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Formation of Terrestrial Planets from the Viewpoints of Astrophysics and Material Science – Formation of Planetesimals by Chemical Reactions at Contact Points between Solids

Shinji Karasawa*

Former Miyagi National College of Technology, Professor Emeritus (Since 2010, Sendai National College of Technology), Japan

***Corresponding author:** Shinji Karasawa, 1-3-6 Oyama, Natorishi, Miyagi 981-1233, Japan; **Tel:** 090-7561-5745; **Fax:** 81-22-382-1879

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Abstract

Where did the sea water originally come from? The water must have originated from interstellar mediums. Comets are born from lumps of dusts, mostly at the edge of the solar system. The lump consists of dust particles and ice (H_2O) and moves toward the Sun due to the Sun's gravitational force. However, in the asteroid belt between Mars and Jupiter exists a snow line. The water collected by comets does not reach the Earth because ice (H_2O) sublimates into vapor around the snow line. It is considered that the sea water of the Earth would have been captured together with interstellar medium before the snow line appeared. The formation of the early Earth must have been in an environment before the nuclear fusion reactions in the Sun. A beginning of clump forms from through point bonds of dusts. The Coulomb force around interatomic distance is approximately 10^{36} times that of gravitational force. A fixed connection will be formed by short-range forces at the local contact point of solids in cold environment. According to experimental results, when solid CO_2 (dry ice) is mixed with iron powder, the powder turns black. But the iron powder does not change by in a gas state of CO_2. The results indicate that the surface of the fine iron powder is locally oxidized by the solid CO_2 and CO_2 is reduced to carbon. The first step of formation of celestial bodies occurred as a result of chemical characteristics of materials. When the Sun underwent gravitational collapse and nuclear fusion reactions began, the Earth was at the last stage of formation. The Earth's seawater accumulated as ice with cosmic dust during the Earth's formation. These initial situations of the solar system led to new scenarios differ from conventional theories. For example, a large planet had formed in the region near the snow line, but one nuclear fusion explosions formed an asteroid belt. The proto-Moon was born in the geostationary orbit of the Earth and once had come into touch slightly with the Earth, resulting in the tilt of the Earth's rotational axis and the inclination of the Moon's orbit. The new scenario of formation Moon-Earth system is characterized as "Little touch" instead of "Giant impact".

Keywords: *Accretion, Cosmic dust, Meteorite, Comet, Asteroid, Satellite, Planet*

Introduction

Many models have been proposed to explain the origin of the solar system. Among them, the Hayashi (Kyoto)-model [1] is a representative example. Many models have attempted to describe the formations of planets [2-4]. The tradiational models tends to adhere to the viewpoint of physics. The physics is universal, but it is abstracted. The world of logic tends to estrange the real world. The real world includes various aspects. Theoreticians tend to dislike a bird's-eye view, and sometimes they failed in "idols of the cave" [5]. The first step of traditional models in the formation of the Sun was the accumulation of hydrogen through gravitation. However, the gravitational force of the hydrogen atom is extremely weak. A planetesimal does not form due to the gravitational force. It was formed by local bonds of dusts. Although the London-Van der Waals attractionis a weak bond, the short-range force is more thirty orders of magnitude stronger than the gravitational force. The short-range forces offsets within a short distance, whereas long range-forces are accumulated very wide range. The accretion models have been discussed [6], while the formation of a solar system from a viewpoint of chemical describes in this paper. When a celestial body becomes sufficiently large to hold hydrogen atoms via gravitation, the hydrogen rich environment increases the body's growth rate at a fast pace. This will correspond to a "gravitational collapse". Before nuclear fusion, the proto-Sun contained large amounts of solids. In this context, the iron currently contained in the Sun is 0.014% of the total mass. The mass of the Sun is about 333,000 times that of the Earth where the mass of iron in the Sun is 46.6 times that of the Earth. The large amount of material of core was released as meteorites by the nuclear fusion of the Sun. The meteorite is the most objects in the solar system. The Japanese Hayabusa 2 mission revealed the rubble-pile structure of asteroid 162173 Ryugu [7]. The gravity of this asteroid is extremely weak with an escape speed of 30 cm/sec. Such a small celestial body does not retain its structure by gravitational force, rather the lump of solid matter is formed into the relevant shape by short-range forces at points of attachment. 51 Pegasi b, is the first exoplanet and was discovered by M. Mayor, D. Queloz, in 1995 [8]. It is a massive planet with a mass approximately

