

Chapter 5: Formation of the Solar System and Other Planetary Systems

Origin of Our Solar System:

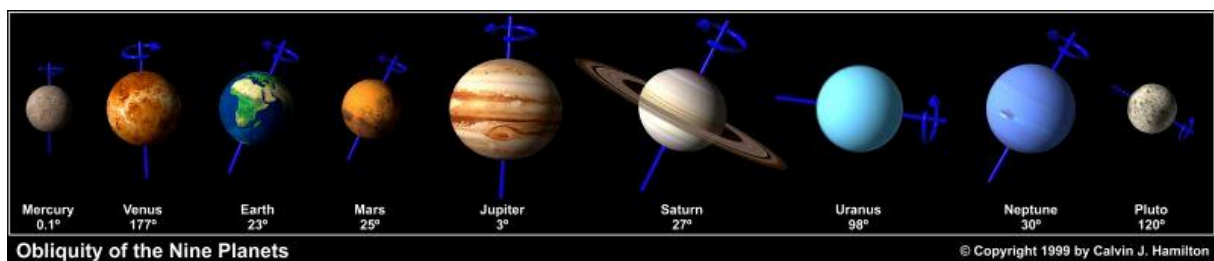
Properties of Planets that a successful theory must explain:

Terrestrial: low mass
small diameter
high density (heavy elements)
thin atmospheres
warm
few or no moons
slow rotation
no rings
near Sun
rocky surface
weak or no magnetic fields

Jovian: high mass
large diameters
low density (hydrogen and helium)
dense atmospheres
cold
many moons
rings
no surface
far from Sun
fast rotation
strong magnetic fields -dynamos

Orbital regularities:

nearly circular orbits
orbits nearly in same plane
counterclockwise revolution
spin axes nearly perpendicular to orbit
orbits of most moons nearly in same plane as ecliptic
moons orbit in counterclockwise direction



Orbital anomalies:

spin axes of Pluto and Uranus
retrograde rotation of Venus
retrograde revolution of a few moons (outermost of Jupiter, Saturn and Neptune)

Nebular Hypothesis: Spinning cloud of gas collapsed into a disk to form Sun and planets. Planets formed out of rings of gas left behind as the Sun collapsed. Proposed during the 18th century by Kant and Laplace.

Explains:

1. Flattened disk of the Solar System.

Flaws: 1. No known way to form planets from gas rings.

2. Spin rate of Sun would be much higher than it is (angular momentum). In other words, we observe that the planets hold most of the angular momentum rather than the Sun.
3. Does not explain differences in compositions of planets (terrestrial vs. gas giants).

Collisional Hypothesis: Star passing close to Sun pulled off gas that condensed into planets. Proposed during the late 19th century.

Explains:

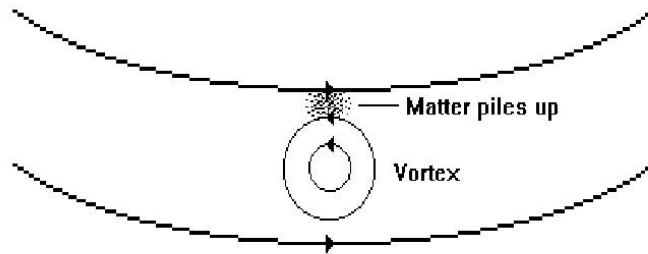
1. Alignment of planetary orbits with the Sun's equator.
2. Planets revolve around the Sun in the same direction.

Flaws: 1. Does not explain why planets have most of the angular momentum.

2. Does not explain composition differences of planets (terrestrial vs. gas giants).
3. Chances of a collision are too small.
4. Hot gases pulled off the Sun will dissipate rather than condense into planets

Modern Hypothesis (Condensation Theory): Revision of the nebular hypothesis to include the role of dust, and turbulence.

Turbulence: material piles up where the gas is moving in opposite directions to form planetesimals and then protoplanets.



Dust: grains of dust, which act as condensation nuclei, collide and stick together. The higher mass of the dust causes them to be drawn closer to the equatorial plane, resulting in more collisions which eventually forms planetesimals (asteroid sized bodies). This helps to explain the composition of the inner planets, where the temperature was too high for volatile elements to condense. The dust particles consisted of less volatile elements, such as carbon, silicon, iron, and oxygen.

Summary of the Modern or Condensation Theory:

1. Dust grains act as condensation nuclei to form clumps of matter.
2. Clumps collide and stick together (accretion) to form objects several hundred km across (planetesimals).
3. Gravitational forces cause planetesimals to collide and merge to form larger objects (protoplanets). Accretion continues with the sweeping up of gases if the protoplanet is large enough.
4. Composition differences between the inner and outer solar system is explained by the high temperatures of the inner solar system which only allowed the heavier elements to remain.

