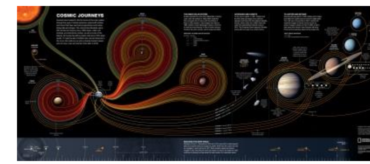
Our Solar System: An Overview

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).

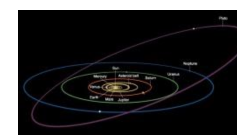


When and how did we learn how to do this?

The early space programs of the 1960s (as we'll see in the To the Moon video)

Geometry of the Solar System:

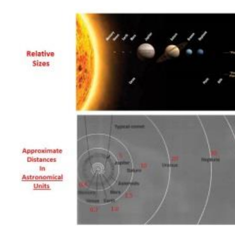
The solar system is essentially flat, i.e. Two – Dimensional.



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

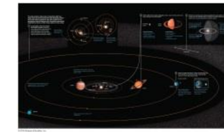
Orbital Distances and Planetary Sizes:

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.

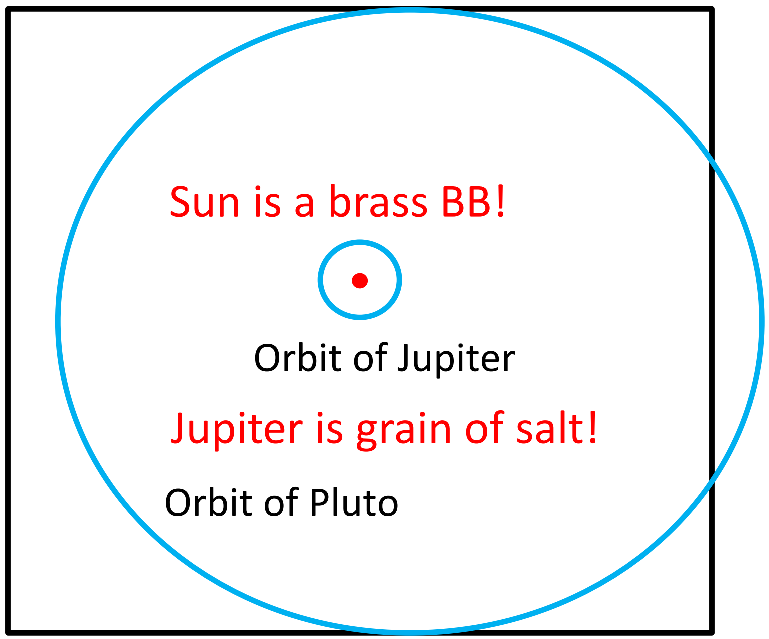


What is the proper scale? Remember when we put the Earth-Moon system in this room? **Let's do the same with the entire solar system. What objects would represent the Sun (LC) and planets?**

~80 AU

Scale: 1 foot ~ 1 AU

~80 AU



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

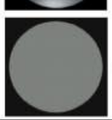
What is NOT to scale in this video? (the orbital speeds)

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

About 57 miles away!

Inventory of the Solar System

TABLE 6.1 The Planetary Data[a]

Photo	Planet	Relative Size	Average Distance from Sun (AU)	Average Equatorial Radius (km)	Mass (Earth = 1)	Average Density (g/cm³)	Orbital Period	Rotation Period	Axis Tilt	Average Surface (or Cloud-Top) Temperature[b]	Composition	Known Moons (2013)	Rings?
	Mercury	·	0.387	2440	0.055	5.43	87.9 days	58.6 days	0.0°	700 K (day) 100 K (night)	Rocks, metals	0	No
	Venus	•	0.723	6051	0.82	5.24	225 days	243 days	177.3°	740 K	Rocks, metals	0	No
	Earth	•	1.00	6378	1.00	5.52	1.00 year	23.93 hours	23.5°	290 K	Rocks, metals	1	No
	Mars	·	1.52	3397	0.11	3.93	1.88 years	24.6 hours	25.2°	220 K	Rocks, metals	2	No
	Jupiter	●	5.20	71,492	318	1.33	11.9 years	9.93 hours	3.1°	125 K	H, He, hydrogen compounds[c]	~~67~~ 92	Yes
	Saturn	●	9.54	60,268	95.2	0.70	29.4 years	10.6 hours	26.7°	95 K	H, He, hydrogen compounds[c]	~~62~~ 83	Yes
	Uranus	●	19.2	25,559	14.5	1.32	83.8 years	17.2 hours	97.9°	60 K	H, He, hydrogen compounds[c]	27	Yes
	Neptune	●	30.1	24,764	17.1	1.64	165 years	16.1 hours	29.6°	60 K	H, He, hydrogen compounds[c]	14	Yes
	Pluto	·	39.5	1160	0.0022	2.0	248 years	6.39 days	112.5°	44 K	Ices, rock	5	No
	Eris	·	67.7	1200	0.0028	2.3	557 years	1.08 days	78°	43 K	Ices, rock	1	No

terrestrial

Jovian

Kuiper Belt

More than everything else combined

Wow!

