Chapter 6
The Solar System
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Early astronomers knew Moon, stars, Mercury, Venus, Mars, Jupiter, Saturn, comets, and meteors
Now known: The solar system has 169 moons, one star, eight planets (added Uranus and Neptune), eight asteroids, more than 100 Kuiper belt objects more than 300 km in diameter, and many smaller asteroids, comets, and meteoroids.
More than 800 extrasolar planets have been found

Understanding planetary formation in our own solar system helps understand its formation as well as formation of other systems
6.2 Measuring the Planets

- Distance from Sun known by Kepler’s laws
- Orbital period can be observed
- Radius known from angular size
- Masses from Newton’s laws
- Rotation period from observations
- Density can be calculated knowing radius and mass
# 6.2 Measuring the Planets

## TABLE 6.1 Properties of Some Solar System Objects

<table>
<thead>
<tr>
<th>Object</th>
<th>Orbital Semimajor Axis (AU)</th>
<th>Orbital Period (Earth Years)</th>
<th>Mass (Earth Masses)</th>
<th>Radius (Earth Radii)</th>
<th>Number of Known Satellites</th>
<th>Rotation Period * (days)</th>
<th>Average Density (kg/m³)</th>
<th>Average Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.39</td>
<td>0.24</td>
<td>0.055</td>
<td>0.38</td>
<td>0</td>
<td>59</td>
<td>5400</td>
<td>5.4</td>
</tr>
<tr>
<td>Venus</td>
<td>0.72</td>
<td>0.62</td>
<td>0.82</td>
<td>0.95</td>
<td>0</td>
<td>-243</td>
<td>5200</td>
<td>5.2</td>
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<tr>
<td>Earth</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1</td>
<td>1.0</td>
<td>5500</td>
<td>5.2</td>
</tr>
<tr>
<td>Moon</td>
<td>—</td>
<td>—</td>
<td>0.012</td>
<td>0.27</td>
<td>—</td>
<td>27.3</td>
<td>3300</td>
<td>3.3</td>
</tr>
<tr>
<td>Mars</td>
<td>1.52</td>
<td>1.9</td>
<td>0.11</td>
<td>0.53</td>
<td>2</td>
<td>1.0</td>
<td>3900</td>
<td>3.9</td>
</tr>
<tr>
<td>Ceres (asteroid)</td>
<td>2.8</td>
<td>4.7</td>
<td>0.00015</td>
<td>0.073</td>
<td>0</td>
<td>0.38</td>
<td>2700</td>
<td>2.7</td>
</tr>
<tr>
<td>Jupiter</td>
<td>5.2</td>
<td>11.9</td>
<td>318</td>
<td>11.2</td>
<td>63</td>
<td>0.41</td>
<td>1300</td>
<td>1.3</td>
</tr>
<tr>
<td>Saturn</td>
<td>9.5</td>
<td>29.4</td>
<td>95</td>
<td>9.5</td>
<td>56</td>
<td>0.44</td>
<td>700</td>
<td>0.7</td>
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<tr>
<td>Uranus</td>
<td>19.2</td>
<td>84</td>
<td>15</td>
<td>4.0</td>
<td>27</td>
<td>-0.72</td>
<td>1300</td>
<td>1.3</td>
</tr>
<tr>
<td>Neptune</td>
<td>30.1</td>
<td>164</td>
<td>17</td>
<td>3.9</td>
<td>13</td>
<td>0.67</td>
<td>1600</td>
<td>1.6</td>
</tr>
<tr>
<td>Pluto (Kuiper belt object)</td>
<td>39.5</td>
<td>248</td>
<td>0.002</td>
<td>0.2</td>
<td>3</td>
<td>-6.4</td>
<td>2100</td>
<td>2.1</td>
</tr>
<tr>
<td>Hale-Bopp (comet)</td>
<td>180</td>
<td>2400</td>
<td>$1.0 \times 10^{-9}$</td>
<td>0.004</td>
<td>—</td>
<td>0.47</td>
<td>100</td>
<td>0.1</td>
</tr>
<tr>
<td>Sun</td>
<td>—</td>
<td>—</td>
<td>332,000</td>
<td>109</td>
<td>—</td>
<td>25.8</td>
<td>1400</td>
<td>1.4</td>
</tr>
</tbody>
</table>

*A negative rotation period indicates retrograde (backward) rotation relative to the sense in which all planets orbit the Sun.*
6.3 The Overall Layout of the Solar System

All orbits but Mercury’s are close to the same plane
Because the planet’s orbits are close to being in a plane, it is possible for them to appear in a straight line as viewed from Earth. This photograph was taken in April 2002.
6.4 Terrestrial and Jovian Planets

In this picture of the eight planets and the Sun, the differences between the four terrestrial and four jovian planets are clear.
6.4 Terrestrial and Jovian Planets

Terrestrial planets:
Mercury, Venus, Earth, Mars

Jovian planets:
Jupiter, Saturn, Uranus, Neptune

Terrestrial planets are small and rocky, close to the Sun, rotate slowly, have weak magnetic fields, few moons, and no rings.