149 times that of the Earth and an orbital period of 4.23 days at 7.8 million km from its host star, this is approximately only one-twentieth of the distance between the Sun and the Earth. This suggests that 51 Pegasi b had fairly formed in the environment before fusion reaction began in the host star. The proto-Earth would grow by accumulating solid forms of H_2O (ice) and solid of CO_2 (dry ice) via point contacts. Reconfiguration of solids occurs at the high-pressure and high-temperature environment of the inner celestial body. When the fusion reactions began in the Sun, the protoplanet of the solar system had become considerably large. This paper describes that the first step in the solar system is the accumulation of nebular dust through the intermolecular bonds of short-range forces [A Reference, https://www.youtube.com/watch?v=fiMgXpUz2GQ].

Adhesion among Fine Particles in a Cold Environment

The Model of Formation of the Solar System Based on Material Science

When an isolated H_2O molecule collides with fine particles, the momentum of the gas molecules is low, and it bounces back. Thus, a chemical reaction does not occur in the gas state. Since the kinetic energy of the collision is concentrated at the contact points between ice and fine particles, a localized chemical reaction may take place. Planetesimals were formed by accretion of cosmic dust in a very cold environment. Formation of a celestial body by cold accretion requires lengthy periods of time. The traditional formation theory ignored the importance of non-uniform phenomena. If the celestial body grows to satellite level, the debris scattered by a meteorite impact will fall onto the original celestial body owing to its gravity. When the proto-Sun became able to maintain hydrogen gas by its gravity, its mass rapidly increased via the positive feedback between mass and gravity in the high-hydrogen-density environment. This is corresponded the "gravitational collapse" in the traditional model. The formation of planets began before the nuclear reactions of the Sun, as shown in Figure 1.

The Sun exploded by nuclear fusion and released a large amount of core material into space. These materials fell onto planets as meteorites. The radial impacts of meteorites from the Sun had slightly changed its circular orbit of the planet. The traditional model on migration of planet and collision with planets is difficult to explain the nearly circular orbits of the planets. The large number of meteorite impacts caused the hot state of the crust to become a magma ocean, and the solid H_2O and CO_2 molecules entered into gas state. The degassed molecules formed the proto atmosphere of the Earth.

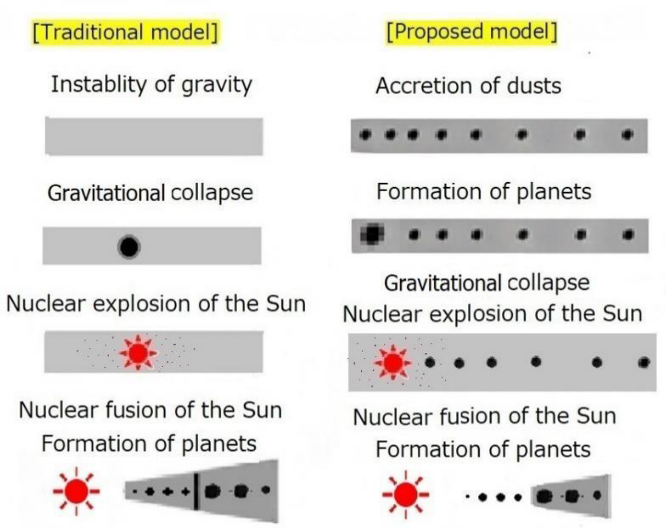

Figure 1: Traditional model and proposing model for the formation of the solar system.

