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EVOLUTION OF THE ECCENTRICITY THE LUNAR ORBIT AND THE ERUPTION HYPOTHESIS OF THE ORIGIN OF THE MOON

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ABSTRACT

The influence of tidal friction on the eccentricity of the lunar orbit is considered. It is shown that the energy dissipation inside the planet is the greater, the higher the eccentricity of the satellite orbit. The conclusion is drawn about decrease in the eccentricity of the lunar orbit. It is also concluded that in the distant past, the Moon had a highly elliptical orbit. So, hypotheses are incorrect, in which it is assumed that the Moon was formed as a result of accretion. The eruption hypothesis of the origin of the Moon is proposed. It is shown that this hypothesis is consistent with current features of the Moon and its orbit. A few experiments to test the new hypothesis have been proposed.

Keywords: Origin of the moon, eruption; tidal friction, eccentricity of the orbit, evolution of the orbit, near-earth objects, meteorites.

INTRODUCTION

Almost half a century ago, the first samples of lunar rocks had been delivered to the Earth. In these rocks there were almost no water-containing minerals that were widely distributed on the Earth. Therefore, among the majority of scientists strengthened the view that there is no water on the Moon. At about the same time, the hypothesis of the origin of the Moon as a result of the giant-impact was put forward. According to this hypothesis, a hypothetical planet Theia, with size of Mars, crashed into the early Earth and knocked out of the Earth's mantle the substance from which the Moon was subsequently formed (Hartmann, 2014). As a result of the collision of two planets, the ejected substance was heated to high temperatures and therefore completely lost water and other volatile compounds. Thus, the giant-impact hypothesis very logically explained the dryness of the Moon compared to the Earth.

Over the past decade, our knowledge of the Moon has changed significantly. Thanks to research from orbital satellites, water ice reserves were found near the poles on the Moon. Some scientists had previously assumed that water in the form of ice of cometary origin could be accumulated near the poles in the shaded craters. It was not expected that such water will be a noticeable amount. On the Moon, there are a low escape velocity and no atmosphere. When a comet hits the lunar soil, the bulk of the water vapor generated by the explosion must leave the Moon. Only a small part of the water vapor can settle on the cold walls of the polar craters. However, according to current estimates, the amount of water in polar craters is estimated at hundreds of millions of tons (Spudis *et al*., 2013). This amount of water reserves is difficult to explain by cometary origin. Therefore, the question arose about the possible endogenous origin of water in the lunar soil and the hydrothermal activity of the Moon (Kartashov *et al*., 2018). If there is a lot of water on the Moon and it is not of cometary origin, then the giant-impact hypothesis is unlikely. There are also other objections to the giant-impact theory (Clery, 2013; Barbuzano, 2018). How was the Moon formed?

Another problem is associated with a very high secular acceleration of the Moon, which indicates its relative youth. If we extrapolate the removal of the Moon into the past, then we can conclude that 2-3 billion years ago the Moon was close to the Earth. However, the age of the most ancient lunar rocks is 4 billion years.

As a result of tidal friction, the Earth transfers energy and angular momentum to the Moon. If we assume that the energy from the Earth to the Moon is transmitted at the speed of light, then there are problems with the transfer of angular momentum. The calculated angular momentum is obtained millions of times smaller than the transmitted one. The article (Yanchilin, 2018) discusses the

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hypothesis of instantaneous transfer of energy from the Earth to the Moon. Another study, Zakharenko developed a model that allows you to create a complex system consisting of electrical, magnetic, gravitational, and co-gravitational subsystems in order to have an estimated gravitational propagation velocity many orders of magnitude higher than the speed of light (Zakharenko, 2017a, 2017b, 2018).

