Solar System Wave Packet

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Abstract

The emptiness of the interplanetary space in the solar system from large objects is very thought-provoking. For example, Consider the distance between Earth and Venus. This distance is about 25 thousand times the total diameter of Earth and Venus. It's like placing two small gravels on either side of a football pitch. Now, it would be self-deception to imagine that the protoplanetary disk didn't have enough material to form dozens of other planets in the wide space between Earth and Venus, and only these two tiny gravels formed in this huge pitch. An event must have cleaned the objects between Earth and Venus from the protoplanetary disk. Here we show that this event is the oscillation of a huge standing wave packet, with the wavelength $\lambda = 0.6\ AU$, in the protoplanetary disk of early solar system. In addition, the Solar System Wave Packet (SSWP) theory explains the reason why the Giant (Jovian) planets are heavier than the terrestrial planets, the reason for the existence of Titius-Bode law and some other phenomena. The SSWP theory can easily overcome the problems of *fragmentation barrier*, *bouncing barrier* and *meter-size barrier*, and unlike current theories, we provide an identical and coherent explanation for the formation of giant and terrestrials planets of solar system, super-Earths and hot Jupiters. The spherical shape of Chondrules tells us that the passage of a wave front was effective in the formation of Chondrules. Here we show that that wave front can be SSWP.

Keywords: Solar system formation, Interplanetary Space, Titius-Bode law, Chondrule, Super Earths, Hot Jupiters

1. Introduction

Scientists researching solar system and exoplanets formation know that, despite decades of theorizing and simulations, there is still no *coherent* theory of planet formation (Raymond & Morbidelli 2022) and in many parts there is ambiguity. For example, the growth from dust particles to kilometer-size planetesimals is a subject for which there is still no satisfactory theory and is still a mystery (e.g., Morbidelli et al 2012, Raymond & Morbidelli 2022, Okuzumi et al. 2012). In principle, one could expect that dust grains, once sufficiently concentrated near the plane of protoplanetary disk, should stick to each other to form progressively larger objects, in an ordered-growth process (Morbidelli et al 2012). But the accretion of dust particles in the disk through pairwise collisions leads to two problems: First, this growth is expected to stop after reaching pebble size (1 mm to 1 cm), because of ‘’fragmentation barrier’’ and ‘’bouncing barrier’’ (e.g., Matsumura 2017; Blum & Wurm 2008; Brauer et al. 2008; Zsom et al. 2010; Windmark et al. 2012). Even if the objects managed to grow beyond this size, there is second problem called the ‘’meter-size barrier’’ or ‘’radial drift barrier’’, which hinders the growth of planetesimals larger than one meter (Weidenschilling 1977, Adachi et al. 1976; Matsumura 2017; Okuzumi et al. 2012).

Three main mechanisms have so far been suggested to explain how dust particles overcome the radial drift barrier (Okuzumi et al. 2012). *Porous Aggregation* theory is one of these mechanisms (Okuzumi et al. 2012). But at best, porous Aggregation could work only in the outer part of the disk (Raymond & Morbidelli 2022), of course if we ignore fragmentation due to collisions and assume that all collisions lead to growth! (Okuzumi et al. 2012). Moreover, meteorites show that the interior structure of asteroids is made mostly of compact particles of 100 microns to a millimeter in size, called chondrules, which is not consistent with the porous Aggregation mode (Raymond & Morbidelli 2022).

Another idea is that dust particles "jump" across the barrier by forming a gravitationally unstable thin dust layer at the midplane and directly collapsing into planetesimal-sized objects (Safronov 1969; Goldreich & Ward 1973; Hayashi et al. 1985). However, this classical scenario (which called *gravitational instability*) has been challenged by the fact that the dust layers are easily stirred up by disk turbulence (Weidenschilling & Cuzzi 1993; Turner et al. 2010) and gravitational instability generally does not occur except for just inside the snow line (Ida & Guillot 2016). Another proposed mechanism to overcome drift barrier is *streaming instability*, which can lead to the fast formation of gravitationally bound dust clumps (e.g., Johansen & Youdin 2007; Johansen et al. 2007; Bai & Stone 2010). However, this mechanism in addition to its very low probability of its occurrence (e.g., Raymond & Morbidelli 2022, Matsumura 2017), contradicts the presence of chondrules (e.g., Raymond & Morbidelli 2022). As you observed, each of the proposed mechanisms of growth has significant problems.

The 'small Mars' problem is another problem that has led physicists to Grand Tack model (e.g., Walsh et al. 2011, Raymond & Morbidelli 2022). Simulations systematically produced planets at location of Mars that were 5-10 times more massive than the real Mars. This issue is commonly referred to as the *small Mars problem* (Wetherill 1991; Chambers 2001; Raymond et al. 2009). The *Grand Tack model* proposed that Jupiter's migration during the gaseous disk phase was responsible for depleting Mars' feeding zone (Raymond & Morbidelli 2022). But the Grand Tack model has a major problem: In order for the Saturn embryo to migrate out with the Jupiter embryo in the Grand Tack model, their mass ratio must always be roughly between 2:1 and 4:1 (Raymond & Morbidelli 2022). And secondly, in order to maintain this ratio, Jupiter and Saturn embryos must collect a certain amount of material during outward migration, which seems very unlikely (Raymond & Morbidelli 2022). Because it is expected that the mass ratio between the gas giants will constantly change at this stage (Raymond & Morbidelli 2022), and on the other hand, geochemical constraints may affect the growth rate of the embryos of these two planets during the outward migration phase (Raymond & Morbidelli 2022). In fact, presentation of such models, like the *Grand Tack* or *Porous Aggregation*, are like sewing a tight suit for someone and trying to wear him.

In addition, although the Grand Tack theory is proposed to explain the formation of the inner planets of the solar system; But in the case of super-Earths (namely a type of planets with a few times the mass of the Earth and close to the parent star) such a theory, namely the growth of planets in the presence of one or two gas giants, cannot be applied. Because observations show that many super-Earths do not have an associated gas giant in their extrasolar system (Raymond & Morbidelli 2022). It would be better if we could provide a similar and identical explanation for the formation of the inner planets of the solar system and super-Earths.

In addition, the inward migration model for super-Earths is proposed in a situation where there is still no agreement on the structure and composition of these planets (e.g., Raymond &

Morbidelli 2022), and if it is proven that most of the structure of these planets is rocky, the inward migration model will face an important problem.

These were some of the problems of current theories about the formation of planets. There are other problems that we will not explore here. So, as you can see, *there is room for presentation another theory about the formation of planets.* If a theory is presented that does not face the problems of, for examples, the meter-size barrier, and provides the same and coherent explanation for the formation of the inner and outer planets of the solar system, super-Earths and hot Jupiters, then this theory is a preferred theory.

But what led me to present a theory in the fall of 2020 was not these issues and problems, but I only introduced the SSWP theory in that year to explain the Titius-Bode law (TBL).

If TBL was only a relation between three, four or even five planets, then we could call it a coincidence, but when it is true for seven planets, plus Ceres and Pluto (nine objects), there is definitely a reason for it. Here, we show that, probably, the existence of a standing and cosinusoidal wave packet in solar system, with the wavelength $\lambda = 0.6\ AU$ and the phase constant $\emptyset_0 = \frac{\pi}{6}$, is the reason for TBL. In this article we obtain the equation of this wave packet. In this article we show that without Solar System Wave Packet, it is not possible to reach to the TBL from the protoplanetary disk.