The Cold Accretion due to Chemical Reeactions at the Contact Points between Solids

The Coulomb force that binds atoms together at interatomic distances is equivalent to ~10^{36} times that of universal gravitation. When fine particles come into contact in the cold vacuum environment of the Universe, atoms near the point of contact may form intermolecular bonds. The interatomic bonds are much stronger forces than the gravitational force. One obstacle in lunar exploration for astronauts is the adhesion of lunar dusts [9]. The adhesion in the environment of the Moon is similar to the adhesion of cosmic dusts. It depends on surface energy, roughness, mechanical properties, and electronic properties. Electronic energy state of fine dust is high compared with that large-size particles. As the size of dust increases, the energy to surface ratio decreases, resulting in a low energy state. According to the Virial theorem, the total energy (E_{total}) becomes minimum at equilibrium for a quantum state (pq=constant). Here,

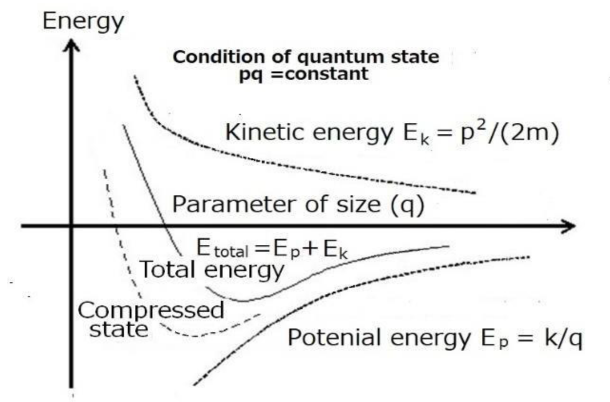

Figure 2: Variation of energy vs. variation of size. The equilibrium state exists at the minimum energy.

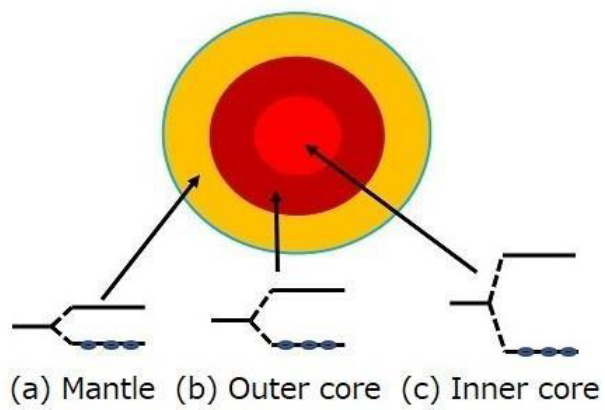

Figure 3: Energy splitting inside of a planet. The interactions yield the lower energy level.

p represents the momentum, and q represents the distance. $E_{total} = E_p + E_k$, where E_p and E_k denote the potential (E_p=-const/q) and kinetic energy [$E_k=p^2/(2m)$] respectively. A downsized equilibrium state results in lower energy as shown in Figure 2. Therefore, the inner temperature of the planet increases. The compressed electronic state of a substance becomes a low energy state, as shown in Figure 3. As the lump of mass grows, the temperature around the gravitational center increases. The change from a chemical mixture into a chemical compound can be explained by the energy state of the core of a planet.

Surface Oxidation of Iron Fine Particles by Mixing with Dry Ice (CO_2)

The adhesion between solids depends not only on surface forces but also on surface roughness and the degree of ductility of the solids themselves [10]. A chemical reaction at a point on the surface indicates the possibility of localized chemical reactions. The following experiments were carried out to confirm the difference in the oxidation of iron particles with solid-state CO_2 compared with gas-state CO_2.

Mixtures of fine iron powder and dry ice were sealed and stored in a freezer at −18°C to confirm the oxidation of iron powder by dry ice. Upon increasing in temperature above −79°C, dry ice sublimates. The iron powder used in the present experiments was reduced-iron produced by the Canadian Pharmaceutical Industry. Iron powder and dry ice were placed in a glass jar, mixed well, and the jar was closed with a cap. The jar was removed from the freezer after 29 h. Next, the processed powder was compared with the initial powder. As shown in Figure 4, black-colored ferrous monoxide (FeO) formed inside the glass jar, but brown-colored Fe2O3 on the jar wall. The SiO2 glass wall functions as a catalyst that extracts electrons from FeO. At the left side of Figure 5, iron powder that was not treated with dry ice is gray, whereas the right side of Figure 5 indicates surface oxidation by dry ice. The blackening was attributable to iron monoxide.

