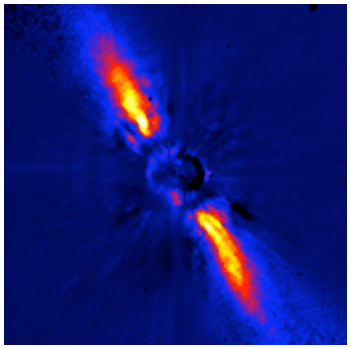
- There are some exceptions
- Venus, Uranus, and Pluto rotate clockwise (orbits are still clockwise)
- Some moons orbit backwards

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.

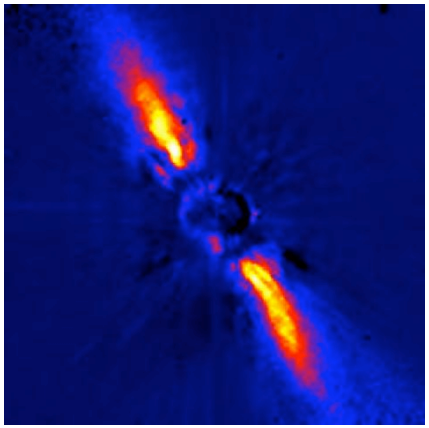




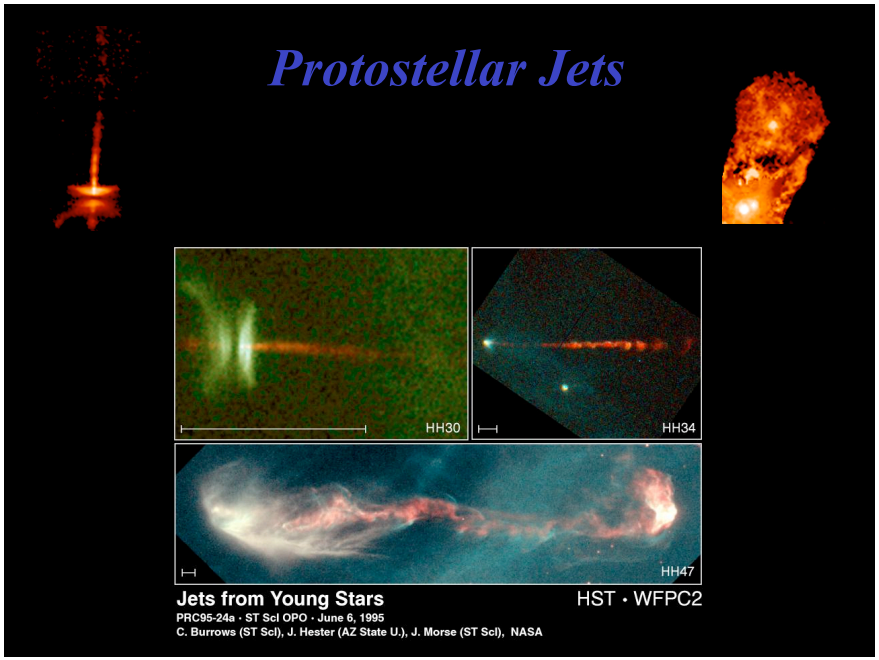
http://www.eso.org/outreach/press-rel/pr-1997/phot-16-97.html
http://antwrp.gsfc.nasa.gov/apod/ap970826.html