Jovian planets are large and gaseous, far from the Sun, rotate quickly, have strong magnetic fields, many moons, and rings.
6.4 Terrestrial and Jovian Planets

Differences among the terrestrial planets:

• All have atmospheres, but they are very different; surface conditions vary as well

• Only Earth has oxygen in its atmosphere and liquid water on its surface

• Earth and Mars spin at about the same rate; Mercury is much slower, Venus is slow and retrograde

• Only Earth and Mars have moons

• Only Earth and Mercury have magnetic fields
Gravitational “slingshots” can change direction of spacecraft, and also accelerate it.
Asteroids and meteoroids have rocky composition; asteroids are bigger.

Asteroid Vesta is 500 km across.
Comets are icy, with some rocky parts.
6.5 Interplanetary Matter

Pluto, once classified as one of the major planets, is the closest large Kuiper belt object to the Sun.
Soviet *Venera* probes landed on Venus from 1970 to 1978
The most recent Venus expedition from the United States was the *Magellan* orbiter, 1990–1994
Discovery 6-2 Spacecraft
Exploration of the Solar System

*Viking* landers arrived at Mars in 1976
Discovery 6-2 Spacecraft
Exploration of the Solar System

*Spirit* took this image on Mars in 2005
Discovery 6-2 Spacecraft Exploration of the Solar System

**Pioneer** and **Voyager** flew through outer solar system. This is **Voyager**.
Discovery 6-2 Spacecraft
Exploration of the Solar System

*Cassini* mission arrived at Saturn in 2004, has returned many spectacular images
6.6 How Did the Solar System Form?

Nebular contraction:

Cloud of gas and dust contracts due to gravity; conservation of angular momentum means it spins faster and faster as it contracts.
Conservation of angular momentum says that the product of radius and rotation rate must be constant.
6.6 How Did the Solar System Form?

Nebular contraction is followed by condensation around dust grains, known to exist in interstellar clouds such as the one shown here.

Accretion then leads to larger and larger clumps; finally gravitational attraction takes over and planets form.
6.7 Jovian Planets and Planetary Debris

Terrestrial (rocky) planets formed near Sun, due to high temperature—nothing else could condense there.
T Tauri stars are in a highly active phase of their evolution and have strong solar winds. These winds sweep away the gas disk, leaving the planetesimals and gas giants.
Jovian planets:
• Once they were large enough, may have captured gas from the contracting nebula
• Or may not have formed from accretion at all, but directly from instabilities in the outer, cool regions of the nebula
Detailed information about the cores of jovian planets should help us distinguish between the two possibilities.

Also possible: The jovian planets may have formed farther from the Sun and “migrated” inward.
6.7 Jovian Planets and Planetary Debris

Asteroid belt:

- Orbits mostly between Mars and Jupiter
- Jupiter’s gravity kept them from condensing into a planet, or accreting onto an existing one
- Fragments left over from the initial formation of the solar system
6.7 Jovian Planets and Planetary Debris

General timeline of solar system formation

- **Solar nebula**
  - Sun forms
  - T Tauri phase
  - Nebular gas ejected

- **Inner solar system**
  - Rocky grains form
  - Accretion and fragmentation
  - Asteroid belt
  - Terrestrial planets formed

- **Outer solar system**
  - Planets accrete nebular gas
  - Icy grains form
  - Jovian cores form
  - Cores accrete gas
  - Ejection of icy planetesimals to Kuiper belt and Oort cloud
  - Jovian planets formed
  - Jovian planets form by instabilities
Icy planetesimals far from the Sun were ejected into distant orbits by gravitational interaction with the jovian planets, into the Kuiper belt and the Oort cloud.

Some were left with extremely eccentric orbits and appear in the inner solar system as comets.
Kuiper belt objects have been detected from Earth; a few are as large as, or larger than, Pluto, and their composition appears similar.

About 1/3 of all Kuiper belt objects (including Pluto) have orbits that are in a 3:2 resonance with Neptune; such objects are called “plutinos.”
Summary of Chapter 6

• Solar system consists of Sun and everything orbiting it

• Asteroids are rocky, and most orbit between orbits of Mars and Jupiter

• Comets are icy and are believed to have formed early in the solar system’s life

• Major planets orbit Sun in same sense, and all but Venus rotate in that sense as well

• Planetary orbits lie almost in the same plane
Summary of Chapter 6 (cont.)

• Four inner planets—terrestrial planets—are rocky, small, and dense

• Four outer planets—jovian planets—are gaseous and large

• Nebular theory of solar system formation: cloud of gas and dust gradually collapsed under its own gravity, spinning faster as it shrank

• Condensation theory says dust grains acted as condensation nuclei, beginning formation of larger objects
Summary of Chapter 6 (cont.)

• The solar system is orderly, not random; need formation theory that explains this

• Condensation theory is the current favorite—large cloud of interstellar gas and dust starts to collapse, the Sun forms at the center, and dust particles act as accretion nuclei to form the planets

• Rocky planets would form close to the Sun; outer planets contain materials that would vaporize or escape at higher temperatures

• Jovian planets may have formed directly from instabilities in the cloud

• Asteroids never condensed into a larger object
Summary of Chapter 6 (cont.)

• Leftover planetesimals were ejected from the main solar system and are now in the Kuiper belt and the Oort cloud. Some occasionally enter the inner solar system as comets