Chapter 10
The Origin of the Solar System

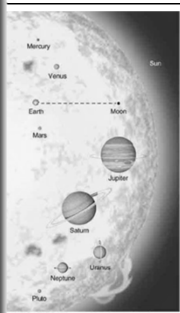
Guidepost

As you explore the origins and the materials that make up the solar system, you will discover the answers to several important questions:

- ❖ What are the observed properties of the solar system?
- ❖ What is the theory for the origin of the solar system that explains the observed properties?
- ❖ How did Earth and the other planets form?
- ❖ What do astronomers know about other extrasolar planets orbiting other stars?

In this and the following six chapters, we will explore in more detail the planets and other objects that make up our solar system, our home in the universe.

A Survey of the Solar System



The solar system consists of eight major planets and several other objects.

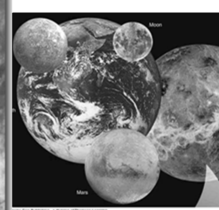
The planets rotate on their axes and revolve around the Sun.

The planets have elliptical orbits, sometimes inclined to the ecliptic, and all planets revolve in the same directly; only Venus and Uranus rotate in an alternate direction.

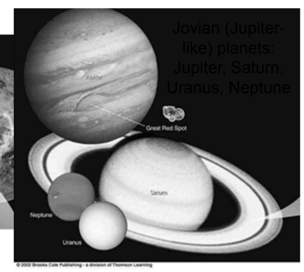
Nearly all moons also revolve in the same direction.

Two Kinds of Planets

Planets of our solar system can be divided into two very different kinds:

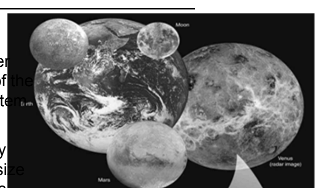


Terrestrial (Earthlike) planets: Mercury, Venus, Earth, Mars



Jovian (Jupiter-like) planets: Jupiter, Saturn, Uranus, Neptune

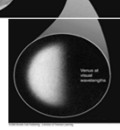
Terrestrial Planets



Four inner planets of the solar system

Relatively small in size and mass (Earth is the largest and most massive)

Rocky surface



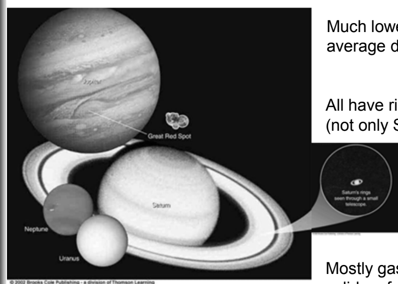
Surface of Venus can not be seen directly from Earth because of its dense cloud cover.

Craters on Planets' Surfaces

Craters (like on our moon's surface) are common throughout the solar system.

Not seen on Jovian planets because they don't have a solid surface.

The Jovian Planets



Much lower average density

All have rings (not only Saturn!)

Mostly gas; no solid surface

Cosmic Debris

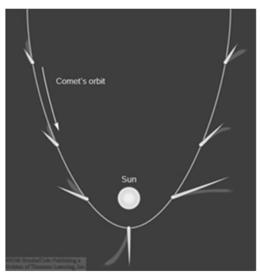
In addition to planets, small bodies orbit the sun: asteroids, comets, meteoroids

Asteroid Eros, imaged by the NEAR spacecraft

Most asteroids orbit the Sun in a region between Mars and Jupiter called the Asteroid Belt

Comets

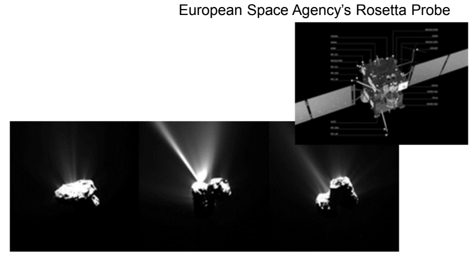
Icy nucleus, which evaporates and gets blown into space by solar wind pressure.



