Astronomy 122

Midterm Next Week! (March 9th)

Homework #6 is posted.

Nightlabs in 2nd week! (or wait until exam week?)

This Class (Lecture 14):

Star Formation

Next Class:

Stellar Evolution: The Main Sequence

Music: *Princes of the Universe* – Queen

HR Diagram

Sketch an HR diagram

1. Label luminosity (what is increasing lum?)
2. Label temperature (what is increasing temp?)
3. Label spectral class (write some values)
4. Label absolute magnitude (what is increasing mag?)
5. Draw the main sequence
6. Label where giants live
7. Label where supergiants live
8. Label where white dwarfs live
9. Label where brown dwarfs live
10. Mark the Sun's location
11. Mark the location of a MS 2 solar mass star
12. Mark the location of a MS 50 solar mass star
13. Mark the location of a MS 0.5 solar mass star

Midterm

- 1 hour exam in this classroom
- Will cover material up to and including star formation
- Approximately 25 multiple choice and 6 short answer.
- Exam will have 105 points graded out of 100 (i.e. extra credit)
- You may bring normal-sized sheet with notes on each side.

Outline

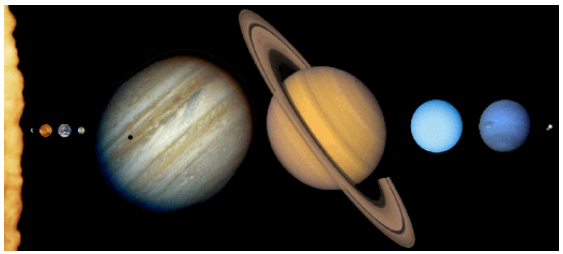
What is the origin of the Solar System?

- 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?

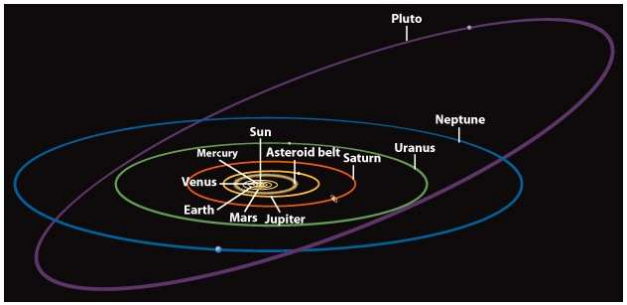
Some Facts of the Solar System

- 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
  - Some moons orbit backwards



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

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

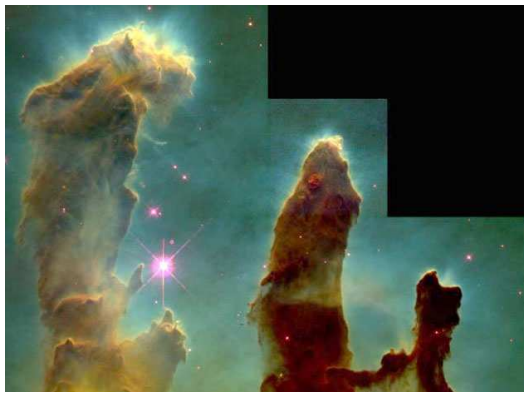
- **Age of Solar System is probably around 4.6 billion years old**

- **Sun could not always have been, nor will it always be… star birth and star death!**

Solar Nebula Theory

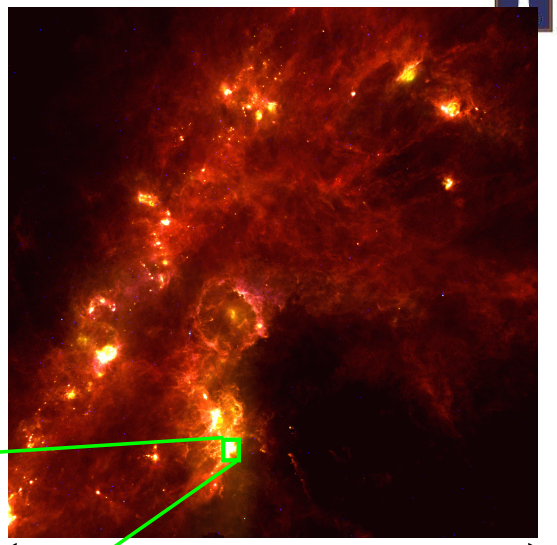
"*nebula*" = space cloud

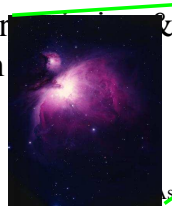
- Proposed by Immanuel Kant (the philosopher)
- The solar system formed from a spinning cloud of gas, dust, and ice
  - Mostly hydrogen and helium
  - 4.6 billion years ago



