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

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7 March 2015

ABSTRACT

According to the planet origin concept proposed in this paper the protosun center explodes resulting in a shock wave running through the pre-solar nebula that then returns to the center and generates a new explosion and a new wave. Recurrent explosions in the pre-solar nebula result in a spherical standing sound wave with its antinodes concentrating dust. Dust then forms rotating rings that transform into planets. The extremely small Sun's angular momentum (0.5%) and the tilt of the equatorial plane (7°) are caused by the asymmetry of the first most powerful explosion. Distinction between internal and external planets is explained by the migration of the solid matter. The Oort cloud is explained by the division of the pre-solar nebula into a spherical internal nebula and a expanding spherical shell of gas during the transit of the first explosion shock wave. The proposed concept can explain the origin and evolution of exoplanetary systems as well as help 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 Kant-Laplace nebular hypothesis of a protoplanetary nebula suggesting that the Sun and the planets condensed out of a spinning nebula of gas and dust (Kant (1755), Laplace (1796)). During the condensation process the nebula spins faster (pirouette effect), and the centrifugal force causes it to form a disk. The center of the nebula turns into a highly compressed and hot gas region – the protosun. Concentration and coalescence of dust particles in the spinning dust disk lead to the formation of planets orbiting the Sun.

This theory shows 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 almost unsolvable paradox. The hypothesis also cannot explain the 7° tilt of the Sun 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 had the matter evenly distributed over the entire volume and thus the resulting planets should not be very different in chemical composition.

The observed regularity in the planetary distances to the Sun also has no explanation – the so-called Titius-Bode law is a single empirical formula describing the approximate location of the planets in the Solar System. This pattern is also observed in many exoplanetary systems discovered in recent years, and it probably is a manifestation of some 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 planets – it consists of trillions of small objects from water, ammonia and methane ice and dust. It is believed that these objects were emitted by the giant planets at the planet system formation stage and then acquired distant circular orbits (about 1 light year) as a result of the pull of gravity from the neighboring stars. Such Oort cloud emergence scenario seems very unlikely for such a large number of bodies.

Neptune is the most distant gas planet. Based on the following decreasing series of giant planet masses: Jupiter – 318 $M_\oplus$, Saturn – 95.3 $M_\oplus$, Uranus – 14.5 $M_\oplus$, we could expect Neptune mass to be several times smaller than that of Uranus. This mass distribution can be explained by the density of the gas nebula decreasing from the center to the periphery, so that every next 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).

Many authors, including Chamberlin (1901), Moulton (1905), Schmidt (1944), von Weizsaecker (1944), McCrea (1960), Woolfson (1964), Safronov (1972), offer a variety of scenarios for the Solar System formation, trying to explain some individual problems related to the planetary origin and evolution and working on 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 planetary system emergence and development that would be consistent with physical principles, and the numerous versions of theories involving converging and then diverging stars and nebulae can only give a very low estimate of the number of planetary systems, since such events should occur quite seldom. A large number of exoplanets discovered recently (1816 confirmed planets by February 2015, NASA Exoplanet Archive[1]) allows us to estimate the number of planets in our galaxy as many millions – and a comprehensive understanding

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

of the processes leading to the emergence of planetary systems becomes critically important.

In this article I present a new concept of the Solar System formation from a pre-solar gas and dust nebula in the field of a standing sound wave; it takes into account the highest number of observed facts and explains them based solely on the known physical laws.

2 THEORETICAL CONSTRUCTION

2.1 A spherical standing sound wave

It is commonly accepted that during a sufficiently strong process of heating, gravitational contraction in the center of the pre-solar nebula starts a thermonuclear fusion of hydrogen into helium. A large amount of energy is emitted and radiation pressure prevents the further contraction of the gas nebula. However, the thermonuclear fusion cannot start quietly, as there is still no balance between the gravity forces tending to compress the nebula and gas pressure increasing together with gas temperature. The highest temperature zone is a relatively small area in the center of the contracting pre-solar nebula, and it is here that the thermonuclear fusion of hydrogen into helium begins. Above this small central region there is a much larger gas area where temperature and pressure are not yet critical, but are very close to becoming critical. Moving even further away from the center, we will see huge amounts of hydrogen at a temperature although much lower than that in the center, but still equal to millions of degrees, and at a fairly high pressure.

