

LEC18 - Solar System Patterns & Formation

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Learning Goals

- Describe several patterns in the Solar System that give us hints to how the solar system formed
- Explain the leading theory of planet formation (the Nebular Theory), and how it would produce the patterns we observe

Pattern 1: Orderly Motion:

- Most bodies orbit in the same plane
- Most orbits move in the same direction (right hand rule)
 - Planets around Sun → Planetary rotation
 - Moon around Earth → Moons around gas giants
- Most planets have a relatively small axial tilt

Pattern 2: Two types of planets:

Terrestrial

- Smaller size and mass
- Higher density
- Mostly made of rock and metal
- Solid surface
- Few (if any) moons and no rings
- Closer to sun with warmer surfaces

Jovian

- Larger size and mass
- Lower density
- Mostly made of hydrogen, helium, and hydrogen compounds
- No solid surface
- Rings and many moons
- Farther from Sun, farther apart, cooler temperatures

Pattern 3: Lots of debris in the solar system:

- "Debris" is small rocky and icy stuff like asteroids and comets
- Found in specific locations, shaped like rings
 - Asteroid belt (between Mars & Jupiter)
 - Kuiper belt (exterior to Neptune)
- Largest objects in Kuiper belt are called dwarf planets
- Trans-Neptunian objects
 - Icy bodies (smaller than the Moon)
 - Many TNOs have irregular orbits
 - Redefined as dwarf planets
- The Oort Cloud
 - Comprised of billions of comets

	H	He	O	C	Fe	Si	Notes
Sun	73%	25%	1%	0.3%	0.2%	0.1%	Upper layers
Jupiter	75%	23%	3%??	1%	0%	0%	Atmosphere
Earth	0.2%	0%	30%	0.1%	31%	16%	And lots of other metals
Interstellar gas	74%	24%	1%	0.4%	0.1%	0.1%	

Pattern 4: Exceptions:

- Uranus & Venus have extreme axial tilts
- Some moons orbit in random directions
- Some moons are larger than expected
 - Earth's moon is comparable to Jupiter's moons

A theory needs to explain all these patterns (Inductive Reasoning)

- There are 4 main patterns a theory would need to explain for the formation of the Solar System: Orderly motion, 2 types of planets, lots of debris in the Solar System, as well as explaining how there are exceptions to these rules

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The Nebular Theory of Planet Formation:

- Interstellar space is not empty space
 - Full of gas and dust called interstellar medium
- Dense pockets of gas and dust are called *W*

1. The original cloud is large and diffuse

- Rotation very slow
- Cloud begins to collapse

2. Cloud spins faster as it collapses

- Conservation of energy → heats up
- Conservation of angular momentum → spins faster

3. Forms into disc shape

- Irregular velocity objects collide and dampen
- Gravity pulls inwards
- Material at "equator" experiences centrifugal force outwards
 - Materials at poles do not experience centrifugal force, so they collapse inwards
- Discs result in orderly motion
 - Planets & Moons form from matter moving in the same direction

4. Composition of Disc

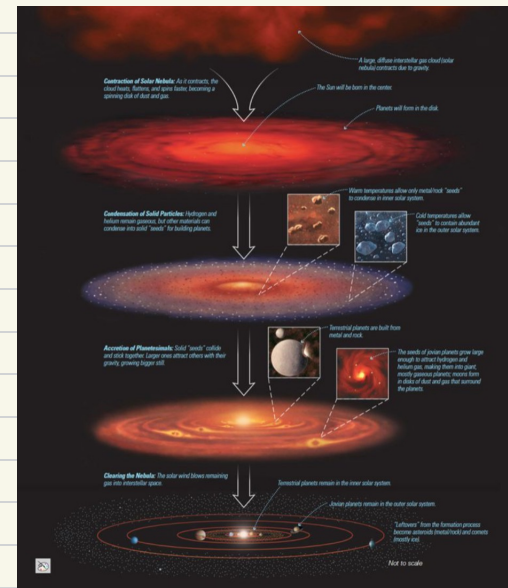
- Dust and ice particles are micron sized (10^{-6} m)
- Can collide and stick together to form bigger compounds
- Disc is hotter in middle → Stars

5. Planet formation

- Tiny particles clump together to form planetesimals
 - Held together by static electricity etc.
- Planetesimals accrete more material and/or collide to grow into planets

6. The frost line

- Inner disc is hotter
 - Rocks & metal are solid, everything else is gas
- Outer region is cooler
 - Some materials condense into ice
 - Solids include metals, rocks, ices
- More solid materials farther out



Asteroids and Comets:

- Asteroids are inner planetesimals left over from rocky planet formation
- Comets are outer planetesimals left over from icy/gas planet formation

- The nebular theory of planet formation is the leading theory of star, planet, and Solar System formation
- Asteroids and comets are leftover planetesimals from the inner and outer planets respectively

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Moon Forming Impact:

- Earth's moon may have been formed because of a major impact between Earth and a Mars sized planetesimal
- Major impact may also explain extreme axial tilts (ex. Venus, Uranus)

Moon Capture:

- Some moons have irregular orbits, so probably didn't originally form from the nebular material surrounding their planet
- Must have lost energy to get captured (transferred to other bodies via collisions/gravity, or to thermal energy via friction with surrounding gas disk)

- Our moon may have formed from a collision between Earth and a Mars sized planetesimal. Such collisions may also explain extreme axial tilts as found on Venus and Uranus
- Planets may also capture moons that originated from other nebular material