In addition to explaining TBL, you will see that SSWP theory can provide a coherent model to explain the formation of planets in the Solar System and extrasolar systems. This theory does not have the problems of the previous theories, which we explained, and it provides the similar and identical explanation for the formation process of the terrestrial and giants planets of the solar system, super-Earths and hot Jupiters. In addition, as we said in the abstract, the SSWP theory provides a different explanation for the cleanliness of interplanetary space. The SSWP can be a suitable candidate to be known as the reason of formation of Chondrules.

2. A Cosinusoidal Standing Wave and Titius-Bode Law

First, we start with Titius-Bode Law. Pluto, Ceres and all planets of solar system except Neptune, with a high approximation, follow a law called TBL, which can by no means be considered as a stochastic event. This law shows that the distance of the planets from the sun in Solar system is regulated. According to TBL, the distance of each planet from the sun is equal to $a = 0.4\ AU + 0.3\ AU \times 2^n$, where $0.4\ AU$ is the distance of Mercury from the sun (or more precisely the length of the semi-major axis of Mercury's orbit) and $n = 0,1,2,3, ...$ (Table. 1) (Carrol & Ostlie 2017). It was historically based on this law that Ceres was discovered in 1801 (Carrol & Ostlie 2017). In this article, we will find the reason for the existence of the TBL. In fact, we prove that, probably, the presence of a cosinusoidal and standing wave packet in solar system is the reason for existence of TBL. TBL does not predict the distance of Neptune from the sun but, this article is able to give us the distance of Neptune.

Planet	Titius-Bode law distance (AU)	Semi-major axis (AU)
Mercury	0.4	0.39
Venus	0.7	0.72
Earth	1.0	1.0
Mars	1.6	1.52
Ceres	2.8	2.77
Jupiter	5.2	5.2
Saturn	10.0	9.58
Uranus	19.6	19.2
Pluto	38.8	38.48

Table. 1. Planets distances from the sun and the prediction of Bode law. TBL cannot predict the distance of Neptune from the sun.

Consider a standing and cosinusoidal wave with a wavelength $\lambda = 0.6\ AU$ in solar system; if we assume that the first node of this wave is at a distance of $0.1\ AU$ from the sun the next nodes are at the distances of $0.4\ AU$, $0.7\ AU$, $1\ AU$, $1.3\ AU$, $1.6\ AU$, ... $2.8\ AU$, and etc. Each node is $0.3\ AU$ ahead from the previous node. If we consider the planets of solar system in the position of the nodes of this wave, in such a case, there is no planet on the first node ($0.1\ AU$) and Mercury is on the second node, Venus is on the third node, Earth is on the fourth node, Mars is on the sixth node, and the position of fifth node ($1.3\ AU$) is empty. The seventh, eighth, and ninth nodes are empty (In section 4.1, we explain why the location of some nodes is empty), and Ceres is on the tenth node. Jupiter is placed on the eighteenth node and Saturn is on the thirty third node, and Uranus, Neptune and Pluto are on the nodes farther from the sun. As you can see, a wave, with the wavelength $\lambda = 0.6\ AU$, easily predicts the position of the planets and therefore, *it seems that a huge standing wave has played a role in determination of the position of the planets in solar system.* Therefore, it seems we have found the reason for the existence of TBL. This standing wave oscillates along the axis perpendicular to the plane of solar system. We call this wave "Solar system wave packet". In this article, we obtain the equation of this wave packet.

3. Solar System Wave Packet

As mentioned, a cosinusoidal *standing* wave, with the wavelength λ = 0.6 AU and $k = \frac{2\pi}{\lambda} = \frac{10\,\pi}{3}$, can predict the position of the planets in solar system. First, we want to derive the phase constant ($\emptyset_0$) of this wave. Each wave in which the variables x and t are entered as a combination of $kx \pm wt$ is a traveling wave (Walker & Halliday 2007). For example, $\sin(kx - wt + \emptyset_0)$ is a traveling wave. Thus, a standing wave is in the form of $cos(wt)\, cos(kx + \emptyset_0)$ or $sin(wt)\, cos(kx + \emptyset_0)$ or $sin(wt)\, sin(kx + \emptyset_0)$ or $\cos(wt)\, \sin(kx + \emptyset_0)$. As mentioned, a *cosinusoidal* standing wave can predict the positions of planets. Therefore, the form of the standing wave of solar system must be either $sin(wt)\, cos(kx + \emptyset_0)$ or $cos(wt)\, cos(kx + \emptyset_0)$. There is no difference between $cos(wt)$ and $sin(wt)$; Because we know from trigonometric identities that: $cos(wt) = \sin\left(wt + \frac{\pi}{2}\right)$. Therefore, we choose the function $cos(wt)\, cos(kx + \emptyset_0)$. For the nodes of this standing wave, we have $cos(kx + \emptyset_0) = 0$. As mentioned previously, Mercury is on the second node of Solar system wave (the second node corresponds to the phase $\frac{3\pi}{2}$ because $Cos\ \frac{3\pi}{2} = 0$). We have:

$$x_{Mercury} = 0.4\ AU \Rightarrow \psi(x_{Mercury}) = 0 \Rightarrow Cos(kx_M + \emptyset_0) = 0 \Rightarrow kx_M + \emptyset_0 = \frac{3\pi}{2} \xRightarrow{k=\frac{10\pi}{3}} \emptyset_0 = \frac{\pi}{6}$$

Having k and $\emptyset_0$, we can easily find the position of the other planets using the equation $kx + \emptyset_0 = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots, \frac{(2m-1)\pi}{2}$ (Where m is the number of node). For example

$$kx_{Venus} + \emptyset_0 = \frac{5\pi}{2} \Longrightarrow \frac{10\pi}{3} x_{Venus} + \frac{\pi}{6} = \frac{5\pi}{2} \Longrightarrow x_{Venus} = 0.7\ AU$$

And

$$kx_{Earth} + \emptyset_0 = \frac{7\pi}{2} \Longrightarrow \frac{10\pi}{3} x_{Earth} + \frac{\pi}{6} = \frac{7\pi}{2} \Longrightarrow x_{Earth} = 1\ AU$$

$$kx_{Mars} + \emptyset_0 = \frac{11\pi}{2} \Longrightarrow \frac{10\pi}{3} x_{Mars} + \frac{\pi}{6} = \frac{11\pi}{2} \Longrightarrow x_{Mars} = 1.6$$

The distances of the other planets can also be calculated in the same way. According to the above equation (namely $kx + \emptyset_0 = \frac{(2m-1)\,\pi}{2}$), Neptune is on the one hundred and second node, which corresponds to the phase $\frac{203\,\pi}{2}$. Contrary to the TBL, which is not able to predict the distance of Neptune, our wave theory predicts the position of Neptune. Therefore, a cosinusoidal and standing wave with $\emptyset_0 = \frac{\pi}{6}$ and $k = \frac{10\,\pi}{3}$ can be attributed to solar system. But what is the general equation of this wave? Since solar system has a certain size and is not infinitely wide, its wave must be localized (a wave packet). If we consider an expression with the form $e^{-\gamma x^2}$ (which is a Gaussian function and plays the role of the wave envelope) in the final equation of SSWP, in such a case, the final formula is a localized wave or a wave packet (Although a Gaussian wave packet is also infinitely wide, but it is very localized). Thus, the primary form of the equation of SSWP is as follows (equation 1) and the planets are on the nodes of this wave packet (Fig. 1):

$$\begin{cases} \psi(x,t) = C\,cos(wt)\,cos(\frac{10\pi}{3}x + \frac{\pi}{6})\ e^{-\gamma x^2} & x \geq 0 \\ \psi(x,t) = C\,cos(wt)\,cos(\frac{10\pi}{3}x - \frac{\pi}{6})\ e^{-\gamma x^2} & x \leq 0 \end{cases} \quad (1)$$

In equation 1, γ and C are constant values.

