A sound nebula – The origin of the Solar System in the field of a standing sound wave

Valeri Beck*
Alfa-Carbon® Beck, Berlin, Germany

ABSTRACT

According to the planetary origin conceptual model proposed in this paper, the protosun centre of the pre-solar nebula exploded, resulting in a shock wave that passed through it and then returned to the centre, generating a new explosion and shock wave. Recurrent explosions in the nebula resulted in a spherical standing sound wave, whose antinodes concentrated dust into rotating rings that transformed into planets. The extremely small angular momentum of the Sun and the tilt of its equatorial plane were caused by the asymmetry of the first, most powerful explosion. Differences between inner and outer planets are explained by the migration of solid matter, while the Oort cloud is explained by the division of the pre-solar nebula into a spherical internal nebula and an expanding spherical shell of gas. The proposed conceptual model can also explain the origin and evolution of exoplanetary systems and may be of use in searching for new planets.

Key words: comets: general, cosmology: theory, (ISM:) planetary nebulae: general, Oort Cloud, solar system: formation, stars: formation

1 INTRODUCTION

The classical theory of the origin of the Solar System is based on the Kant–Laplace nebular hypothesis suggesting that the Sun and the planets condensed out of a spinning protoplanetary nebula of gas and dust (Kant, 1755; Laplace, 1796). During the condensation process, the spin of the nebula accelerated (the ‘pirouette’ effect), and the resulting distribution of angular momentum caused it to form a disc. The centre of the nebula evolved into a hot, highly compressed gas region – the protosun. Concentration and coalescence of dust particles in the remainder of the spinning disc led to the formation of planets orbiting the Sun.

This theory accounts for the general nature of the origin of the Solar System, but it cannot explain many of the observed facts. One problem is the angular momentum distribution: the Sun has more than 99.8% of the entire system mass, but only about 0.5% of the total angular momentum, with the remaining 99.5% residing in the orbiting planets. The classical theory views this as an essentially unresolvable paradox. The hypothesis also fails to explain the 7° tilt of the Sun’s equatorial plane relative to the average orbital plane of the planets.

Another serious problem is the distinction between small solid-surface inner planets and outer gas giants: the original nebula of gas and dust would have had the matter evenly distributed over the entire volume, and thus one would not expect the resulting planets to be very different in chemical composition.

Moreover, the observed regularity in planetary distances from the Sun – the so-called Titius–Bode law, a single empirical formula describing the approximate location of the most planets in the Solar System – has no explanation. There is evidence to suggest that this pattern may also be observed in many exoplanetary systems discovered in recent years, and is possibly a manifestation of general physical processes taking place during the formation of planetary systems.

It is difficult to explain the existence of the Oort cloud beyond the Solar System’s planets. It consists of trillions of small objects composed of dust and water, ammonia and methane ice. It is believed that these objects were scattered outwards by the gas giants at the planetary formation stage and then acquired distant circular orbits (out to about one light year) as a result of gravitational forces due to nearby stars. Such an Oort cloud emergence scenario seems very unlikely for such a large number of bodies.

Neptune is the most distant gas planet. Based on the decreasing series of giant planet masses – Jupiter: 318 $M_\oplus$; Saturn: 95.3 $M_\oplus$; Uranus: 14.5 $M_\oplus$ – we could expect Neptune’s mass to be several times smaller than that of Uranus. Such a mass distribution can be explained by decreasing density of the gas nebula from the centre to the periphery, so that each planet has less gaseous substance than the previous one. In reality, Neptune has a mass of 17.5 $M_\oplus$, which is greater than the mass of the previous planet (Uranus).

Authors such as Chamberlin (1901), Moulton (1905), Schmidt (1944), von Weizsäcker (1944), McCrea (1960), Woolfson (1964), and Safronov (1972) have offered a variety of scenarios for the Solar System’s formation, attempting to explain some individual problems of planetary origin and evolution based on either the nebular hypothesis or the theory of close passage of two or more bodies. However, none of the existing theories is able to give a comprehensive picture of the emergence and development of the planetary system that would be consistent with physical principles, and numerous versions of theories involving stars and nebulae that moved closer together and then farther from each other can only give a very low estimate of the number of planetary systems, since such events should occur quite seldom. A large number of recently discovered exoplanets (1816 confirmed planets by February 2015, NASA Exoplanet Archive[1]) allows us to estimate the number of planets in our

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[1] http://exoplanetarchive.ipac.caltech.edu

* Email: v.beck@alfa-carbon.de

galaxy as many millions, so that a comprehensive understanding of the processes leading to the emergence of planetary systems becomes critically important. In this article we present a new conceptual model of the Solar System's formation from a pre-solar gas and dust nebula in the field of a standing sound wave, taking into account many more observed facts than competing theories and explaining them based solely on known physical laws.