Giant Molecular Clouds

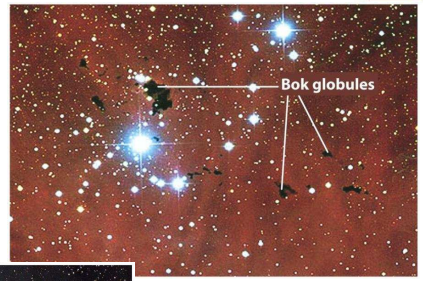
- Cool: < 100 K
- Dense: $10^2 - 10^5$ H_2 molecules/cm^3 (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 - 10^6$ solar masses
- CO molecular [illegible] dust emission structure

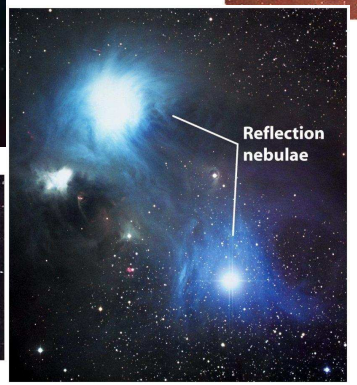


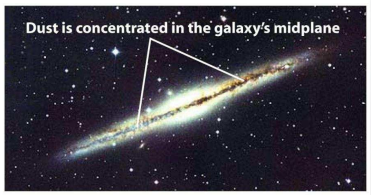


Infrared image from *IRAS*

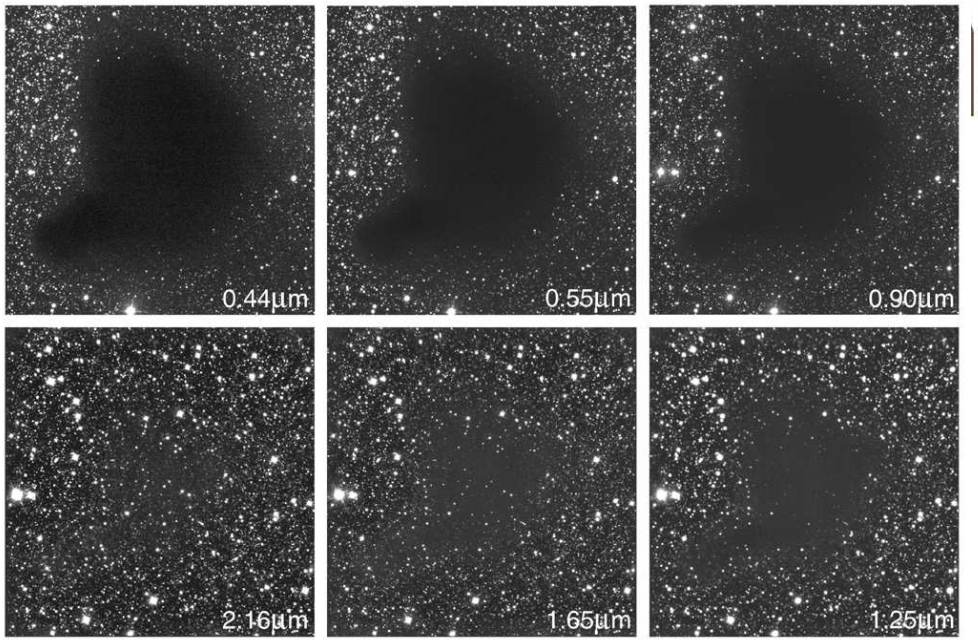
Interstellar Clouds







We see spiral galaxy NGC 891 nearly edge-on

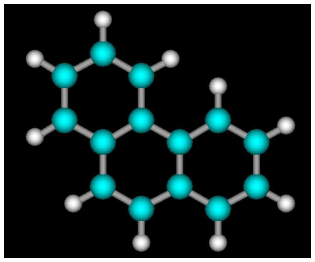