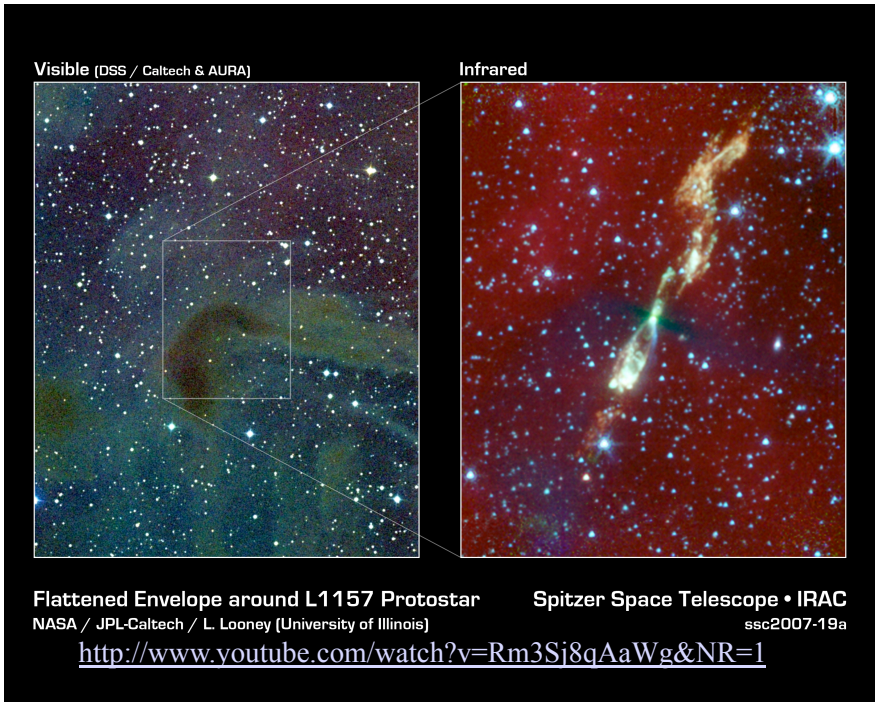
Disks Around Young Stars

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

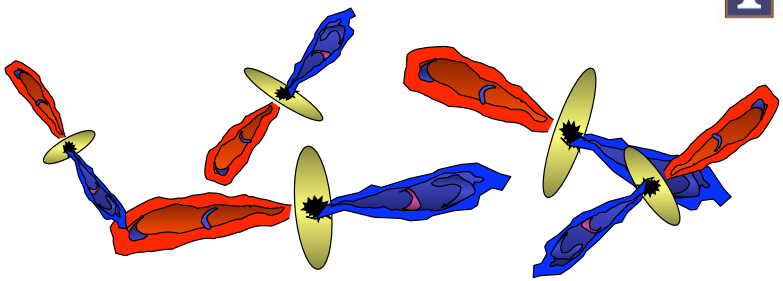


Protostellar Jets





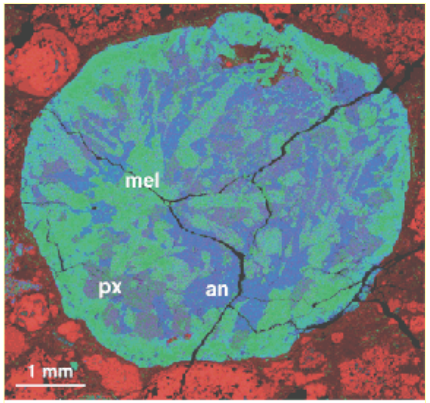
Young Stars in Groups

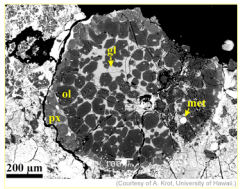


- Most stars are in multiple systems and clusters
- What about us?

The Earliest Pre-Solar Dust Grains

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



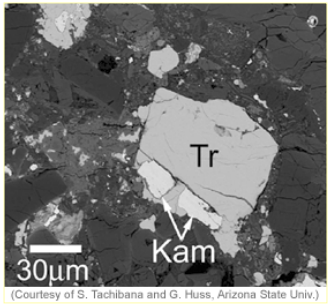


Formed 4,700,000,000 years ago

CAIs Once Contained ^{60}Fe

- Contain decay products of ^{26}Al and ^{60}Fe
- As seen by an excess of nickel
- Most likely 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



