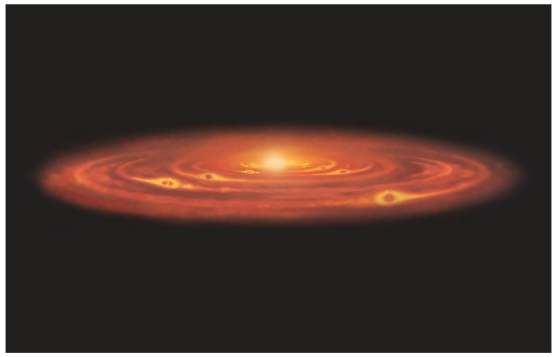
Chapter 8
Formation of the Solar System



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?

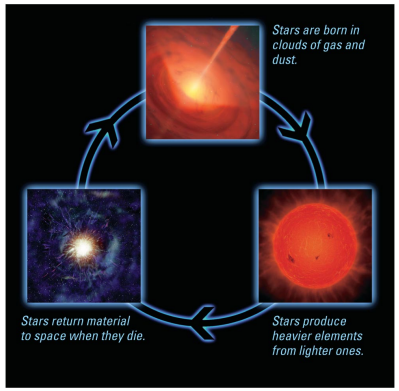
- The *nebular theory* states that our solar system formed from the gravitational collapse of a giant interstellar gas cloud—the *solar nebula*
  (Nebula is the Latin word for cloud)
- Kant and Laplace proposed the *nebular hypothesis* over two centuries ago
- A large amount of evidence now supports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

Where did the solar system come from?

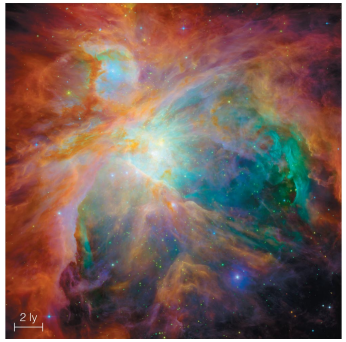
Galactic Recycling



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

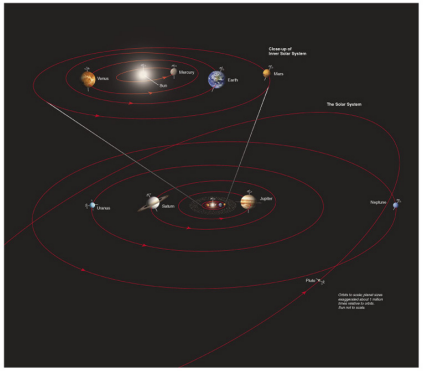
Evidence from Other Gas Clouds

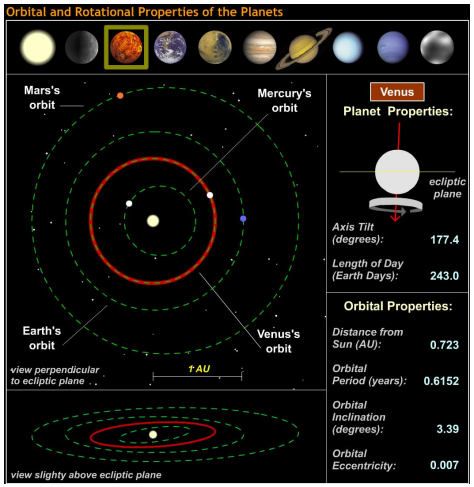
- We can see stars forming in other interstellar gas clouds, lending support to the nebular theory