The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

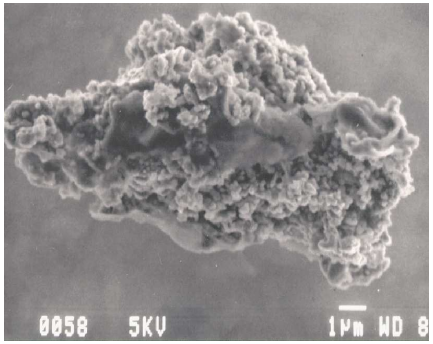
ESO PR Photo 29b/99 (2 July 1999)

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)



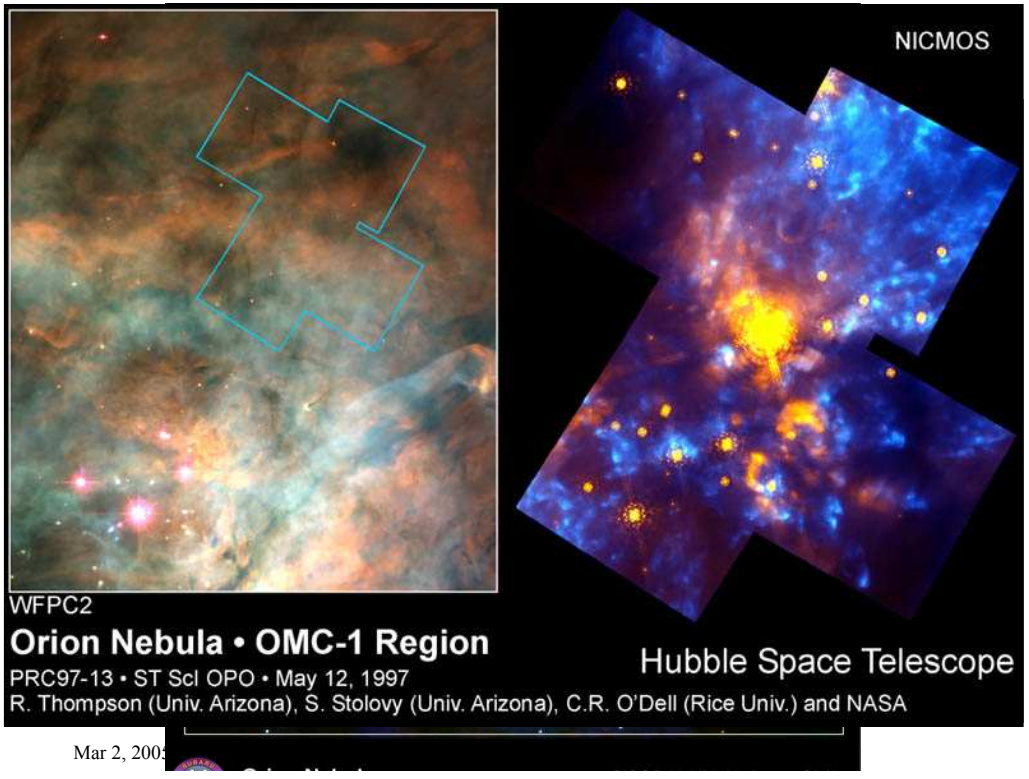
Dust particle (interplanetary)

Solar Nebula Theory

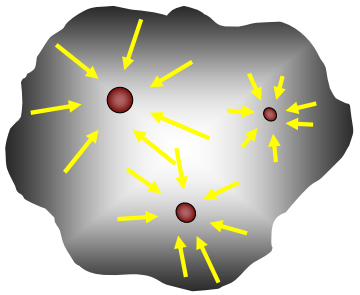
- In these clouds are small clumps that become gravitationally unstable
- The gas and dust has mass (thus gravity)
- Gravity pulls it toward the center – contracts!
- **Question:** What do you think happens?