2 THEORETICAL CONSTRUCTION

2.1 A spherical standing sound wave

It is generally accepted that during a sufficiently strong process of heating, gravitational contraction in the centre of the pre-solar nebula started thermonuclear fusion of hydrogen into helium. A large amount of energy was emitted and radiation pressure prevented the further contraction of the gas nebula. However thermonuclear fusion could not start quietly, because as there was still no balance between the gravitational forces tending to compress the nebula and the increasing gas pressure and temperature. The zone of highest temperature formed a relatively small region in the centre of the contracting pre-solar nebula, where the thermonuclear fusion of hydrogen into helium began at around 15000000 K. Outside this small central region a much larger gas region formed, where temperature and pressure were not yet critical, but very close to becoming so. Moving even farther away from the centre, huge amounts of hydrogen existed at a temperature which, although much lower than that in the centre, was still in the millions of kelvins, and at a fairly high pressure, determined by the gravitational force.

The thermonuclear fusion originating in the centre of the gas nebula resulted in a rapid temperature and pressure increase in the adjacent layers, where hydrogen burning also began. The process resulted in an explosion that caused a spherical shock wave originating from the central region. Gas temperature and pressure rose rapidly at the bow shock, resulting in an explosive hydrogen fusion process within a growing mass of gas, emitting more and more energy, which in turn fed the shock wave and gave it more and more power. After a certain time, the shock wave reached less contracted regions with lower temperatures, where passage of the shock wave could not cause thermonuclear fusion. By this time, however, the shock wave had already accumulated a huge amount of energy and continued to move away from the centre of the pre-solar nebula to the periphery. The specific explosion mechanism accompanied by the thermonuclear fusion processes is beyond the scope of this article; we note here only that the power of the explosion would have been large enough for the shock wave to spread all over the pre-solar nebula.

As the wave intensity decreased with increasing distance from the centre of the nebula, according to the inverse square law, the amplitude of gas particle oscillations would nevertheless have kept growing due to the decrease in gas density. As the wave propagated, the gas particles in the pre-solar nebula oscillated radially, for two reasons: first, as with sound propagation in the Earth's atmosphere, the difference in gas pressure; and secondly, the gravitational pull toward the centre of the nebula. Pressure and gravitational pull would have significantly different effects in the extremes of the oscillating gas particles, given the scale of many millions of miles. The second factor began to play a crucial role at large distances from the central attracting mass concentrations: at some point, the accelerated gas particles at the bow shock would no longer return under the influence of gravity. Gas density at this distance from the centre would have been so low that the pressure difference could no longer cause the return movement of gas particles. The peripheral part separated, and the protoplanetary nebula was thus divided into a central spherical region and an expanding spherical shell of gas (Fig. 1).

Gas particles at the boundary of the central spherical nebula fell under gravity towards the centre then stopped when the pressure of the lower gas layers exceeded the gravitational pull, and began to move in the opposite direction. As a result of the interaction between gravity and contracting gas back-pressure, the boundary of the spherical nebula began to oscillate radially and a reverse spherical wave propagated from the periphery towards the centre, repeating the path of the initial wave with corresponding changes in wavelength and increasing intensity.

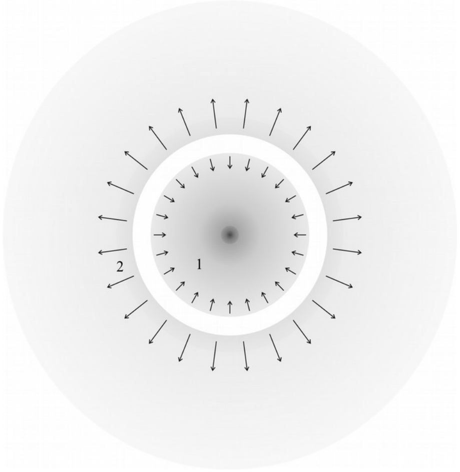

Figure 1. Separation of the pre-solar nebula into (1) a central spherical gas nebula and (2) an expanding spherical shell.

