Our Solar System: An Overview

Our solar system, the Sun, planets, and assorted debris, represents about $10^{-39}$ the volume of the observable Universe – but it’s our backyard!

Without a doubt, this is a great time to be studying our solar system . . . Why?

As of 2015, all of the planets, AND Pluto, have been visited by our unmanned space probes (some comets and asteroids too).

Geometry of the Solar System:

The solar system is essentially flat, i.e. Two – Dimensional.

A better way to say this is: all of the planets orbit the Sun in nearly circular orbits in nearly the same plane.

Orbital Distances and Planetary Sizes:

You should have an idea of the relative sizes and approximate distances to the planets - - i.e. the scale of the solar system.
The Scale of the Solar System

Many of the pictures depicting the solar system show the orbital distances to scale, but the sizes of the planets aren’t to scale, even in your text.

**What is the proper scale?** Remember when we put the Earth-Moon system in this room? Let’s do the same with the entire solar system. What objects would represent the Sun (LC) and planets?

Scale: 1 foot ~ 1 AU

Sun is a brass BB!
Orbit of Jupiter
Jupiter is grain of salt!
Orbit of Pluto

~80 AU

On this scale, how far away is the nearest star (i.e. the next BB)?

*About 57 miles away!*

Here are some guys who take this game to the extreme! (The Apollo astronaut quotes are from: *In the Shadow of the Moon*)

What is NOT to scale in this video? (the orbital speeds)
# Inventory of the Solar System

## Table 6.1 The Planetary Data

<table>
<thead>
<tr>
<th>Photo</th>
<th>Planet</th>
<th>Relative Size</th>
<th>Average Distance from Sun (AU)</th>
<th>Average Equatorial Radius (km)</th>
<th>Mass (Earth = 1)</th>
<th>Average Density (g/cm³)</th>
<th>Orbital Period</th>
<th>Rotation Period</th>
<th>Axis Tilt</th>
<th>Average Surface Temperature (°C)</th>
<th>Known Moons (2013)</th>
<th>Rings?</th>
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</thead>
<tbody>
<tr>
<td><img src="image" alt="Mercury" /></td>
<td>Mercury</td>
<td>*</td>
<td>0.387</td>
<td>2440</td>
<td>0.055</td>
<td>5.43</td>
<td>87.9 days</td>
<td>58.6 days</td>
<td>0.0°</td>
<td>700 K (day) 100 K (night)</td>
<td>Rocks, metals</td>
<td>0</td>
</tr>
<tr>
<td><img src="image" alt="Venus" /></td>
<td>Venus</td>
<td>*</td>
<td>0.723</td>
<td>6051</td>
<td>0.82</td>
<td>5.24</td>
<td>225 days</td>
<td>243 days</td>
<td>177.3°</td>
<td>740 K</td>
<td>Rocks, metals</td>
<td>0</td>
</tr>
<tr>
<td><img src="image" alt="Earth" /></td>
<td>Earth</td>
<td>*</td>
<td>1.00</td>
<td>6378</td>
<td>1.00</td>
<td>5.52</td>
<td>1.00 year</td>
<td>23.93 hours</td>
<td>23.5°</td>
<td>290 K</td>
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<td><img src="image" alt="Mars" /></td>
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<td>*</td>
<td>1.52</td>
<td>3397</td>
<td>0.11</td>
<td>3.93</td>
<td>1.88 years</td>
<td>24.6 hours</td>
<td>25.2°</td>
<td>220 K</td>
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<tr>
<td><img src="image" alt="Jupiter" /></td>
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<td>⋄</td>
<td>5.20</td>
<td>71,492</td>
<td>318</td>
<td>1.33</td>
<td>11.9 years</td>
<td>9.93 hours</td>
<td>3.1°</td>
<td>125 K</td>
<td>H, He, hydrogen compounds</td>
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<tr>
<td><img src="image" alt="Saturn" /></td>
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<td>⋄</td>
<td>9.54</td>
<td>60,268</td>
<td>95.2</td>
<td>0.70</td>
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<tr>
<td><img src="image" alt="Uranus" /></td>
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<td>97.9°</td>
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<tr>
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<td>24,764</td>
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<td>1.64</td>
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<td>60 K</td>
<td>H, He, hydrogen compounds</td>
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<tr>
<td><img src="image" alt="Pluto" /></td>
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<td>⋄</td>
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<td>0.0022</td>
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<td>44 K</td>
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<td>0.0028</td>
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<td>1.08 days</td>
<td>78°</td>
<td>43 K</td>
<td>Ices, rock</td>
<td>1</td>
</tr>
</tbody>
</table>

*Including the dwarf planets Pluto and Eris; Appendix E gives a more complete list of planetary properties.*