The thermonuclear fusion that originated in the center of the gas nebula results in a rapid temperature and pressure increase in the adjacent layers, where the thermonuclear fusion of hydrogen burning also begins. The process results in an explosion that causes a spherical shock wave originating from the central region. Gas temperature and pressure rise rapidly at the bow shock, resulting in a detonation hydrogen combustion process within a growing mass of gas, emitting more and more energy, which in turn feeds the shock wave and gives it more and more power. After some time the shock wave reaches the regions that were not so heated and less contracted, where passage of the shock wave cannot cause thermonuclear fusion. However, by this time the shock wave has already accumulated a huge amount of energy and continues moving away from the center to the periphery of the pre-solar nebula. The specific explosion mechanism accompanied by thermonuclear fusions is not the subject of this article; it should only be noted that the power of the explosion should be large enough for the shock wave to spread all over the pre-solar nebula.

As the wave intensity decreases with increasing distance from the center according to the inverse square law, the amplitude of gas particle oscillations is yet growing due to the decrease in gas density. As the wave propagates, the gas particles in the pre-solar nebula oscillate radially. This is caused by two reasons. First reason, similar to the sound propagation in the atmosphere, is the difference in gas pressure, and the second one is the gravitational pull toward the center of the nebula, with both pressure and gravitational pull being significantly different in the extremes of the oscillating gas particles as we are referring to distances of many millions of miles. Another factor starts playing a crucial role at large distances from the central attracting masses: at some point the accelerated gas particles at the bow shock can no longer go back due to the pull of gravity. Gas density is now so low that the pressure difference can no longer cause the return movement of gas particles. The peripheral part separates and the protoplanetary nebula is divided into the central spherical part and a expanding spherical shell of gas (Fig. 1).

Gas particles at the boundary of the central spherical nebula fall towards the center, pulled by gravity, then stop when the pressure of the lower gas layers exceeds the pull of gravity and begin to move in the opposite direction. As a result of interaction between gravity and contracting gas backpressure, the boundary of the spherical nebula begins to oscillate radially and a spherical backward wave starts spreading from the periphery to the center: it repeats the path of the direct wave with the appropriate changes in wavelength and increasing intensity.

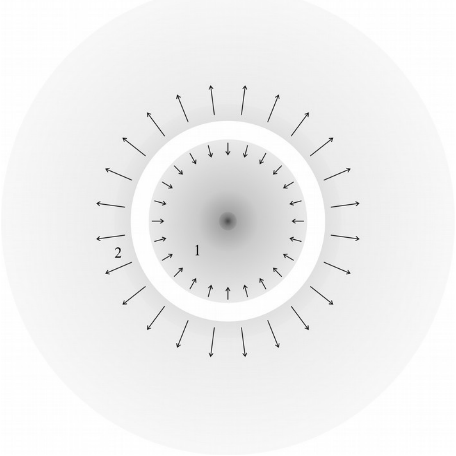

Figure 1. Separation of the pre-solar nebula into a central spherical gas nebula (1) and a expanding spherical shell (2).

The sound wave seems to reflect from the "gravitational wall" – a spherical region, where the speeds of gas particles are not high enough to overcome the gravity pull from the central part of the pre-solar nebula and the gas particles that have shifted away from the center due to oscillations return back, that is, their speeds are lower than the escape velocity:

$$v_e = \sqrt{\frac{2GM}{r}} \, , \tag{1}$$

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

The center of the pre-solar nebula becomes quiet after the first massive explosion: the central part that was heated due to emission of large energy amounts expands, as gravity is not yet strong enough to resist the highly increased gas pressure, and the thermonuclear fusion of hydrogen combustion diminishes. A large mass of gas (10-30% of the total mass) is emitted into the surrounding space and in the center remains the compact region of compressed and heated gas - protosun. Several hundred years later the backward wave from the boundary of the spherical nebula reaches the protosun, concentrates in the center and then begins to propagate toward the periphery again. A rapid pressure increase results in a rise of temperature in the center of the protosun and there is 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 goes all the way from the center to the periphery of the spherical nebula, is reflected from the "gravitational wall" and then comes back again, causing another explosion. This process is repeated several times, and eventually regular oscillations are established: the wave propagates from the center to the edge, is reflected from the boundary of the spherical nebula, comes back and causes another explosion that compensates for wave energy loss. The wave causes explosions while acquiring the energy it needs. A self-oscillating process is established with the oscillation period being defined by the free oscillations of the spherical nebula boundaries and equaling hundreds of years.

