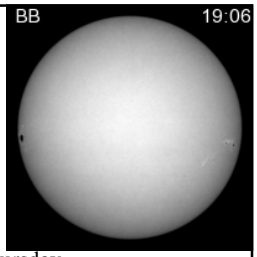
Chapter 8
Formation of the Solar System

Agenda



- Announce:
  - Mercury Transit
  - Part 2 of Projects due next Thursday
- Ch. 8—Formation of the Solar System
- Philip on *The Physics of Star Trek*
- Radiometric Dating Lab

8.1 The Search for Origins

- What properties of our solar system must a formation theory explain?
- What theory best explains the features of our solar system?

What properties of our solar system must a formation theory explain?

1. Patterns of motion of the large bodies
   - Orbit in same direction and plane
2. Existence of two types of planets
   - Terrestrial and Jovian
3. Existence of smaller bodies
   - Asteroids and comets
4. Notable exceptions to usual patterns
   - Rotation of Uranus, Earth's moon, etc.

What theory best explains the features of our solar system?

- The *nebular theory* states that our solar system formed from the gravitational collapse of a giant interstellar gas cloud—the *solar nebula*
  (*Nebula* is the Latin word for cloud)
- Kant and Laplace proposed the *nebular hypothesis* over two centuries ago
- A large amount of evidence now supports this idea

Close Encounter Hypothesis

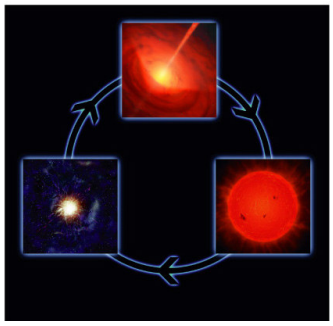
- A rival idea proposed that the planets formed from debris torn off the Sun by a close encounter with another star.
- That hypothesis could not explain observed motions and types of planets.

8.2 The Birth of the Solar System

- Where did the solar system come from?
- What caused the orderly patterns of motion in our solar system?

Where did the solar system come from?

Galactic Recycling

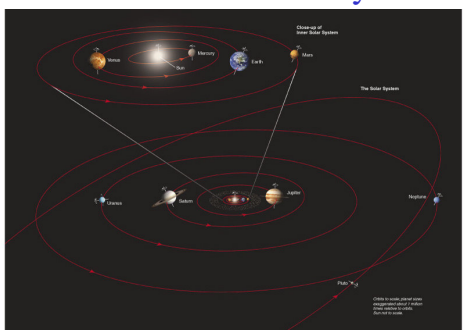


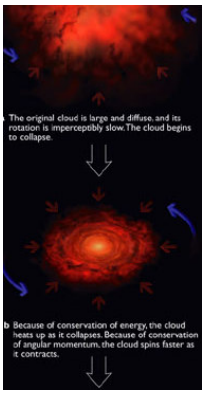
- Elements that formed planets were made in stars and then recycled through interstellar space

Evidence from Other Gas Clouds

- We can see stars forming in other interstellar gas clouds, lending support to the nebular theory

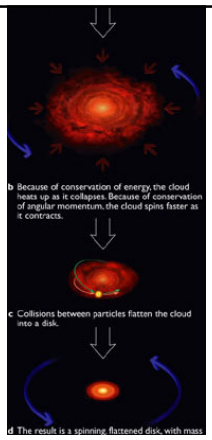
What caused the orderly patterns of motion in our solar system?





Conservation of Angular Momentum

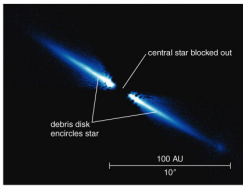
- Angular momentum = r * m * v
- Rotation speed increased as the cloud contracted…v gets big when r gets small

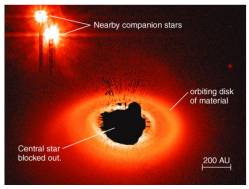


Flattening

- Collisions between particles in the cloud caused it to flatten into a disk

Disks around Other Stars



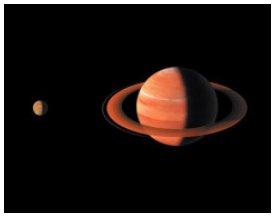


- Observations of disks around other stars support the nebular hypothesis

8.3 The Formation of Planets

- Why are there two types of planets?
- How did terrestrial planets form?
- How did jovian planets form?
- What ended the era of planet formation?