The sound wave would have appeared to reflect from the gravitational pause – a spherical shell where the gas particles' velocities were not high enough to overcome the gravitational pull from the centre of the nebula and the gas particles that had moved outwards returned due to oscillations; that is, their velocities were lower than the escape velocity,

$$v_e = \sqrt{\frac{2GM}{r}} , \qquad (1)$$

where G is the gravitational constant, M is the mass of the attraction centre and r is the distance of the gravitational pause from the centre.

The centre of the pre-solar nebula became quiescent after the first massive explosion: the central part, having been heated due to the emission of large amounts of energy, expanded, since the gravitational field was not yet intense enough to resist the much increased gas pressure, and the thermonuclear fusion of hydrogen combustion diminished. A large mass of gas (10–30% of the total mass) was ejected into the surrounding space while the compact region of compressed and heated gas – the protosun – remained at the nebula's core. Several hundred years after this, the wave returning from the boundary of the spherical nebula reached the protosun, concentrated in the centre, and then began to propagate towards the periphery again: a rapid pressure increase resulted in a dramatic rise in temperature at the centre of the protosun, generating a new hydrogen explosion, much weaker than the first one but still strong enough to give extra energy to the wave reflected from the central region. The reflected wave travelled all the way from the centre to the periphery of the spherical nebula, was reflected from the gravitational pause and then returned to the centre again, causing another explosion. This process, repeated several times, eventually established regular oscillations: the wave propagated from the centre to the edge, was reflected from the boundary of the spherical nebula, and returned, causing another explosion that compensated for wave energy loss. Thus, the wave caused explosions while acquiring the energy it needed, establishing a self-sustaining process whose period, defined by the free oscillations of the spherical nebula boundaries, equalled hundreds of years.

The acoustic radiation pressure prevented gravitational contraction of the pre-solar nebula and compensated for deviations from the spherical shape that might result, for example, from the nebula's rotation or gas turbulence. Waves travelling from the centre and from the periphery interfered with each other to form a giant spherical acoustic cavity resonator the size of the modern Solar System, including the Kuiper belt and scattered disc (Fig. 2). This resonator contained a standing wave with nodes and antinodes, the number of which would have been at least 11 for the pre-solar system: 8 planets + the asteroid belt + the Kuiper Belt + the scattered disc.

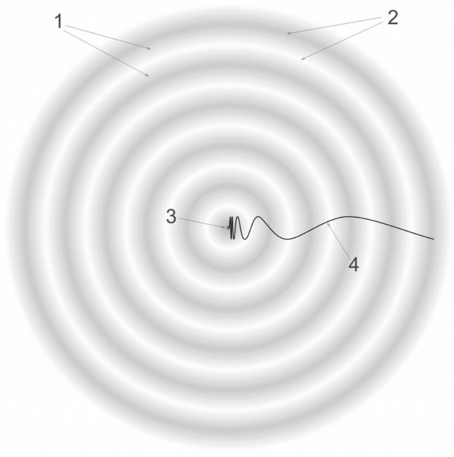

Figure 2. The standing wave in the pre-solar nebula: (1) nodes, (2) antinodes (gas compression and expansion), (3) protosun, (4) real-scale wave. Nodes and antinodes are evenly spaced for illustration purposes; in reality, separations would increase dramatically with increasing distance from the centre.

This article does not include a calculation of exact distances between the antinodes (regions of compression) of the standing wave; we may simply state that the wavelength increases with increasing distance from the centre of attraction. Section [3.4] outlines some regularities that allow us to make some observations about the physical reasons underlying planetary positions in the Solar System.

2.2 Dust concentration in the antinodes

In our model, the pre-solar system can keep 'sounding' for many millions of years, as the periodic central explosions significantly retard the gravitational contraction of the protosun and the acoustic radiation pressure stabilizes the gas nebula, preventing its collapse. The dust present in the pre-solar nebula gradually concentrates in the antinodes of the acoustic oscillating system. Apart from gas viscosity, the process of solid particle concentration in the standing wave also relies on attraction from the large gas masses that periodically emerge in the antinodes of the standing wave. This attractive force makes the dust particles move towards the gas clusters in the antinodes and collide with each other, causing redistribution of their velocity vectors in such a way that the dust particles come to rest in the centre of the antinode (Fig. 3).