Oxidation of Ultrafine Iron Particles by Sprinkling on Dry Ice

Ultrafine Fe particles were obtained from (FeC2O4·$2H_2O$) via heating at 200°C. Red light emissions were observed when the pyrophoric iron particles were sprinkled on dry ice, as shown in Figures 6 and 7.

Figure 4: Ion powder with dry ice in a bottle.

When the dry ice and pyrophoric iron metal were in contact, the iron particles were oxidized by the oxygen in the dry ice. The black-colored particles correspond to FeO, while the red particles indicate the state of oxidation. The relevant video demonstration has been uploaded online [https://www.youtube.com/watch?v=eyq3qbxFahw].

Figure 5: Left, iron powder without dry ice, right, iron powder oxidized after dry ice treatment.

Figure 6: Sprinkling of pyrophoric iron on dry ice.

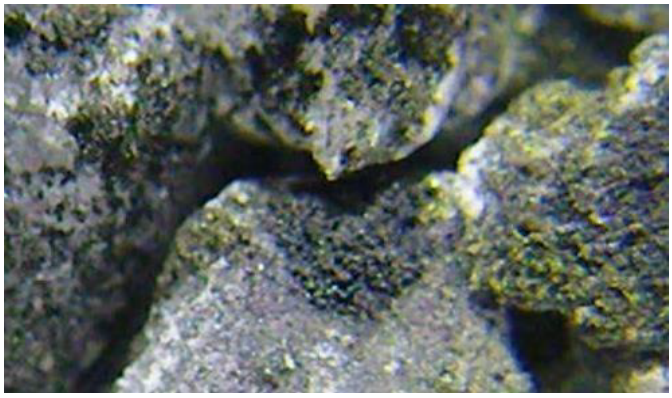

Figure 7: CO_2 reacts with pyrophoric iron as an oxidizer.

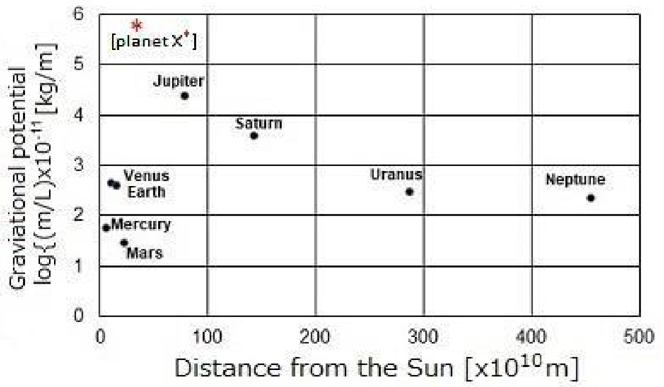

Figure 8: The gravitational potential collected by planets.

Distribution of the Interstellar Medium in the Solar System

Distribution of Interstellar Medium Estimated from the Masses of Gas Planets

Figure 8 shows the relationship between the common logarithm of the value of (m planet/L Sun-planet vs. the distance from the Sun on the horizontal plane). Here, the data were obtained from chronological scientific tables [11]. Planet X* represents a hypothetical planet. As explained section 3.2, planet X* disappeared after a single nuclear explosion, leaving asteroids and meteorites in the asteroid belt. The relationship for the distribution of the interstellar medium is estimated from the relationship between the distance of gas planets from the Sun (L Sun-planet) and their mass (m planet). The gravitational potential energy of the planet by the Sun is defined by setting an infinity point for 0 and the change at the current position from the Sun. According to Newton's mechanics, the gravitational potential energy of a planet is inversely proportional to its distance from the gravitational center (L Sun-planet). Therefore, the value of potential energy (Φ planet) on a planet, obtained by collecting the interstellar medium in the surrounding area is proportional to the mass of the planet (m planet) and inversely proportional to distance (L Sun-planet), as expressed by Eq. (1).

Φ planet = G (m planet)/(LSun-planet) (1).

Where, G is the constant of gravitation.