The acoustic radiation pressure prevents the gravitational contraction of the pre-solar nebula and compensates for the deviations from the spherical shape that can result, for example, from the nebula rotation or gas turbulent motions. The waves going from the center to the periphery and backward waves interfere with each other and actually form a giant spherical acoustic cavity resonator of the size equal to the current Solar System including the Kuiper belt and scattered disc (Fig. 2). This resonator has a standing wave with nodes and antinodes, the number of which should be at least 11 for the pre-solar system: 8 planets + the asteroid belt + the Kuiper Belt + the scattered disc.

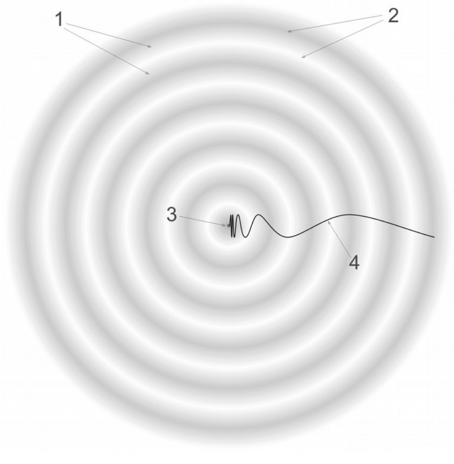

Figure 2. The standing wave in the pre-solar nebula, 1 - nodes, 2 - antinodes (gas compression and expansion), 3 - protosun. Nodes and antnodes are evenly spaced for illustration purposes; in reality distances between them would strongly increase with increasing distance from center: 4 - real-scale wave.

This article does not include a calculation of exact distances between the antinodes of the standing wave; we can just say that the wavelength increases with increasing distance from the center of attraction. Section [3.4] outlines some regularities that allow us to make some observations about the physical reasons behind the planetary positions in the Solar System.

2.2 Dust concentration in the antinodes

The pre-solar system can keep "sounding" for many millions of years as the periodic explosions in the center significantly slow down 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 regions of compression (the antinodes) of the standing wave. This attractive force makes the dust particles move toward 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 stop in the center of the antinode (Fig. 3).

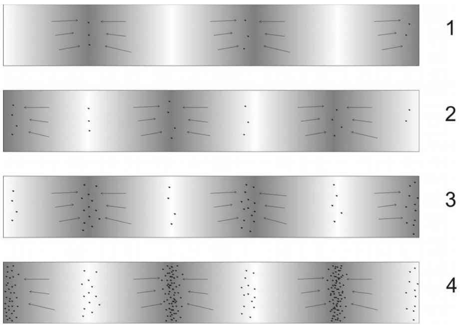

Figure 3. Dust concentration in the antinodes of the standing wave during phases 1 - 4. Dark areas stand for gas compression in the antinodes, light areas – for expansion.

During gas expansion phase dust particles in the antinode are pulled by gravity toward two neighboring antinodes where gas at this point is in the compression phase. The two sources of gravity in these antinodes largely cancel each other out and, moreover, they are far away, so 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 – they also stop due to collisions with each other and viscosity of the compressed gas.

2.3 Migration of solid matter and formation of rings

A certain period of time after the standing wave is established most of the dust will be concentrated in the areas of spherical antinodes. Due to increased dust concentration the number of particle collisions significantly increases, which causes their coalescence and increase in size and weight. Dust particles are affected by centrifugal force of the spinning protoplanetary nebula, which reaches its peak value in the equatorial plane. Pull of gravity from the antinodes and the centrifugal force together cause dust to concentrate and form equatorial rings, with radii corresponding to the antinodes of the standing sound wave (Fig. 4).

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 they are affected by attraction from the central gas masses – the protosun .

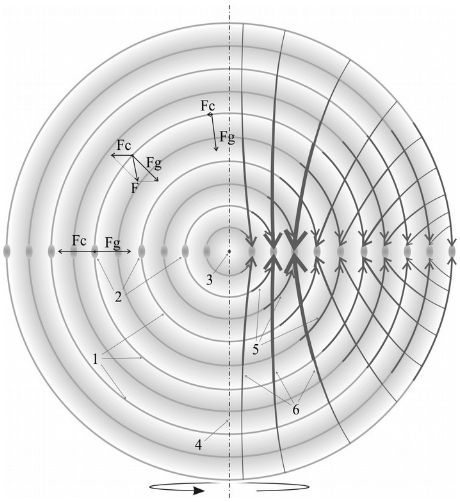

Figure 4. Migration of solid matter in the spherical nebula. Fg - the gravitational pull toward the center, Fc - the centrifugal force, 1 - spherical dust clusters in the antinodes, 2 - dust clusters in the equatorial rings, 3 - protosun, 4 - nebula rotation axis, 5 - direction of dust migration in the antinodes, 6 - direction of large dust cluster migration across the antinodes under the influence of the resultant force F.

