The Formation of our Solar System

The Nebular-Condensation Theory

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Abstract

Our solar system formed 4.6 billion years ago from a huge nebular cloud of dust and gas but the scientific evidence of its formation were on the randomness of other solar system forming in different nebular cloud or in other galaxies as seen today. At first the huge cloud of dust collapsed in its own gravity under the influence of nearby stellar pressure, contraction, swirling and huge temperature at the center created our sun, surrounding smaller balls of different material contracted and condensated forming eight planets, hundreds of moons, millions of asteroids and comets, this took almost billion years to form a complete and clean solar system.

Keywords:- Nebular Theory, Solar Nebula, Nebula Contraction, Condensation nuclei, Accretion, Proto-planets, Asteroid Belt, Kuiper Belt, Oort Cloud:

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1. The Nebular Contraction and Condensation

A large cloud of interstellar dust and gas is called **nebula**, spanned in space across a light year or more. Now suppose that due to some external influence, such as a collision with another interstellar cloud or perhaps the explosion of a nearby star, the nebula starts to contract under the influence of its own gravity.

In 1796 the French mathematician-astronomer Pierre Simon de Laplace showed mathematically that conservation of angular momentum (*objects spin faster as they shrink*) demands that our hypothetical nebula must spin faster as it contracts, becoming denser and hotter at its centre. The increase in rotation speed, causes the nebula's shape to change as it shrinks. Centrifugal forces (*the outward push, due to rotation*) tend to oppose the contraction in direction perpendicular to the rotation axis, this makes the nebula collapse most rapidly along the rotation axis. As shown in *figure 1*, by the time of few million years it has shrunk to about 100 AU, the cloud has flattened into a pancake-shaped disk. This swirling mass will further become our solar system. It is usually referred to as the **solar nebula.** The idea that the planet formed from such a disk is called the **nebular theory.**

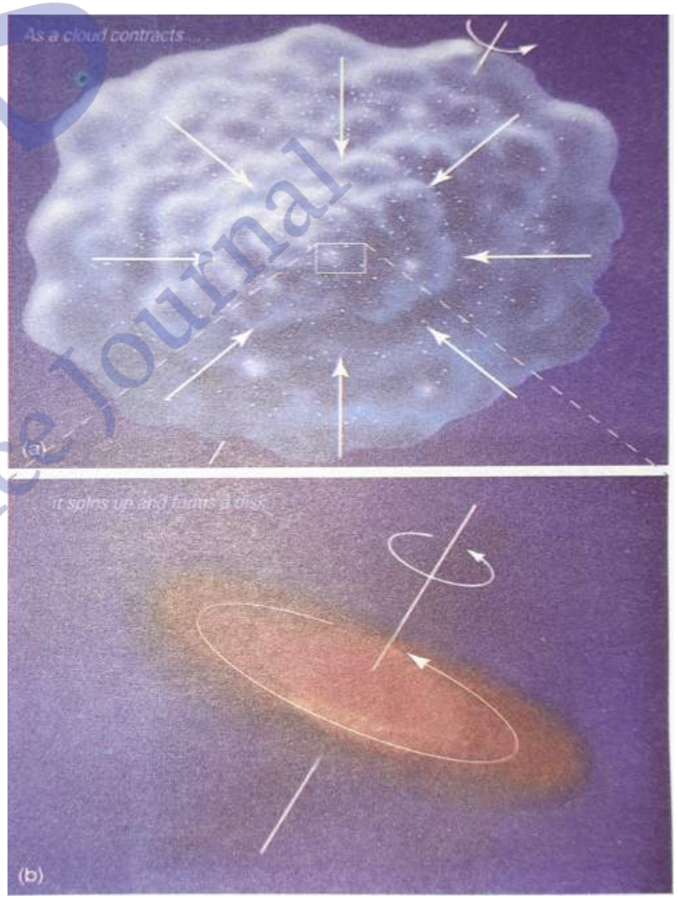


Figure 1.

