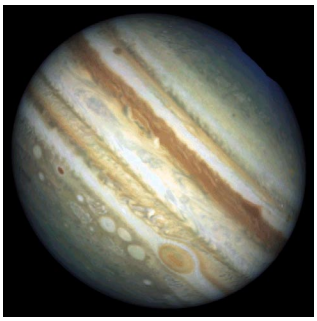
# Formation of the Solar System

- Questions
  - Why are rocky planets close to the sun?
  - Why is solar system a disk?
  - How did the planets form?
  - Asteroids
  - Meteorites—"fossils" from the birth of the solar system
  - How old is the solar system?
- Test 2 on Tues, Feb 27
  - Covers
    - Large majority on solar system
    - Some question on telescopes & topics covered in test 1
  - Format similar to Test 1
  - Practice test: link on syllabus
- Missouri Club
  - Thurs, 7:30-8:30pm, room 1410

# Terrestrial & Jovian Planets

- Why are the planets near the sun dense (rock) and the farther planets less dense (like water)?

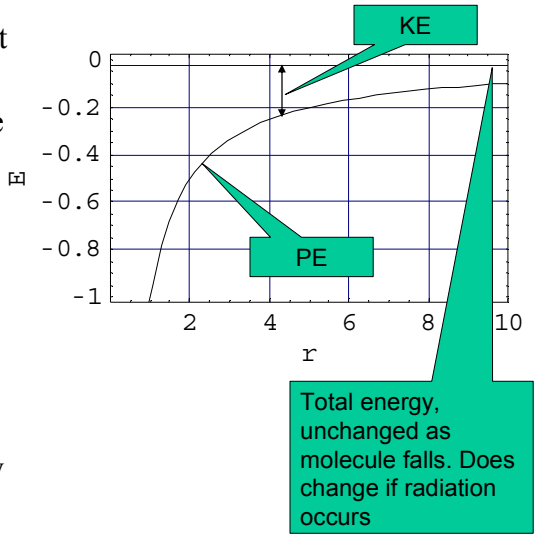


Jupiter; 1.3 gm/cm3

Mercury; 5.4 gm/cm3

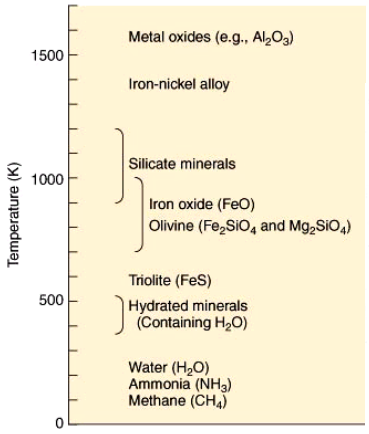
# Collapse of the Protosolar Cloud

- I am a hydrogen molecule in the cloud that will become the sun.
- My energy is kinetic (due to motion) and potential (due to gravity).
  - Energy = KE + PE
  - KE is proportional to $v^2$
  - PE depends on distance r to center of cloud
- When I fall from r = 5 to r = 1, my KE (and temperature) increases by a factor 5.



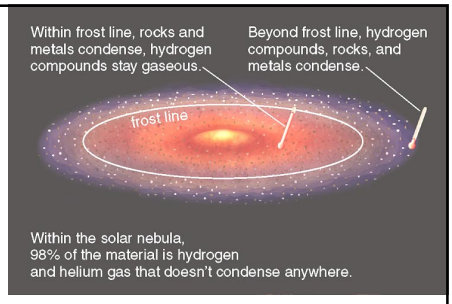

# Thermal history of the Solar System

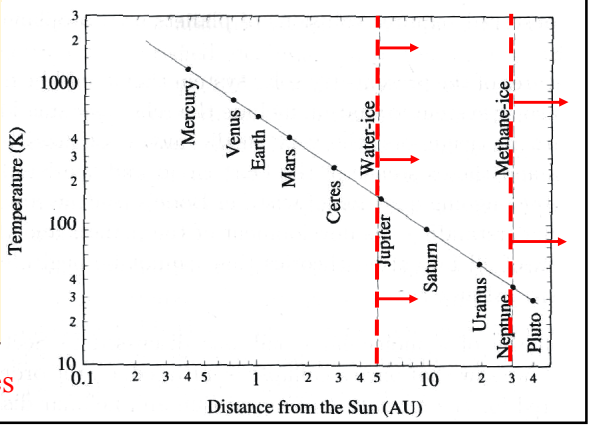
- Terrestrial vs. Giant Planets
- Asteroids vs. comets