*Surface temperatures for all objects except Jupiter, Saturn, Uranus, and Neptune, for which cloud-top temperatures are listed.*

*Includes water (H₂O), methane (CH₄), and ammonia (NH₃).*

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The Two Major Classes of Planets

As I wrote on the previous table, we divide the planets into two classes:

**Terrestrial Planets:** relatively small, composed of rock and metal.
   Mercury, Venus, Earth, & Mars (also maybe the Moon and large satellites of Jupiter and Saturn)

**Jovian Planets:** relatively large, composed mostly of gas (H and He), no solid surface. Jupiter, Saturn, Uranus* and Neptune*

This is primarily based on the planet’s average density:

\[
\text{Density}, \ \rho = \frac{\text{Mass}}{\text{Volume}}
\]

Measuring a planet’s volume is easy; how do you measure its mass? *(LC)*

Remember Newton’s form of Kepler’s 3rd Law?

If the planet has a moon, it’s orbital period and semimajor axis will give the mass of the planet.

*Because of the larger concentration of ices in these planets, some astronomers are beginning to call them “Ice Giants.”

Typical Densities

- Gases: \( \rho \ll 1 \ g/cm^3 \)
  (at low pressure)
- Liquid Water: \( \rho = 1 \ g/cm^3 \)
- Rock: \( \rho \sim 3 \rightarrow 5 \ g/cm^3 \)
- Metals: \( \rho > 5 \ g/cm^3 \)
Planetary Atmospheres
(not in the book, but important)

Some planets and one moon have gaseous atmospheres:
• Venus has a thick atmosphere; Earth’s & Mars’ are fairly thin
• Saturn’s large moon Titan has a substantial atmosphere
• The Jovian Planets are all atmospheres of light gases

Other planets have essentially no atmospheres at all:
• Mercury & the Moon
• All other moons (except Titan)

Also, the Earth has no light gases (H & He) in it’s atmosphere, but the Jovian planets are mostly light gases.

What determines whether a planetary body can retain an atmosphere?
Heat from Sunlight
tries to drive the gas away

Gravity of the planet
tries to hold on to the gas
The Origin of the Solar System

Where did our system of planets come from?

• Today it is believed that the formation of planets is a natural consequence of the way that stars form.
• Stars form from the gravitational collapse of large cool clouds of gas and dust - we’ll talk about it in Chapter 13.
• As the cloud collapses, most of the material goes into the central star, but because of rotation, a small amount forms a rotating disk. It’s in this disk where planets form.

Solar Nebula Theory

Currently accepted theory of how planets form.
(developed to explain our solar system; currently being applied to other solar systems – we’ll talk about this in Chapter 10.)

Observational Facts:

• The solar system is relatively flat; all of the planets’ orbital inclinations are less ~5 degrees
• Almost all of the rotation in the solar system is in the same sense
• Solid Terrestrial planets are near the Sun, gaseous Jovian planets are further out
Solar Nebula Theory

Composition of the Nebula:

- ~98% Hydrogen (H₂) and Helium (He)
- ~1.4% Hydrogen compounds (water, H₂O; methane, CH₄, ammonia, NH₃)
- ~0.4% Rocky material (minerals of carbon, C, and silicon, Si)
- ~0.2% Metals, mostly Iron, Fe; Nickel, Ni, and Aluminum, Al

The nebular disk would be hotter nearer the center where the Sun was forming and cooler further away; so different materials would condense in different parts of the disk.

So:

- Solid rock/metal planets would form in the inner disk forming the Terrestrials Planets
- Solid rock/metal and Hydrogen compound ices would form in the outer disk forming the cores of the Jovian Planets.

We see disks like this around many forming stars, e.g. the Orion Nebula.
How Do You Make Planets*?

Terrestrial Planets (Solid Accretion):
• In the inner part of the disk, grains of solid material (metal/rock) are orbiting in a gas cloud
• The grains gently collide with each other and grow by accretion into planetesimals
• When the planetesimals get large enough, they gravitationally perturb each other into crossing orbits and combine through energetic collisions.
• Solar Wind blows the remaining gas away.

Jovian Planets (Two Possibilities):
• **Solid Core Accretion and Gas Capture:** Further out in the disk, accretion of solids and ices grow cores grow to objects about ten Earth masses. This is sufficient to attract and hold the light gases Hydrogen and Helium.
• **Gravitational Collapse of the Nebular Cloud:** Theoretical Calculations show that Jovian or Gas Giant planets may form early in the formation process by the direct gravitational collapse of gas in the orbiting disk.
• *Which one is right? (LC)*

*We’ll talk about the origin of the Moon, asteroids & comets, and the ages of Lunar rocks and meteorites later.*