In this article we will consider how tidal friction affects the eccentricity of the lunar orbit. Simple calculations show that the eccentricity of the orbit should be reduced by the action of tides. Consequently, in the past the Moon orbit was more elongated than it is now and in the distant past its orbit was highly elliptical. If this is the case, then the Moon could not have been formed as a result of accretion. Therefore, most modern theories, which including the process of accretion of the Moon, cannot be correct. The author puts forward a new hypothesis of the origin of the Moon as a result of eruption. It is shown that the eruptive hypothesis explains the most problematic properties of the Moon and its orbit. The author also proposes several experiments to test the new hypothesis.

Eccentricities of Satellite Orbits

The Moon orbits the Earth in an elliptical orbit with an average eccentricity of 0.055. The perigee of the lunar orbit varies from 356,400 km to 370,400 km, and the apogee varies from 404,000 km to 406,700 km. Thus, the distance from the Earth to the Moon changes by about 15%. Is it a lot or a little? For comparison, the eccentricity of the Earth's orbit is 3 times less and amounts to 0.0167; the eccentricity of the Venus orbit is almost an order of magnitude smaller and equal to 0.0068.

It is not entirely correct to compare the orbits of the planets and the orbits of the satellites, since satellite orbits are more susceptible to secular change under the influence of tidal friction. For example, the tides created by the Earth on the Moon slowed the rotation of the Moon around its axis. Therefore, the Moon faces the Earth by one side. The tides formed by the Moon on the Earth slow down the rotation of the Earth around its axis. And the Earth transmits its momentum to the Moon. Therefore, the Moon moves away from the Earth by 3.8 cm per year. The tides formed by the Sun on Earth are 2.2 times smaller than the lunar ones. The tides formed by the Earth on the Sun are negligible and their influence on the rotation of the Sun is also negligible.

Tidal forces decrease in proportion to a distance cubed. These forces have a more impact on the motion of satellites than on the motion of the planets. Therefore, all regular satellites face their planets by one side as the Moon faces the Earth. Let's compare the eccentricities of satellite orbits with the magnitude of the eccentricity of the lunar orbit.

Mars has only 2 satellites: Phobos and Deimos. The eccentricities of their orbits are 0.0151 and 0.0002, respectively. Thus, the eccentricity of Phobos is almost 4 times smaller than the lunar one, and the eccentricity of Deimos is negligible.

Jupiter has only 4 large moons: Io, Europa, Ganymede, and Callisto. The eccentricities of their orbits are respectively 0.0041, 0.0094, 0.0011, and 0.0074. It must be emphasized that these are forced eccentricities caused by the interaction of satellites with each other. The proper eccentricities of the orbits of these satellites are much smaller. Galilean moons are comparable in mass and size with the Moon. The next largest satellite of Jupiter is Amalthea. Its mass is tens of thousands of times smaller. Jupiter has only 4 small regular satellites: Metis, Adrastea, Amalthea, and Thebe in order of ascending of distances from Jupiter. The eccentricities of their orbits are respectively: 0.00002, 0.0015, 0.0032, and 0.0175.

There are also numerous irregular satellites in the Jupiter system. More than 70 of them are already discovered. These are small objects that revolve around Jupiter at great distances. Most of them move in retrograde orbits. The orbits of these satellites have high eccentricities: from 0.1 to 0.6.

In the Saturn, Uranus and Neptune satellite systems, all regular satellites move in more circular orbits than the Moon, and all irregular satellites move in highly elliptical orbits.

Tidal forces decrease rapidly with distance. Therefore, tidal forces from the central planet act primarily on regular satellites and almost do not act on irregular satellites. Regular satellites move in orbits, which have an eccentricity hundreds and thousands of times smaller than the eccentricity of irregular satellite orbits. Burns considered the small eccentricity of regular satellites to be a remarkable feature of the orbital motion (Burns, 1986). It can be assumed that tidal forces from the planet gradually reduce the eccentricities of regular satellites.