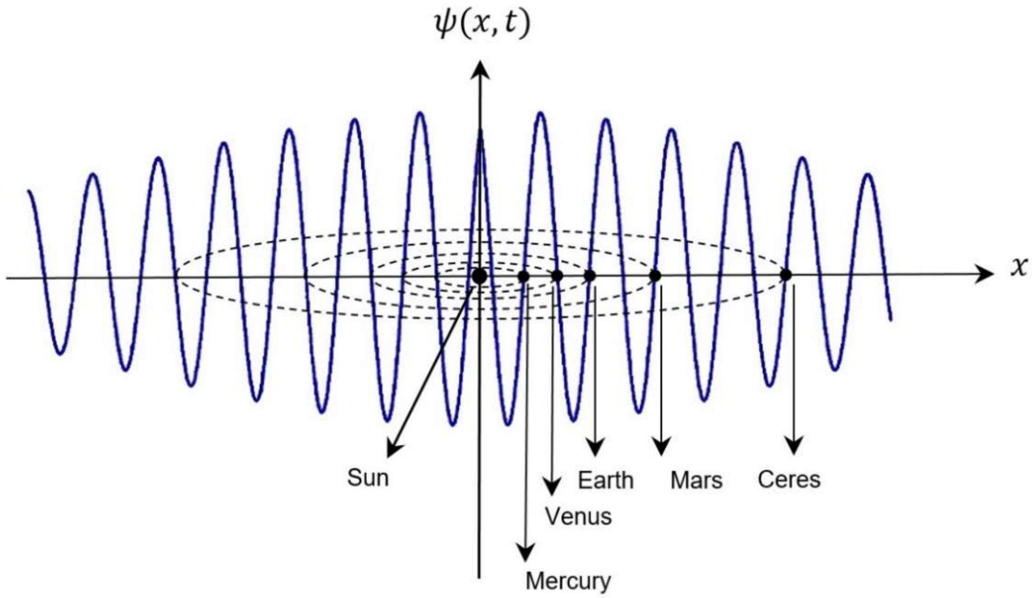


Fig. 1. Standing solar system wave packet with λ = 0.6 AU and $\emptyset_0 = \frac{\pi}{6}$. Diagram of $\psi(x,t)$ at the moment t = 0. The value of $\psi(0,0)$ equals $\sqrt{3}C/_2$. This diagram is drawn by certain values C and γ in equation 1 ($C = 0.75$ and $\gamma = 0.03$). As you can see, the planets are on the nodes of the wave packet. Jupiter, Saturn, Uranus, Neptune, and Pluto are on the nodes farther from the sun. The reason why there is no planet in some nodes will be explained in the section 4.1.

The oscillation of SSWP in Fig. 1 along the ψ axis has caused the formation of planets in certain orbits. Section 4 is dedicated to explaining this issue.

In equation 1, we have considered the value of C and γ to be 0.75 and 0.03 accidentally.

As you observed, we were able to attribute a wave to the solar system based on TBL. Is this a coincidence? This is very improbable.

4. SSWP and Nebular theory

In this section we show that the nebular theory without SSWP theory is an incomplete theory and SSWP theory must be attached to the nebular theory in order to explain the formation of solar system.

4.1. Formation of Planets and Moon of the Earth

In cylindrical coordinate we have $x = r\cos\theta$. So, the equation 1 in cylindrical coordinate is:

$$x = r\cos\theta \Rightarrow \psi(r,\theta,t) = C\,cos(wt)\,cos(\frac{10\pi}{3} r\,cos\,\theta + \frac{\pi}{6})\;e^{-\gamma(r\,cos\,\theta)^2} \qquad (2)$$

Fig. 2 is the shape of Fig. 1 in three dimensions based on equation 2 (C = 0.75 and $\gamma = 0.03$).

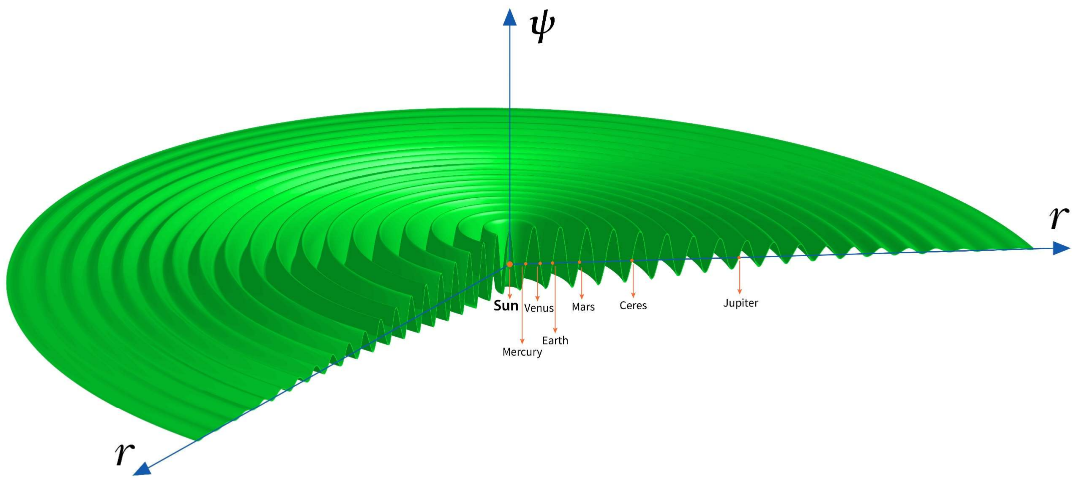


Fig. 2. Solar System Wave Packet in three dimensions. Diagram $\psi(r, \theta, t)$ at the moment t = 0. Here the wave packet of Fig. 1 is shown in three dimensions. Fig 2 is drawn in cylindrical coordinates using equation 2. Based on equation 2 because of exponential factor, the amplitude of the wave decreases while we move away from the ψ-axis.

If you look carefully at Fig. 2, you will see that almost after Jupiter, the wave is strongly attenuated, and in such a case, the effect of the wave on distant planets such as Saturn and Uranus is practically zero. The rapid damping of the wave packet in Fig. 2 is due to the fact that we have considered the gamma value equal to 0.03 (As we said, in equations 1 and 2, we have considered C=0.75 and γ=0.03 accidentally). If we consider the value of γ to be lower than 0.03, you will see that, in Fig. 1 and Fig. 2, the speed of damping of wave decreases, that is, the amplitude of the wave It drops less as it moves away from the ψ axis. In such a case, the distance planets are also affected by the wave packet. The true value of C and γ is probably affected by the initial value of the characteristics of the solar system and the sun, like mass.