Mostly objects in highly elliptical orbits, occasionally coming close to the sun.

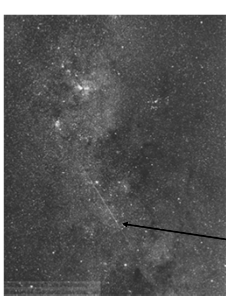
Comets

European Space Agency's Rosetta Probe



Comet 67P/Churyumov–Gerasimenko approaches perihelion, August 2015

Meteoroids

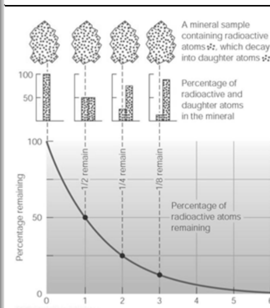


Small (µm – mm sized) dust grains throughout the solar system

If they collide with Earth, they evaporate in the atmosphere.

→ Visible as streaks of light: meteors.

The Age of the Solar System



Sun and planets should have about the same age.

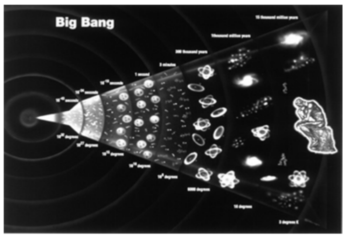
Ages of rocks can be measured through **radioactive dating:**

Measure abundance of a radioactively decaying element to find the time since formation of the rock

Dating of rocks on Earth, on the Moon, and meteorites all give ages between 4.4 and 4.6 billion years.

The Great Chain of Origins (1)

The atoms in your body began with the Big Bang, 13.7 billion years ago!

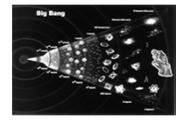


http://scienceblogs.com/startswithabang/2010/04/21/big-bang-alternatives-anyone/

The Great Chain of Origins (2)

The initial conversion of energy to matter created protons, neutrons and electrons in just the first few minutes.

- Not long afterwards, simple atoms – H and He – began to form.



- A few million years later, matter collected to form galaxies with billions of stars. Nuclear fusion in these stars generated C, N, O, Ca and other atoms.
- A supernova explosion in our part of the Milky Way produced larger atoms, such as Fe, Ag, Au and U. The cloud of gas and dust later became our solar system.

The Great Chain of Origins (3)

Early hypotheses on the origins of the solar system included:

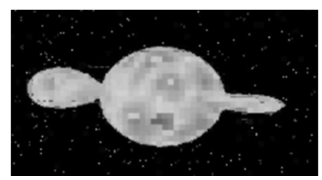
- The Vortex Hypothesis (Descartes) – explained properties known in 1644.

http://holographicgalaxy.wordpress.com/author/quantauniverse/page/7/

The Great Chain of Origins (4)

Early hypotheses on the origins of the solar system included:

- The Passing Star Hypothesis (Buffon) – didn't explain orbits well.

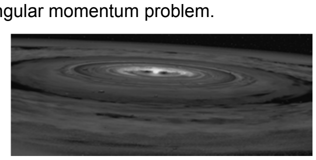


http://metaresearch.org/solar%20system/origins/original-solar-system.asp

The Great Chain of Origins (5)

Early hypotheses on the origins of the solar system included:

- The Nebular Hypothesis (Laplace) – a rotating, contracting disk of matter generates concentric rings of matter = planets; mathematical using Newton's laws but has angular momentum problem.



http://www.universetoday.com/63580/astronomy-without-a-telescope-%E2%80%93-the-nice-way-to-build-a-solar-system/

The Great Chain of Origins (6)

Basis of modern theory of planet formation.

Planets form at the same time from the same cloud as the star.

Planet formation sites observed today as dust disks of T Tauri stars.

Sun and our Solar system formed ~ 5 billion years ago.