Gravity follows the inverse square law, so closer = stronger. Once it falls in a little, it gets pulled in more.

RUNAWAY GRAVITY!



Cloud Contraction



Interlude: Angular Momentum

Spinning or orbiting objects in closed system have angular momentum.

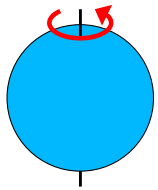
Keep same dist. to axis → velocity same

Move closer to axis → speed up!

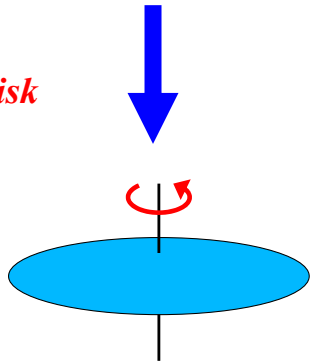
Recall Kepler 2nd law – really due to angular momentum!

When Doves Cry and Stars Form

Gravity vs Angular Momentum

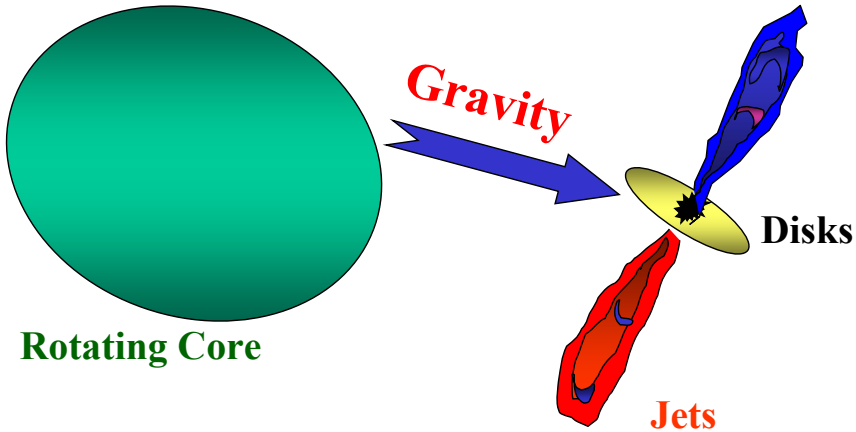


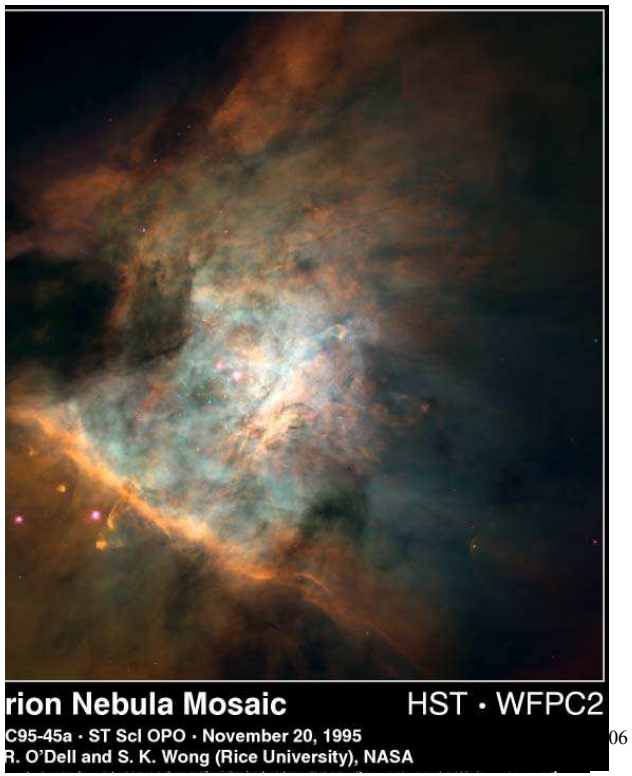
- If fall perpendicular to spin axis
  speed up → resistance centrifugal force
- If fall parallel to spin axis then
  same speed, so no resistance
  → forms ***protoplanetary disk***
  - Origin of ecliptic!
  - Organizes orbits in same direction
  - Organizes spins along initial spin axis