Let us approach this problem differently. As a result of tidal friction, part of the kinetic energy is converted into heat. However, the total angular momentum of the entire system is conserved. Therefore, the system tends to the minimum of energy at a constant angular momentum. The total orbital energy (kinetic and potential) of a satellite depends on the major semi-axis of its orbit. The total orbital angular momentum of the satellite depends on the area of the orbital ellipse. If the angular momentum is conserved, and the energy decreases, the orbit will be rounding off. We can conclude that tidal interaction between the planet and the satellite leads to a decrease in the eccentricity of the orbit.

A Modern View on the Evolution of the Lunar Orbit Eccentricity

George Darwin was one of the first to consider the effect of tides on the evolution of the lunar orbit. He came to the conclusion that because of the tides, the Moon must move away from the Earth. Therefore, Darwin hypothesized the fission of the Moon from the Earth as a result of rotational instability due to the very rapid rotation of the Earth (Darwin, 1898). The rate of removal of the Moon has been measured and it equals 3.8 cm/year. If this process is extrapolated into the past, it can be calculated that the Moon was close to the Earth about 1.6 billion years ago (Murray and Dermott 1999). The gravitational interaction of the Earth and the Moon is very complex and depends on many parameters. In addition, the viscosity of the Earth and its elasticity are unknown. It is not known how these parameters are distributed inside the Earth. Therefore, it is impossible to strictly calculate the tidal evolution of the lunar orbit.

Darwin believed that the Moon separated from the Earth as a result of rotational instability. Based on this, we can conclude that the orbit of the young Moon was almost circular. Now the Moon's orbit is elongated, therefore Darwin concluded that when the Moon was removed, its orbit's eccentricity should increase. Tidal effect tends to increase the distance from the Earth to the Moon. The effect of tidal force at apogee increases the distance in the perigee and vice versa. The effect of tidal forces at perigee is greater than at the apogee. Based on this, Darwin concluded that the apogee increases faster than perigee. Consequently, the eccentricity of the lunar orbit should increase (Darwin, 1898).

This conclusion was supported by many scientists. The basis of the modern theory of the origin of the Moon, including the giant-impact hypothesis, is its formation as a result of accretion. According to this theory, the Moon was formed from dust in the Earth orbit. In this case, the initial eccentricity of the lunar orbit should be negligible. However, now the eccentricity of the lunar orbit is quite high. Why? It is natural to assume that this eccentricity grew while removal of the Moon from the Earth.

Here is how Goldreich comments on this conclusion. The height of the tide is inversely proportional to the distance cubed to the Moon. The force with which the tidal hump acts on the Moon is inversely proportional to the distance squared. As a result, the tidal effect decreases in proportion to the 6th power of the distance. Therefore, we can assume that the Moon receives almost all the additional angular momentum only in the perigee. Consequently, the orbit apogee increases significantly faster than perigee (Goldreich, 1963). Jeffreys (1961) adheres to the same point of view. Let us analyze this viewpoint carefully.

First, if the apogee did grow much faster than perigee, now the Moon would move in a highly elliptical orbit, with its apogee several times higher than perigee. But it is not so. The apogee of the lunar orbit is higher than perigee only by 11%.

Secondly, despite the fact that tidal forces decrease in proportion to the 6th power of the distance, the effect of their action decreases much less. The angular momentum created by the tidal forces is proportional to the distance. In addition, the angular momentum transmitted to the moon at a certain portion of its orbit is proportional to the time in which the moon passes this portion. The moon passes perigee much faster than the apogee, because the arc length in the perigee is less, and the orbital speed is higher than at the apogee. Finally, the angular momentum transmitted to the Moon is very much dependent on the angle of delay of the tides. This angle depends on the relative angular velocity of the Earth and the Moon. When the Moon passes the perigee, its angular orbital velocity increases, and the relative angular velocity of the Earth and the Moon decreases. Therefore, the lag angle is also reduced. Now there is no theory that would allow calculating this angle.

