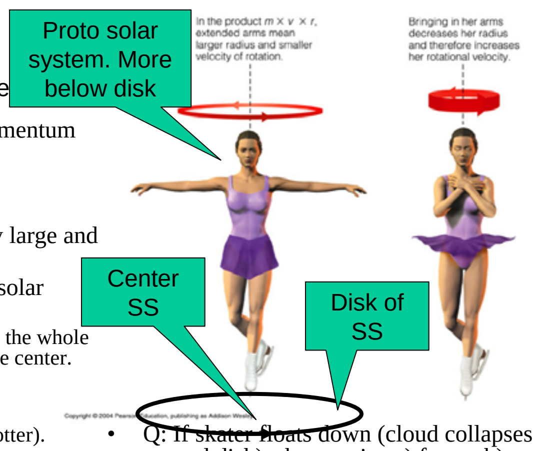
Formation of the Solar System

- Questions
  - Why are rocky planets close to the sun? ✓
  - Why is solar system a disk?
  - How did the planets form?
  - How are asteroids & comets related to planets?
  - How old is the solar system?
- Test 2 is Tues, March 3rd.
  - Covers material through "terrestrial planets," 2/17
  - Large majority on solar system
  - A few question on topics covered on Test 1
  - Format same as Test 1. One cheat sheet.
  - Practice test: link on syllabus
  - Missouri Club is 7:00pm, Mon., March 2nd

Why is the solar system spinning & disk shaped?

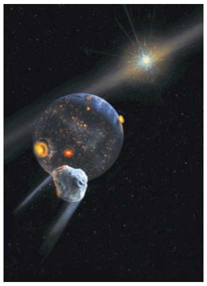
Piece of protosolar system is pulled by gravity of the whole

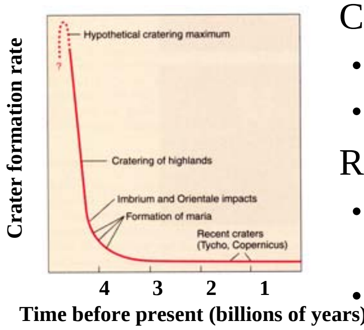
- Conservation of Angular Momentum
  - L = m r v
  - r is distance to rotation axis
  - v is speed of rotating motion
- The protosolar system is very large and spins slightly.
- Consider a piece of the protosolar system.
  - It is pulled by the gravity of the whole protosolar system toward the center.
  - It falls toward the center.
    - It spins faster.
    - It moves faster (gets hotter).
  - It can fall parallel to the axis all the way to the disk.
  - It falls toward the axis and spin faster until force and acceleration of moving in a circle balance.



- Q: If skater floats down (cloud collapses toward disk), skater spins a) faster, b) same, c) slower
- Q: If material falls toward rotation axis, material spins ___. Same foils.

Building Planets





Before the Sun started to produce its own energy

- Small “dust” grains condensed from nebula.
  - mm-sized.

Clumped up into <u>planetesimals</u>

- 10’s of km in diameter.
- comets and asteroids.

Run away growth into <u>protoplanets</u>

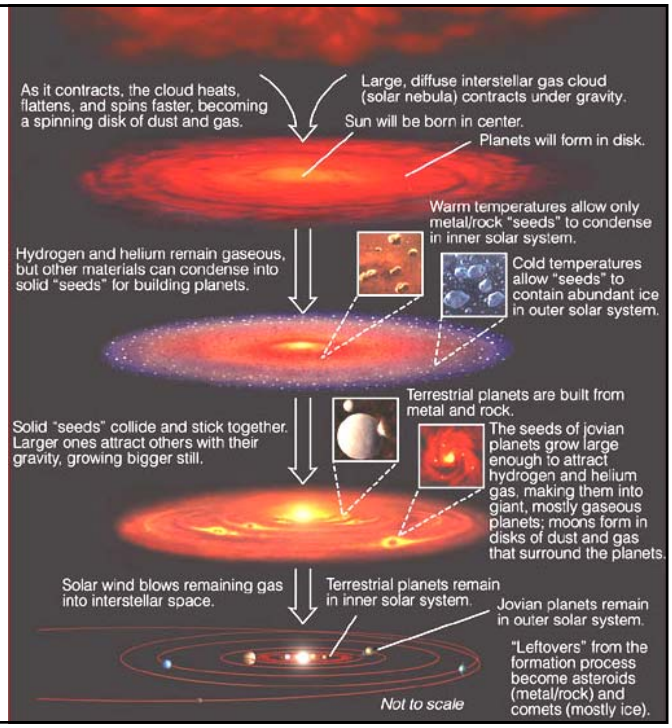
- With more gravitational attraction, larger bodies collected lots of smaller bodies.
- A few Mercury/Mars-sized objects rapidly accreted further planetesimals.