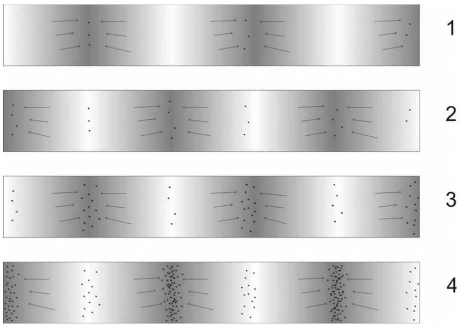

Figure 3. Dust concentration in the antinodes of the standing wave during four successive phases of compression and expansion. Dark areas stand for gas compression in the antinodes, light areas for expansion.

During the gas expansion phase, dust particles in each antinode are gravitationally attracted towards two neighbouring antinodes (gas at this point is in the compression phase). The two gravitational sources in these antinodes largely cancel each other out and, moreover, are remote, so that the dust particles in the gas expansion phase mostly remain in the same place. The next phase of compression attracts new dust particles to the antinode, which also come to rest due to collisions with each other and to the viscosity of the compressed gas.

2.3 Migration of solid matter and formation of rings

A certain period of time after the standing wave was established, most of the dust would have been concentrated in the regions of spherical antinodes. Due to increased dust concentration, the number of particle collisions significantly increased, causing their coalescence and increase in size and mass. The gravitational field within the antinodes and the centrifugal force together caused dust to concentrate and form equatorial rings, with radii corresponding to the antinodes of the standing sound wave (Fig. 4).

The model predicts that the increase in mass of the solid particles clusters also makes it increasingly difficult for them to stay at the antinodes of the standing sound wave as at the same time that they are affected by attraction from the central gas masses, principally the protosun.

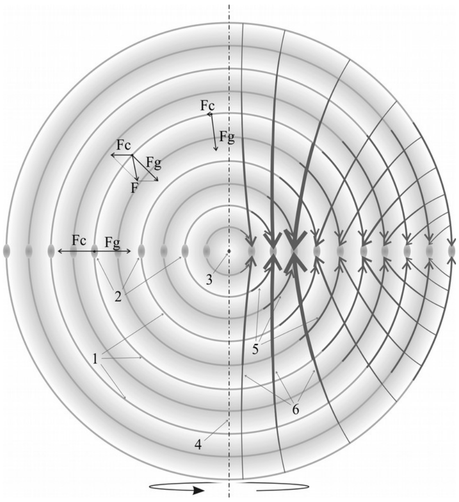

Figure 4. Migration of solid matter in the spherical nebula. F_g represents the gravitational pull toward the centre and F_c represents the centrifugal force. (1) spherical dust clusters in the antinodes, (2) dust clusters in the equatorial rings, (3) protosun, (4) nebula rotational axis, (5) direction of dust migration in the antinodes, (6) direction of massive dust cluster migration across the antinodes under the influence of the resultant force *F*.

The largest clusters of dust fall toward the centre; this results in migration of solid matter from the outer regions of the protoplanetary nebula towards the internal zones, while the centrifugal force does not allow the clusters to fall directly onto the protosun. The gravitational attraction of the gas masses in the antinodes directs the matter falling towards the rings forming in the equatorial plane, where the solid matter comes to rest. A significant amount of solid matter collected in the region of the orbits of Venus and Earth, as it was concentrated here from most of the protoplanetary nebula volume.

This dust, gathered in compact rings, is thousands of times more concentrated here than in the primary gas and dust nebula, greatly accelerating the coalescence of particles and leading to the emergence of increasingly massive dust clusters.

Agglomerated clusters of dust in narrow spinning rings move in almost identical circular orbits around the protosun and have very small relative velocities. Since their collisions do not result in fragmentation, they form massive planetesimals relatively quickly, which in turn agglomerate to form planets and their satellites. In this model, are no catastrophic collisions between the nascent planets, their satellites or other massive objects; the planets keep the circular orbits and planes of the equatorial dust rings.

2.4 Birth of the Sun

Gravitational contraction of the protosun, which had been significantly slowed as a result of regular explosions in the centre, still continued, and millions of years after the establishment of the standing sound wave gas temperature at the centre of the protosun became sufficiently high for thermonuclear fusion of hydrogen into helium to continue between explosions, resulting in the birth of a new star – the Sun. The newborn Sun stopped augmenting the sound wave by periodic explosions, and the standing wave diminished. The gas shell previously supported by acoustic pressure began to shrink, forming gas-giant planets around already existing solid nuclei. Jupiter acquired the greatest share of mass, as it was located in the region of highest gas density. All the other gas planets were situated in a lower density environment and thus obtained smaller masses. Jupiter also received large amounts of gas from the inner-planet region, blown outwards by the strong solar wind in the first few millions of years after the birth of the Sun.

