Research Essay

“On the Origin of the Solar System”

Russell J Lowke, May 9th, 2001.

The origin of the Solar System is one of the oldest unsolved problems in science. It was first separated as a question distinct from the Origin of the Universe in the 17th century, when Copernicus made it meaningful to use the modern phrase "Solar System" and the Sun began to be thought of as one of many stars. Other questions began to arise, such as if the Solar System developed autonomously, or did came into existence through the actions of an outside entity, like an encounter with another star? Is planet formation the natural result of star formation, or a process that might be very rare?[1] What is evident is that our Solar System has certain characteristics that are striking manifestations of order (regularities) which formed under very definite circumstances. The aim of this essay is to trace the evolution of major theories on the Origin of the Solar System, to today's generally accepted modern model - which might well still be incorrect. Before beginning with the theories, it's good to have an understanding of the known regularities of the Solar System, these are:

1. Each planet is in relative isolation in space, with progressively larger distances from the Sun, each planet being roughly twice as far from the Sun as its next inward cousin. This manifestation used to be referred to as the Titius-Bode "law" until the discovery of Neptune whose non conforming distance broke the pattern. Neptune lies at 30 Astronomical Units (A.U.)[2], where the Titius-Bode rule would place Neptune at 38.8 A.U. Regardless, there is a definite trend in the dispersion of the planets.[3]

2. Orbits of all the planets are nearly circular with the exception of Mercury which has some elliptical and of Pluto, which is highly elliptical. Pluto is constantly the exception to the regularities and there is growing indication that Pluto is not actually planet. Its properties are more moonlike than planet like and many astronomers believe Pluto to be the largest or nearest member of ice asteroids found in the outer Solar System.[4]

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[1] Stephen G. Brush, *A History of Modern Planetary Physics, Vol 1.* (U.K. : Cambridge, 1996): 3.
[2] An Astronomical Unit (A.U.) is the average distance between the Earth and the Sun.
[3] Chaisson/McMillan, *Astronomy Today, 3rd Ed.* (U.S.A. : Prentice-Hall, 1999): 134.
[4] Chaisson/McMillan: 309.

3. Orbits of the planets all lie in nearly the same plane, that of the Sun's equator. This alignment is accurate to within a few degree's, with the slight exception of Mercury and Pluto.[5]

4. The planets all orbit the Sun in the same direction that the Sun spins - counter clockwise as viewed from above the earth's North Pole.[6]

5. The planets spin in the same direction that the Sun is spinning, counter clockwise, except for Venus, Uranus and Pluto, all of which have retrograde spin. Venus is particularly unusual with a 243 day rotation period and an axial tilt of 177.4 degrees (compared to 23.5 in the case of Earth), the north pole being below the ecliptic plane. The Venus day is a little more than half a Venus year. It's thought that Venus collided with another solar body during its late stage of formation.[7]

6. Most of the moons revolve around their parent planets in the same direction that the parent spins.[8]

7. The Solar System is highly differentiated. Terrestrial planets (small, rocky, slow spinners, with high density, moderate atmosphere and few or no moons) are all close to the Sun, while the Jovian planets (large, gassy, fast spinners, with low densities, thick atmospheres and many moons) are farther from Sun.[9] The satellite system of Jupiter mirrors the densities found for the planets in the Solar System. Its two closest satellites, Io and Europa are rocky bodies, while the more distant Ganymede and Callisto consist of fifty percent ice.

8. The planets and various satellites have very small eccentricities of their circular orbits, while comet orbits have very large eccentricities and inclinations that seem to be at random.[10]

All these regularities must be accounted for (or dismissed) in any comprehensive theory on the origin of the Solar System. As our knowledge of the planets, satellites, comets and asteroids expands, so do problems faced by theorists. The earliest hypothesis were far less restrained. It

[5] Chaisson/McMillan: 338.
[6] Ibid.
[7] Chaisson/McMillan: 205.
[8] Chaisson/McMillan: 338.
[9] Ibid.
[10] Stephen G. Brush: 22.

wasn't until the publication of Isaac Newton's laws of motion and gravitation in 1687 that speculation became truly possible. The first theory was proposed in 1755 by the German philosopher Immanuel Kant. His idea was that the Solar System began as a cloud of scattered particles and that gravitational attraction of the particles caused them to collide and bond. As these groups became larger they coalesced more rapidly, ultimately forming the planets. This early model doesn't explain the planets moving around the Sun in uniform direction and in the same plane, nor does it explain their revolution.[11]