End Game

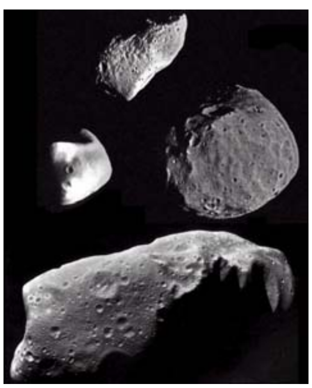
- The Sun became a star
  - *Solar wind* **(**high velocity particles streaming outwards from Sun) blew away the remaining H and He gas.
  - Left just protoplanets + remaining planetesimals to finish up their interactions.
  - Timescale to this point: only ~ 10 million years.

The Solar Nebula

[Fig 6.27]



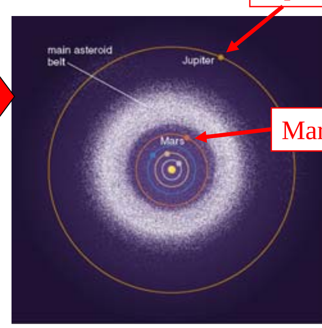
Asteroids



- Small, rocky objects in orbit around the Sun.
  - Sizes up to 940 km.
  - 26 known with sizes > 200 km (width of MI).
- 250,000 currently have designations.
  - **+** estimated > 1 million asteroids < 1 km in size.
- But total mass probably less than mass of Moon.

Asteroid Belt

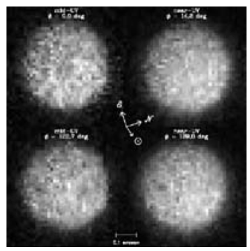
- semi-major axis 2.2 - 3.3 AU.
- Between orbits of Mars and Jupiter
- Includes 75% of known asteroids.
- Mostly orbiting sun in same direction of planets, and in plane of solar system.



[Fig. 9.3]

Ceres

- The largest asteroid
  - 940 km diameter.
- Estimated to contain ~ half the total mass of the asteroids.
- Orbit: 2.8 AU
- C-type.

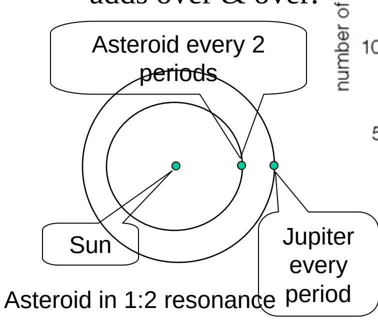


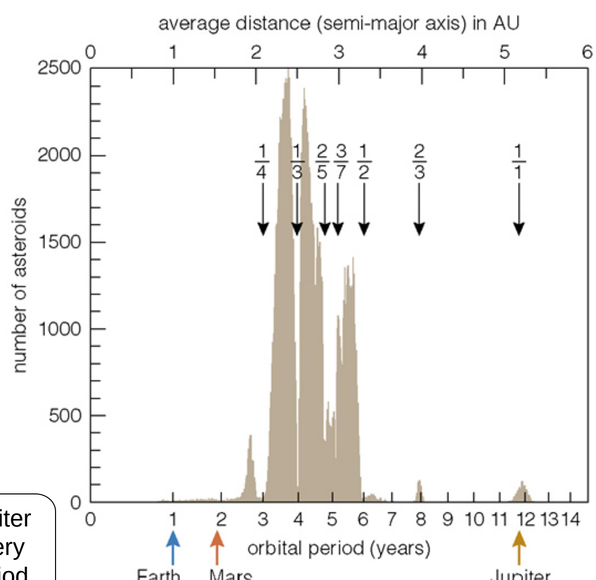
HST images in ultraviolet

Infrared image, taken from Earth

Jupiter prevented planet from forming

- Gaps in asteroid belt correspond to resonances with orbit of Jupiter
  - In a resonance, pulling by Jupiter adds over & over.