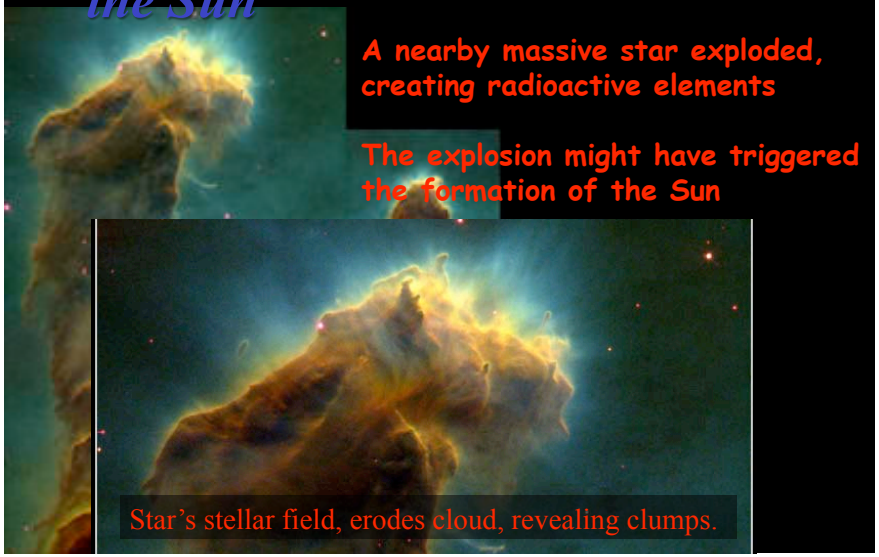
Half life 1.5 million years

The Birth of the Sun

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

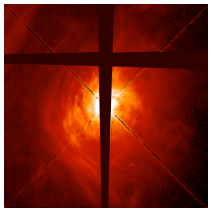
A nearby massive star exploded, creating radioactive elements

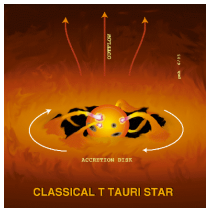
The explosion might have triggered the formation of the Sun



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

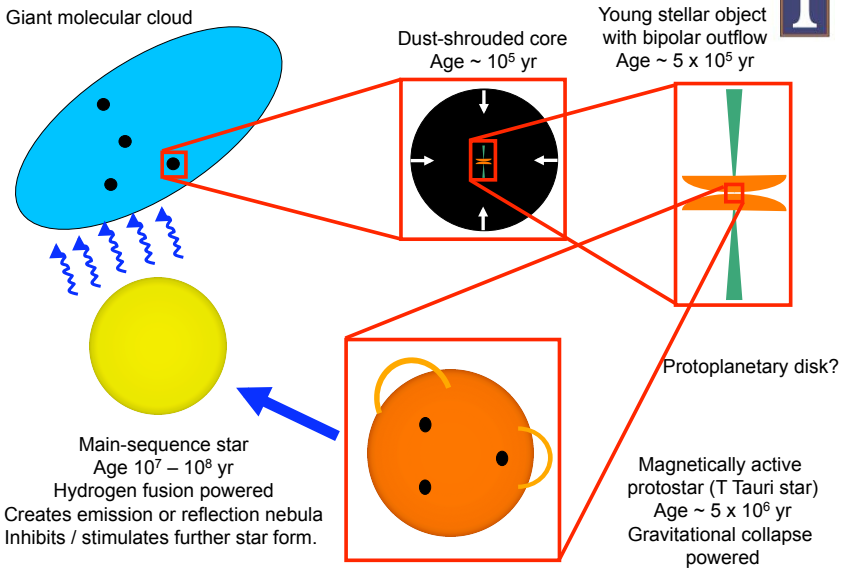
On to the Main Sequence: A Star is Born!