2.5 The Oort cloud

The spherical expanding shell that separated from the spherical part of the nebula during the passage of the shock wave from the first explosion moved faster than the escape velocity v_e and could not return to the centre as the pull of gravity from the central masses was too weak at such distance. With its expansion, this spherical shell accumulated increasing quantities of highly rarefied gas from the primary nebula at its inner edge, while its expansion rate gradually slowed and eventually stopped at a distance of about 1 light year from the centre. This formed a giant spherical region containing dust, ice and frozen gases particles in addition to gaseous hydrogen and helium. Over time the gas component of the shell dissipated in space, while solid particles were concentrated in increasingly large chunks of ice and dust – the cometary bodies – to form the Oort cloud (Oort, 1950), which has a weak gravitational connection with the central part of the system.

2.6 Neptune, the Kuiper belt and scattered-disc objects

After expansion of the gas shell ceased in the Oort cloud, a weak reverse wave formed within the shell and moved towards the centre of the spherical nebula of gas, where planets had already emerged. Hundreds of thousands or millions of years later the reverse wave from the Oort cloud collided with the outer boundary of the central spherical nebula, causing a redistribution of matter on the edge of the Solar System. Large gas masses from the outer antinodes of the standing sound wave were shifted, and the planet Neptune formed a little closer to the Sun relative the original position of the 9th antinode, while its mass increased several times by capture of gas from the reverse wave from the Oort cloud. Scattered-disc objects such as the minor planet Eris acquired highly elongated orbits, as there was a long period under the influence of gravitational pull from the gas masses transported by the reverse wave from the Oort cloud. Minor planets in the Kuiper belt also gained significant eccentricity. The periphery processes were very slow, developing over many hundreds of thousands or millions of years, and were relatively weak in their effect on the central region of the pre-solar system. The reverse wave from the Oort cloud only caused the formation of the Kuiper belt, an offset of Neptune's formation and its mass increase. The rest of the Solar System was and is still affected by the region of the Oort cloud only through comets.

3 DISCUSSION

3.1 Terrestrial and giant planets

The difference in chemical composition of the inner and outer planets is explained by the migration of solid matter from the outer spherical shells to the internal ones. Before concentrating in stable spinning dust rings, the heavy chemical elements travelled farther towards the centre of the system and were incorporated by the inner planets, with Earth and Venus having more matter, and Mercury and Mars having less. The region between Mars and Jupiter had insufficient solid matter left for a proper planet, so only the minor planets of the asteroid belt were formed. Lighter and more volatile chemical compounds, such as water, methane or ammonia, could not remain in the solid phase as they were too close to the protosun. They remained in significant quantities in the colder regions beyond the asteroid belt, and became the compositional basis of the giant planets.

3.2 Rotation in the Solar System

If we assume that the first powerful explosion in the centre of the protosun was not absolutely symmetrical, slight asymmetry in the explosion led to a redistribution of the angular momentum in the pre-solar nebula, with the less massive peripheral zone of the pre-solar nebula beginning to rotate faster as it gained a significant increment of the angular momentum from the protosun gas mass. In addition, an initial asymmetry could produce the observed 7° equatorial plane tilt relative to the Sun's plane of rotation. The Sun's rotation slowed, in accordance with the law of angular momentum conservation, but its current rate of rotation approximately equals the initial rotational speed of the pre-solar nebula.

Currently the Sun has more than 99.8% of the entire Solar System mass but only about 0.5% of the total angular momentum. If the rotational kinetic energy were evenly distributed over the original pre-solar nebula, the resulting rotation (taking into account the pirouette effect) would be thousands or millions of times slower than the current rotation of the planets. The angular momentum was initially distributed evenly in the pre-solar nebula, and this means that such weak rotation cannot result in the process of dust disc formation as described by the nebular hypothesis.

However, these discs are visible in images of some young stars (Fig. 5), and in some cases their internal structure can be identified. If a spherical dust cluster such as described in this article were observed from one side, it would be impossible to observe any individual spheres as they would overlap in the line of sight. The stage at which a significant amount of solid matter has already accumulated in the equatorial plane would give such a system the appearance of a disc, despite the fact that there are significant gaps between individual rings.