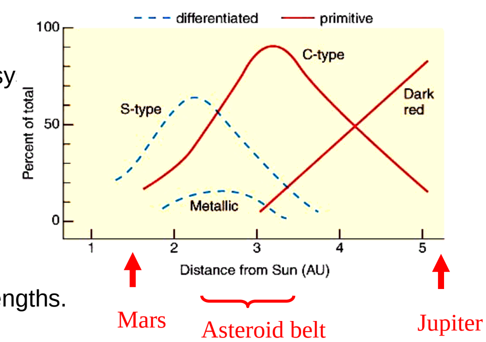
[Fig. 9.4]

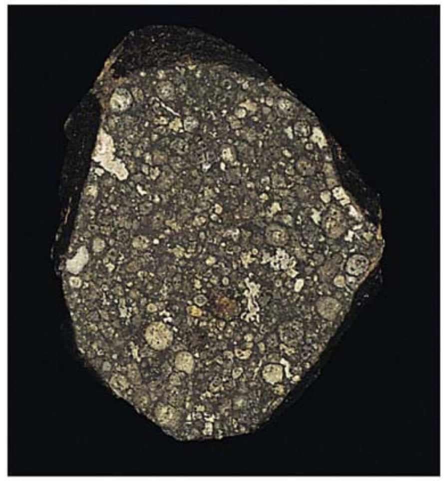
- Q: From what we know about the formation of the solar system, we can deduce that the composition of asteroids to vary with distance from the sun. Asteroids with more carbon should be found ___ and asteroids with more silicon should be found ___.
  A. closer to sun & closer to sun
  B. farther from sun & closer to sun
  C. closer to sun & farther from sun
  D. farther from sun & farther from sun

Asteroids

- Failed planets
- Primitive bodies
  - chemically unchanged since initial formation of Solar System
  - "Fossils" from the birth of the solar sy
- Low reflectivity (3-4%)
- Most are carbon-rich "C-type"
- Also stony "S-type",
  - dark carbon compounds missing.
- A few metal-rich "M-type"
  - Especially reflective at radar wavelengths.
  - Remnants of a differentiated body.

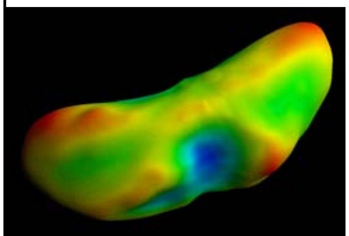
Where Different Types of Asteroids are Found



- Primitive meteorites (not melted)
  - Stony (left). Formed in inner asteroid belt
  - Carbon-rich (right). Formed in outer asteroid belt


- Processed meteorites (melted)
  - Iron (left). Large iron crystals => cooled very slowly =>part of a large object
  - Stony (right).



Colors show elevation (blue=low)

433 Eros

- Near Earth asteroid: 1.13 to 1.78 AU
- S-type
- 35 x 15 x 13 km (size of Lansing)
- You would weigh 3 oz on Eros (little bag of potato chips)
- 20 mph speed limit
- NEAR spacecraft orbited for 1 year, then landed Feb. 2001.
  - NEAR found that Eros is not differentiated.

124 km orbit movie

Comets [9.2]

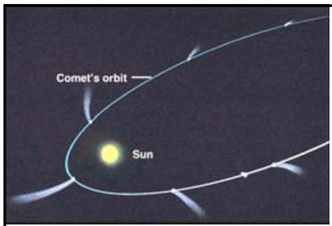
- Small icy nucleus.
- "Dirty snowball" model
  - mostly water ice
  - + other ices
  - mixed with silicate grains and dust
- Outer layers of nucleus vaporize when comet approaches sun.
  - Little geysers and eruptions observed.
  - Comet's head (Coma) often as large as Jupiter
    - up to 250,000 km diameter.
    - Primarily H_2O gas.
    - + few percent CO, CO_2 and hydrocarbons.
  - Huge hydrogen clouds around head can get bigger than sun.