For exoplanets (Jupiter, Saturn, and Uranus), the value of (m planet/L Sun-planet) decrease exponentially with respect to their distance from the Sun. This indicates that gas planets grew in a state where the interstellar medium was distributed exponentially with respect to the distance from the Sun. Optical data indicate the existence of comet clusters in the main asteroid belt [12]. This refers to the region where material accumulation was active due to the molecule are state of H_2O that changes to the liquid or solid state around the snow line located almost in the center of the planetary belt. However, no large planets exist in this region, as shown in Figure 8. Where did the accumulated substances exist? Although several scenarios attempt to explain the behavior of planets through collisions among celestial bodies, it has been challenging to provide an orbit that has remained the same orbit for a long time at equilibrium.

A scenario of Formation of an Asteroid Belt

Once Existed Planet X Leaved Debris in the Asteroid Belt by a Nuclear Explosion*

The meteorites were created inside of a large planet. The gravitational force cannot shatter a large celestial body. The planet X* increased enormously in the snow line region rapidly collects hydrogen due to gravitational collapse. A scenario that the planet X* has grown to a size of approximately more than 10fold that of Jupiter, and 3.8 billion years ago, it exploded with deuterium nuclear fusion [13] was proposed. Material that scattered as a result of this explosion did not return to the original planet X*, and the explosion ended only once. The author proposed a scenario entitled as "Asteroid belt formed by debris of the planet that failed to become the second Sun". The relevant video demonstration has been up-loaded online [https://www.youtube.com/watch?v=QY8C7XK6k7I].

[Time series of events for the formation of an asteroid belt]

1. Rapid accumulation of materials takes place around the snow line.
2. Rapid increase of planet X* takes place due to gravitational collapse.
3. Nuclear explosion occurs in the rapidly grown planet X*.
4. Planet X*'s core is shattered to pieces by a nuclear explosion.
5. Most of the ejected fragments fall onto the Sun.
6. The asteroid belt is formed by the debris in the orbit of the exploded planet X*.

The nuclear explosion of planet X* likely explains the late heavy bombardment of meteorites approximately 3.8 billion years ago. The fall of many meteorites on Earth heated the crust, followed by degassing of crustal H_2O and CO_2.

The Rotational Speed of Gas Planets Increases with Increasing Planet's Mass

A planet grows by accumulating material orbiting around it. When a planet increases in size, its gravitational potential increases. The orbital speed of interstellar material that lands on the planet increases. Therefore, the rotation period shortens as planet grows large. Except

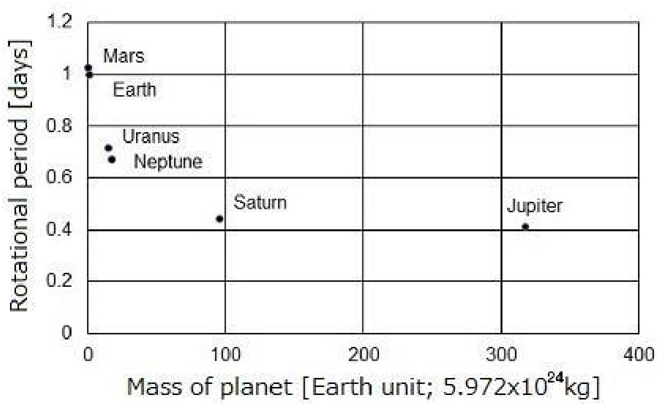

Figure 9: Relationship between the period of rotation and mass of planets [13].

for Mercury and Venus, the rotational period of planets is shortened as their mass increase, as shown in Figure 9.

The rotational period of the Sun is 25.38 days, and we consider that the slow rotation speed of the Sun is caused by the large amount of interstellar medium that had been collected without orbiting the Sun at the beginning of the formation.

How Galilean Satellites Formed

The interior structures of the four Galilean moons are shown in the animation at [https://www.esa.int/ESA_Multimedia/Videos/2021/07/Inside_the_Galilean_moons]. The internal materials in the Galilean moons are shown in Figure 10. These facts suggest the formation process.

The average density of the Galilean moons Io, Europa, Ganymede, and Callisto decreases with their distance from Jupiter, as presented in Table 1.

The geostationary orbit is a region in which material accumulation by accretion thrives. The formation of a celestial body at a geostationary orbit shifts the gravitational center towards Jupiter. The geostationary orbit of Jupiter can be determined using Eq.(2). The radius of Jupiter's geostationary orbit ($L_{\text{geostationary orbit}}$) is short compared with the orbits of the Galilean moons.