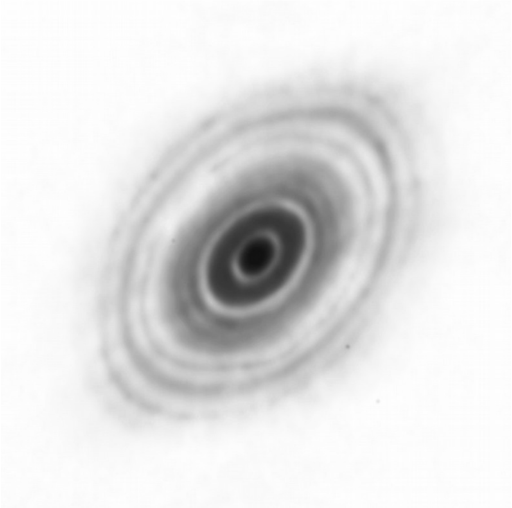

Figure 5. An image of a protoplanetary dust nebula around HL Tauri received by ALMA[2]

3.3 Exoplanetary systems

Generally speaking, the explosion in a protostellar nebula can either accelerate the gas shell rotation around the future star, slow it down or even give it a spin in the opposite direction. The latter case has been observed in some exoplanetary systems (Narita, 2009; Winn, 2009, 2010a; Triaud, 2010; Queloz, 2010; Bayliss, 2010; Hébrard, 2011) and the standard nebular hypothesis cannot explain it, since it implies that the central star and its planets should always rotate and revolve in the same direction, following the rotation of the protostellar disc.

An asymmetry in the initial explosion in the centre of the protostar can also lead to a very strong tilt of the equatorial plane of the planetary system, with tilts of 45° or even 90° not impossible (Pont, 2010; Simpson, 2010; Winn, 2010b; Hirano, 2010).

3.4 Background for a physical and mathematical model of the Solar System

We now consider building a physical and mathematical model of a standing wave in a spherical gaseous protoplanetary nebula. Oscillations occur in an environment where gravitational field intensity and gas pressure change

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[2] The Atacama Large Millimeter/submillimeter Array , http://www.eso.org/public/images/eso1436a/

substantially within a wavelength (by radius). It can be assumed that the wavelength is inversely proportional to the product of average values of gravitational acceleration g, which is inversely proportional to the square of the distance to the centre of attraction, and gas pressure p, which in turn depends directly on g:

$$\lambda \sim \frac{1}{g \times p}, \tag{2}$$

or, supposing that $p \sim g$:

$$\lambda \sim r^4, \tag{3}$$

where λ is the acoustic wavelength, g and p are the average values of gravitational acceleration and gas pressure as function of r, the distance from the centre.

Fig. 6 shows the distribution of planetary distances from the Sun. The planet Neptune is not shown on the figure for the reasons outlined in Section [2.6], its place being taken by Pluto. The planets originated in the antinodes, so the figure also shows the distribution of the standing wave in the protoplanetary gas nebula.

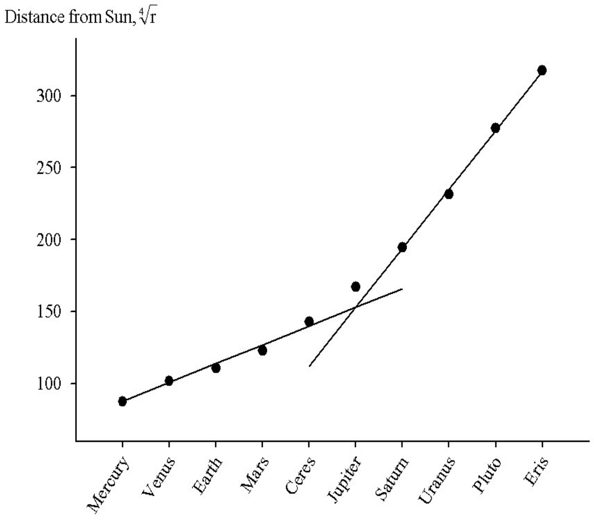

Figure 6. Distribution of planetary distances from the Sun. The vertical axis shows the fourth root of distance in kilometres.