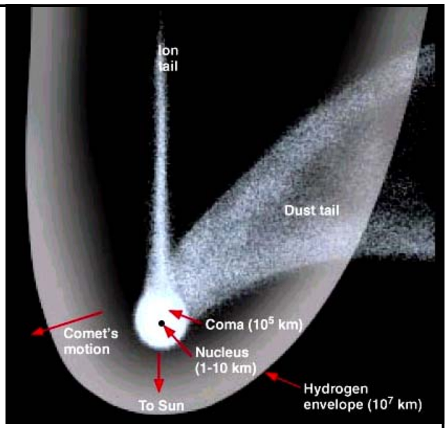
Hale-Bopp (1997)

Comet Hale-Bopp February 7, 2000
This fading super comet continues to be visible in small telescopes almost 5 years after it was discovered. Despite now being out beyond the orbit of Saturn, the comet continues to display a strong coma.
The image is a combination of 3, 3-minute exposures using a 416xt CCD and a 12" f/6 newtonian telescope at prime focus. Taken by Maurice Clark

Comet Hale Bopp (1995 o1)
april 9, 1997

Tails



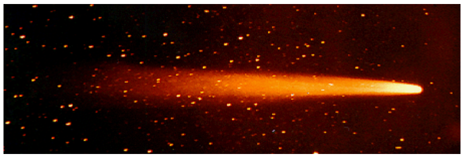


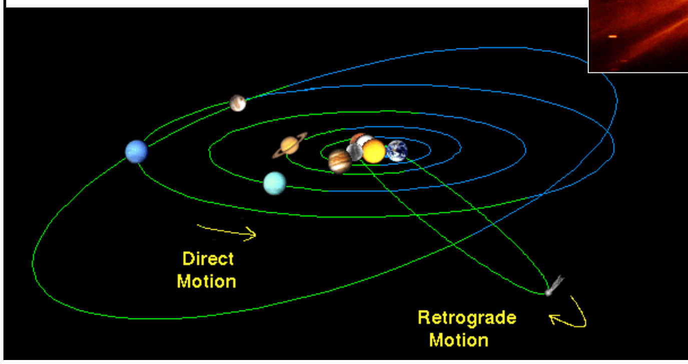
- dust tail
  - up to 10 million km long
  - smoke-sized dust particles
  - driven off nucleus by escaping gases
  - pushed outwards by Sun's radiation
  - competing force of Sun's gravity ➔ curve in tail.
- ion tail
  - Up to 100's of millions km long
  - small charged particles, pushed out by charged particles from Sun (solar wind).

45 minute animation

Halley's Comet

- first observed 239 BC
- 76 year average period
- most recent visit 1986
- fizzled out last time around

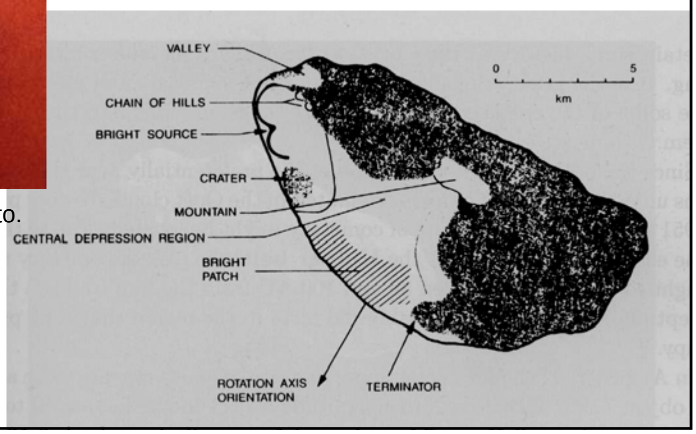




Halley's nucleus.

Picture taken by Giotto.
Sun is at lower left.

- Nucleus is 10×15 km (6×10 mi)
- Nucleus is irregular in shape
- Nucleus is jet black
- Evaporation is confined to small regions



Oort Cloud & Kuiper Belt

- The Oort Comet Cloud
  - Some comets: orbital directions are not that of planets & orbits are not close to plane of planets.
  - 10^{11} - 10^{12} comets in loosely bound solar orbits at 50,000AU
  - Ejected by Jupiter into random directions
  - Gravitational perturbations occasionally deflect one in.
  - Guesstimate: 1 trillion (10^{12}) comets total

