The Origin of the Solar System

Questions:

- How did the various constituents of Solar System form?
  What were the physical processes involved?
- When did they form?
  Did they all form more-or less simultaneously?
- Why did they form?
  What circumstances initiated the formation?
- How did they evolve?
  Do they change with time? How? Why?
- How will they evolve?
  Are changes ongoing? What causes them?

Related Questions:

- Are there planetary systems about other stars?
  Are they like our own?
- What is the rôle played by the appearance of life?
  Is life (or intelligent life) to be found elsewhere?

What Do We Know?

Inventory & Demographics

Sun, Jovian Planets, Terrestrial Planets, Satellites, Asteroids & Meteoroids, Comets, TNOs & KBOs, Interplanetary Dust, The Oort Cloud (?)

Orbital Systematics

Similarities and Differences; Short- and Long-Period Comets
Direct, un-eccentric, un-inclined, spacing regularity, ...

Jovian & Terrestrial Bodies: Systematics

Orbits and Rotations
Masses, Sizes, and Mean Densities; Compositions
Asteroids and TNOs
Satellites

Ages

Earth, the Moon, Asteroids, and Mars (about 5.6 Gyr)
The Sun and Stars

The Rôle of Exceptions, Anomalies, and Oddities

The Atmosphere of the Earth
Planetary Rotations: The Origin of the Moon and other satellites.
Gravitational Interactions: Venus, Tidal Couplings, Orbital Resonances
The interplanetary dust (comets)

Theories for the Origin of the Earth, the Sun, and the Solar System

Examples

- Mythology: Testing Hypotheses (why theology fails...)
- The Random Capture Hypothesis (satellites of asteroidal origin)
- The Encounter Hypothesis (The Moon. Nemesis?)
- The Nebular Hypothesis and its Variants
  - Star Formation and the Planetesimal Hypothesis

Details?

Planetary Evolution

- Condensation & Accretion: Jovian and Terrestrial bodies.
- Differentiation: The internal structure of the Earth
- Vulcanism & Terrestrial Life: The evolution of atmospheres

Predictions

- Oort Cloud (Long period comets)
- Additional members (Neptune, Pluto, KBOs, ...)
- Other planetary systems (200 and counting ...)

The Random Capture Hypothesis

1. Planets form independently in space.
2. The Sun gravitationally captures them

Shortcomings

- Poorly motivated.
- Presumption of interstellar planets.
- Requires three-body interaction, or
- Requires close encounter with tidal interaction

Predictions, Expectations, and Failures

Failed Expectation/Predictions

Orbits of high eccentricity
Orbits of random inclination and direction
Diversity in locations, types, ages

No predictive value regarding systematics

Jovian/Terrestrial differences
Asteroids and icy Bodies; comets

Summary: It explains almost nothing, has minimal predictive value, and its predictions are generally unsupported.

Note: Capture <u>can</u> occur. See, *e.g.*, Martian satellites (inclined, retrograde, *etc.*)

The Encounter Hypothesis

(Buffon 1745)

Scenario:

1. A “near miss” encounter occurs between the Sun and a passing star.
2. Material is pulled from the stellar surfaces by tidal forces.
3. Material cools and condenses to form planetary bodies.

Principal Shortcoming: This Requires a highly unlikely event

Calculation: Collision rate is proportional to

Relative speed

Collision Cross-Section (How close is “close”?)

Density of stars

This gives a typical collisional interval of 10^{20} years!