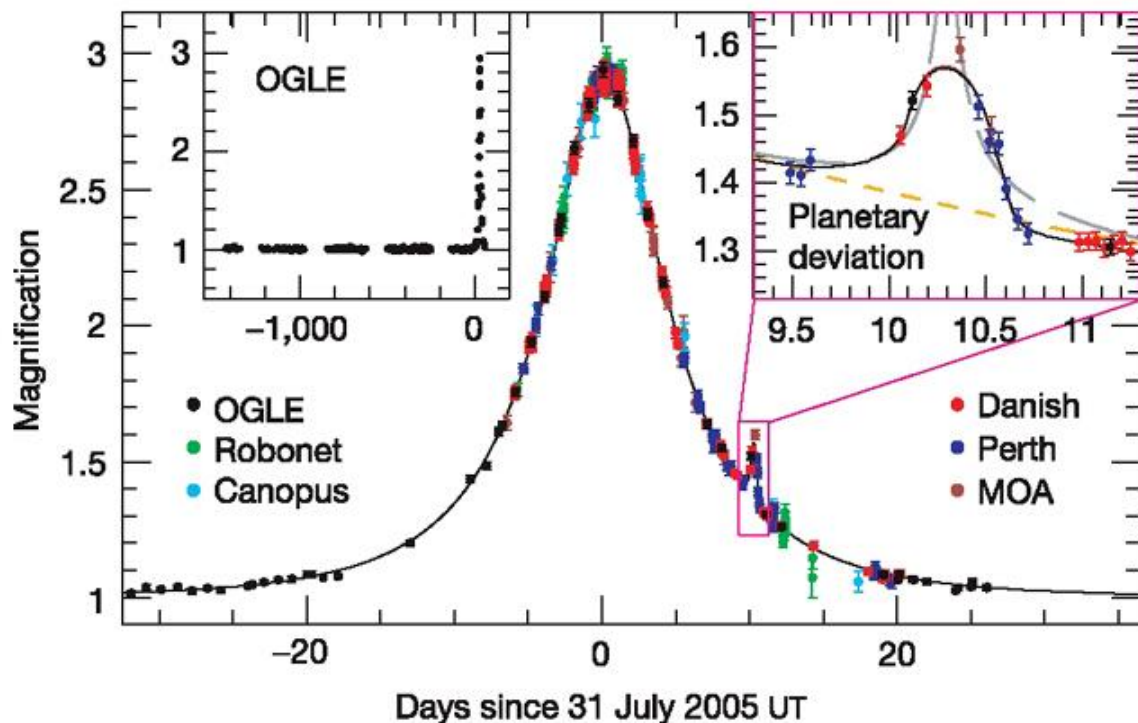
Angular Momentum Problem: Sun has less angular momentum than predicted by the condensation theory. Magnetic field of the solar nebula interacted with the plasma (loose

electrons and protons that act like an electrical current) in the disk, causing a transfer of angular momentum to the disk (magnetic braking).

Other Solar Systems:

Detected indirectly by:

- a. Wobbling of stars about a center of mass (unseen companion). This can be detected in two ways:
 - i. A deviation from a straight line as the star moves relative to background stars (proper motion).
 - ii. Motion along the line of sight, using a spectrograph (a tool that breaks star light into its component colors).
- b. Infrared emissions of dust in the disks.
- c. Transits of planets in front of their parent stars can be detected by a small dimming of the star's light. Amateur astronomers, using the newer CCD cameras and modest telescopes, can observe these transits (~ \$5,000 worth of equipment).
- d. Gravitational Microlensing – an effect predicted by Einstein's theory of general relativity that occurs when two objects line up with the Earth. When a foreground star having a planet lines up with a background star the foreground star and its planet both act as gravitational lenses causing the background star to brighten.



To date over 160 extra-solar planets have been discovered. Most are many times more massive than Jupiter and have orbits that are very close to their stars. A couple of lower

mass planets with masses of 5.5 to 7.5 times the mass of the Earth have been detected. A few of the systems detected include:

- | | | |
|------------------|--------------------------|----------------|
| 1. HD 114762B | 2. PSR 1957+12 (B, C, D) | 3. 51 Pegasi B |
| 4. 70 Virginis B | 5. 47 U. Majoris B | |
| 6. Rho Cancri B | 7. Lalande 21185 (B, C) | |

Concept Test

What mechanism does the modern theory of the Solar System's formation use to explain the slow rotation of the Sun?

- a) Slow rotation of nebula.
- b) Presence of dust.
- c) Difference in chemical composition between inner and outer nebula.
- d) Magnetic braking.