It is unacceptable to imagine that the wave packet of solar system is not related with an object. In my opinion, SSWP belongs to an object in the solar system. I think that object is Sun. As you can see in Fig. 2, the Sun is in the center of SSWP and it is also the heaviest object in Solar System (more than 99 percent of the total mass of the Solar System belongs to the Sun.). Therefore, it is reasonable to assume that SSWP belongs to the Sun. So, we can call SSWP the *associated wave packet of Sun.*

The orbital velocity of the mass m to be able to rotate around the sun at a distance r, on a circular orbit, is equal to:

$$m\frac{v^2}{r} = \frac{GmM_{sun}}{r^2} \Rightarrow v = \sqrt{\frac{GM}{r}} \qquad (3)$$

We use this equation in this section and in the following sections.

Imagine the early years of protoplanetary disk formation. Gas-dust particles rotate counter-clockwise around the center of the disk. As you know, the sun was formed earlier than the planets (e.g., Carrol & Ostlie 2017). Simultaneously with the formation of the sun, about 4.6

billion years ago, we assume that its associated wave packet was also formed[1]. The oscillation of this wave packet collected the gas-dust particles of Protoplanetary disk in regular orbits (the nodes of wave packet). Just like the standing wave pattern on the kettledrum head in Fig. 3. As you can observe in Fig. 3, by a mechanical oscillator at the upper left of the photograph, the powder particles are collected at the circular nodes (Rossing 1982). Similarly, because of oscillation of SSWP in the early years of formation of solar system, the gas-dust particles of protoplanetary disk were collected, in the nodes of SSWP. Fig. 4a explains this issue. In Fig. 4a, we have shown the gas-dust particles of the protoplanetary disk (dotted curves) that are circulating around the Sun and in two hypothetical regions A and B; So that one of the SSWP nodes (red dotted line) is the border between these two regions, which is located at a distance r from the sun. In Fig. 4a we have assumed that the mass distribution in the protoplanetary disk is perfectly ideal and uniform. Due to the presence of gas inside the disk, the dusts move at a sub-Keplerian velocity (less than formula 3) and spiral inward (Weidenschilling 1977).

Fig. 3. Standing wave pattern on a kettledrum head. One of many possible standing wave patterns on a kettledrum head, made visible by dark powder sprinkled on the drum head. As the head is set into oscillation at a single frequency by a mechanical oscillator at the upper left of the photograph, the powder particles are collected at the nodes. Similarly, because of oscillation of SSWP in the early years of formation of solar system, the gas-dust particles between the nodes were collected in the nodes of SSWP.

[1] The wave packet of solar system probably was created either when the sun was a protostar or when the newborn Sun was entered to the Main-sequence. The distance between these two phases is very short (less than 50 million years) (Zeilik 2002) and both phases occurred before the formation of the planets. In both states, we have no idea how and why this wave packet was formed.

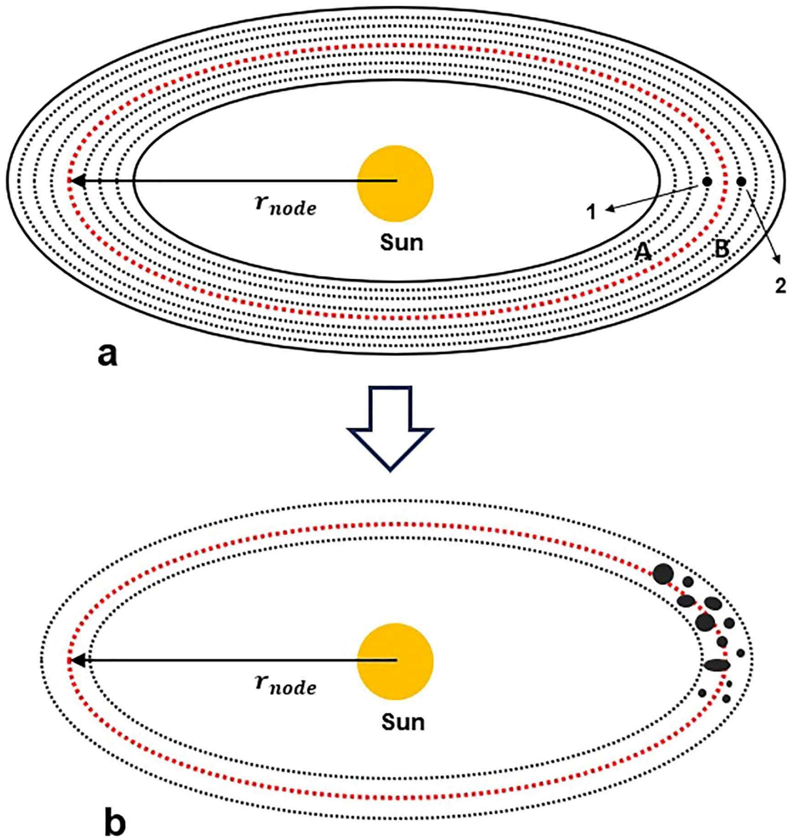


Fig. 4. The stages of planet formation in SSWP theory. In Fig. a, we have shown the counter-clockwise circulation of a part of the gas-dust particles of the protoplanetary disk of the solar system, in two hypothetical regions A and B, and we have assumed that these particles are uniformly distributed in the disk (black dotted curves). In Fig. b, after electrostatic and molten and semi-molten collisions and gravitational interactions, we end up with a collection of planetesimals and planetary embryos of various sizes distributed throughout the ring. Here we have shown only a part of them. In fig. b, the two black dotted lines are the hypothetical boundary of the annular band of objects and do not represent gas-dust particles as in Fig. a.

Simultaneously with the emergence of SSWP and its oscillation, along the perpendicular to the plane of the disk, the particles of regions A and B move towards each other and collide with each other in the location of the node through asymptotic collisions. These collisions are a type of gentle touch because the particles on both sides of the node have close velocities. Consider two particles 1 and 2 on both sides of the node and along a radius (Fig. 4a). Because of oscillation of SSWP, particle 1, which has a higher orbital velocity than particle 2, approaches particle 2 through a diagonal line and hits it from the side. The collision between particle 2 and 1, due to the difference in velocity, causes static electricity between the two particles. This static electricity attracts two particles together and the particles become larger (The oscillation of SSWP keeps these objects in circular orbit of the node and the regions close to it. Of course, the velocity of the wave packet oscillation should not be slow and should be high enough). This mode of growth stops for pebbles larger than centimeters because particles of cm-size are too small for gravity to be effective in particle-particle collisions, and too big to stick together through electrostatic forces (Morbidelli et al 2012). From here on, the growth of the objects continues in another process. *In fact, this process is the most important process that led to the formation of planetesimals*: The spherical shape of chondrules, which are among the primordial bodies that make up the solar system, suggest that the passage of a shock wave was involved in the formation of Chondrules (e.g., Miura et al. 2008, Jones et al., 2000, Hewins 1996, Boss 1996, Arakawa & Nakamoto 2019). The passage of a shock wave caused partial or total melting of suspended particles in the early solar system. We argue in section 6 that this shock wave could be SSWP (You can read section 6 now.). Therefore, it can be assumed that probably a significant part of the objects in the nodes of the SSWP were in a molten or semi-molten state due to the SSWP effect, and the adhesion between these objects during the pairwise collisions caused the formation of pebbles *much larger* than Centimeters (namely planetesimals). Because the probability of an inelastic collision, and subsequently the formation of larger objects, in the collision of two suspended molten and semi-molten bodies is higher than in the case of the collision of two rigid bodies (Arakawa & Nakamoto 2019, Ciesla 2006). Therefore, we observe that with the theory of *molten and semi-molten collisions*, it is possible to overcome the fragmentation barrier and the bouncing barrier and reach to the planetesimals. *Of course, the process of collisions of molten and semi-molten objects even in the first stage, i.e., the stage of growth of dust particles to pebbles smaller than one centimeter, is also the main stage of accretion. And, as you will see in section 6, only a small part of the accretion of objects is due to gentle touch and electrostatic interaction.*