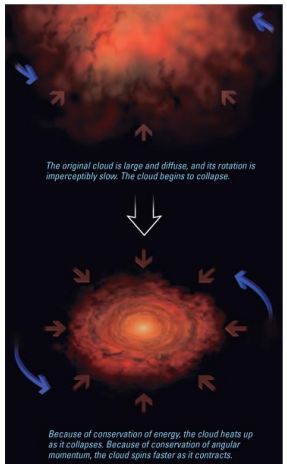


Interactive Figure

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

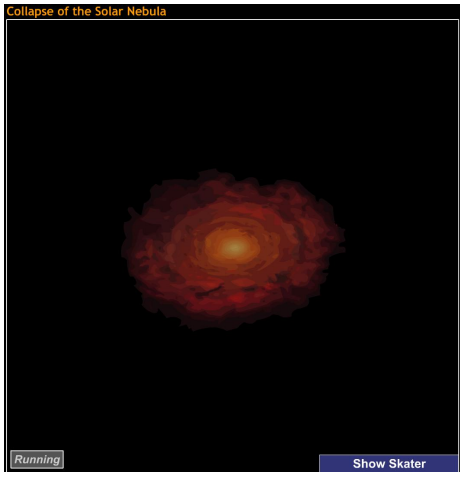




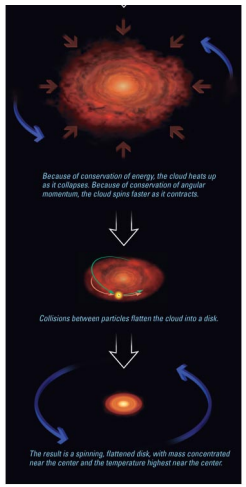


Conservation of Angular Momentum

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

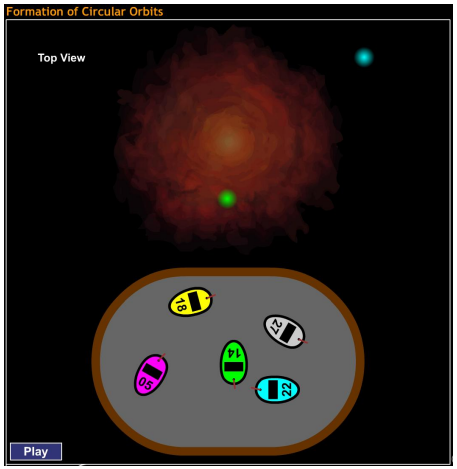


Rotation of a contracting cloud speeds up for the same reason a skater speeds up as she pulls in her arms

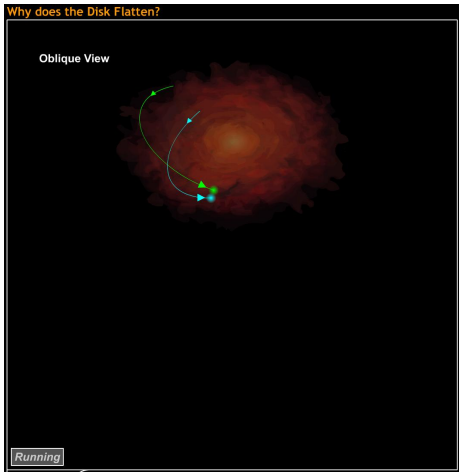


Flattening

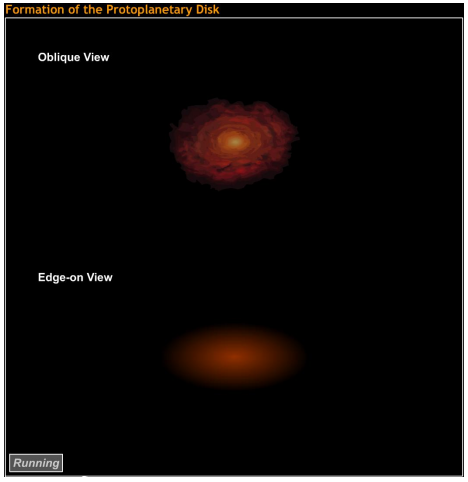
- Collisions between particles in the cloud caused it to flatten into a disk



Collisions between gas particles in cloud gradually reduce random motions

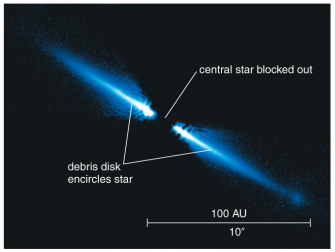


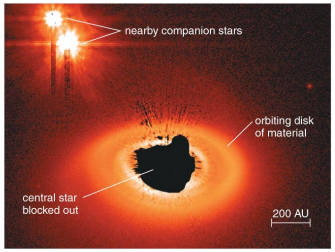
Collisions between gas particles also reduce up and down motions



Spinning cloud flattens as it shrinks

Disks around Other Stars





- Observations of disks around other stars support the nebular hypothesis

Why are there two major types of planet?