$L_{\text{geostationary orbit}}= \{G \cdot m_{\text{Jupiter}} (T/2\pi)^2\}^{1/3} = 1.6\times10^8 \text{m}$ (2)

Rotational period of all Galilean satellites is synchronized with the revolution. There exists a gravitational coupling between Jupiter and the Galilean moons those had born in the geostationary orbit. The rotational speed of Jupiter will be fast due to the increase in mass, as described in Section 3.2. The coupling due to gravitational force accelerates the orbital speed of the Galilean moons. Even if Jupiter's rotation speed did not change, the speed at which satellites accelerate their orbit due to gravitational coupling will be faster speed for the moons away from Jupiter. The effect of magnetic couplings among parallel-running charged particles partially collided with solar wind also contributes to the Galilean moons moving away from Jupiter.

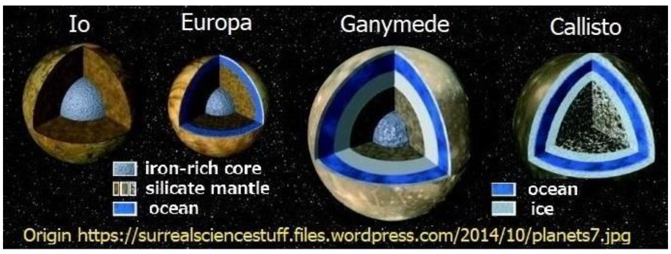

Figure 10: The internal structure of Galilean moons those suggests the process of satellite formation. The figure was reproduced from https://surrealsciencestuff.files.wordpress.com/2014/10/planets7.jpg.

According to Aharonov-Bohm effect, the conventional consideration that set the geomagnetic field first and describe the behavior of charged particles is incorrect [15]. The magnetic coupling energy (Um) between charged particles must be considered the vector potential (A) instead of the magnetic field (B). Um for a point charged particle (q) with velocity (v) is expressed in Eq. (3). Here, the negative sign is set to be low when v and A are parallel. The relationship between A and magnetic flux density (B) is defined by Eq. (4).

$Um= - (qv)\cdot A.$ (3).

$B = \text{rot } A.$ (4).

$\Phi=\int B ds= \oint A \, dx.$ (5).

Here, rot is an operation in which the orbital direction of A in a minute area around a circle is added. Eq. (5) is expressed as the magnetic flux (Φ) of the penetrating area and is given by a line integral of the point field of A around the penetrating area. The chain of magnetic coupling among charged particles forms a donut shape of rotating charged particles. The movement of charged particles above the Arctic and Antarctic regions shown at Aurora are slow owing to the slow rotational speed of charged particles inside planet. Assuming that the Galilean moons were born in the Jupiter's geostationary orbit and migrated from Jupiter, the order of birth of the Galilean moons will be Callisto, Ganymede, Europa, and Ion.

How Today's Moon-Earth system Formed

Migration of the Moon due to the Tidal Effect

The rotation period of the Moon is synchronized with the revolution of the Moon. The current distance from the Earth to the Moon is 380,000 km, and the Moon moves away at a rate of 3.8 cm per year. The assumptions that the Moon formed in the geostationary orbit of Earth, and if the velocity of migration due to the acceleration of the orbital speed of the Moon described in section 3.3 has been remained the same, today's distance will require the time of 10^{10} years. Considering that the tidal effect is large when the Moon is close to the Earth, it is estimated that the Moon was born and formed near the Earth's geostationary orbit. In the Giant Impact Theories, Lagrangian point (L_S) is one of candidate of place where the Moon formed [16]. However, L_S is 395 times of the current orbital radial of the Moon.

The Small Impact Model is Suitable to Explain the Current State of Moon-Earth system

The traditional model considered that the Moon formed by a large off-centered collision nearly at the end of the Earth's formation [17]. Several simulations have dealt with the giant impact [18]. However, where did impactor originate from and where did it end. The giant

Table 1: Characteristics of Jupiter's four Galilean moons { *[14], **[11] }.