[a]Including the dwarf planets Pluto and Eris; Appendix E gives a more complete list of planetary properties. [b]Surface temperatures for all objects except Jupiter, Saturn, Uranus, and Neptune, for which cloud-top temperatures are listed. [c]Includes water (H_2O), methane (CH_4), and ammonia (NH_3).

The Two Major Classes of Planets

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

TABLE 6.2 Comparison of Terrestrial and Jovian Planets

Terrestrial Planets	Jovian Planets
Smaller size and mass	Larger size and mass
Higher density	Lower density
Made mostly of rock and metal	Made mostly of hydrogen, helium, and hydrogen compounds
Solid surface	No solid surface
Few (if any) moons and no rings	Rings and many moons
Closer to the Sun (and closer together), with warmer surfaces	Farther from the Sun (and farther apart), with cool temperatures at cloud tops

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.

Typical Densities

Gases : $\rho << 1\ g/cm^3$ (at low pressure)

Liquid Water: $\rho = 1\ g/cm^3$

Rock: $\rho \sim 3 \rightarrow 5\ g/cm^3$

Metals: $\rho > 5\ g/cm^3$

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

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

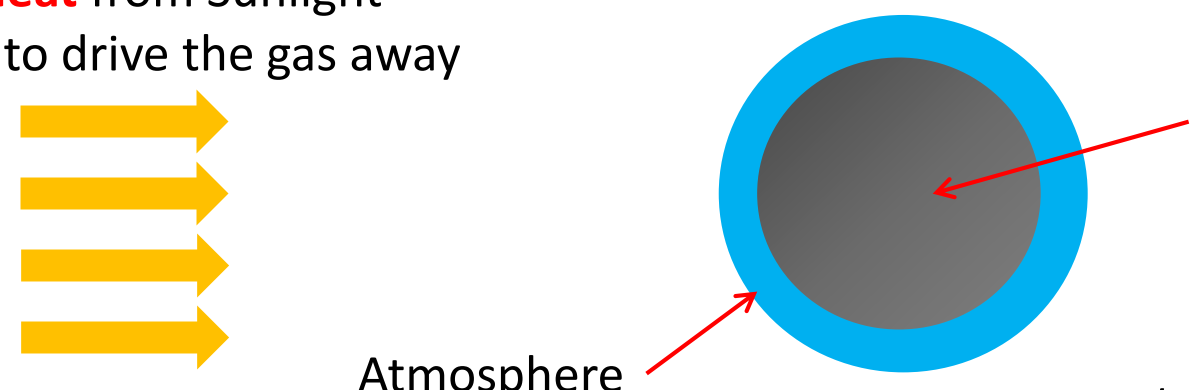
Other planets have essentially no atmospheres at all:

- Mercury & the Moon
- All other moons (except Titan)

Also, the Earth has no light gases (H & He) in its 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



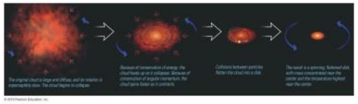
Gravity of
the planet
tries to hold
on to the gas

Do the Moon, Jupiter, & Earth

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*.)

(Cartoon summary)

Observational Facts:

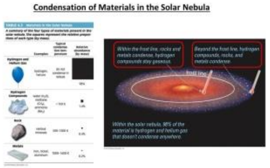
- **The solar system is relatively flat; all of the planets' orbital inclinations are less ~5 degrees**
- **Almost all of the rotation in the solar system is in the same sense**
- **Solid Terrestrial planets are near the Sun, gaseous Jovian planets are further out**

Solar Nebula Theory

Composition of the Nebula:

- ~98% Hydrogen (H_2) and Helium (He)
- ~1.4% Hydrogen compounds (water, H_2O; methane, CH_4, ammonia, NH_3)
- ~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.**



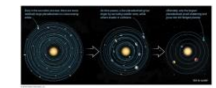
So:

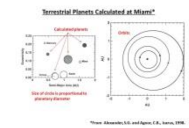
- Solid rock/metal planets would form in the inner disk forming the Terrestrials Planets
- Solid rock/metal and Hydrogen compound ices would form in the outer disk forming the cores of the Jovian Planets.

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 to objects of about ten Earth masses. This is sufficiently massive to attract and hold the light gases Hydrogen and Helium.
- **Gravitational Collapse of the Nebular Cloud:** Some 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)***

Right now, no one knows . . . but here's some recent news.

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