What does the solar system look like?

The solar system exhibits clear patterns of composition and motion. These patterns are far more important and interesting than numbers, names, and other trivia.
Relative sizes of planets, sun
What does the solar system look like?

1. Large bodies in the solar system have orderly motions. All planets have nearly circular orbits going in the same direction in nearly the same plane. Most large moons orbit their planets in this same direction, which is also the direction of the Sun's rotation.
What does the solar system look like?

2. Planets fall into two major categories: Small, rocky terrestrial planets and large, hydrogen-rich jovian planets.
What does the solar system look like?

Swarms of asteroids and comets populate the solar system. Vast numbers of rocky asteroids and icy comets are found throughout the solar system, but are concentrated in three distinct regions.
What does the solar system look like?

Several notable exceptions to these trends stand out. Some planets have unusual axis tilts, unusually large moons, or moons with unusual orbits.

Uranus’s odd tilt

Earth’s relatively large moon
Planets are very tiny compared to distances between them.
Sun

- Over 99.8% of solar system's mass
- Made mostly of H/He gas (plasma)
- Converts 4 million tons of mass into energy each second
What features of our solar system provide clues to how it formed?
Motion of Large Bodies

- All large bodies in the solar system orbit in the same direction and in nearly the same plane.
- Most also rotate in that direction.
Two Major Planet Types

- Terrestrial planets are rocky, relatively small, and close to the Sun.
- Jovian planets are gaseous, larger, and farther from the Sun.
Swarms of Smaller Bodies

- Many rocky asteroids and icy comets populate the solar system.
Notable Exceptions

• Several exceptions to normal patterns need to be explained.
What is the nebular theory?

The solar system's layout and composition offer clues to the process by which it formed. The nebular hypothesis holds that the newly formed Sun emitted a cloud of gas and dust, which then collapsed under its own gravity to form the planets. The gas and dust were drawn into the plane of the Sun, creating the solar system's plane. As the cloud collapsed, it flattened into a disk, with the planets forming from the material that remained. This process is thought to have occurred over millions of years.
Origin of the Nebula

• 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. Here we see the Orion nebula, with six insets showing nascent solar systems forming.
What caused the orderly patterns of motion?
• The rotation speed of the cloud from which our solar system formed must have increased as the cloud contracted.
Collisions between particles in the cloud caused it to flatten into a disk.
Collisions between gas particles in a cloud gradually reduce random motions.
Collisions between gas particles also reduce up and down motions.
The spinning cloud flattens as it shrinks.
Disks Around Other Stars

- Observations of disks around other stars support the nebular hypothesis.

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Why are there two major types of planets?

Planets fall into two major categories: Small, rocky terrestrial planets and large, hydrogen-rich jovian planets.

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

<table>
<thead>
<tr>
<th></th>
<th>Can condense at temperatures below</th>
<th>Relative abundance (by mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydrogen and Helium Gas</strong></td>
<td>hydrogen, helium</td>
<td>do not condense in nebula</td>
</tr>
<tr>
<td><strong>Hydrogen Compounds</strong></td>
<td>water (H₂O), methane (CH₄), ammonia (NH₃)</td>
<td>150 K</td>
</tr>
<tr>
<td><strong>Rock</strong></td>
<td>various minerals</td>
<td>500–1300 K</td>
</tr>
<tr>
<td><strong>Metals</strong></td>
<td>iron, nickel, aluminum</td>
<td>1000–1600 K</td>
</tr>
</tbody>
</table>

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As gravity causes the cloud to contract, it heats up.
• Inner parts of the 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
Tiny solid particles stick to form *planetesimals.*
Gravity draws *planetesimals* together to form planets.

This process of assembly is called *accretion*. 

*Summary of the Condensates in the Protoplanetary Disk*
Accretion of Planetesimals

- Many smaller objects collected into just a few large ones.
The gravity of rock and ice in jovian planets draws in H and He gases.
- Moons of jovian planets form in miniature disks.
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
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 the outer solar system.
How do we explain "exceptions to the rules"?

Several notable exceptions to these trends stand out. Some planets have unusual axis tilts, unusually large moons, or moons with unusual orbits.

Uranus’s odd tilt

Earth’s relatively large moon
Captured Moons

- The unusual moons of some planets may be captured planetesimals.

a  Phobos

b  Deimos
Giant Impact

A Mars-sized planetesimal crashes into the young Earth, shattering both the planetesimal and our planet.

Hours later, our planet is completely molten and rotating very rapidly. Debris splashed out from Earth’s outer layers is now in Earth orbit. Some debris rains back down on Earth, while some will gradually accrete to become the Moon.

Less than a thousand years later, the Moon’s accretion is rapidly nearing its end, and relatively little debris still remains in Earth orbit.

...then accreted into the Moon.
Odd Rotation

- Giant impacts might also explain the different rotation axes of some planets.
• Review of the nebular theory
Thought Question

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

A. Jovian planets would have formed closer to the Sun.
B. There would be no asteroids.
C. There would be no comets.
D. Terrestrial planets would be larger.
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How do we know the age of the solar system?

- We cannot find the age of a planet, but we can find the ages of the rocks that make it up.
- We can determine the age of a rock through careful analysis of the proportions of various atoms and isotopes within it.
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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Age dating of meteorites that are unchanged since they condensed and accreted tells us that the solar system is about 4.6 billion years old.
Dating the Solar System

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