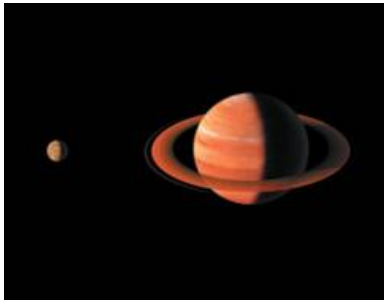


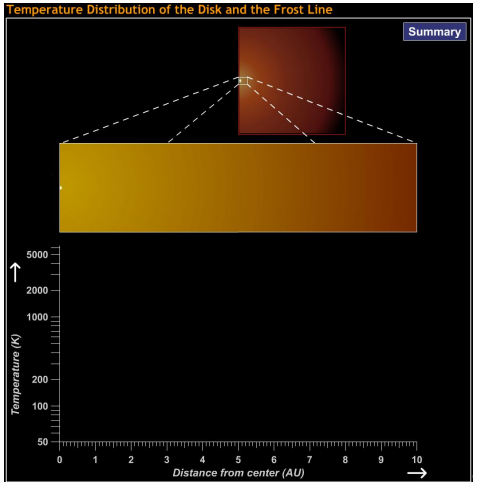
Table 8.1 Materials in the Solar Nebula

A summary of the four types of materials present in the solar nebula. The squares represent the relative proportions of each type (by mass).

	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%

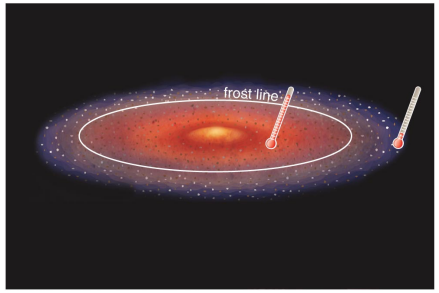
Conservation of Energy

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.

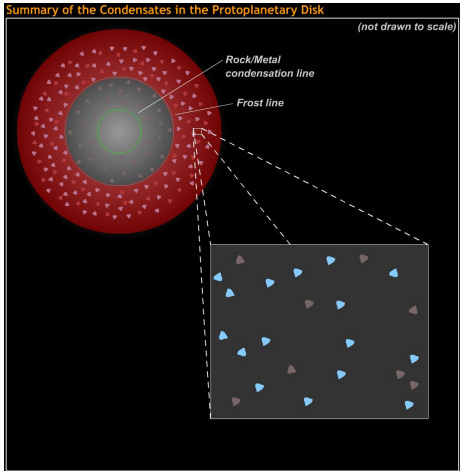


Inside the ***frost line***: Too hot for hydrogen compounds to form ices.

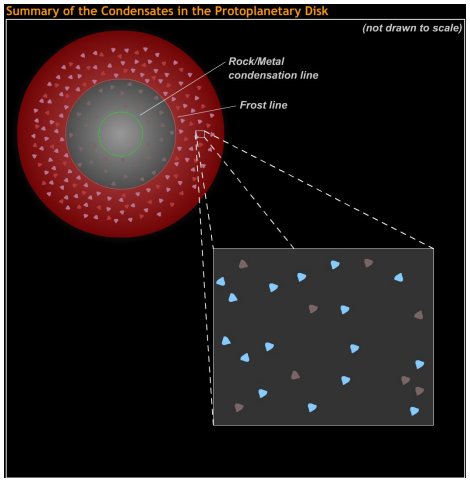
Outside the ***frost line***: Cold enough for ices to form.

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



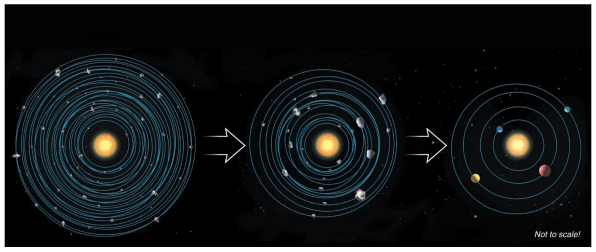
Tiny solid particles stick to form ***planetesimals.***