When planetesimals become large enough through these processes, they can attract other objects through gravity. Although another process is involved in the accretion in this stage: When the planetesimals formed inside a node due to electrostatic and molten collisions, they have different orbital velocities due to chaotic nature of mentioned collisions. This speed difference causes faster objects to collide with slower objects from behind. This kind of collision of large planetesimals is *the collision from the back*. Since in the SSWP theory, planetesimals move on the nodes, the percentage of happening of collision from behind is greater than gravitational attraction. (Note: Here it is necessary to mentioned that the distribution of planetesimals throughout the nodes is a 360-degree distribution. Because we considered the mass distribution in the initial disk to be homogeneous and isotropic and 360 degrees, the possibility of a uniform and 360-degree distribution of planetesimals throughout the rings is high).

Therefore, protoplanets or embryos are formed through two ways of collision from the back and gravitational absorption of planetesimals (It is necessary to mention that we assumed in our theory that a very high percentage of the mass of a planet is obtained through the process of inelastic collisions of planetesimals from behind not gravitational attraction).

Planetesimals and embryos continued to collide, and some embryos became planets by absorbing mass, and some were broken into smaller objects. In Fig. 5, we have shown the stages of the formation of a planet, based on the SSWP theory.

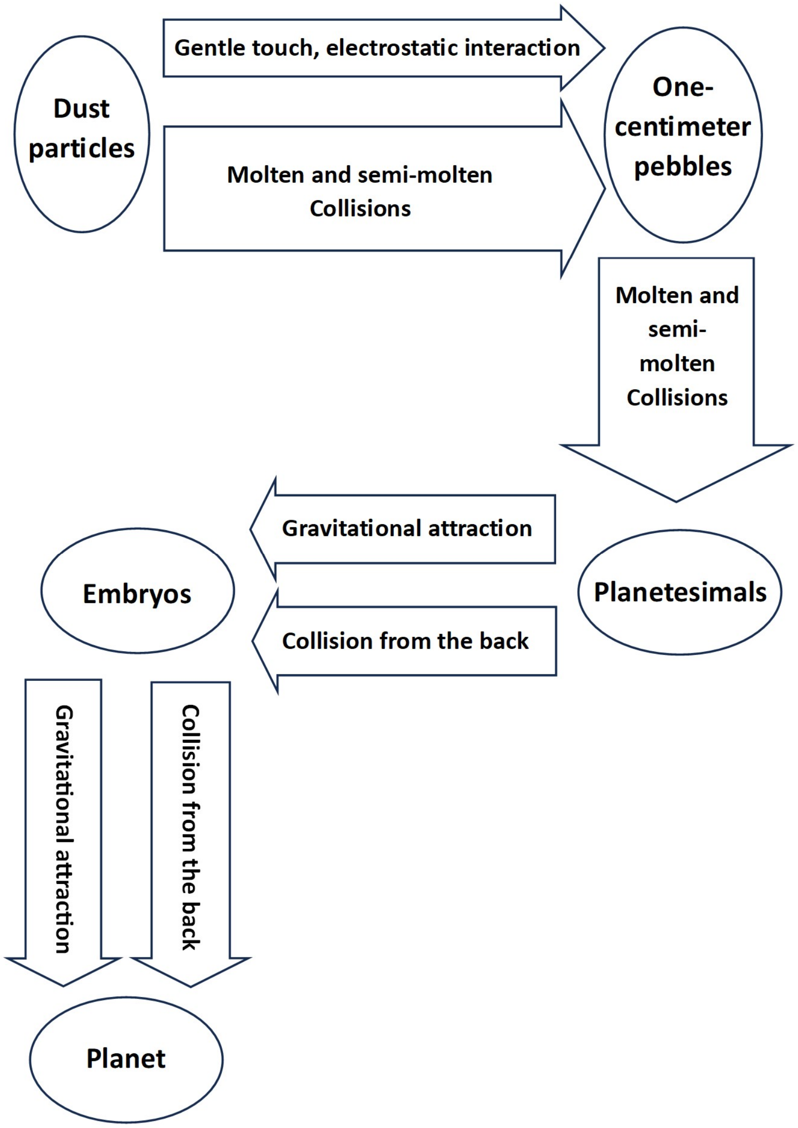


Fig. 5. Processes involved in planet formation in SSWP theory. The greater width of the first arrow indicates the greater contribution of the molten and semi-molten interaction than the electrostatic interaction. Because of oscillation of SSWP and subsequently *gas frictional heating*, in stages 1 and 2, we have *molten and semi-molten collisions* of dust particles and pebbles to form planetesimals

Therefore, after several years in our solar system, we had circular bands consisting of probably a few planets, several hundreds of large planetesimals, thousands of small planetesimals and billions of pebbles and gas-dust particles (Fig. 4b). These objects, after the death of SSWP, based on equation 3 depending on their orbital velocity and their distance from the Sun, either they stay in the orbit or they deviate towards the Sun or out of the solar system. In the orbits of Mercury, Venus, and Mars only one planet remained, and the rest of the objects were removed from the orbit. In the earth's orbit, the orbital velocity of the earth, just before the wave packet disappeared, was equal to $v_E = \sqrt{GM_{Sun}/r}$. At the same time, the Moon was moving near the Earth and behind it with an orbital velocity slightly higher than the v_E. And if the wave packet did not disappear, moon would gradually get closer to the Earth and hit it from behind. But the death of the wave packet caused the moon, due to its orbital velocity, to leave the orbit and go outside the solar system. But during the exit, due to its proximity to the Earth, it fell into the trap of the earth's gravity and became the Moon of Earth. On the basis of this explanation, the closeness of the characteristics of the moon and Earth, like the equality of similar elements isotopes percentage, can be explained. Because both of planets belong to the same node.

In the orbits of Jupiter, Saturn, Uranus and Neptune, in addition to the main planets, several large planetesimals remained which later became part of the *non-main* moons of these planets. We will explain these topics in the following. In some nodes, all the objects, because they could not satisfy the relation 3, left their orbits and the node became empty. *This is why some nodes of SSWP are empty*.

Note: In Fig. 2, a part of the gas-dust particles of the protoplanetary disk, i.e., the particles that are located exactly on the anti-nodes or are close to them, were thrown out of the solar system by the upward force of the SSWP.

If we assume that the distribution of gas-dust particles in the early protoplanetary disk was uniform, in this case, as we move further away from the Sun, due to the increase in the circumference of each node, there was more material on that node. As a result, we would expect a planet that forms on a node far from the Sun, through the collision from back, to be heavier than a planet on a closer node. *This is why the outer planets of the solar system are heavier than the inner planets.* We have discussed the ideal state here. If we see that, for example, contrary to the trend, the mass of Mars is less than Earth, or the mass of Saturn is less than Jupiter; This is because there is always some deviation from ideality, indicating that the distribution of dust particles in the early protoplanetary disk was not completely uniform along the radius. In fact, the lower mass of Mars than Earth is due to there was less dust collected on the sixth node of the SSWP to form the planet.