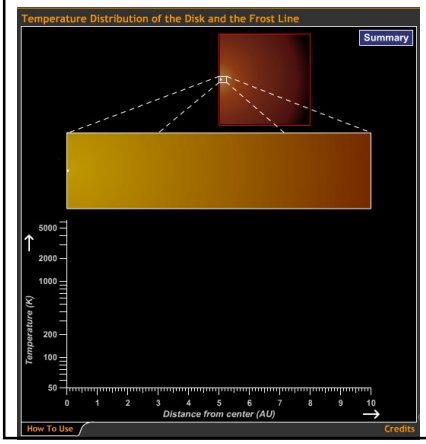
Why are there two types of planet?



	Examples	Typical Condensation Temperature	Relative Abundance (by mass)
Hydrogen and Helium Gas	hydrogen, helium	do not condense in nebula	98%
Hydrogen Compounds	water (H_2O) methane (CH_4) ammonia (NH_3)	<150 K	1.4%
Rock	various minerals	500–1,300 K	0.4%
Metals	iron, nickel, aluminum	1,000–1,600 K	0.2%

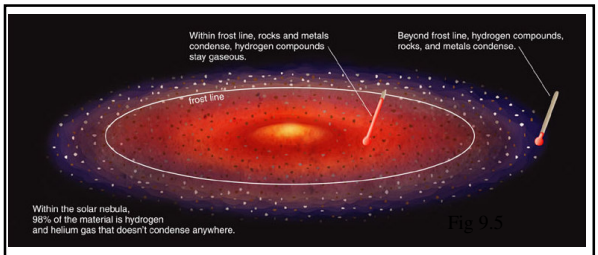
Conservation of Energy

As gravity causes cloud to contract, it heats up



Inner parts of disk are hotter than outer parts.

Rock can be solid at much higher temperatures than ice.



Inside the ***frost line***: Too hot for hydrogen compounds to form ices.

Outside the ***frost line***: Cold enough for ices to form.

How did terrestrial planets form?

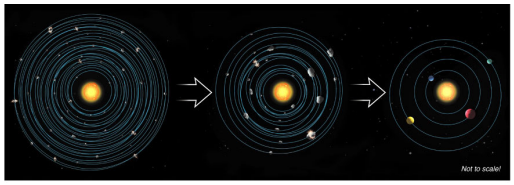
- Small particles of rock and metal were present inside the frost line
- Planetesimals of rock and metal built up as these particles collided
- Gravity eventually assembled these planetesimals into terrestrial planets

Tiny solid particles stick to form ***planetesimals.***

Gravity draws ***planetesimals*** together to form planets

This process of assembly
is called ***accretion***

Accretion of Planetesimals

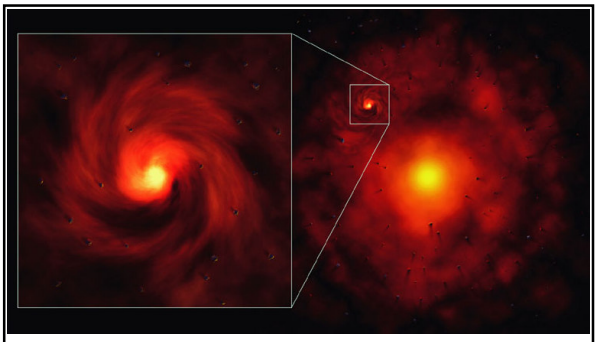


- Many smaller objects collected into just a few large ones

How did jovian planets form?