Forty years later, Pierre-Simon Laplace wrote a popular book on astronomy. In the appendix he made some suggestions about the origin of the Solar System. It's this relatively minor work for which he is best remembered. Laplace's model starts with the Sun formed and its atmosphere extending beyond the distance of the farthest planet. Laplace concluded that the rotating Sun would cool as it radiated heat. In response to this cooling, the Sun would contract. Due to the law of conservation of angular momentum a size decrease in the Sun would be accompanied by an increase in rotation. Centrifugal acceleration would push material outward, while gravitational attraction would pull material inward. Where forces balanced a series of concentric rings would remain, each of which subsequently coalescing to form a planet. This model leds to the planets revolving around the Sun in the same plane and in the same direction that the Sun rotates. Laplace's and Kant's theories are often referred to as the Laplace-Kant Nebular Hypothesis.[12] Laplace's model was widely accepted for about 100 years.

Like Laplace, William Herschel (1738-1822) was also famous for his astronomical discoveries. His discovery of Uranus in 1781 and two of its satellites, Titania and Oberon, quite affected Solar System theories. These three bodies were included by Laplace in his count of direct motions of the Solar System, strengthening his single cause argument. But in 1798 Herschel announced that they all had a retrograde motion. Laplace identified that Uranus's axis is nearly

[11] Encyclopædia Britannica Online. <http://members.eb.com/bol/topic?eu=118792&sctn=3>
[12] Ibid.

perpendicular to the axis of the ecliptic, this was confirmed spectroscopically. Herschel did not think that the retrograde motion of Uranus and its moons seriously compromised the general uniformity of motions in the Solar System; in 1806 he wrote that while they deviated from the motion of other bodies, at least they agreed with each other.[13] Many theorists disagreed. Other satellites were discovered with retrograde orbits, and asteroids found with highly eccentric orbits. Venus has a highly retrograde rotation, although this was unknown until the 1960's, when radar allowed us to peek below Venus's highly reflective atmosphere.[14]

An issue with the Nebular Hypothesis is that 99.9 percent of the mass of the Solar System (just about all of it) is in the Sun. Diagrams showing planetary orbits often misleadingly suggest distribution is quit different; the very thickness of the lines used to draw orbits and the dots to denote Sun and planets often give a misleading cozy impression. The reality of the Solar System is difficult to draw as a diagram. If the Sun is represented as a ball 6 inches in diameter, Mercury is about 7 yards away, Venus about 13 yards away, the Earth 18 yards away, Mars 27 Yards, Jupiter 90 yards, Saturn 170 yards, Uranus about 350 yards, Neptune 540 yards, and Pluto 710 yards. On such a scale the Earth is represented by a speck of dust.[15] In this paradigm the planets seem less like coalesced amalgamations, and more like small very distantly orbiting debris.

Laplace's model is in direct conflict with the very principles which Laplace himself expounded in his book *Mécanique Celeste*.[16] While the Sun contains 99.9 percent of the mass of the Solar System, the planets (principally the outer planets) carry more than 99 percent of the system's angular momentum. Laplace has the Sun contracting as it is formed, which is accompanied by an increase in rotation. This is of importance as angular momentum is conserved. No internal forces or action in a system can alter the total amount, although it may be transferred from one part of the system to another, - this holds true, even though the forces involve friction and degrade

[13] Stephen G. Brush: 32.
[14] Chaisson/McMillan: 205.
[15] Fred Hoyle, *The Cosmogony of the Solar System*, (U.K. : Cardiff, 1979): 9.
[16] Fred Hoyle: 5.

energy into heat. Forces from outside could change it, but such forces are negligible as the system is isolated in space.[17] For the Nebular Hypothesis to work, either the Sun should to be rotating much more rapidly or the planets should be revolving around it more slowly. The inequality of distribution of angular momentum appears to arise from a slow rotation of the Sun, rather than any idiosyncrasy of the planets.[18]

During the early 1900's several scientists independently decided that deficiencies of the Nebular Hypothesis were so great that it was no longer tenable. The Americans Thomas Chrowder Chamberlin and Forest Ray Moulton, along with Sir James Jeans and Sir Harold Jeffreys, of Britain, separately developed variations on an idea that the planets were formed from a close encounter of the Sun with another star (catastrophically).[19] The basis of this model was that when two stars passed very close, to less than a few diameters, material would be drawn out from one or both stars and coalesce to form planets. A discouraging aspect of this theory is the implication that formation of planetary Solar Systems must be extremely rare, close encounters between stars being highly unusual.[20]