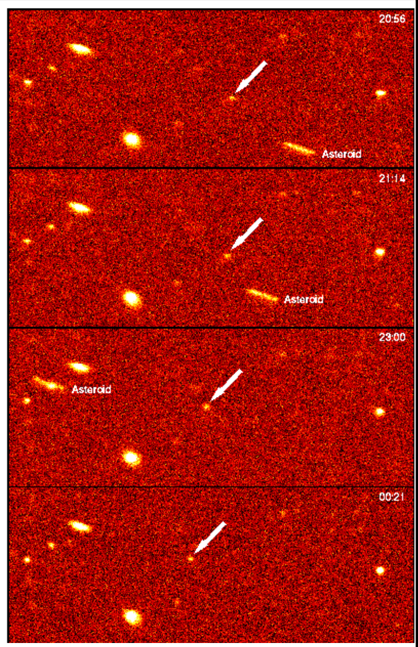
    x 10^{-10} earth-mass/comet = 10^{2} earth masses total.

Second source of comets: Kuiper Belt

- Some comets have orbits nearly in the plane of the planets & orbit in same direction as planets.
- At 30-50 AU,
  - just beyond Pluto.
- 60 faint objects spotted so far.

applet

- 40% have 2:3 orbital resonances with Neptune, similar to Pluto’s.
- Pluto and its moon Charon probably in this class.



How old is the solar system? Age of rocks

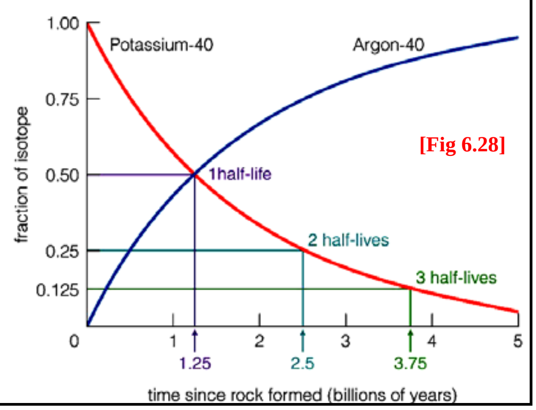
- Radioactive decay
  - Unstable atomic nucleus decays into stable nucleus
    - Examples:

      $^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He$ (uranium splits into lead and helium in 4.5Byr)

      $^{40}K \rightarrow {}^{40}A + e^{+}$ (Potassium decays into argon in 1.25 Byr)

      (19p⁺, 21n) **(18p⁺, 22n)**

- Half-life
  - Time for 1/2 of radioactive nuclei to decay
- Minerals form with radioactive elements
  - "Daughter" nuclei that shouldn't be in pure mineral.
  - Ratio of daughter/parent nuclei determine time since mineral formed.



Finding the age of a meteorite

- $^{40}K \rightarrow {}^{40}Ar + e^{+}$ (half life is 1.25 Billion years)
- Argon is a gas, which escapes unless made inside the rock.
- Q: A meteorite is found with ^{40}K and ^{40}Ar in the ratio 2:1. Its age is ______ 1.25 Byr.
  a. older than
  b. close to
  c. younger than

- Q The nuclear chemist is concerned about the asteroid heating during its passage through the earth's atmosphere. The surface of the meteorite would appear be ___ than the center if heating is significant.
  a. younger
  b. older

Isotopes in primitive meteorites date the formation of solar system

- Primitive meteorites have very narrow range of ages
  - 4.48 - 4.56 billion yrs. Average = **4.54 billion yrs.**
- Primitive meteorites contain ^{129}Xe (an isotope of xenon with 129 nucleons)
  - ^{129}I (iodine 129) is made in supernovae (exploding stars)
  - ^{129}I decays into ^{129}Xe with a half life of 17 million years
  - Xenon is a gas even at low temperatures
- Conclusion: Meteorite formed a few tens of millions of years after a supernova
- **A supernova triggered collapse of cloud that became solar system**

Formation of the Solar System

- Questions
  - Why are rocky planets close to the sun? ✓
  - Why is solar system a disk?
  - How did the planets form?
  - How are asteroids & comets related to planets?
  - How old is the solar system?
- Test 2 is Tues, March 3rd.
  - Covers material through “terrestrial planets,” 2/17
  - Large majority on solar system
  - A few question on topics covered in Test 1
  - Format same as Test 1. One cheat sheet.
  - Practice test: link on syllabus
  - Missouri Club is 7:00pm, Mon., March 2nd