Thirdly, if the apocenter of satellite orbits is growing faster than the pericenter, then the orbits of satellites of other planets would also have high eccentricities. But it is not so. As we have already noted, all regular satellites have orbits eccentricities lower than those of the Moon. For example, Tethys moves around Saturn in an orbit with a radius of less than 300 thousand km. It would seem that the eccentricity of its orbit should be greater than that of the Moon. But it is not so. The eccentricity of the orbit of Tethys is very small: it equals 10^{-4}. Why?

Goldreich (1963) suggested that the tides created by the planet on the satellite, reduce the eccentricity of its orbit. However, tides on the satellite and tides on the planet are one and the same physical phenomenon because the satellite differs from the planet only in size. If the satellite causes the tide on the planet, which slows down its rotation, then the rotation of the planet goes into the orbital motion of the satellite and the distance between them increases. For example, the distance between the Earth and the Moon increases. The Earth and the Moon move in orbits around a common center of mass. When the distance between them increases, the orbital moment of the Earth and the orbital moment of the Moon also increase. The Earth is 80 times heavier than the Moon. So the radius of its orbit and its orbital speed around a common center of mass is 80 times smaller. The orbital angular moment is equal to the product of the mass, velocity, and radius of the orbit. Consequently, the orbital angular moment of the Earth is 80 times smaller than the orbital angular moment of the Moon and can be neglected.

Tides created by the planet on the satellite, also lead to the redistribution of angular momentum in the system. If the satellite is small, then the change in the orbital moment of the planet can be ignored. But this is the only difference between the planet and the satellite. If the tides created by the planet on the satellite lead to a decrease in eccentricity, then it is natural to expect that the tides created by the satellite on the planet also lead to a decrease in eccentricity. Let us explore this problem.

Evolution of Orbital Eccentricity

Consider a satellite that moves around the planet in a highly elliptical orbit. The satellite creates a tidal wave on the planet, which slows down its rotation. As a result, the rotation of the planet is transmitted to the satellite, and it moves away from the planet. The tidal forces acting on the satellite in the pericenter are much larger than in the apocenter. Let us calculate consequences of this. When the satellite is in the pericenter, it receives a powerful orbital momentum and, as a result, its apocenter increases. In the apocenter, tidal forces are much weaker. Therefore, many scientists believe that the apocenter grows faster than the pericenter. Let us calculate and find out whether it is the case.

An increase in the apocenter is proportional to the transmitted angular momentum. The transmitted angular momentum is equal to the product of the moment of forces and time. What time should we take? It depends on the choice of arc length. What arc should we choose? Should we confine ourselves to a small arc of the orbit near the pericenter? No. To find the change in angular momentum ΔL_A in the apocenter, we must take an integral from the moment of forces $M(t)$ along the entire trajectory of motion from the apocenter to the apocenter:

$$\Delta L_A = \int_{t_1(A)}^{t_2(A)} M(t)dt \tag{1}$$

Here $t_1(A)$ is the time when the satellite is in the apocenter; $t_2(A)$ is the time when the satellite is in the apocenter on the next orbit.

Let us find the change in angular momentum in the pericenter ΔL_p. To do this, we need to take an integral from the moment of forces $M(t)$ along the entire trajectory of movement from the pericenter to the pericenter:

$$\Delta L_p = \int_{t_1(p)}^{t_2(p)} M(t)dt \tag{2}$$

Here $t_1(p)$ is the time when the satellite is in the pericenter; $t_2(p)$ is the time when the satellite is in the pericenter on the next orbit.

Comparing the integrals (1) and (2), we see that this is one and the same integral taken along the entire trajectory of motion for one period. Therefore, we can conclude:

$$\Delta L_p = \Delta L_A \tag{3}$$

Regardless of where tidal forces are greater, the increase in angular momentum is the same at the pericenter and apocenter. Therefore, in the first approximation, the eccentricity of the orbit will remain constant. Let us find out how the eccentricity will change over long time.