Evaporation Temperatures

[Fig. 6.20]



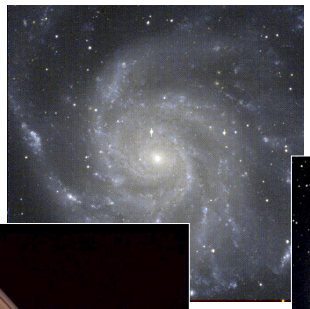



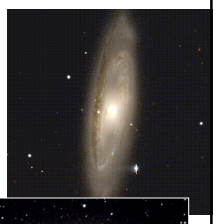
## Giants vs. Terrestrials

- In inner solar system.
  - Lighter elements evaporated away.
  - Planetesimals contained only heavy elements.
  - Growth stopped at Earth-sized planets.
  - Continuing impacts with planetesimals altered the planets
    - Earth's moon
    - Reversal of Venus' rotation, etc.
    - Dumped much of atmospheres onto planets
- In outer solar system.
  - Ices as well as silicates available for solid bodies.
  - Larger protoplanets resulted.
  - These cores able to attract surrounding H & He gas in order to build giant planets.
  - Gravitational field of giant planets perturbed orbits of remaining planetesimals.
    - Most comets ejected into Oort Cloud

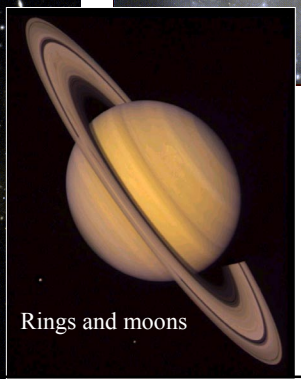
## Why is the solar system spinning & disk shaped?