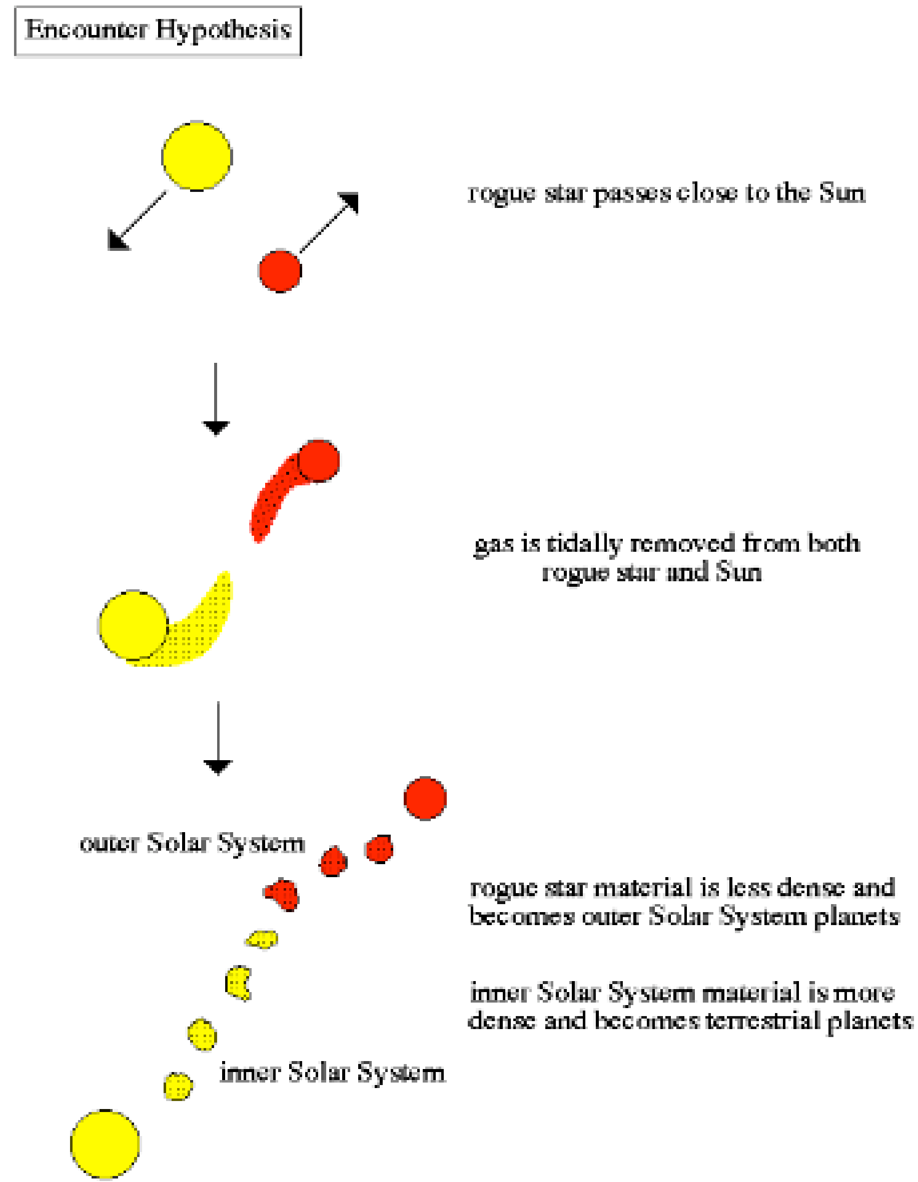
Predictive Successes:

- Direct, coplanar, low eccentricity orbits.
- Common planetary ages (but an older Sun)

But it Doesn’t Work:

- Ejected gas escapes before cooling ($V^2_{esc} = 2GM/r$, $V^2_{therm} = 3kT/m$)
- Deuterium Problem: Present in planets, none in the Sun (for good reason!)

A problem for any hypothesis involving obtaining raw material from the Sun.
But *internal* encounters (and collisions) have occurred - and do. (Moon, Jupiter)


Encounter Hypothesis
rogue star passes close to the Sun
gas is tidally removed from both rogue star and Sun
outer Solar System
rogue star material is less dense and becomes outer Solar System planets
inner Solar System material is more dense and becomes terrestrial planets
inner Solar System

The Nebular Hypothesis & Protoplanets

- The Sun forms from a collapsing cloud of cold interstellar gas and dust.
- The material forms a proto-Sun surrounded by a cool gas and dust disk.
- Small particles form and grow in the disc by collisional accretion.
- Larger bodies (planetesimals) accrete rapidly with the aid of gravity.
- Planetesimals grow by accretion of gas, dust, and other planetesimals
  - gradually clearing the disk of remaining material.
  - maintained in molten or gaseous states by collisional heating.
- The remaining molten or gaseous objects are protoplanets.
  - surfaces cooling and solidifying as accretion slows
  - atmospheres dissipate at a decreasing rate
- The protoplanets evolve with time to become the present-day planets.
  - differentiation of terrestrial planets

Note: Satellites are formed by accretion in disks about protoplanets or acquired by later capture or result from collisions.