The Protostar Stage

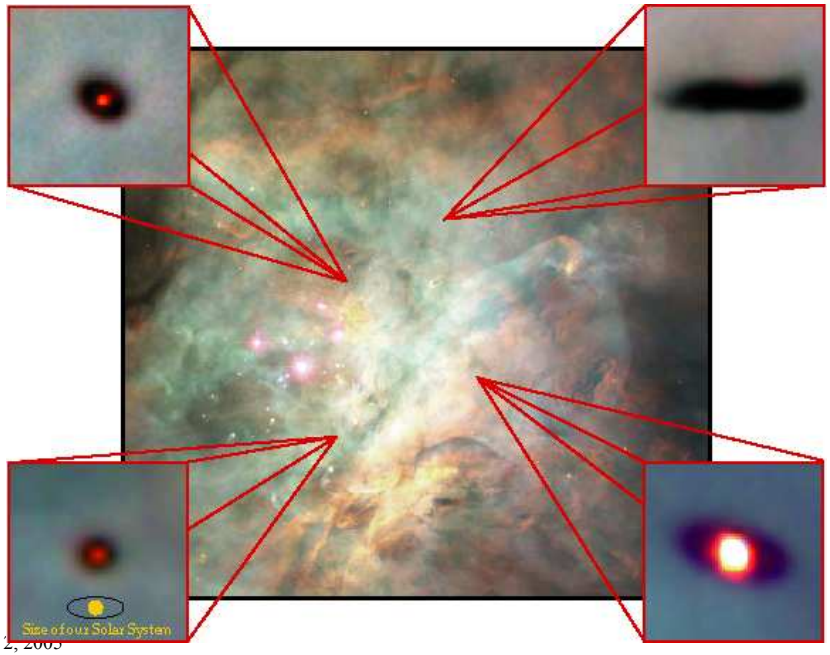
Gravity, Spin, & Magnetic Fields



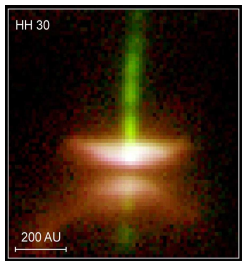


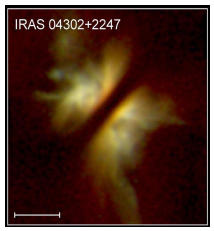
The Orion Nebula

Disks around Young Stars are Common

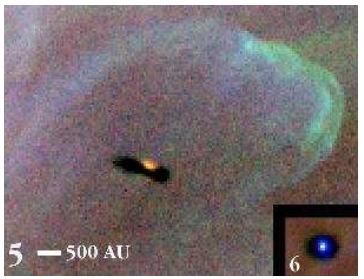


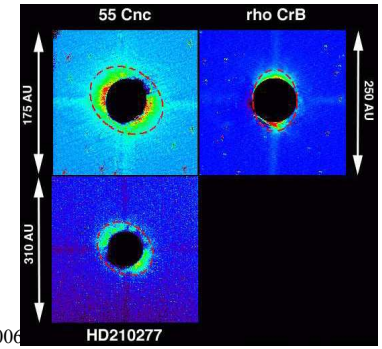
And Disks around Young Stars are Common



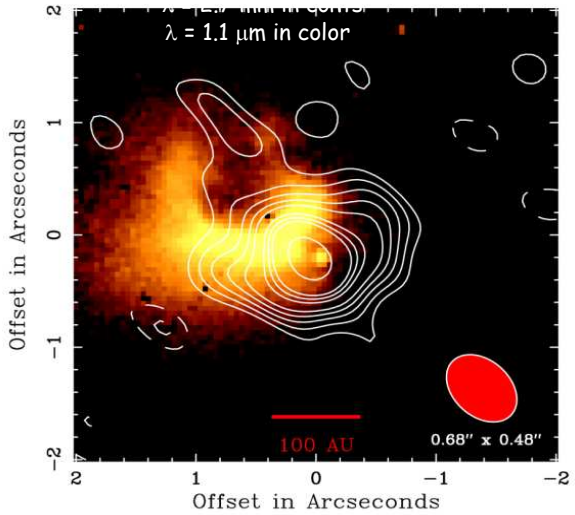


http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm