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

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

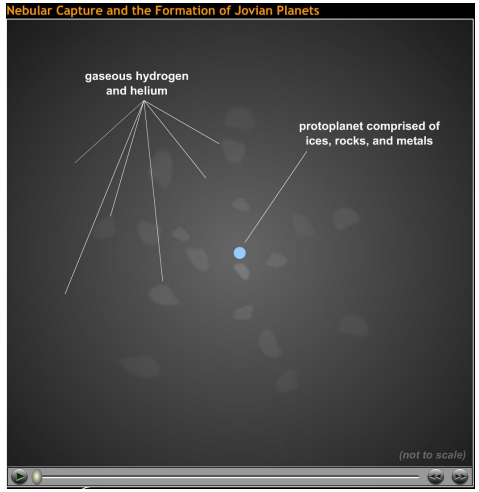
Accretion of Planetesimals



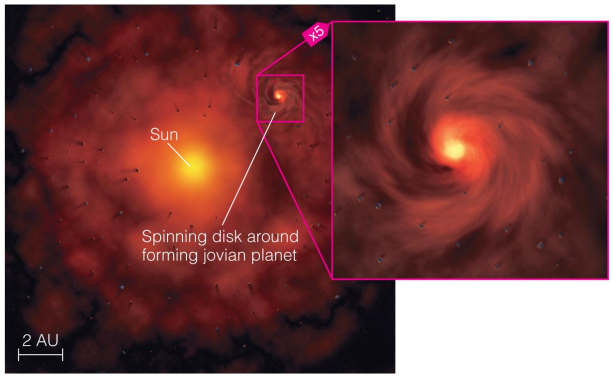
- Many smaller objects collected into just a few large ones

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.

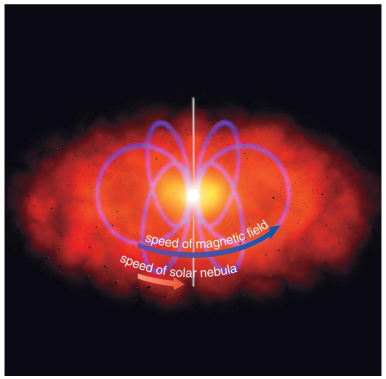


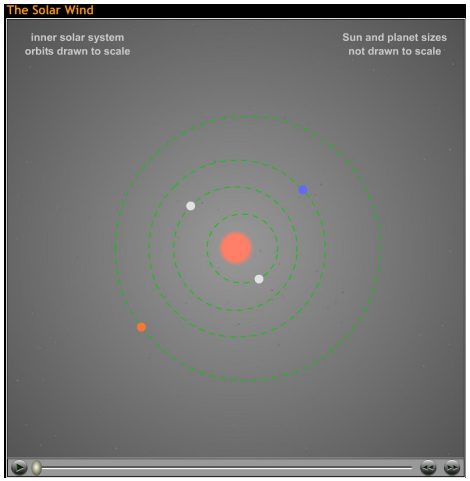
Gravity of rock and ice in jovian planets draws in H and He gases



Moons of jovian planets form in miniature disks

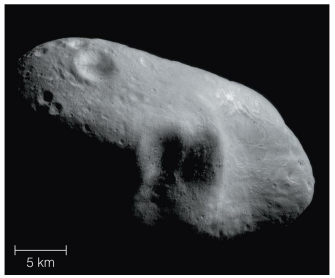
What ended the era of planet formation?



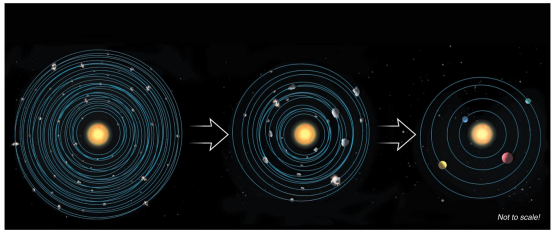


A combination of photons and the ***solar wind*** —outflowing matter from the Sun—blew away the leftover gases

Where did asteroids and comets come from?

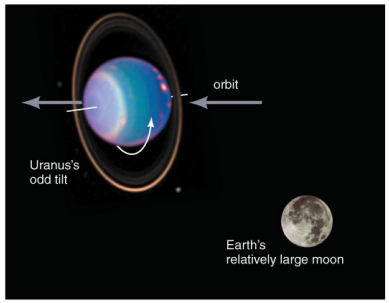


Asteroids and Comets



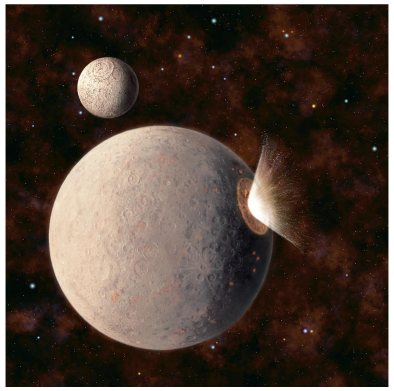
- Leftovers from the accretion process
- Rocky asteroids inside frost line
- Icy comets outside frost line

How do we explain "exceptions to the rules"?