The largest clusters of dust fall toward the center: this results in migration of solid matter from the outer regions of the protoplanetary nebula to the internal zones, and the centrifugal force does not let the clusters fall directly on the protosun. Pull of gravity from the gas masses in the antinodes directs the falling matter towards the forming rings in the equatorial plane, where the solid matter stops. A significant amount of solid matter happens to be in the Venus and Earth region, 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, and it greatly accelerates the coalescence of particles and leads to emergence of increasingly large and 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. Their collisions do not result in fragmentation and relatively quickly form large and massive planetesimals, which in turn agglomerate resulting in the formation of planets and their satellites. There are no catastrophic collisions between the forming planets, their satellites or other massive objects; the planets keep their circular orbits and planes of the equatorial dust rings.

2.4 Birth of the Sun

Gravitational contraction of the protosun, that has significantly slowed down as a result of regular explosions in the center, still continues, and millions of years after the establishment of the standing sound wave gas temperature at the center of the protosun rises so high that the thermonuclear fusion of hydrogen into helium also keeps going between explosions: this is the birth of a new star – the Sun. The newborn Sun stops feeding the sound wave by periodic explosions and the standing wave diminishes. The gas shell that was previously held by the acoustic pressure begins to shrink, forming gas giant-planets around the already existing solid nuclei. Jupiter acquired the greatest share of mass, as it was located in the area with the 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 planets: these gas amounts were blown away by the strong solar wind in the first 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, moves faster than the escape velocity v_e and cannot return to the center as the pull of gravity from the central masses is too weak at such distance. With its expansion, this spherical shell accumulates increasing masses of highly rarefied gas from the primary nebula in its front, while its expansion rate is gradually slowing down and eventually stops at a distance of about 1 light year from the center. This forms a giant spherical region that contains dust, ice and frozen gases particles in addition to gaseous hydrogen and helium. Over time the gas component of the shell dissipates in space, while solid particles are concentrated in increasingly large chunks of ice and dust – the cometary bodies – and 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 stopped in the Oort cloud, there was a weak backward wave formed within the shell. It moved towards the center of the spherical nebula of gas, where planets had already emerged. Hundreds of thousands or millions years later the backward wave from the Oort cloud collided with the outer boundary of the central spherical nebula and there was 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 was formed a little closer to the sun, while its mass increased several times using gas from the backward wave from the Oort cloud. Minor planet Eris and other scattered-disc objects acquired highly elongated orbits, as there was a long period under the influence of gravity pull from the gas masses of the backward wave from the Oort cloud. Minor planets of the Kuiper belt also gained significant eccentricity. The periphery processes were very slow, developed over many hundreds of thousands or millions of years and were relatively weak to affect the central region of the pre-solar system. The backward 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 only affected and is still affected by the region of the Oort cloud through comets.

3 DISCUSSION

3.1 Terrestrial planets and giant planets

The difference in chemical composition of the inner and outer planets is explained by migration of solid matter from the outer spherical shells to the internal ones. Before concentrating in stable spinning dust rings, the heavy chemical elements went a longer way toward the center of the system and became part of the inner planets, with Earth + Moon and Venus having more matter, and Mercury and Mars having less. The region between Mars and Jupiter had so little solid matter left that it was not enough for a proper planet so only 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 condensed state as they were too close to the protosun. They were remained in significant quantities in the colder regions beyond the asteroid belt and became the nuclei of the giant planets.

3.2 Rotation in the Solar System

The first powerful explosion in the center of the protosun was not absolutely symmetrical; slight asymmetry of the explosion led to a redistribution of the angular momentum in the pre-solar nebula: the less massive peripheral zone of the pre-solar nebula began to rotate faster as it gained a significant increment of the angular momentum from the emitted from the protosun gas mass. In addition, the planetary system gained a 7° equatorial plane tilt relative to the Sun rotation plane. The Sun started rotating slower, in accordance with the law of angular momentum conservation, but its current 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 rotation energy is evenly distributed over the original pre-solar nebula, the resulting rotation (taking into account the pirouette effect) will 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 disks are visible in the pictures of some young stars (Fig. 5), and in some cases their internal structure can be defined. If we looked at the spherical dust clusters described in this article from a side, it would be impossible to observe any individual spheres as they would overlap in the line of sight. The stage where a significant amount of solid matter has already accumulated in the equatorial plane would make such system look like a disk, despite the fact that there are significant gaps between individual rings.