Consider a satellite that moves around the planet in its equatorial plane on a circular orbit. The day on the planet is shorter than the orbital period of the satellite. For simplicity, we assume that the parameters of the planet depend only on the distance to the center and do not change along the equator. Therefore, the satellite forms on the planet a tidal wave of constant height H, which moves at a constant speed V. This wave slows down the rotation of the planet transmitting the energy E and angular momentum ΔL to the satellite in one full revolution. Let W_D is a work that the wave performs in one day, that is, for one revolution around the planet. In the article (Yanchilin, 2018) it was calculated that the Efficiency of such a process is:

$$\text{Efficiency} = \frac{T_D}{T_M} \tag{4}$$

Here T_D is the star day, T_M is the star month. Consequently:

$$\Delta E = W_D \frac{T_D}{T_M} \tag{5}$$

$$Q_T = W_D\left(1 - \frac{T_D}{T_M}\right) \tag{6}$$

Here, Q_T is the amount of heat that is released inside the planet in one day due to tidal friction. For example, the sidereal lunar month is 27.3 days. Therefore, the efficiency of tidal friction created by the Moon on Earth is 3.7%. When the Earth loses energy due to tidal friction, only 3.7% of this energy is transferred to the Moon, and 96.3% is lost in the form of heat.

We considered a satellite that moves around the planet in its equatorial plane in a circular orbit. Suppose that there is exactly the same system in which the satellite moves in the same orbit, but the satellite orbit has a slight eccentricity $e << 1$. Suppose that the big semi-axis of the second satellite is equal to the radius of the orbit r of the first satellite. In this case, the orbital period of the second satellite will be equal to the orbital period of the first satellite and the orbital energies of both satellites will also be equal.

The 1st satellite creates a tidal wave of height H, which moves at a constant speed V. The second satellite creates a tidal wave, whose height varies slightly near the average value of H, and the speed changes slightly near the average value V. We have two almost identical processes. In both cases, the tidal wave slows down the movement of the planet and, as a result, a part of the angular moment of the planet is transmitted to the orbital angular moment of the satellite. A part of the energy of the planet goes into heat and dissipates.

In which of the two systems will the efficiency of this process be less?

In order to maintain the tidal wave, energy is needed. This energy is taken from the planet-satellite system. Let E_1 is the energy that is needed to maintain the tidal wave of the first satellite for one orbital period. Let E_2 is the energy that is needed to maintain the tidal wave of the second satellite for one orbital period. Which value is greater than E_1 or E_2?

In the first case, the power that is spent on maintaining the wave is constant. In the second case, the power increases when the height of the tidal wave increases because the additional wave pulling requires energy. When the wave height begins to decrease, only a part of its energy returns to the system. It is because the efficiency of any physical process is less than 100%. Thus, a wave of variable height requires more energy for its existence than a wave of constant height. Similar arguments apply for acceleration and deceleration of the wave. Power to maintain a tidal wave increases when its speed increases because the acceleration of a wave requires additional energy. When the wave speed begins to decrease, some of its energy returns to the system. And some of this energy is lost in this process. Thus, a variable speed wave requires more energy for its existence than a constant speed wave:

$$E_2 > E_1 \tag{7}$$

We have come to a fairly obvious conclusion. To maintain the tidal wave of the second satellite, more energy is required because the height and speed of this wave vary near the mean value. Each of these processes leads to additional energy dissipation. Thus, in one orbital period more heat is released in the second system and, therefore, the efficiency of energy transfer from the planet to the satellite is lower in the second system. Where it leads? This will lead to the fact that the second satellite will receive less orbital energy than the first satellite. Consequently, the orbit of the second satellite will be gradually rounded off. This orbit will be rounded off until the efficiency of energy transfer in the 2nd system increase up to the maximum value (4), which corresponds to a circular orbit.