Our Solar System

Characteristic Properties of the Solar System

1. Disk shape – orbits nearly in the same plane, and a common direction of rotation and revolution
2. Two planetary types (Jovian and Terrestrial)
3. Planetary rings and large satellite systems for Jovian planets, but not for Terrestrial planets
4. Space debris, with asteroids most like inner planets
5. Common age of ~4.6 billion years measured or inferred

The Story of Planet Building

Planets formed from the same protostellar material as the sun, still found in the sun's atmosphere.

Rocky planet material formed from clumping together of dust grains in the protostellar cloud.

Mass of less than ~ 15 Earth masses:	Mass of more than ~ 15 Earth masses:
Planets cannot grow by gravitational collapse	Planets can grow by gravitationally attracting material from the protostellar cloud
Earthlike planets	Jovian planets (gas giants)

The Condensation of Solids

To compare densities of planets, compensate for compression due to the planet's gravity:

Only condensed materials could stick together to form planets

Temperature in the protostellar cloud decreased outward.

Further out → Protostellar cloud cooler → metals with lower melting point condensed → change of chemical composition throughout solar system

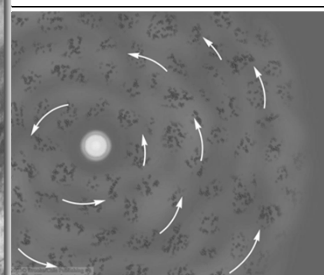
Observed and Uncompressed Densities

Planet	Observed Density (g/cm^3)	Uncompressed Density (g/cm^3)
Mercury	5.44	5.30
Venus	5.24	3.96
Earth	5.50	4.07
Mars	3.94	3.73
(Moon)	3.36	3.40

The Condensation Sequence

Temperature (K)	Condensate	Planet (Estimated Temperature of Formation; K)
1500	Metal oxides	Mercury (1400)
1300	Metallic iron and nickel	
1200	Silicates	
1000	Feldspars	Venus (900)
680	Troilite (FeS)	Earth (600)
		Mars (450)
175	H_2O ice	Jovian (175)
150	Ammonia–water ice	
120	Methane–water ice	
65	Argon–neon ice	Pluto (65)

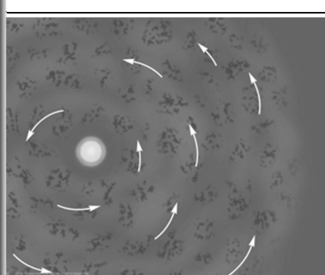
Formation and Growth of Planetesimals



Planet formation starts with clumping together of grains of solid matter: planetesimals

Planetesimals (few cm to km in size) collide to form planets.

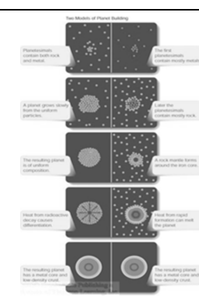
Formation and Growth of Planetesimals



Planetesimal growth through condensation and accretion.

Gravitational instabilities may have helped in the growth of planetesimals into protoplanets.

The Growth of Protoplanets



Simplest form of planet growth:

Unchanged composition of accreted matter over time

As rocks melted, heavier elements sink to the center → *differentiation*

This also produces a secondary atmosphere → *outgassing*

Improvement of this scenario: Gradual change of grain composition due to cooling of nebula and storing of heat from potential energy

The Jovian Problem

Two problems for the theory of planet formation:

1) Observations of extrasolar planets indicate that Jovian planets are common.

2) Protoplanetary disks tend to be evaporated quickly (typically within ~ 100,000 years) by the radiation of nearby massive stars.

→ Too short for Jovian planets to grow!

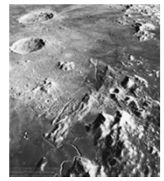
Solution:

Computer simulations show that Jovian planets can grow by direct gas accretion without forming rocky planetesimals.