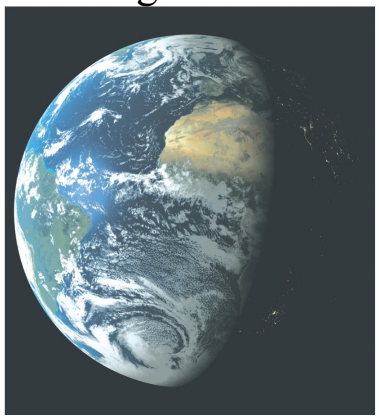
4. Several notable exceptions to these general trends stand out, such as planets with unusual axis tilts or surprisingly large moons, and moons with unusual orbits.

Heavy Bombardment



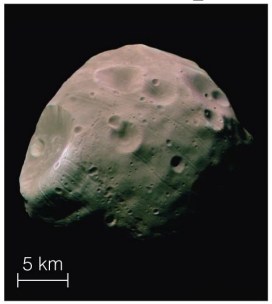
- Leftover planetesimals bombarded other objects in the late stages of solar system formation

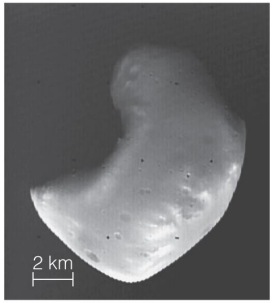
Origin of Earth's Water



- Outgassing from vents in the surface
- Water may have also come by way of icy planetesimals (comets).

Captured Moons



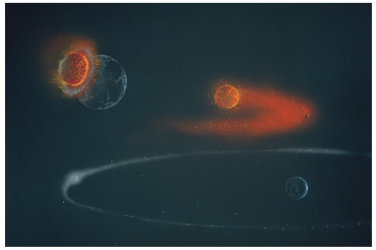


- Unusual moons of some planets may be captured planetesimals

How do we explain the existence of our Moon?

Giant Impact

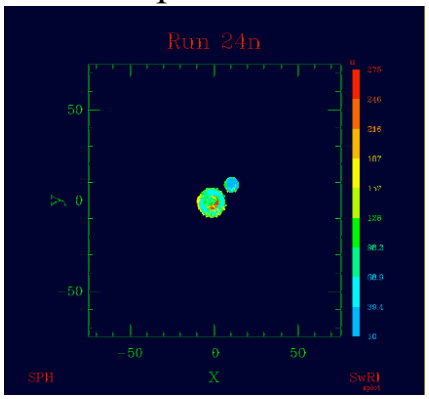
Giant impact stripped matter from Earth's crust.



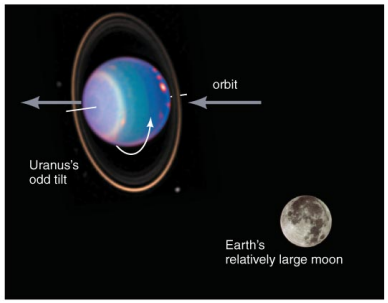
Stripped matter began to orbit…

…then accreted into Moon.

Giant Impact Simulation



Odd Rotation



4. Several notable exceptions to these general trends stand out, such as planets with unusual axis tilts or surprisingly large moons, and moons with unusual orbits.

- 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

Thought Question

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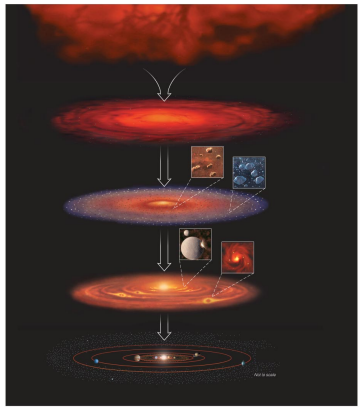
Was our solar system destined to be?



- 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).

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

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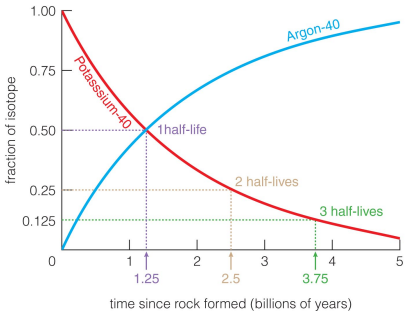
Radioactive Decay



- 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