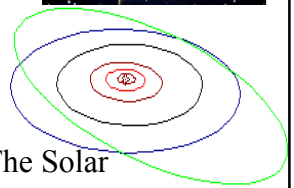

Accretion disks around black holes



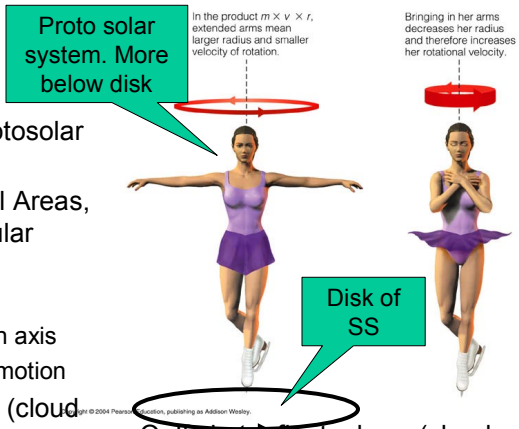



Spiral galaxies


Rings and moons

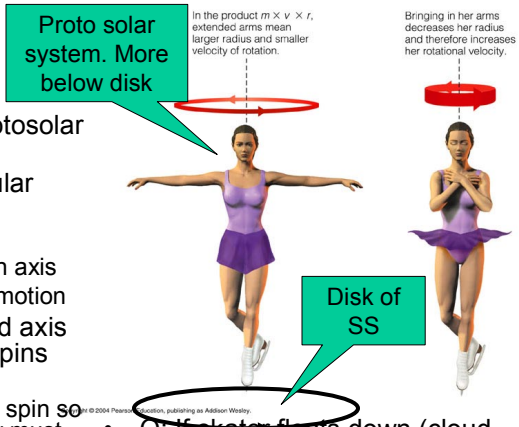

The Solar System

## Why is the solar system spinning & disk shaped?



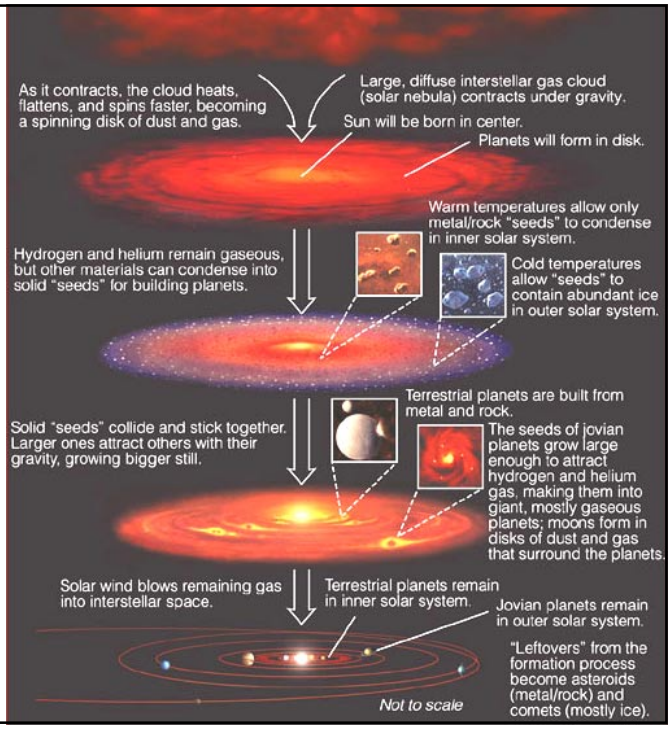

- Skater represents protosolar system
- Kepler's Law of Equal Areas, Conservation of Angular Momentum:
  - L = m r v
  - r is distance to rotation axis
  - v is speed of rotating motion
- If skater pulls arms in (cloud shrinks horizontally), skater spins faster.
- Q: If skater floats down (cloud collapses toward disk), skater spins a) faster, b) same, c) slower
- Q: If material falls toward sun, material spins___. Same foils.

## Why is the solar system spinning & disk shaped?

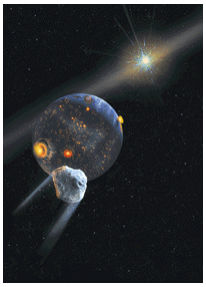


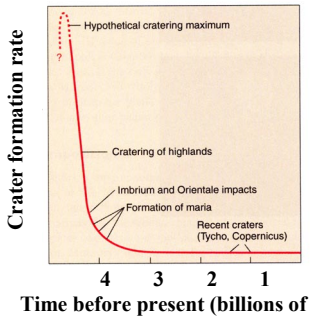

- Skater represents protosolar system
- Conservation of Angular Momentum
  - L = m r v
  - r is distance to rotation axis
  - v is speed of rotating motion
- If cloud shrinks toward axis (horizontally), cloud spins faster.
  - Real cloud can only spin so fast because gravity must hold gas in orbit.
- Cloud can shrink along spin axis without butting against angular momentum. Cloud can flatten.
- Q: If skater floats down (cloud collapses toward disk), skater spins a) faster, b) same, c) slower
- Q: If material falls toward sun, material spins___. Same foils.

## The Solar Nebula
[Fig 6.27]




## Progressive Buildup of the Planets






Before the Sun started to produce its own energy:

- Small "dust" grains condensed from nebula.
  - mm-sized.
- Clumped up into *planetesimals*
  - 10's of km in diameter.
  - comets and asteroids.

protoplanets

Run away growth into *protoplanets*

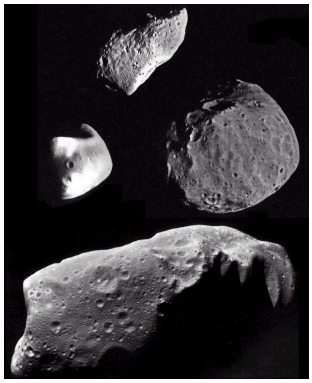
- larger bodies had more gravitational attraction
  - collected lots of smaller bodies.
- ➔ a few Mercury/Mars-sized objects.
  - rapidly accreted further planetesimals.
- Impacts heated interior of growing planet.
  - ➔ differentiation in molten interiors.

## The End Game

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

1. The terrestrial planets are rocky because
   a. The sun evaporated the lighter materials
   b. The lighter materials escaped the planet's gravity
   c. The lighter materials could not condense because the proto planet fell too far and became too hot.
   d. The sun prevented the lighter materials from condensing.

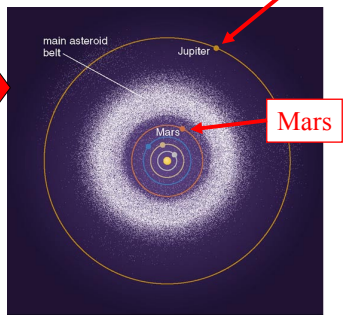
# Asteroids



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

## Asteroid Belt

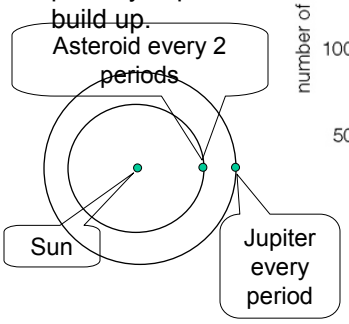
- semi-major axis 2.2 - 3.3 au.
- Between orbits of Mars and Jupiter
- Includes 75% of known asteroids.
- Mostly orbiting sun in same direction of planets, and in plane of solar system.