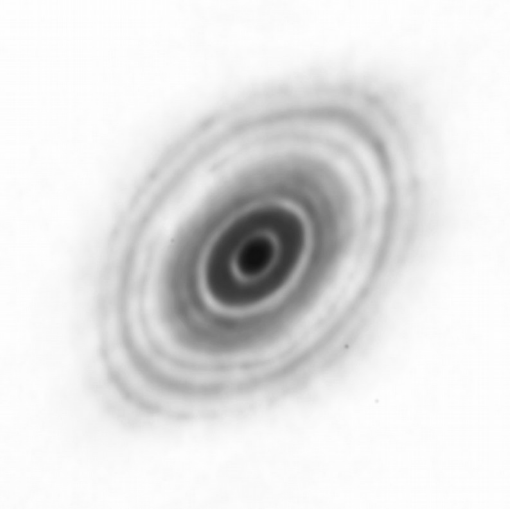

Figure 5. An image of a protoplanetary dust nebula around HL Tauri received by ALMA[2]

3.3 Exoplanetary systems

Generally speaking, the explosion in a protostellar nebula can both accelerate the gas shell rotation around the future star and slow it down or even give it a spin in the opposite direction. The latter case was observed in some of the exoplanetary systems (Narita (2009), Winn (2009) (2010a), Triaud (2010), Queloz (2010), Bayliss (2010), Hébrard (2011)) and the classical theory still has no explanation for it, since it was believed that the central star and the planets should always rotate in the same direction, following the rotation of the protostellar disk.

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

If the rotation of the dust nebula around the protostar significantly slows down or completely stops after the first powerful explosion, the formation of planets is impossible and, despite the emergence of a spherical standing wave and the presence of dust, only a single star is formed from this protostellar nebula.

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

Building a physical and mathematical model of a standing wave in a spherical gaseous protoplanetary nebula draws our interest. Oscillations occur in an environment where the pull of

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[2] ALMA (ESO/NAOJ/NRAO), http://www.eso.org/public/archives/images/screen/eso1436a.jpg

gravity and gas pressure change substantially within the 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 center of attraction, and gas pressure p, which in turn depends on g:

$$\lambda \sim \frac{1}{g \times p}, \qquad (2)$$

or, supposing that $p \sim g$:

$$\lambda \sim r^4, \qquad (3)$$

where λ is the length of the sound wave, g and p are the average values of gravitational acceleration and gas pressure and r is the distance to the center.

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 is 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.

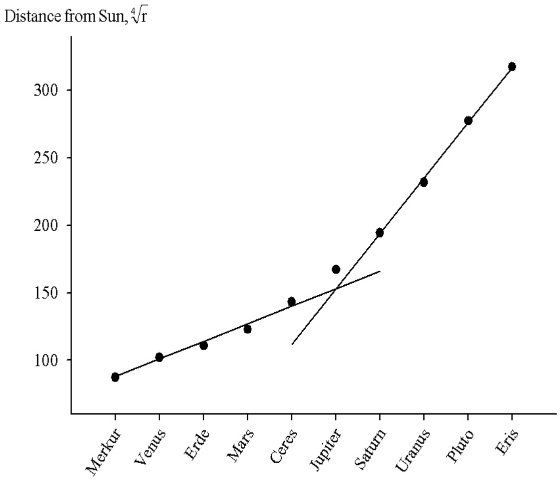

Figure 6. Distribution of planetary distances from the Sun. The vertical axis shows distances in kilometers as fourth root.

We can see that the points on the graph are approximated by straight lines, and this confirms our hypothesis that locations of the standing wave antinodes depend on r^4.

As we get closer to the Sun the wavelength increases and this can be explained by the fact that the speed of the sound wave rises with increasing gas temperature $c \sim \sqrt{T}$, consequently, with f=*const*:

$$\lambda \sim \sqrt{T}, \qquad (4)$$

where c is the speed of the sound wave, T – temperature, λ – length and f – frequency of the sound wave.