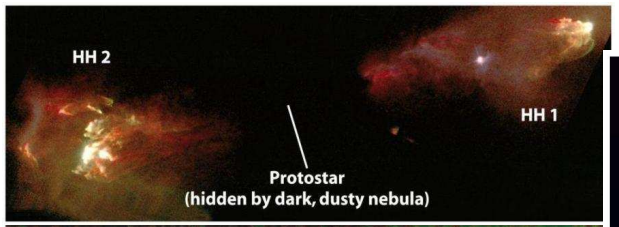


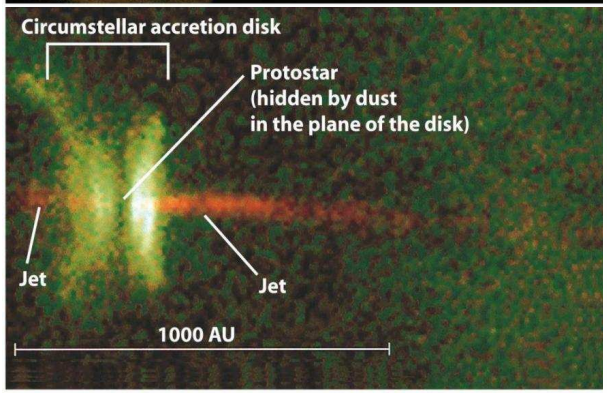


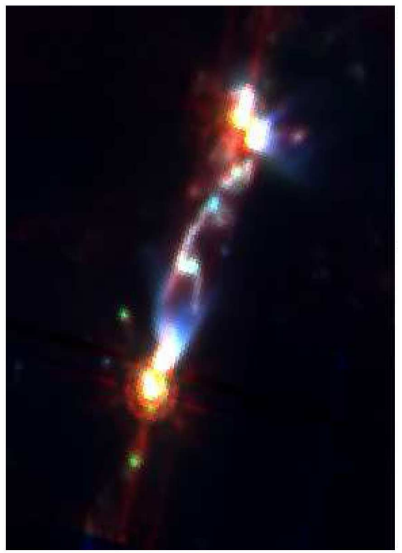
The Circumstellar Disk of HL Tauri



Outflows from Young Stars







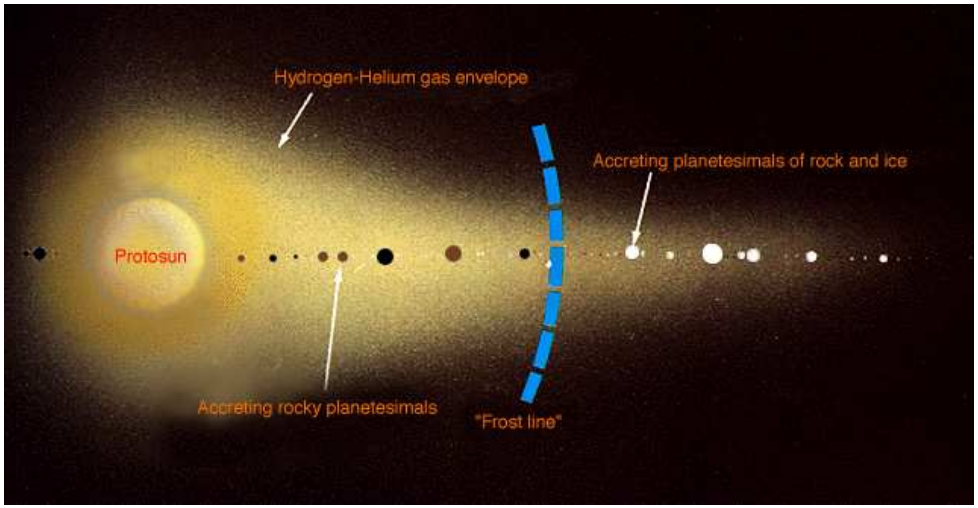
Formation of the Solar System 4.6 billion years ago

Planet Formation in the Disk

Heavy elements clump and then

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

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…

Earth's Water Source?