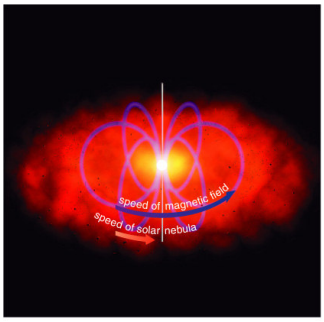
- Ice could also form small particles outside the frost line.
- Larger planetesimals and planets were able to form.
- Gravity of these larger planets was able to draw in surrounding H and He gases.

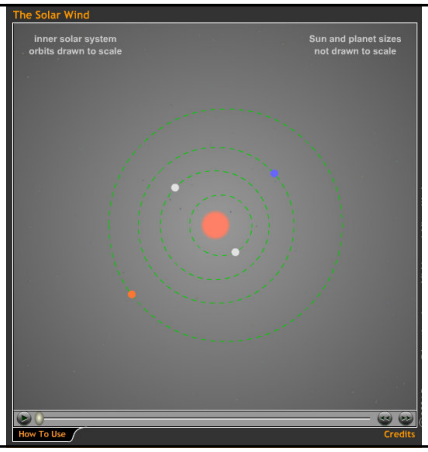
Gravity of rock and ice in jovian planets draws in H and He gases



Moons of jovian planets form in miniature disks

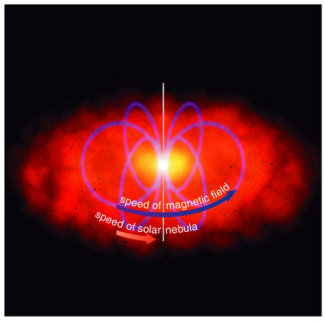
What ended the era of planet formation?





Outflowing matter from the Sun -- the ***solar wind*** -- blew away the leftover gases

Solar Rotation



- In nebular theory, young Sun was spinning much faster than now
- Friction between solar magnetic field and solar nebular probably slowed the rotation over time..*magnetic braking*

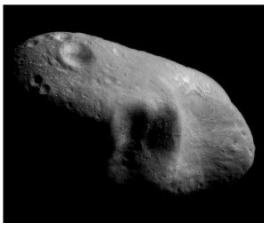
What have we learned?

- Why are there two types of planets?
  - Only rock and metals condensed inside the frost line
  - Rock, metals, and ices condensed outside the frost line
- How did the terrestrial planets form?
  - Rock and metals collected into Planetesimals
  - Planetesimals then accreted into planets
- How did the jovian planets form?
  - Additional ice particles outside frost line made planets there more massive
  - Gravity of these massive planets drew in H, He gases
- What ended the era of planet formation?
  - Solar wind blew away remaining gases
  - Magnetic fields in early solar wind helped reduce Sun's rotation rate

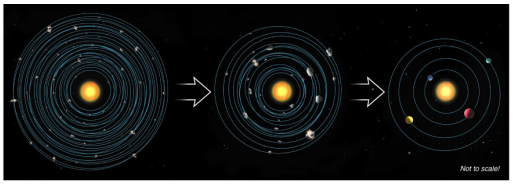
8.4 The Aftermath of Planet Formation

- Where did asteroids and comets come from?
- How do we explain "exceptions to the rules"?
- How do we explain the existence of Earth's moon?
- Was our solar system destined to be?

Where did asteroids and comets come from?

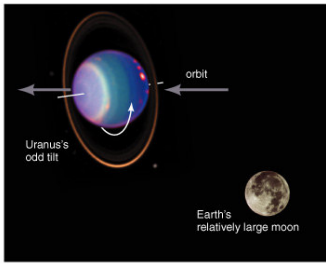


Asteroids and Comets



- Leftovers from the accretion process
- Rocky asteroids inside frost line
- Icy comets outside frost line

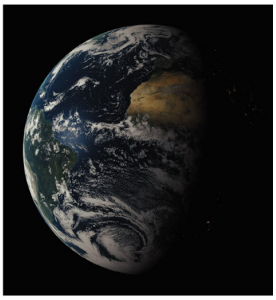
How do we explain "exceptions to the rules"?