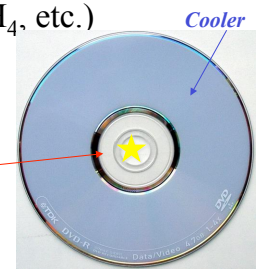
- For 1 solar mass star, process takes about 10 million years
- Density increase, temperature increases until fusion can occur.
  - Blows away most of its natal circumstellar material.
  - Becomes a hydrogen burning star
  - http://www.youtube.com/watch?v=jhYEQgLW5NM

Star Formation - Summary

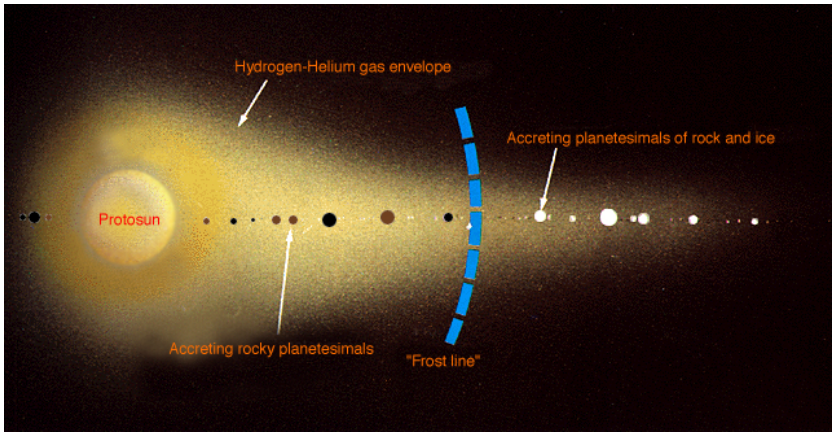


Everyone *Loves* Disks

- 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?



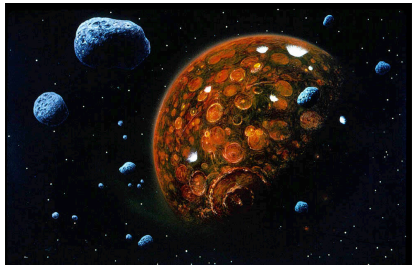
Temperature is the key factor!

Why are the Objects 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
  - Asteroids!
- Outer Solar System: Cold
  - Too cold to evaporate ices to space
  - Rock & ice "seeds" grew large enough to pull gasses (H, He) onto themselves
  - Comets!

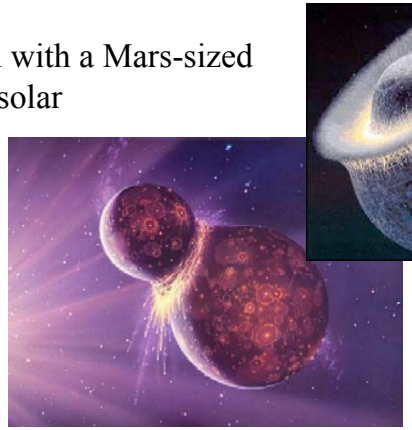
Heavy Bombardment

- 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
  - And speaking of the Moon….



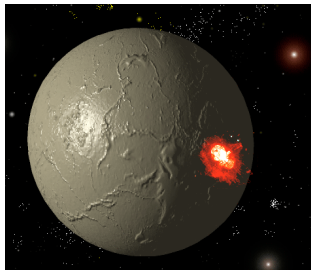
Formation of the Moon: Smack

- Collision of Earth with a Mars-sized body early in the solar system's history
- Iron-rich core of the impactor sank within Earth
- Earth's rotation sped up
- Remaining ejecta thrown into orbit, coalesced into the Moon
- http://www.youtube.com/watch?v=ibV4MdN5wo0&feature=related



Implications

- **Hot, Hot, Hot!** Even if the moon theory is incorrect, other smaller bodies were playing havoc on the surface.
- When they impact, they release kinetic energy and gravitational potential.
- The planetesimals melt, and the Earth went through a period of differentiation.



http://www.udel.edu/Biology/Wags/wagart/worldspage/impact.gif

Early Earth

- No atmosphere
- No water
- High temp
- No life…….
- Big rocks keep falling on my head…

http://www.black-cat-studios.com/catalog/earth.html

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

Formation of the Solar System 4.6 billion years ago