Chapter 8
Formation of the Solar System

8.1 The Search for Origins
Our goals for learning:
- 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.

What have we learned?

- What properties of our solar system must a formation theory explain?
  - Motions of large bodies
  - Two types of planets
  - Asteroids and comets
  - Notable exceptions like Earth’s moon
- What theory best explains the features of our solar system?
  - Nebular theory states that solar system formed from a large interstellar gas cloud.
8.2 The Birth of the Solar System

Our goals for learning:

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

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

- Rotation speed of the cloud from which our solar system formed must have increased as the cloud contracted.

Rotation of a contracting cloud speeds up for the same reason a skater speeds up as she pulls in her arms.
Flattening

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

Collisions between gas particles in cloud gradually reduce random motions

Collisions between gas particles also reduce up and down motions
What have we learned?

- Where did the solar system come from?
  - Galactic recycling built the elements from which planets formed.
  - We can observe stars forming in other gas clouds.
- What caused the orderly patterns of motion in our solar system?
  - Solar nebula spun faster as it contracted because of conservation of angular momentum.
  - Collisions between gas particles then caused the nebula to flatten into a disk.
  - We have observed such disks around newly forming stars.

8.3 The Formation of Planets

Our goals for learning:

- Why are there two major types of planets?
- How did terrestrial planets form?
- How did jovian planets form?
- What ended the era of planet formation?
As gravity causes cloud to contract, it heats up.

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.

A combination of photons and the *solar wind*—outflowing matter from the Sun—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

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 have we learned?

- 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

Our goals for learning:
• Where did asteroids and comets come from?
• How do we explain "exceptions to the rules"?
• How do we explain the existence of our Moon?
• Was our solar system destined to be?

Asteroids and Comets

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

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

Captured Moons

• Unusual moons of some planets may be captured planetesimals

Giant Impact

Giant impact stripped matter from Earth’s crust.

Stripped matter began to orbit…

…then accreted into Moon.
Odd Rotation

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

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

What have we learned?

- Where did asteroids and comets come from?
  - They are leftover planetesimals, according to the nebular theory
- How do we explain "exceptions to the rules"?
  - Bombardment of newly formed planets by planetesimals may explain the exceptions
- How do we explain the existence of Earth’s moon?
  - Material torn from Earth’s crust by a giant impact formed the Moon
- Was our solar system destined to be?
  - Formation of planets seems inevitable.
  - Detailed characteristics could have been different.
8.5 The Age of the Solar System

Our goals for learning:
- 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
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

What have we learned?

- How does radioactivity reveal an object’s age?
  - Some isotopes decay with a well-known half-life
  - Comparing the proportions of those isotopes with their decay products tells us age of object
- When did the planets form?
  - Radiometric dating indicates that planets formed 4.5 billion years ago