We can see that the points on the graph may be approximated by two straight lines, supporting our hypothesis that locations of the standing wave antinodes depend on r^4.

Closer to the Sun, the constant of proportionality determining the wavelength increases, which may be explained by the fact that the speed of the sound wave increases with rising gas temperature: $c \sim \sqrt{T}$; consequently, with the frequency *f* of the sound wave constant,

$$\lambda \sim \sqrt{T}, \tag{4}$$

where c is the speed of the sound wave, λ is its wavelength and T is the temperature.

The dependence hypothesis $\lambda \sim r^4$ provides a background for developing a more complex physical and mathematical model for the Solar System's origin and evolution, as well as for planetary systems around other stars. Such a model could facilitate the search of exoplanets, predicting the probable future planetary locations for stars around which exoplanets have already been discovered.

4 CONCLUSIONS

According to the proposed conceptual model of planetary origin from the gas and dust pre-solar nebula in the field of a standing sound wave, only single stars or multiple stars with large distances between individual components can have planetary systems. Systems with closely located multiple star components cannot sustain the reverse wave after the explosion in the centre of one of the stars causes further periodic explosions due to the motion of the stars, so that it will fade out, while a gas-dust nebula that is not stabilized by the field of a standing sound wave will relatively swiftly accrete to the central stars without any planet formation.

The existing theories of planetary systems origin, including the Kant–Laplace hypothesis, suggest that rotation of the pre-solar nebula is essential for the formation of a dust disc around the central star. The proposed conceptual model does not require such an assumption. If a pre-solar nebula does not rotate, after the first asymmetric explosion the central protostar and the peripheral gas masses will gain equal angular momentum, but opposite in sign. The gas-dust nebula will start spinning and at the same time a standing sound wave will emerge, beginning the process of planet formation. The resulting planetary system will have the central star and planets rotating in opposite directions, but this does not conflict with observed data (see Section [3.3]).

The proposed scenario of planetary system origin answers many open questions related to the origin and evolution of solar systems. Several known facts and their explanations within the framework of this conceptual model are listed below.

4.1 Facts and explanations

4.1.1 Planetary distances to the Sun are not random – there are certain regularities (Titius–Bode law).

In our model, planets are formed at the antinodes of a giant standing sound wave, emerging after a powerful thermonuclear explosion at the protosun's centre and repeated transmission of forward and reverse sound waves through the spherical protoplanetary gas-dust nebula.

4.1.2 There are inner silicate planets and outer gas giant planets.

The distinction between inner and outer planets is explained by migration of solid matter from the spherical dust concentration zones in the antinodes of the standing wave.

4.1.3 The Sun contains > 99.8% of the mass, but only 0.5% of the angular momentum of the Solar System.

The asymmetry of the first explosion in the protosun’s centre resulted in a redistribution of angular momentum: the rotation of the peripheral portion of the gas-dust nebula was significantly accelerated, acquiring an increment of angular momentum from the large gas mass emitted from the protosun during this explosion (~ 10–30% of the Sun’s mass).

4.1.4 There is a 7° tilt of the Sun’s equatorial plane in relation to the average plane of the planetary orbits.

The equatorial plane of the planetary system tilted during the first powerful explosion in the centre of the presolar nebula because of the slight asymmetry of the explosion.

4.1.5 The Oort cloud is a source of comets visiting the inner Solar System. Its existence is not confirmed by direct observations, but is very likely.

The expanding shell that separated from the interior part of the pre-solar nebula during the passage of the shock wave from the first explosion concentrated large masses of rarefied gas in front of it and stopped at a distance of about 1 light year from the Sun, forming a spherical region where comets are formed – the Oort cloud.

4.1.6 Neptune is closer to the Sun than is implied by the Titius–Bode distribution.

The material that formed Neptune was shifted towards the Sun by a reverse wave from the Oort cloud.

4.1.7 The mass of Neptune (17.5 $M_{\oplus}$) is significantly greater than would be expected based on the decreasing sequence of masses: Jupiter (318 $M_{\oplus}$), Saturn (95.3 $M_{\oplus}$) and Uranus (14.5 $M_{\oplus}$).

Neptune gained a significant (multiple times) mass increase from the reverse wave from the Oort cloud.

ACKNOWLEDGEMENTS

I am grateful to my wife, Svetlana, as well as the Alfa-Carbon® Beck company for their great help in the preparation of this article. This research has made use of the NASA Exoplanet Archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program.

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