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

4 CONCLUSIONS

According to the proposed concept of the 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 will not let the backward wave after the explosion in the center of one of the stars cause further periodic explosions due to the motion of the stars, and it will fade out, while a gas-dust nebula that is not stabilized by the field of a standing sound wave will relatively fast accrete to the central stars without any planet formation.

The existing theories of planetary systems origin, including the Kant-Laplace hypothesis, suggest rotation of the pre-solar nebula, which is essential for the formation of a dust disk around the central star. The proposed concept does not require such an assumption. If a pre-solar nebula does not rotate, after the first asymmetric to the center of masses explosion the central protostar and the peripheral gas masses will get equal, but opposite in sign angular momentum. 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 that does not conflict with observed data (see Section 3.3).

The mechanism of self-oscillations of the protoplanetary nebula outlined in this paper can be applied to explain the periodic pulsations of variable stars such as Cepheids. Pulsating atmosphere boundary of such star generates spherical sound waves, which concentrate in the center and periodically cause an increased emission of energy, thereby maintaining the pulsation. Frequency and waveform parameters are defined by the spherical acoustic cavity resonator and can be practical constant for long time.

The proposed scenario of the 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 concept 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).

Planets are formed in the antinodes of a giant standing sound wave, emerging after a powerful thermonuclear explosion in the center of the protosun and repeated passage of forward and backward sound waves through the spherical protoplanetary gas-dust nebula.

4.1.2 There are internal silicate planets and outer gas giant planets. The hypothesis of a rotating protoplanetary disk cannot explain such distribution, as the rotating disk has the whole mass of dust influenced by the centrifugal force, which prevents migration of the matter.

> Distinction between inner and outer planets is explained by migration of the 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.

> Asymmetry of the first explosion in the protosun center resulted to 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 explosion (~ 0.1 - 0.3 of the Sun mass).

4.1.4 There is a 7° tilt of the Sun 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 center of the presolar nebula because of the small 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 concentrates large masses of rarefied gas in front of it and stops 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 Planet Neptune is closer to the Sun than what is implied by the Titius-Bode distribution.

> Neptune was shifted towards the Sun by a backward wave from the Oort cloud.

4.1.7 The mass of Neptune (17.5 $M_\oplus$) is significantly greater than what could 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 (a number of times) mass increase from the backward wave of the Oort cloud.

ACKNOWLEDGEMENT

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.

REFERENCES

Bayliss, D., Winn, J., Mardling, R., Sackett, P. 2010, ApJ, 722, L224
Chamberlin, T. C. 1901, Astrophys.J. 14, 17
Hébrard, G., Ehrenreich, D., & Bouchy, F. et al. 2011, A&A, 527, L11
Hirano, T., Narita, N., Shporer, A., et al. 2010, PASJ, sub. [arXiv:1009.5677]
Kant, I. 1755, Allgemeine Naturgeschichte und Theorie des Himmels (Königsberg: Petersen)
Laplace, P. S. 1796, Exposition du Systéme du Monde (Paris: Imprimerie Cercle-Social)
McCrea, W. H. 1960, Proc. R. Soc. 256, 245
Moulton, F. R. 1905, Astrophys. J. 22, 165
Narita, N., Sato, B., Hirano, T., Tamura, M. 2009, PASJ, 61, L35
Oort, J. 1950, Bull. Astron. Inst. Neth., 11, 91
Pont, F., Endl, M., Cochran, W. D., et al. 2010, MNRAS, 402, L1
Queloz, D., Anderson, D., Collier Cameron, A., et al. 2010, A&A, 517, L1
Safronov, V. S. 1972, Evolution of the Protoplanetary Cloud. (Jerusalem: Israel Program for Scientific Translations)
Schmidt, O. Y. 1944, Dokl. Akad. Nauk. SSSR 45, No. 6, 229
Simpson, E. K., et al. 2010, MNRAS, sub. [arXiv:1011.5664]
Triaud, A., Collier Cameron, A., Queloz, D., et al. 2010, A&A, 524, A25
von Weizsaecker, C. F. 1944, Z. Astrophys,.22, 319
Winn, J. N., Johnson, J. A., Albrecht, S., et al. 2009, ApJ, 703, L99
Winn, J. N., Howard, A., Johnson, J., et al. 2010a, AJ, 141, 63
Winn, J. N., Johnson, J. A., Howard, A. W., et al. 2010b, ApJ, 723, L223
Woolfson, M. M. 1964, *Proc. Roy. Soc.*, A. 282, 485