- There are two ideas on where Earth's water came from:
  - Released from within by volcanic vents
  - Brought to Earth by comets during the heavy bombardment

Fates of the Planetesimals

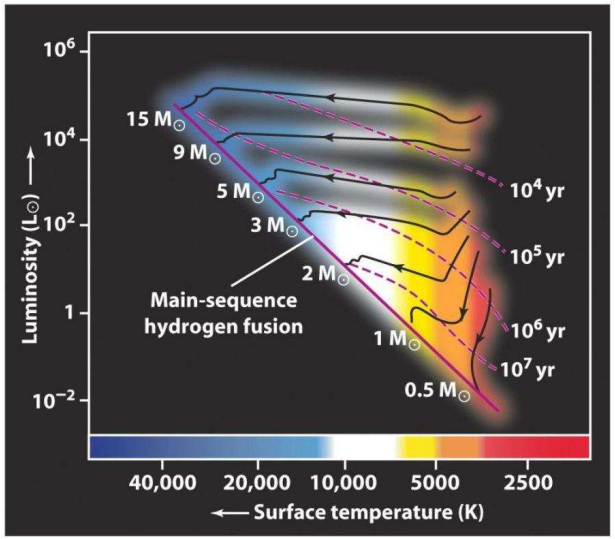
- Between Mars and Jupiter
  - Remain as the asteroids
- Near Jupiter & Saturn
  - Ejected from the solar system
- Near Uranus & Neptune
  - Ejected to the Oort Cloud
- Beyond Neptune
  - Remain in the Kuiper Belt

Results

- Most disk matter goes into the planets
- Asteroids and comets are left-over planetesimals
  - "Fossils" of solar system birth!
- The Solar System continues to evolve, but slower
  - Outer planets still contracting
  - Earth and Venus are still volcanically active
  - Impacts from left-over planetesimals continue

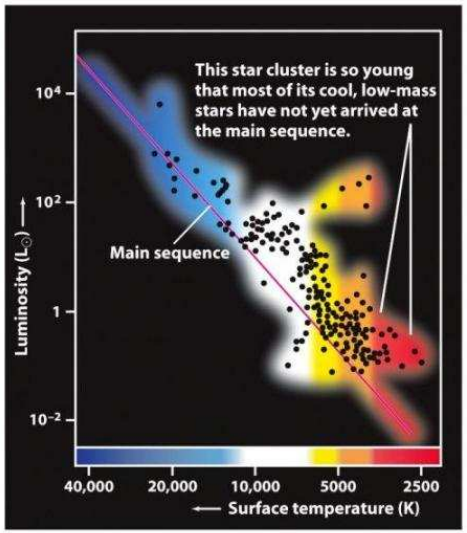
Moving To the Main Sequence

- When a protostars burns hydrogen into helium: it is a main sequence stars!
- They start cold, move toward the left with gravitational energy (remember Jupiter again).
- Path to the main sequence is different depending on mass.



Very Young Cluster

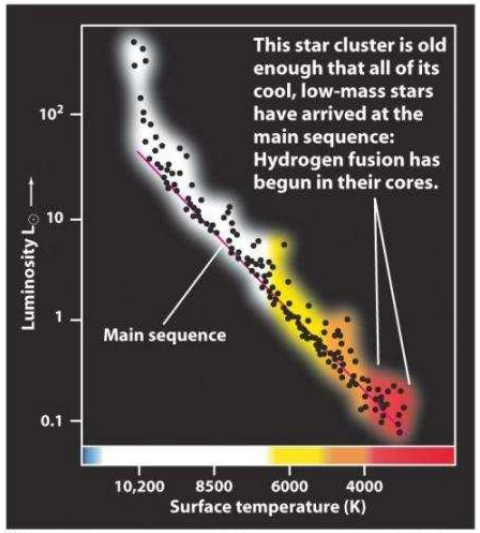
(a) The star cluster NGC 2264



(b) An H-R diagram of the stars in NGC 2264

Older Cluster

(a) The Pleiades star cluster



(b) An H-R diagram of the stars in the Pleiades