We considered at the tides that the satellite creates on the planet. Tides created by the planet on the satellite behave in a similar way. The higher the eccentricity of the orbit, the more energy is dissipated in one period. Therefore, the tides on the planet and the tides on the satellite reduce eccentricity. So, when the satellite moves away from the planet due to tidal friction, its orbit is gradually rounded off.

Problems Associated with the Origin of the Moon

There are many hypotheses of the origin of the Moon, and all of them can be divided into three large groups.

- The Moon has separated from the Earth
- The Moon was formed in another place and then was captured by the Earth.
- The Moon was formed in the Earth orbit as a result of accretion

It must be emphasized that there is still no generally accepted theory of the origin of the Moon because all existing hypotheses have contradictions. The origin of the Moon is discussed in detail in (Wood, 1977).

The Moon has a number of properties, each of which creates serious problems for any scenario of its origin. There is no scenario for the origin of the Moon, which would explain the basic properties of the Moon and its orbit without introducing unlikely additional assumptions. Here is a list of the most intriguing properties of the Moon.

1. The average density of the Moon is 1.6 times less than that of the Earth.
2. Lunar rocks are united by iron, compared to the Earth.
3. The Moon has no noticeable iron core.
4. The isotopic composition of some basic chemical elements on the Moon and the Earth is the same.
5. The Moon has retained large reserves of water ice.
6. The moon very quickly moves away from the Earth.
7. The moon has too much inclination relative to the Earth's equator.
8. The orbit of the moon has a significant eccentricity.

According to modern concepts, the Solar System was formed from a gas and dust cloud. From this point of view, the chemical composition of the planets, their satellites, and the Sun should be approximately the same. At the same time, small planets must contain helium and hydrogen substantially less than large planets and the Sun. For example, it is assumed that the chemical composition of the Sun coincides with that of the Earth, except for hydrogen and helium.

How, then, to explain the low density of the Moon? The Moon is much smaller than Earth. By virtue of its smallness and weak gravity, it could lose light elements, but not iron. For example, Kaula (1968) believed that the hypothesis of the simultaneous formation of the Earth and the Moon as a binary system is incorrect due to a significant difference in density.

Why is the moon depleted in iron compared to earth? Iron is the most common element in the Solar System after hydrogen and helium. For example, the Earth contains 32% of iron. Could it be that the lunar rocks are united by iron due to the fact that iron was separated from them and sank to the center of the moon? No, it is not. The Moon has no iron core.

We see that the Moon is not at all like Earth. Its average density is much lower, it has almost no iron, and it has no core. Maybe the Moon was formed somewhere very far away, and then it was captured by the Earth?

The capture hypothesis was widely discussed before the beginning of the space age. However, after samples of lunar soil were delivered to Earth, it turned out that the oxygen isotopic composition in lunar rocks is exactly the same as in terrestrial rocks. It should be noted that oxygen is one of the most common elements and Earth's substance has 30% of this element, almost as much as iron. The exact coincidence of the isotopic composition of the two bodies evidences that these bodies were formed in one place and similar processes took place in them (Galimov and Krivtsov, 2012). Therefore, now the capture hypothesis has few supporters.

In area where the terrestrial planets were formed, water could exist only in gaseous form due to low pressure and rather high temperature. How could a little Moon collect a lot of water? This problem is exacerbated if we assume that the Moon was formed as a result of a giant-impact.

The rapid removal of the Moon from the Earth is a problem for all existing hypotheses of the origin of the Moon. Therefore, it is assumed that now there are special conditions on Earth that facilitate the rapid removal of the Moon, and in the past there were no such conditions (Murray and Dermott, 1999). To solve the problem of the rapid removal of the Moon, MacDonald (1964) put forward a hypothesis of many moons, which were originally in near-earth orbit.