Name	Position (m)*	Period (days)*	Diameter (m)*	Mass(kg)**	Density(g/cm³)
Io	4.22×10^8	1.77	3.64×10^6	9.0×10^{22}	3.53
Europa	6.79×10^8	3.55	3.12×10^6	4.8×10^{22}	3.01
Ganymede	10.7×10^8	7.15	5.26×10^6	14.8×10^{23}	1.94
Callisto	18.8×10^8	16.7	4.82×10^6	10.8×10^{23}	1.85

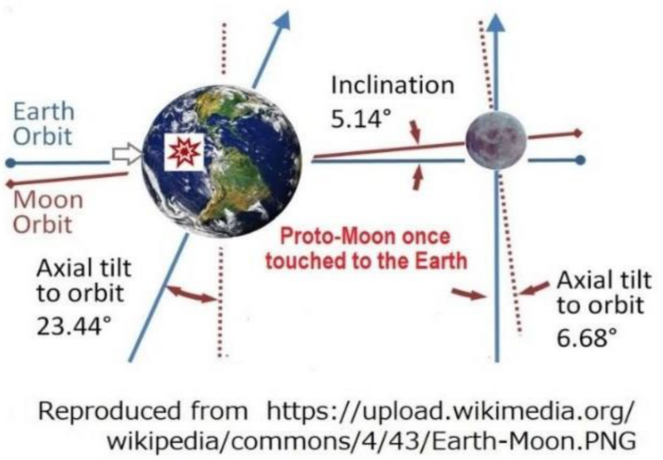

Figure 11: The model describes that proto-Moon touches on the Earth, ✸ marks the position of contact.

impact model must result in a large migration of the orbits. Although far side of the Moon is thick and is composed of light material, shape of the current Moon is nearly spherical, a more accurate description is "slightly pear-shaped". The highest point on the Moon is +10.75 km and the lowest point is -9.06 km, both at the far side form the Earth. Taking into account the rotation period of Moon is synchronized with the revolution, a scenario of formation of Moon-Earth system was proposed as follows. Proto-Moon was born near the geostationary orbit of the Earth as described in the section 3.3. The proto-Moon includes many voids. As the Moon grew in size, the distributed mass reorganized and the center of mass shifted to the side of the Earth. Thus, the orbital period of the Moon and the rotational period of the Moon coincided. A migration of Moon that caused the Moon was in contact with the Earth was triggered by the fall of materials released from the Sun's core at the early nuclear explosion of the Sun. The Moon's orbit was slightly accelerated by the contact with rotating Earth to form an elliptical orbit. After the contact, the distance from the Earth to the Moon has been expanding due to the tidal effect of the sea water of the Earth. Proposing scenario is suitable to explain the current Moon-Earth system. The new scenario is characterized as "Little touch" (Figure 11).

The proposed model according to which the proto-Moon lightly touched the Earth is the most suitable candidate to explain following facts. Inclination of the orbit of the Moon is 5.14°. Rotational axis of the Earth is tilted by 23.4° relative to the equatorial plane of the Sun. The tilt of the Earth shifts as a precession in a cycle of 26,000 years, with the direction of the Sun as the axis of the rotation.

Summary

The formation of the solar system was examined from viewpoint of astrophysics and material science. Although orbital motion is explained by Newtonian mechanics, a celestial body is formed by chemical bonds at contact points at first. Traditional studies tend to extrapolate from current facts using serial logics. Even though the correct calculation on the chemical bonds is hard, the assumption or preconditions for a study must be carefully set real facts as the base. This paper describes the protoplanet of the solar system had become considerably large, when the fusion reactions began in the Sun. The verifications based on different viewpoint will reveal new aspects of the world. It led to new scenario that differs from conventional scenarios. For example, the geostationary orbit is a region in which material accumulation by accretion thrives. The formation of a celestial body at a geostationary orbit shifts the gravitational center towards the gravitational center. There exists a gravitational coupling between the planet and satellites those had born in the geostationary orbit. Therefore, a rotation period of all Galilean satellites is synchronized with the revolution. Asteroid belt had formed by debris of the planet that failed to become second Sun. A model of "Little touch" instead of "Giant impact" of the proto-Moon with the Earth resulted in the tilt of Earth's rotational axis and the inclination for Moon's orbit. These results will contribute to present the preconditions for the study of or to the understanding of the solar system.

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