Heavy Bombardment

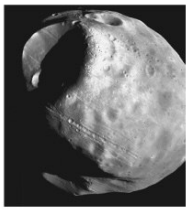
- Leftover planetesimals bombarded other objects in the late stages of solar system formation

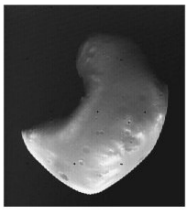
Origin of Earth's Water



- Water may have come to Earth by way of icy planetesimals from outer solar system

Captured Moons



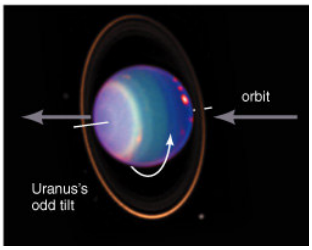


- Unusual moons of some planets may be captured planetesimals

How do we explain the existence of Earth's moon?

Giant Impact

Odd Rotation



- Giant impacts might also explain the different rotation axes of some planets

Thought Question

How would the solar system be different if the solar nebula had cooled, with a temperature half its actual value?

a) Jovian planets would have formed closer to Sun
b) There would be no asteroids
c) There would be no comets
d) Terrestrial planets would be larger

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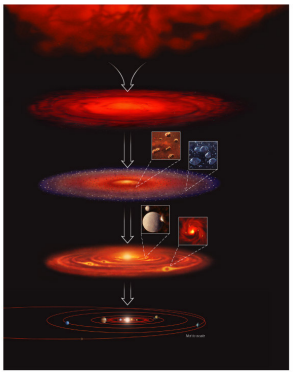
Was our solar system destined to be?



- Formation of planets in the solar nebula seems inevitable
- But details of individual planets could have been different

Thought Question
Which of these facts is NOT explained by the nebular theory?

a) There are two main types of planets: terrestrial and jovian.
b) Planets orbit in same direction and plane.
c) Existence of asteroids and comets.
d) Number of planets of each type (4 terrestrial and 4 jovian).

Thought Question
Which of these facts is NOT explained by the nebular theory?

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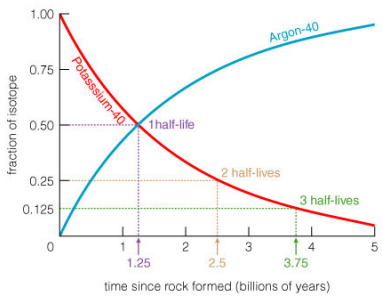
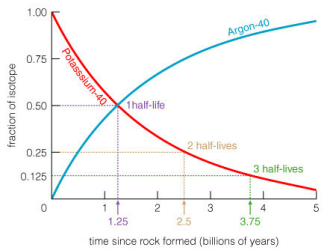
8.5 The Age of the Solar System

- How does radioactivity reveal an object's age?
- When did the planets form?

How does radioactivity reveal an object's age?



Radioactive Decay



- Some isotopes decay into other nuclei
- A **half-life** is the time for half the nuclei in a substance to decay

Thought Question

Suppose you find a rock originally made of potassium-40, half of which decays into argon-40 every 1.25 billion years. You open the rock and find 15 atoms of argon-40 for every atom of potassium-40. How long ago did the rock form?

a) 1.25 billion years ago
b) 2.5 billion years ago
c) 3.75 billion years ago
d) 5 billion years ago

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When did the planets form?

- Radiometric dating tells us that oldest moon rocks are 4.4 billion years old
- Oldest meteorites are 4.55 billion years old
- Planets probably formed 4.5 billion years ago

Final Thoughts

Physics in the Theory

- Conservation of energy—collapse heats up
- Conservation of ang. Momentum—regular motion of large bodies
- Theory of gravity—clumping, formation of planets
- Temperature/Phase Transition—difference between Terrestrial and Jovian planets

Physical Theories

- Here we had a choice of two competing theories:
  - One relied less on improbable events
  - One supported by evidence (other similar systems observed)
  - One accommodated all the features
- Started with simple hypothesis: nebula
  - Worked out consequences to explain features
  - Added/modified: impacts create our moon, tilt Uranus
- Still open to other theories