With the Nebular Hypotheses out of vogue many various alternatives emerged. In 1944 the Capture Theory was suggested by O.Y. Schmidt, proposing that the Sun could have captured an envelope of gas and dust during a passage through an interstellar cloud, this envelope formed the planets.[21] A theory brought forward by H. Alfvén in 1954 has the formation of the planets from gas falling in towards the Sun. Owing to electromagnetic action the gas was ionized and some stopped at certain distances, which roughly correspond to the present situation of the main groups of planets.[22] Another theory hypothesizes that the planets coalesced from ionized flares escaping the Sun's gravity during very active stages of the Sun's formation. With parameters of magnetic field,

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[17] Henery Norris Russell, *The Solar System and its Origin*, (New York : MacMillan, 1935): 13.
[18] Henery Norris Russell:18.
[19] Encyclopædia Britannica Online. <http://members.eb.com/bol/topic?eu=118792&sctn=3>
[20] Henery Norris Russell: 99.
[21] John R. Dormand, *The Origin of the Solar System, the capture theory,* (U.K. : Horwood, 1989): 34.
[22] H. Alfvén, *On the Origin of the Solar System*. (Oxford: Clarendon, 1954): 6.

electric field, angle of ejection and velocity of ejection for such a capture being very limited the material would generally fall back into the Sun but some of material would be captured in an orbit. Maxwell's equations for charged plasma's in a magnetic field being very angle dependent means that a uniform planetary system could be created.[23]

Mid twentieth century scientists became more aware of the processes by which stars form and the behavior of gases under astrophysical conditions, leding to a realization that hot gases from a stellar atmosphere simply dissipate in space rather than condensing to form planets. The basic idea of planet formation through hot matter out of the Sun became impractical. Moreover, growth in knowledge of the interstellar medium, the gas and dust distributed in the space separating the stars, indicated that clouds of such matter exist and stars form from these clouds. Planets must somehow be created in the process that forms the stars themselves. This prompted scientists to reconsider the earlier notions of Kant and Laplace.[24]

Despite recent findings of planets orbiting other stars we have little information on their properties and absolutely no evidence of Earth like planets anywhere beyond our Solar System - present theories must still rely on information from our own Solar System.[25] The current paradigm for the Solar System origin suggests formation began with the contraction of a spherical interstellar cloud of dust and gas. Contraction of the cloud caused it to rotate faster and faster, forming a flattened disk around a central condensation (as in the Laplace model). This heats up enough in the interior for nuclear reactions to ignite, giving birth to a star.

Meanwhile, material in the outer disk collides, coalesces, and gradually forms larger and larger objects (as in Kant's theory), collisions and near misses of this material can cause it to move in eccentric orbits, having dramatic effects and producing anomalies like the strangely high density of Mercury, the retrograde rotation of Venus and possibly the large size of the Earths Moon. At distances such as that of Jupiter and beyond the temperature is cold enough that ice forms, and

[23] From discussions with Dr J J Lowke of CSIRO, Telecommunications and Industrial Physics, Sydney.
[24] Encyclopædia Britannica Online. <http://members.eb.com/bol/topic?eu=118792&sctn=3>
[25] Chaisson/McMillan: 338.

objects at these distances are able to acquire much more mass than objects forming closer to the Sun. This explains the extensive differences between the inner and outer planets. The availability of ice In the outer Solar System leds to the formation of giant planets, whose formation resembled that of the Sun itself - each with its own little nebula forming a disk and central condensation.

At some point after most of the matter in the Solar System had formed an increase in the intensity of the solar wind cleared the remaining gas and dust out of the system.[26] The solution to angular momentum problem that defeated Kant and Laplace seems to lie in this solar wind. The loss of mass via stellar wind is sufficient to reduce the rate of the Sun's rotation. Thus the planets preserve the angular momentum that was in the original solar nebula, but the Sun has gradually slowed down in the 4.6 billion years since it formed.[27]

This paradigm resolves the Solar System's regularities with the inconsistencies, but there still is much debate, particularly with the issues of angular momentum. Many intricacies are yet to be explained in detail, like specifics on the Suns the solar wind and solar flares. A modern hypothesis called Condensation Theory suggests the presence of interstellar dust cooled the Solar System, reducing pressure and temperature and aiding the process of planet formation.[28]

We have yet to model the Origin of the Solar System conclusively. Nebular theory has swayed into and out of popularity as various laws are discovered and theories dismissed. Laplace lived in the so-called age of reason, when it was believed that, aside from a few small addenda (like magnetism and electricity), the laws governing the universe were well known. We suffer from the same illusion today.[29] Hopefully, as more is discovered about planets in neighboring systems, and faster computers utilize more extensive computer models, the Origin of the Solar System might become solved.

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[26] Encyclopædia Britannica Online. <http://members.eb.com/bol/topic?eu=118792&sctn=3>
[27] Ibid.
[28] Chaisson/McMillan: 341.
[29] Fred Hoyle: 1.

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