In the solar nebula the large blob at the centre remain contracting under its own gravity which increases the density and temperature at its core, the temperature at the core was so intense that the atoms get ionized, when the central temperature reached 10^7K, Hydrogen fusion starts, giving the birth to a new star, this is how our sun was formed.

But the real scenario of the nebular theory was contradicting the process of formation of planets. As a disk of gas would not form clumps of matter that would subsequently evolve into planets because any clumps in the gas would tend to disperse, not contract further. However, the model currently favoured by most astronomers, known as the **condensation theory.** It is an extension of nebular theory that incorporates interstellar dust as key ingredients. Dust grains play an important role in the evolution of any gas cloud. These grains act as **condensation nuclei**, on which accretion of matter occurs. Clumps of matter form around the condensation nuclei. These clumps collide, stick together, forming larger and larger balls of matter (*this is similar to the way raindrops form in the Earth's atmosphere*). These large balls of matter collapses further, forming into proto-planets.

2. Planets Formation

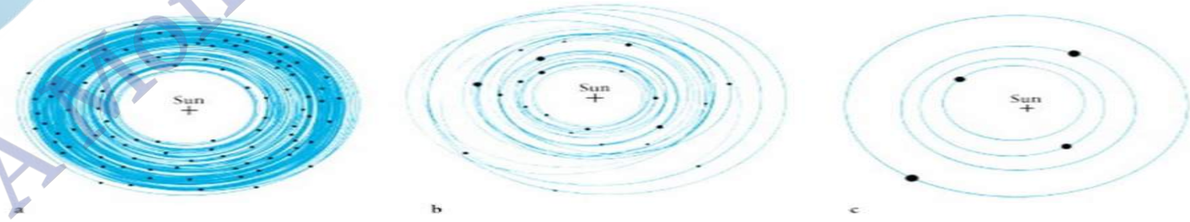
The formation of planets can be explained through condensation theory, which says that the planets were formed from the solar nebula in three distinct stages.
The first two stages explain the formation of terrestrial planets whereas the third stage explain the formation of outer solar system.

The **first stage** of the planets formation began when dust grains in the solar nebula formed condensation nuclei around which matter began to accumulate. This vital step greatly hastened the critical process of forming the first small clumps of matter. Once these clumps formed, they grew rapidly by sticking to other clumps (*Imagine a snowball thrown through a fierce snowstorm, growing bigger as it encounters more snowflakes*). As these clumps grew faster, their surface areas increased and the rate at which they swept up new material is accelerated. These clumps formed larger and larger objects. Eventually, this process of **accretion** (*the gradual growth of small objects by collision and sticking*) created objects few hundred kilometers across. At the end of first stage of the planets formation, the solar system was made up of hydrogen and helium gas and millions of **planetesimals** (*objects the size of small moon, having gravitational fields just strong enough to affect their neighbours*).

During the **second stage** of planet formation, gravitational forces between planetesimals caused them to collide and merge, forming larger and larger objects (*to the size of moon*).

As the larger bodies exert stronger gravitational pulls, eventually almost all the planetesimal materials was swept up into a few large **proto-planets** (*accumulations of matter that would eventually evolve into the planets we know today, depicted in figure 2 below*).

Figure 2



Start: 100 planetesimals   30 my: 22 protoplanets   441 my: 4 planets

As the proto-planets grew, their strong gravitational fields produced many high speed collisions between planetesimals and proto-planets. These collisions led to fragmentation as small objects broke into still smaller chunks that were then swept up by the proto-planets. Only a relatively small number of 10-100 km fragments escaped by a planet or a moon and became the asteroids and comets.

After about 100 million years, the primitive solar system had evolved into eight proto-planets, dozens of proto-moons and a glowing proto-sun at the center. Roughly a billion more years were required to sweep the system clear of interplanetary trash. This was a period of intense meteoritic bombardment whose effects on the moon and elsewhere are still evident today.