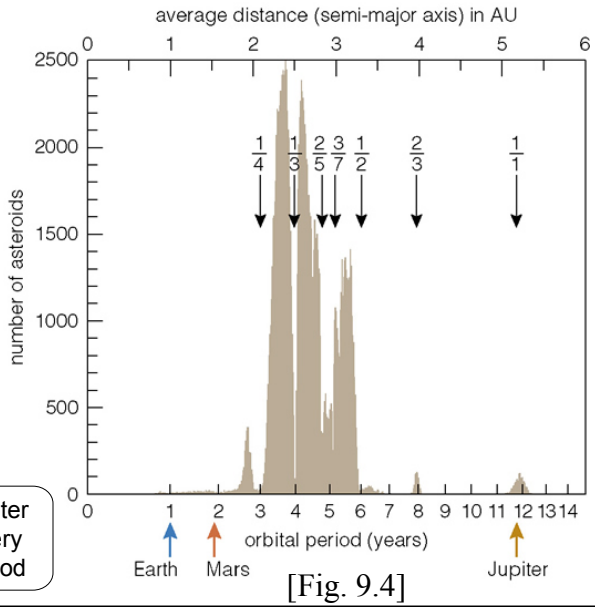



[Fig. 9.3]

# Jupiter prevented planet from forming

- Gaps in asteroid belt correspond to resonances with orbital period of Jupiter
  - In a resonance, pulls by Jupiter build up.



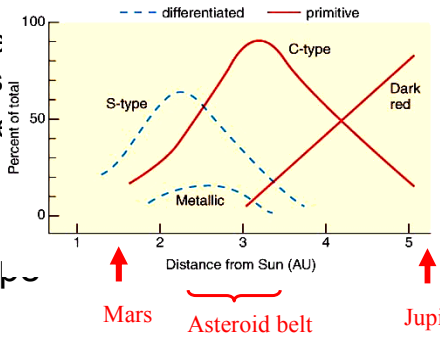



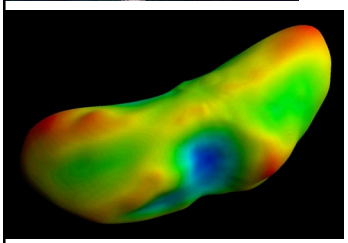

[Fig. 9.4]

# Asteroids

- Failed planets
- Primitive bodies
  - chemically unchanged since initial formation of Solar Sys
  - "Fossils" from the birth of the system.
- 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

Where Different Types of Asteroids are Found



## 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.

Colors show elevation (blue=low)

124 km orbit movie

## Meteors (often pieces of comets)

- Small particles burning up in Earth's atmosphere.
  - Typical meteor = 1 gram (size of a pea)
  - Bright fireballs = golf-ball sized particle.
  - Bowling balls would make it to Earth's surface.

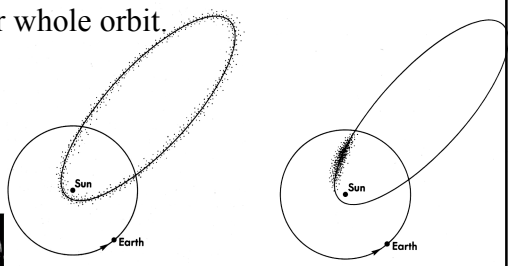
## Meteorites (always pieces of asteroids)

- The particles that make it to the Earth's surface.
  - Allende meteorite (Mexico): 2 tons of fragments recovered after airburst.

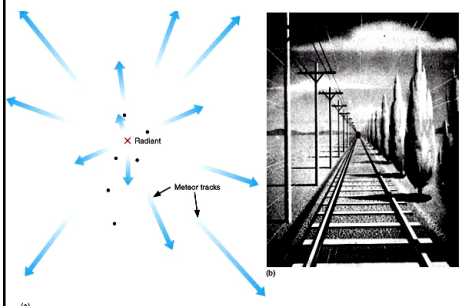
Peekskill, NY early '90s

## Meteor showers

- Result of Earth passing through trail of debris from an old comet.
  - Some trails spread out over whole orbit.
  - Others are clumped up.