The Nebular Hypothesis

SOME HISTORY:

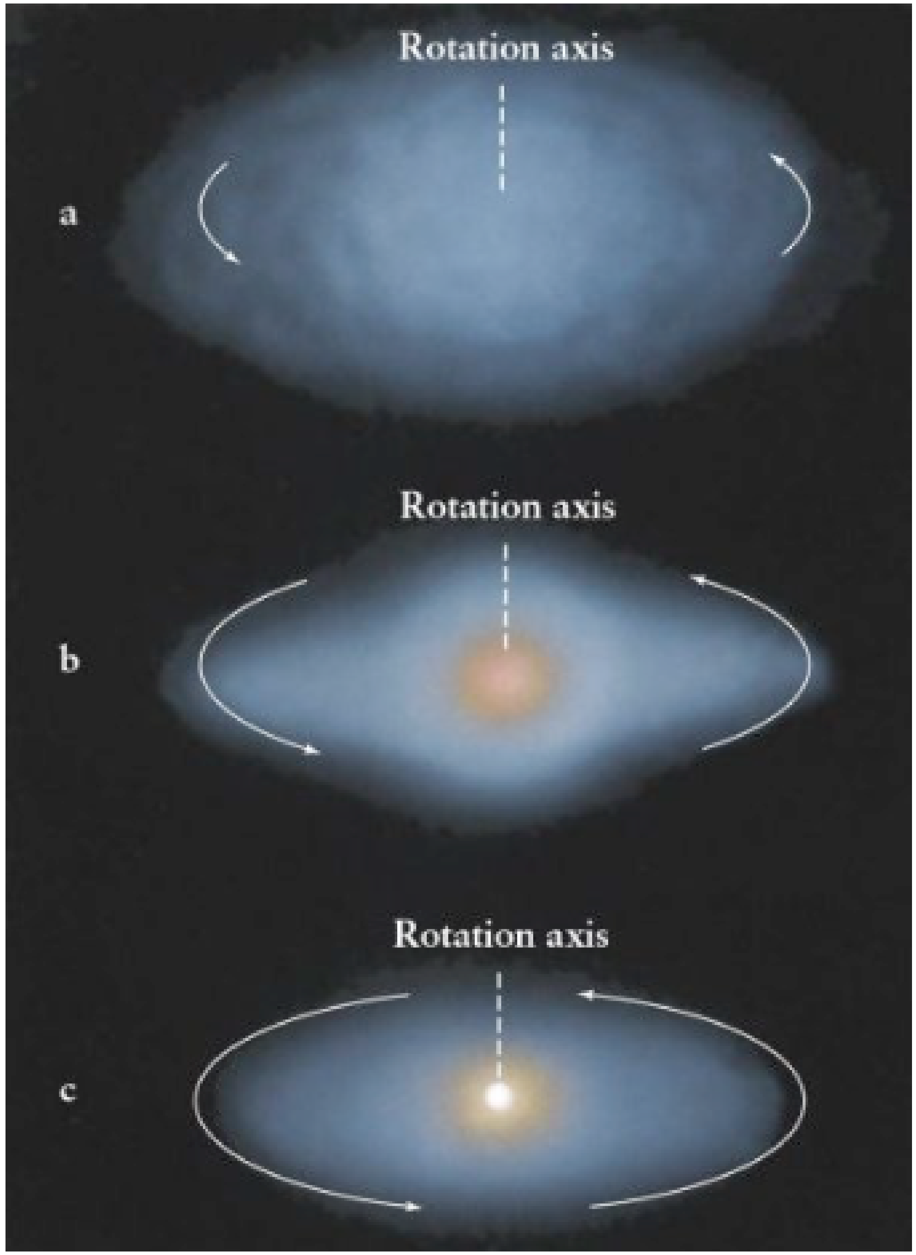
- Descartes 1644: Eddies & whirlpools in a turbulent disk
- Kant 1755: Planet formation in a rotating Keplerian disk
- Laplace 1796: A disk with “tidal rings” (*cf*. Kirkwood gaps, Saturn’s rings)
- von Weisäcker 1941: Turbulent eddies in a gas disk

SOME VIRTUES:

- Cool early environment allows formation of larger solid bodies.
- Planet and star (Sun) formation are part of a single process.
- Accounts for gross orbital properties.
- Accounts for composition similarities and differences (Jovian/Terrestrial).
- Explains cratering history of old surfaces.
-

CURRENT STATUS:

- Very great explanatory and predictive power. Eminently testable.
- No fundamental issues or problems outstanding.
- Is a successful model for star formation as well as stellar systems.
  (Stars are now known and observed to form from cool interstellar clouds.)
- No viable competing model has been forthcoming.


Rotation axis
a
Rotation axis
b
Rotation axis
c