Clearing the Nebula

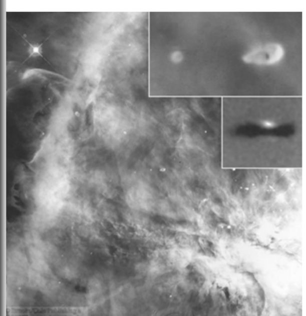
Remains of the protostellar nebula were cleared away by:

- Radiation pressure of the sun
- Sweeping-up of space debris by planets
- Solar wind
- Ejection by close encounters with planets



Surfaces of the moon and Mercury show evidence for heavy bombardment by asteroids.

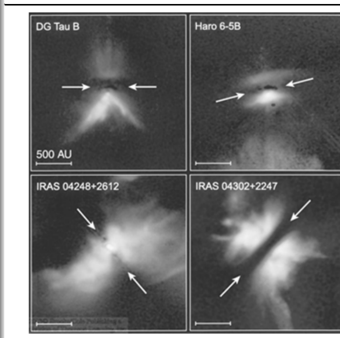
Evidence for Ongoing Planet Formation



Many young stars in the Orion Nebula are surrounded by dust disks:

Probably sites of planet formation right now!

Dust Disks Around Forming Stars



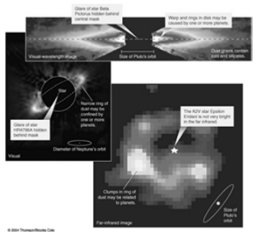
Dust disks around some T Tauri stars can be imaged directly (HST).

Extrasolar Planets

Modern theory of planet formation is evolutionary

→ Many stars should have planets!

→ planets orbiting around other stars = “extrasolar planets”

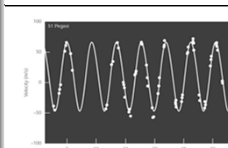


Extrasolar planets can not be imaged directly.

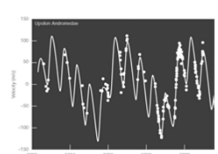
Detection using same methods as in binary star systems:

Look for “wobbling” motion of the star around the common center of mass.

Indirect Detection of Extrasolar Planets



Observing periodic Doppler shifts of stars with no visible companion:



Evidence for the wobbling motion of the star around the common center of mass of a planetary system

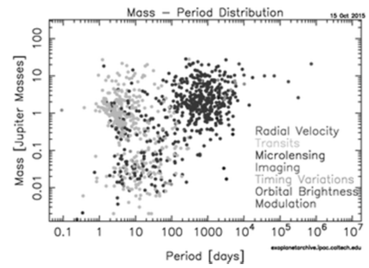
Indirect Detection of Extrasolar Planets

Other methods of detection currently include:

- Transit Method (shadow of planet dims star)
- Transit Timing Variation (TTV) (transits vary due to gravity of other planets in systems)
- Gravitational Microlensing (General Relativity)
- Pulsar Timing Anomalies (caused by planets orbiting pulsar)

A total of 1901 such planets (including 436 multiple planetary systems) have been identified as of October 15, 2015.

Indirect Detection of Extrasolar Planets



http://exoplanetarchive.ipac.caltech.edu/exoplanetplots/

Indirect Detection of Extrasolar Planets

Most confirmed extrasolar planets have now been found using speace-based missions such as COROT (launched December 2006) and Kepler (launched March 2009) are the two currently active space missions dedicated to searching for extrasolar planets. The Hubble Space Telescope and MOST have also found or confirmed a few planets. The Gaia mission, to be launched in October 2013, will use astrometry to determine the true masses of 1000 nearby exoplanets.

There are currently 21 confirmed “earth-like” planets in a habitable zone around their star. The closest of these is 12.7 light years away (Kapteyn b) and is more massive than Earth (4.8x) and orbits a red dwarf star.

Information from Wikipedia and additional sources.