3. Formation of Jovian World

In the **third stage**, Jovian or outer solar system are being formed, and for the formation of these large gas giants, two different views have emerged.

In the first scenario depicted in *figure 3*(*c and d*), the four largest proto-planets in the outer solar system grew rapidly, their strong gravitational field swept up large amounts of gas directly from the solar nebula.

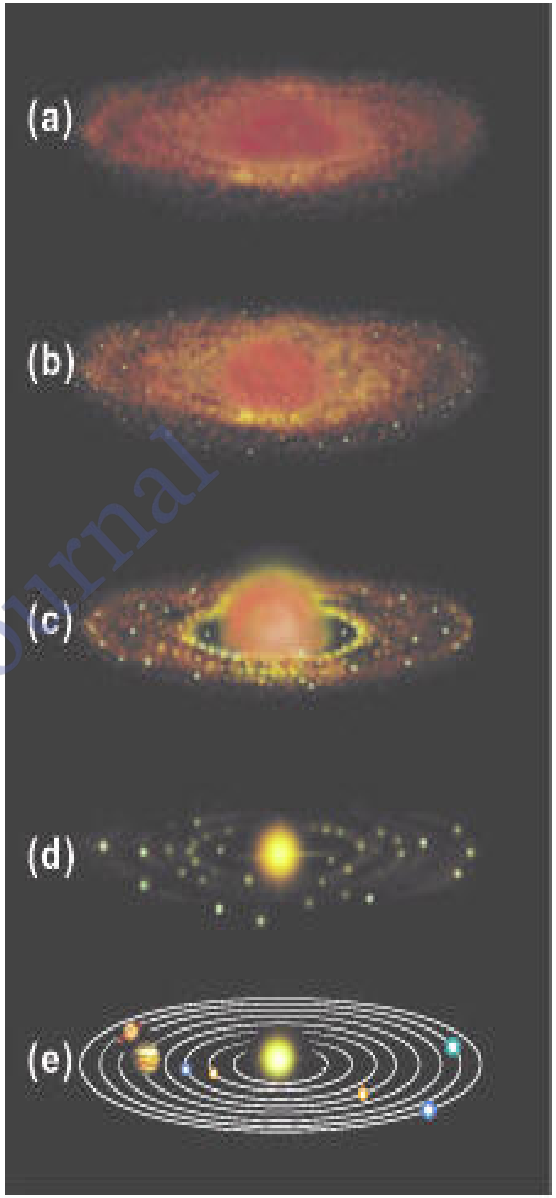


Figure 3

As there was a lot more raw material available for planets building in the outer solar system, so the outer proto-planet grew much faster than the inner proto-planet. It took just less than few million years to the formation of the core of the Jovian world, whereas for the formation of terrestrial proto-planet , the rate was very slow taking almost 100 million years.

In the second scenario, the giant planets formed through instabilities in the cool outer region of the solar nebula. In this view, the Jovian proto-planets formed directly and very rapidly, skipping the first two stages of accretion and perhaps taking less than a thousand years to acquire much of their mass.

Once the nebular gas began to flow into the large Jovian proto-planets, it seems to resemble like a mini solar nebula, with condensation and accretion continuing to occur, helped the large moons of outer planets form in this way.

4. Primitive Temperature of Solar System

During the initial stage of the solar system, temperature at any given location was different and the only materials to condense out were those able to survive the temperature there. In the innermost regions, around Mercury's present orbit, only metallic grains could form because this region was very near to the star, putting under extremely condition for any other materials to exist there. Farther at a distance of about 1 AU, it was possible for rocky, silicate grains to form. Beyond about 3 or 4 AU , water ice could exist, and so on, depicted in *figure 4.*

The composition of the grains at any given distance from the sun determined the type of planetesimal and ultimately planet formed there. Beyond about 5 AU from the center, the temperature was low enough to allow several abundant gases, water vapour, ammonia and methane to condense into solid form. These compounds were destined to form the core of Jovian planets which we even see today in their atmosphere.