Note: The oscillation of the SSWP simultaneously collected a huge collection of gas-dust particles in the nodes; which this happen increased the speed of planets formation in the nodes. Therefore, in our theory, the speed of planets formation is much higher than the previous theories. In the previous theories, the mass of objects gradually increases through the processes of runaway/oligarchic growth or the pebble accretion because there are no special places where gas-dust particles are collected. But in our theory, the materials required for the formation of planets are collected simultaneously in certain places (nodes), which this happen increases the speed of planets formation. Because of this high speed of planets formation, the embryos of Jupiter and Saturn quickly reached the necessary mass to absorb hydrogen and helium and absorbed these two gases before these gases were dispersed by the solar T Tauri wind.

4.2. Cleanliness of the Interplanetary Distances

As we said in the Abstract, it is logical to expect to see several planets in the distance between for example Earth and Venus. When there is not even a planet in the huge space between Earth and Venus, it means that something has cleaned this space completely. We can explain the cleanliness of interplanetary space using the SSWP theory. We said that the oscillation of SSWP has driven all the gas-dust particles of the protoplanetary disk from the space between the nodes, as a result, there is no material in these distances from which planet can form.

Question: If the interplanetary distances were cleaned by the oscillation of SSWP, why were the asteroids in the asteroid belt not cleaned from the internodal distances? Because the asteroid belt is the remnants of objects that were located in the 8th, 9th, 10th and 11th nodes of the SSWP and spread in space after the death of the SSWP. We will explain how to spread it in the next section.

Note: In the SSWP theory, the gas molecules collect in the SSWP nodes and under the influence of wave packet oscillations, they have chaotic motion, so in this case, the gas is no longer in a *hydrodynamic equilibrium*, and as a result, we are not faced with the problem of a meter-size barrier; Because this problem occurs only in a gas that is in *hydrodynamic equilibrium* (Weidenschilling 1977).

4.3. The Reason for Existence and the Widening of Asteroid Belt

First, let's look at what we know about the asteroid belt. The asteroid belt is wide at a distance 2.2 AU to 3.2 AU from the sun; with various Orbital eccentricities (from zero to above 0.3) and various Orbital inclinations (from zero to >20°). The heaviest object of the asteroid belt (namely Ceres), which has almost 30 % of the total mass of the belt, is at distance 2.77 AU from the sun (e.g., Bennett et al. 2012). These are some of the human findings about the asteroid belt that we need here.

As we said, when SSWP was lost, the objects of each node were in a special state. Earth and Moon were in the fourth node. At the third node there was only Venus, and at the eighth (2.2 AU), ninth (2.5 AU), tenth (2.8 AU) and eleventh (3.1 AU) nodes we had hundreds of planetesimals that were not merged with each other, through a series of collisions from behind. For example, there were Ceres, Pallas and several hundreds of planetesimals in the $10th$ node. Most of these objects after the death of the SSWP, due to not satisfying the relation 3, left the orbit and spread across the solar system. These objects collided with each other while leaving the nodes and created smaller objects, namely asteroids, and thus the belt widened. Ceres and Pallas, which were formed in the 10th node, after the disappearance of the wave packet, due to the gravitational force of the Sun, were placed in an elliptical orbit of 2.77 AU.

Asteroids, depending on the power and direction of collisions of the planetesimals, gained velocities with different values and directions, which caused their various eccentricities and orbital inclinations. Orbital resonance with Jupiter, in the years after the widening of the asteroid belt, affected the orbits of some asteroids and forced them out of certain orbits. This is why we have gaps in asteroid belt in some orbits.

4.4. Axial tilt of Uranus, Venus and Pluto

From the SSWP theory and Fig. 4b, we can understand the reason for the unusual tilt of the axis of Uranus, Venus and Pluto. In the process of hitting from the back of the planetesimals, when a set of planetesimals hits a front planetesimal, these collisions are to the different parts of the target planetesimal, not at one point. Therefore, depending on the location of the collision, the target planetesimal undergoes a rotation, whether the collision is elastic or inelastic. Just like the accident of two cars. The direction of deviation of the front car depends on whether the car behind collides on the right side of the rear bumper or on the left side. Therefore, the collision direction of the last planetesimals, if they have enough mass and velocity, determine the direction of the planet's rotation. For example, in the case of Uranus, the last planetesimals have hit the bottom of the planet from behind and caused Uranus to rotate counterclockwise around the horizontal axis (I hope I was able to convey my meaning).

4.5. Extrasolar Multiplanetary Systems and Formation of Jovian planets main moons and Rings

Several studies have been conducted that show that in extrasolar multi-planet systems, it is possible to predict the location of planets using formulas similar to TBL (Lara et al. 2019, Mousavi-Sadr et al. 2021). Some studies have reported 78 percent success rate of these predictions (Lara et al. 2019). Although our solar system is part of one percent of special systems in the world (Raymond & Morbidelli 2022), but if we accept that the distribution of planets in extrasolar systems is regular, we should be able to attribute wave packets similar to SSWP to those systems; Because it has been proven that the laws of physics are the same throughout the world. The distances of the main moons of the Jupiter and Saturn from the parent planet also follow regular patterns (Blagg-Richardson Equation) (e.g., Carrol & Ostlie 2017). This requires that we have some wave packets around these planets. In my opinion, wave packets can be attributed to both Jupiter and Saturn and extrasolar systems, bearing in mind that some wave packet nodes can be empty.

For example, if we consider the distance from Io to Jupiter equal to 1; In such a case, the distances of Amalthea, Europa, Ganymede, and Callisto from Jupiter are 0.42, 1.59, 2.53, and 4.46, respectively. If you check these distances, you can see that a wave packet with a wavelength 0.6 and a phase constant $\pi/6$ can be assigned to Jupiter.

As move away from the jovian planets, the mass of their main moons increases. In addition, the rotation of most of the moons is in the equatorial plane of the planet and counterclockwise. From these, we can conclude that the form of formation of the moons of jovian planets was probably the same as the formation of the planets of the solar system. To explain the action of the wave packets of Jovian planets, consider Jupiter's wave packet as an example. With the death of the SSWP, the wave packet of Jupiter did not disappear. Rather, its oscillation collected the gas-dust particles of the local disk of Jupiter, in the nodes of the Jupiter's wave packet, and similar to the process of the formation of the planets, Jupiter's main moons were formed. Based on this explanation, it is possible to explain the closeness of the features of the moons of Jovin planets and the parent planet, such as the high similarity of the type of elements.

Of course, the story of the life of some of the moons of the Jovian planets was probably the same as the story of the birth of the Earth's moon, which we explained earlier. As we said, these are non-main moons.

The reason of formation of rings of the Jovian planets, like the rings of Saturn, are due to the oscillation of the wave packet of the parent planet, just like the way the asteroid belt is created. At the same time of the formation of planetesimals in the nodes of SSWP, several planetesimals were also formed in the nodes of the Saturn's wave packet, due to the oscillation of the Saturn's wave packet, in the form of a 360-degree distribution. After the death of Saturn's wave packet, the planetesimals that did not satisfy the formula 3 were removed from their orbits and due to collision with each other, they turned into smaller components and spread on the equatorial plane of Saturn, thus forming Saturn's rings.

Probably, due to the fact that the wave packet and accretion disk of Saturn was smaller than SSWP and protoplanetary disk, the planetesimals that were formed on its nodes were smaller than the planetesimals on SSWP nodes. Therefore, these planetesimals have created smaller objects than the asteroids of the asteroid belt after colliding with each other. This is why objects on Saturn's rings are smaller than asteroids in the asteroid belt.