In almost all modern theories, including the giant-impact hypothesis, it is assumed that the Moon was formed as a result of accretion in near-earth orbit. In this case, it should have been formed on an almost circular orbit lying in the equatorial plane of the Earth. However, it is not the case. Goldreich extrapolated the movement of the Moon into the past and obtained the following result. The inclination of the lunar orbit to the Earth's equator has always exceeded 10º and, therefore, the modern lunar orbit is incompatible with the equatorial orbit in the past (Goldreich, 1966). Therefore, Urey and MacDonald (1971) conclude that the Moon could not have been formed as a result of the accretion of particles in the equatorial plane of the Earth.

Why is the moment of inertia factor of the Moon the same as that of a homogeneous ball?

The moment of inertia factor of a homogeneous ball is exactly 0.4. The moment of inertia factor of the Moon is 0.393 (Williams *et al*., 1996). Consequently, the density distribution inside the Moon is on average almost the same as that of a homogeneous ball. Thus, the average density on the Moon surface and in its center is almost equal. Why? For example, the density of the Earth gradually increases with depth. The average density of the crust is 2.8 g/cm^3, the average density of the mantle at a depth of 400 km is 3.7 g/cm^3. At a depth of 1000 km, the density of the mantle increases to 4.6 g/cm^3. At a depth of 2.900 km, the density of the mantle is 5.6 g/cm^3. The core of the Earth begins deeper and the density increases abruptly to 9.4 g/cm^3, and in the center of the Earth the density reaches 17.2 g/cm^3. Therefore, the moment of inertia factor of the Earth is noticeably less than that of a homogeneous ball and is equal to 0.331.

Why is the Moon not differentiated in density along its radius unlike the Earth? Even in the last century there was no such problem. It was assumed that only large objects like the Earth should be differentiated in density along the radius. For example, the moment of inertia factor of Mars is 0.366. Consequently, the density of Mars with depth does not increase as fast as that of Earth. The Moon is 8 times lighter than Mars; perhaps its mass is not enough for the density to increase markedly with depth. In the XXI century it became clear that this is not the case.

Thanks to the Galileo spacecraft, which investigated the Jupiter system from 1995 to 2003, the moments of inertia factor of all Galilean satellites became known. The results were surprising (Bagenal *et al*., 2004). The satellite of Jupiter Io is markedly differentiated in density along its radius and its moment of inertia is 0.378. The satellite Europe is differentiated in density along a radius stronger than Mars. Its moment of inertia is 0.346. Ganymede was a record for this indicator among the solids of the Solar System. Its moment of inertia is only 0.311. It is steeper than on Earth. The moment of inertia factor for Callisto is 0.355. Thus, all objects of lunar sizes in the Jupiter system are significantly differentiated in density along their radius.

Saturn's satellite Titan is differentiated in density along its radius and its moment of inertia factor is 0.341 (Iess *et al*., 2010). Saturn moon Enceladus is 700 times lighter than the Moon, but its density increases markedly with depth. The moment of inertia factor of Enceladus is estimated to be 0.335 (Iess *et al*., 2014). Even the dwarf planet Ceres is differentiated in density along its radius. Its moment of inertia factor is estimated to be 0.37 (Park *et al*., 2016).

We see that all known bodies of lunar sizes are differentiated in density along their radius. In addition, some objects that are significantly smaller than the Moon are also differentiated in density along their radius. Why is the Moon an exception?

The Eruption Hypothesis of the Origin of the Moon

Now we formulate a hypothesis of the origin of the Moon, which explains all the above features of the Moon and its orbit.

At its early stage of evolution, the Earth rotated much faster than it does now making one revolution in about 6-7 hours. This follows from the extrapolation of the movement of the Moon into the past. In addition, we assume that young Earth's volcanic activity was much more powerful than it is now. The combination of rapid rotation and volcanic activity led to the following. An object consisting of the crust and the upper mantle, as a result of endogenous activity, received a speed higher than the orbital one and had come off the Earth. If there were no volcanic activity, then this object would receive speed strictly in the equatorial plane of the Earth. If the Earth did not rotate around its axis, the ejection could have occurred in any direction. The combination of these two factors led to the fact that the object was thrown at a certain angle to the equatorial plane, possibly in the range of 10-15º. In addition, due to a strong volcanic explosion, the object was thrown into a highly elliptical orbit.