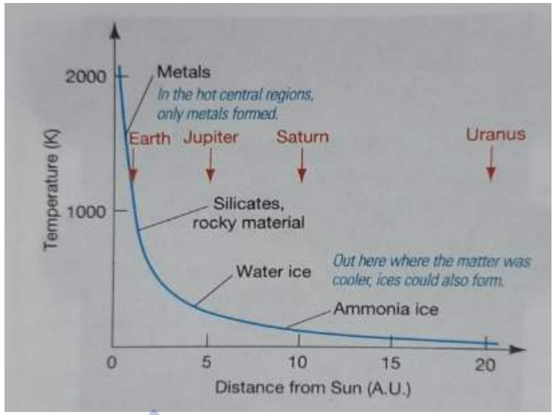


Figure 4

In the inner region of the primitive solar system, the environment was too hot for ice to survive. Many of the abundant heavier elements, such as silicon, iron, magnesium and aluminium, combined with oxygen to form a variety of rocky materials. Planetesimals in the inner solar system were therefore, rocky or metallic which ultimately destined to form the terrestrial world.

The inner region of the nebula had to wait for the temperature to drop so that a few rocky grains could appear and began the accretion process, whereas accretion in the outer solar system began almost as soon as the solar nebula collapsed into a disk.

5. Formation of Asteroids and Comets

In the inner solar system, most rocky planetesimals collide with or were ejected by the growing terrestrial planets. Which later constituent the asteroid belt. Many planetesimals failed to accumulate beyond mars because of the strong gravitational field by the giant Jupiter and locked in between orbit by the combined gravitational pull of the sun and Jupiter.

The remaining planetesimals in the outer solar system were kicked by the gravitation of giant planets mainly Jupiter and Saturn and most of them stood up in the orbit, taking them far from the sun. Those outer fragments now make up the **Oort cloud**. Most of the original planetesimals formed beyond the orbit of Neptune are still there, making up the **Kuiper belt**.

Computer simulations indicate that, during the ejection process, Jupiter moved slightly closer to the sun while the other giant planets migrated outward, possibly by as much as 10 AU in the case of Neptune. The deflection of icy planetesimals into the inner solar system played an important role in the evolution of the terrestrial planets too. Mainly for earth, during its initial stage of formation earth's temperature was too high and very low gravity due to which most of the gases escaped away, but the bombardment game was played by the icy planetesimals on terrestrial planet that brought water on them.

But a question comes in mind, the dust cloud which helped to form solar system, why don't we see it today throughout the planetary system? All young stars apparently experience a highly active evolutionary stage known as the *T-Tauri* phase, during which their radiation emission and stellar wind are very intense. When our sun entered this phase, any gas remaining between the planets was blown away into interstellar space by solar wind and the sun's radiation pressure. Afterward, all that remained were proto-planets and planetesimal fragments, ready to continue their long evolution into the solar system we know today.

6. Conclusion

As mentioned earlier the nebular theory accounted to the formation of the protosun which later evolve to sun but it wasn't able to explain the formation of planets, which later through by the condensation theory. In the condensation theory, that capacity is provided by the randomness inherent in the encounter that combined planetesimals into proto-planets. As the number of large bodies decreased and their masses increased, individual collisions acquired greater and greater importance. The effect of these collision still can be seen today in many parts of the solar system.

But few explanations remained uncertain by either of these theory, the large regularity of the spacing between each planets, Why the planets orbit are nearly circular?, with exception of mercury's highly elliptic orbit. All planets in the same plane, and in same direction as the sun's rotation on its axis, again with an exception of retrograde motion of Uranus around the sun. The anomalously slow and retrograde rotation of Venus.

Scientists usually do not like to invoke random events to explain the observations. However, there seem to be many instances where pure chance has played an important role in determining the present state of the universe.

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