It should be noted that here, like other theories, we consider the existence of the Cassini gap due to orbital resonance with Mimas.

4.6. Super-Earths and Hot Jupiters

What we have said so far was to explain the formation of the planets of the solar system. We expect the same process in the formation of exoplanets.

Hydrogen and helium are observed in the atmosphere and structure of hot Jupiters (e.g., Bennett et al. 2012) and super Earths also seem to have volatile matters (e.g., Owen & Wu 2017). This cannot be explained with theories similar to the theories of the formation of the solar system. Scientists are therefore forced to consider inward migration processes to explain hot Jupiters and super-earths (e.g., Raymond & Morbidelli 2022). But the formation of these planets in our theory is possible without taking into account the inward migration process: As you know, hydrogen and helium have been removed from the protoplanetary disk due to the wind blowing from the parent star in the T-Tauri phase. If the planets reach enough mass much earlier than the dispersion of hydrogen and helium, they have the ability to absorb these gases due to gravity. Fortunately, it seems that the possibility of this happening is available in our theory. Just like the SSWP, the oscillation of the wave packet of a star simultaneously collects a huge collection of gas-dust particles in the nodes of the wave packet; which this happen definitely increases the speed of planet formation in the nodes. Therefore, in our theory, the speed of formation of planets is much higher than the previous theories. In the previous theories, the mass of objects gradually increases through the processes of runaway/oligarchic growth or the pebble accretion because there are no special places where gas-dust particles are collected. But in our theory, the materials required for the formation of planets are collected simultaneously in certain places (nodes), which this happen increases the speed of planet formation. Therefore, in our theory, the formation of super-Earths and hot Jupiters near the star before the T Tauri wind is possible.

4.7. The shape of protoplanetary disk

In a protoplanetary disk, with the disappearance of the wave packet of star, billions of dust particles, pebbles and gas particles on the nodes, due to random and chaotic collisions with each other, leave the nodes and enter the spaces between the nodes of defunct wave packet. In addition, the orbital motion of the formed planets plays an essential role in cleaning the objects on the nodes and sweeps the objects inside the nodes in each rotation. Therefore, after a while of the death of the star's wave packet, we have a disc like Fig. 6.

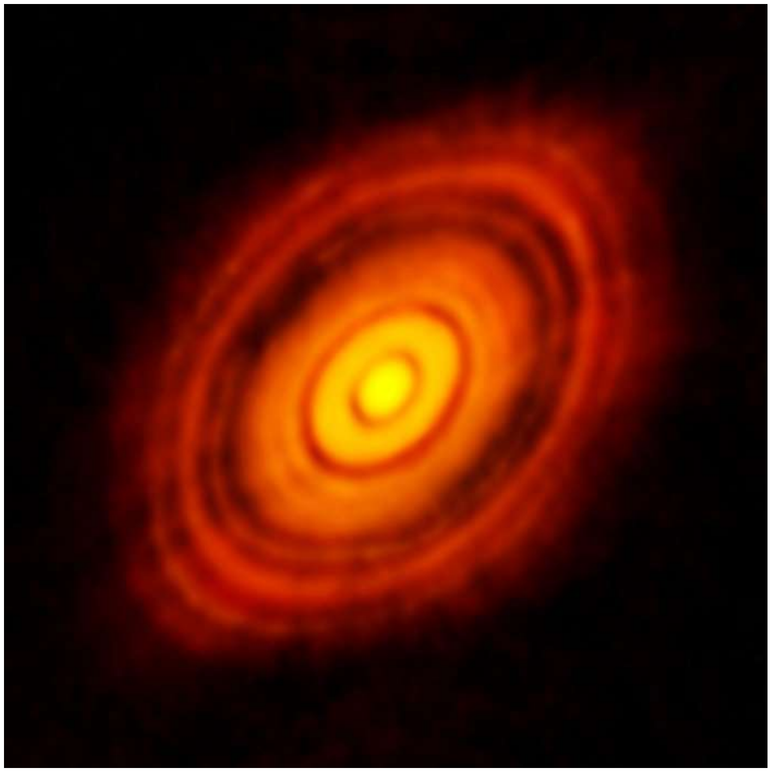


Fig. 6. ALMA image of protoplanetary disk of HL Tauri star. In our theory, we consider this image to be the image of the protoplanetary disk after the death of the HL Tauri star's wave packet.

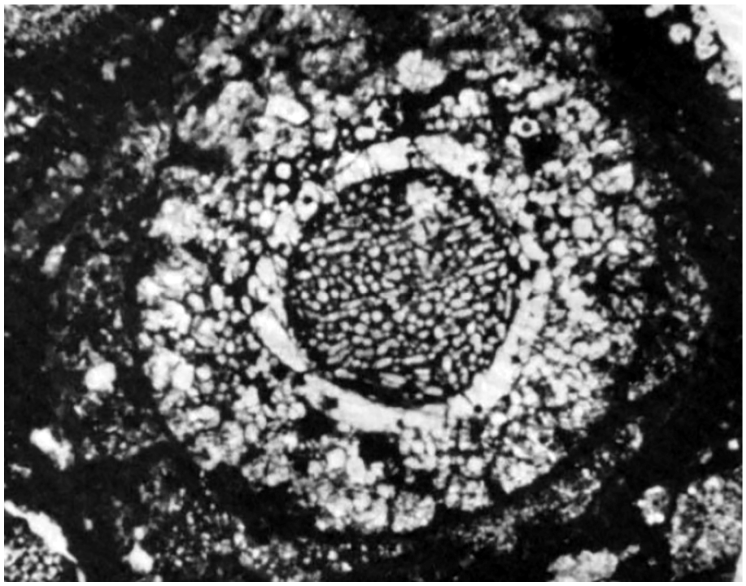
5. What is Waving?

What is the nature of SSWP? Although I have thought a lot about the answer of this question, unfortunately I still have no idea about it. But there is not any problem. The *nature* of SSWP is a separate topic from this article. This article only is about the reasons of *existence* of SSWP. For more than 200 years, the nature of gravity was not known, but everyone accepted Newton's theory and the existence of gravity. Or the nature of dark matter is still unknown but its existence is accepted. Maybe in the coming years someone will discover the nature of SSWP, but I have no idea now.

6. Chondrules as another evidence

So far, we have shown that the existence of TBL and cleanliness of the interplanetary distances from large objects can be considered as two reasons for the existence of SSWP. But there is another important evidence. The spherical shape of the chondrules tells us that the passage of a wave front caused the melting of the precursors of the chondrules. After the passage of the wave, these molten precursors became spheres due to surface tension and then cooled due to evaporation and radiation and became chondrules (e.g., Miura et al. 2008, Jones et al. 2000, Hewins 1996, Boss 1996, Arakawa & Nakamoto 2019). Here we show that that wave front can be SSWP. Various theories have been presented about the formation of Chondrules, but the theory of *gas frictional heating* due to the pass of the wave front has been given more attention (Hood & Horanyi 1991, Ruzmaikina & Ip 1994, Tanaka et al. 1998, Ciesla & Hood 2002, Miura & Nakamoto 2005). In addition, it seems that some of the chondrules and their surrounding igneous rims were affected by the shock wave several times (Matsumoto &

Arakawa 2023, Hewins 1997). In fact, the shape of some chondrules confirms this theory. For example, three stages of melting can be seen in Fig. 7 (Hewins 1997). All this can lead us to accept the presence of an oscillatory wave in the newborn solar system. A wave whose oscillations has affected the precursors of chondrules and igneous rims several times. Because it is very unlikely that several supernova waves have passed through the protoplanetary disk of the solar system at different times (Some previous theories had introduced waves from supernova explosions as the origin of the shock wave. Although different theories have been proposed about the *source* of this shock wave, but there is still no consensus (Boley et al 2013).).