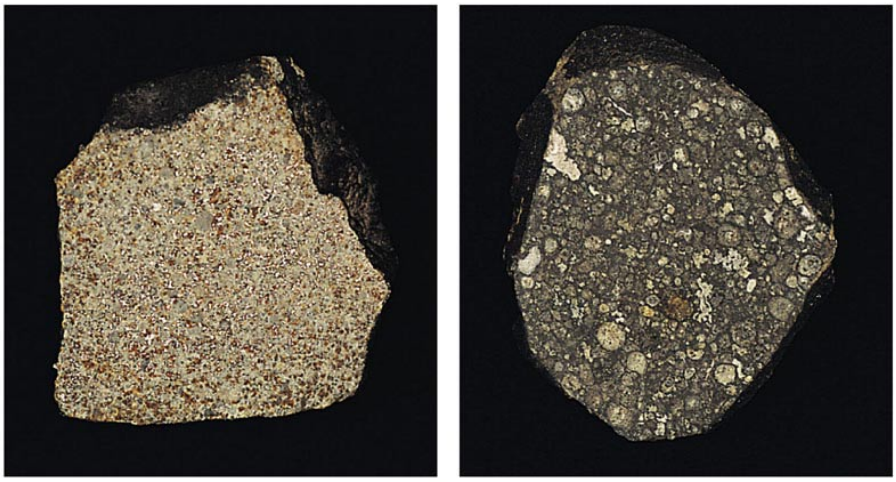



See [Fig. 9.9]



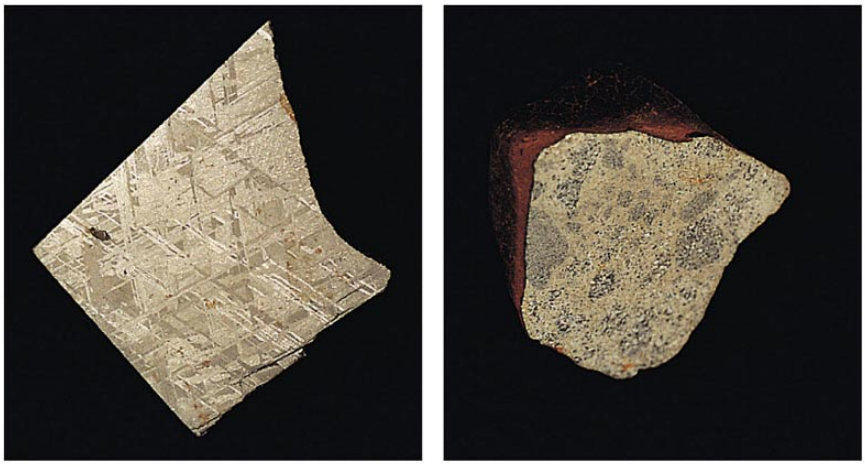



Radiant
- The direction from which the meteors appear to come.
- Determined by combination of motion of meteors and motion of Earth.



- 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).

## How old is the solar system? Age of rocks

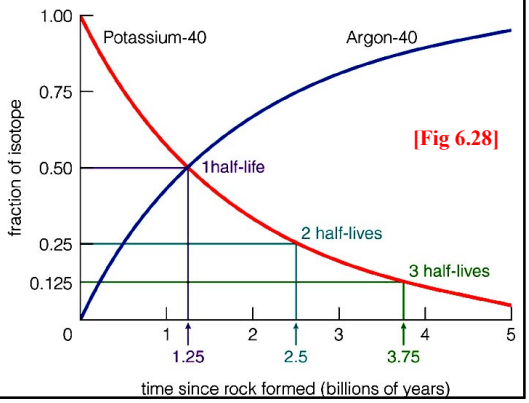
- Radioactive decay
  - unstable atomic nucleus decays into stable nucleus (different element)
    - Examples:

      Uranium-238 ➔ Lead-206 + 8 x Helium-4 (4.5Billion years)

      Potassium-40 ➔ Argon-40 + $e^+$ (1.25 Billion years)

      **($19p^+$, 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 ➔ age since mineral formed.




[Fig 6.28]

K-40 ➔ Ar-40 + $e^+$ (1.25 Billion years)

- Q A meteorite is found with K40 and Ar40 in the ratio 2:1. Its age is ___ 1.25 Byrs.
  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 of 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 Xenon-129
  - Iodine-129 is made in supernovae (exploding stars)
  - Iodine-129 → Xenon-129 (17 Million years)
  - Xenon-129 is a gas even at low temperatures

  ⇒Meteorite form a few tens of millions of years after a supernova

  ⇒**A supernova triggered collapse of cloud that became solar system**