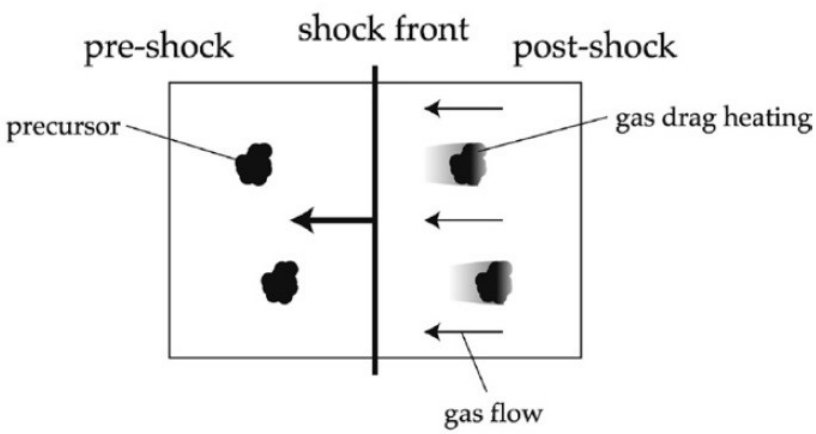
Source: Hewins 1997

Fig. 7. Barred olivine chondrule, surrounded by porphyritic olivine pyroxene chondrule, surrounded by igneous rim. At least three stages of melting can be recognized in this figure (Hewins 1997). We hypothesize in our theory that the oscillation of the SSWP and subsequently *gas frictional heating* caused these three stages of melting.

The mechanism and formalism of the effect of shock waves on precursors through gas frictional heating has been discussed in several articles (Hood & Horanyi 1991, Ruzmaikina & Ip 1994, Tanaka et al. 1998, Ciesla & Hood 2002, Miura & Nakamoto 2005), and here we use the achievements and results of these articles to investigate how SSWP affects precursors. Investigation of the passage of SSWP from precursors requires a detailed and separate article, but the mechanism of effect of SSWP is simply as follows: Consider Fig. 4a. As a result of the first oscillation of SSWP, gas molecules and dust particles, for example, in region A are affected by an impact force. Due to the fact that the mass of gas molecules is much lower than the mass of dust particles, gas molecules gain more acceleration based on $a = F/m$ and pass by the dust particles at a very high velocity, and this causes frictional heating of the dust particles. This heating melts dust particles completely or partially (Fig. 8). After the wave passes, the melted particles turn into a sphere due to surface tension; And then they cool due to evaporation and radiation. Now these objects are chondrules (albeit *simple chondrules*). Therefore, after the first oscillation of SSWP, the objects on the node include simple Chondrules, dust particles, and gas molecules. As we said, objects and gas molecules that are placed on the node tend to leave the node due to random and chaotic movements and collisions.

But after the first oscillation, the subsequent multiple oscillations of the wave packet always hit the objects on the node (namely dust particles, gas molecules and simple chondrules) from the left and right. These shocks make these objects stay in the node and according to the mechanism we mentioned, the chondrules go into a molten or semi-molten state with every impact of the wave. This state of chondrules increases the ability to form larger objects through inelastic *collisions*, and as we said in section 4, in this way large planetesimals and subsequently planets can easily be formed.

Formation of igneous rims: After the formation of simple chondrules, due to the subsequent oscillations of SSWP, molten dust particles interact with these simple chondrules and accretion on their surfaces in the form of igneous rims, and in addition, as a result of the collision of two or more molten and semi-molten simple Chondrules, a *compound Chondrule* is formed.



Source: Miura et al. 2008

Fig. 8. Gas frictional Heating melts the Precursors of Chondrules, because of passing of shock front of SSWP.

Note: The way the precursors melt depends on the velocity of the gas molecules passing by the precursors, the pre-shock gas density and the kind of elements of the precursors (Fig. 8). If the heating caused by friction is lower than the melting point of the elements of some precursors, those precursors will not go into a molten or semi-molten state and remain solid. In this case, the attraction between these particles is, as we said at the beginning of section 4.1, through electrostatics. So, after the oscillations and effects of SSWP we have two groups of objects on the nodes. The group that are in a solid state and the group that are in a molten or semi-molten state. As we said in section 4, the first group objects cannot pass the *fragmentation barrier* and the *bouncing barrier*. But the objects of the second category can gradually become large planetesimals.

7. The age of SSWP

Using Pb-Pb dating, the absolute ages of chondrules has been determined between 4.563–4.567 billion years; that is, they were formed during the first 4 million years of the solar system (e.g., Connelly et al. 2012; Bollard et al. 2017). This means that the SSWP was born at least 4.567 billion years ago and has lived for at least 4 million years.

Conclusion

Little did I know that I had discovered only the tip of an iceberg when I proposed the SSWP theory to explain the cause of TBL. This theory has many capabilities and can solve many problems. Unlike the current theories, this theory provides a coherent explanation for the formation of all planets in the universe. As we have said in section 4.6, in our theory, due to the wave packet oscillations of the parent star, a huge amount of gas-dust particles simultaneously are collected in certain locations (namely nodes of wave packet). This event causes increase in the speed of planets formation, and therefore the possibility of forming super-Earths and hot Jupiters near the parent star, before the T-Tauri wind blows, is high. And so, we don't need the inward migration theory to explain the formation of super-Earths and hot Jupiters. In addition, as we said in Section 4.2, SSWP easily explains the cleanliness of interplanetary space from other planets. SSWP can be a suitable candidate to explain the reason for the formation of Chondrules. As we said, to explain the formation of chondrules and igneous rims around them, we need the passes of shock waves from solar system for several times. Now the question is, which shock wave, other than the SSWP, passed through the solar system for several times?

As you see in introduction, the accretion of dust particles in a disk through pairwise collisions leads to two problems: First, this pairwise growth is expected to stop after reaching pebble size (1 mm to 1 cm), because of the ''fragmentation barrier'' and the ''bouncing barrier''. And the second is a problem called the ''meter-size barrier'' or ''radial drift barrier'', which hinders the growth of planetesimals larger than one meter. In this article, because of oscillation of SSWP and subsequently *gas frictional heating*, we have *molten and semi-molten collisions* of dust particles and pebbles to form planetesimals, as a result of which the first problem can be overcome; and we said about the second problem that the meter-size barrier problem is the result of the *hydrodynamic equilibrium* in the protoplanetary disk, which the SSWP oscillation disturbs this equilibrium, and so we do not encounter the second problem.

Here, we showed that it is very improbable for TBL to be a coincidence; because it is valid for nine objects, not two or three objects. In this article and in section 4, we merged nebular theory with SSWP theory and we proved that nebular theory without SSWP theory is an incomplete theory. Without SSWP, it is not possible to reach to the TBL from the protoplanetary disk. Is the description of TBL by a wave a coincidence? This is very improbable.

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