The angular momentum of a rapidly rotating body is equal to the sum of the angular moments of all its parts. Therefore, the ejected object quickly rotated around its axis. The object, moving away from the Earth, was inside the Roche zone, and tidal forces from the Earth were stretching it in different directions. In addition, the pressure drop inside and outside the object has changed dramatically after the object was thrown from the bowels of the Earth. The pressure inside the object ceased to be compensated by external pressure and an explosion occurred. As a result, the object broke up into several bodies, which were moving away from each other at high speeds. Some of these bodies, having momentum in the retrograde direction, fell back to Earth. Some of the bodies overcame gravity and became asteroids. The largest body remaining in Earth orbit became the Moon. The young Moon was moving in a highly elliptical orbit with a perigee at an altitude of 3 or 4 Earth radii and an apogee at an altitude of 20-30 Earth radii. Being the largest body in Earth orbit, the Moon swallowed part of the near-Earth bodies, and threw the rest into heliocentric orbits. These bodies became asteroids crossing the Earth's orbit. Gradually, due to the tidal friction, the Moon moved away from the Earth, and the eccentricity of its orbit decreased to the present-day value.

The new eruptive hypothesis differs from the fission hypothesis as a result of rotational instability. According to the hypothesis of rotational instability, the young Moon was moving in a circular orbit in the equatorial plane of the Earth. This is contrary to the modern orbit of the Moon. According to the eruptive hypothesis, the young Moon was moving in a highly elliptical orbit tilted to the Earth's equator by 10-15º. This is consistent with the modern orbit of the Moon. In addition, the eruptive hypothesis is devoid of the energy problem that exists in the rotational separation hypothesis.

According to the eruptive hypothesis, the average density of the Moon should be less than that of the Earth because the Moon was formed from the mantle of the Earth. According to the eruptive hypothesis, the Moon should contain less iron than the Earth because it was formed from the Earth's substance after the massive iron core separated from this substance. For the same reason, the Moon should not have an iron core. The Moon is not differentiated in density along its radius because it was formed from the Earth's mantle and crust, whose substance has already been differentiated.

The isotopic composition of the basic chemical elements on the Moon and the Earth is the same because lunar substance was formed in the Earth's mantle. Large reserves of water inside the Earth, including in the form of hydrates, were transferred to the Moon. The Moon has lost some of this water, but much of it has been preserved at great depths and even near the surface on the darkened slopes of polar craters.

Within the framework of the eruptive hypothesis, there is no problem of rapid removal of the Moon. The Moon could have separated from Earth even 2 billion years ago. In this case, we should look for the fossil remains of bacteria and other microorganisms in the lunar ice. The discovery of the fossil remains of terrestrial microorganisms in the lunar ice will be direct evidence of the eruptive hypothesis and put an end to the problem of the origin of the Moon. We should also look for organic matter of biogenic origin in the lunar ice.

It is possible that the Moon had separated from Earth more than 4 billion years ago. However, due to the fact that the young Moon was moving in a highly elliptical orbit, the efficiency of tidal friction was significantly lower than for a circular orbit (1). At the same time, the orbital period of the Moon around the Earth was an order of magnitude longer than for a circular orbit with the same perigee. As a result, the rate of removal of the Moon was noticeably lower. Thus, by extrapolating the motion of the Moon into the past, taking into account its initial highly elliptical orbit, it is possible to obtain an earlier time for the separation of the Moon. However, additional calculations are required.

In the history of the Moon, there was a period of so-called late heavy bombardment, which occurred about 700 million years after the formation of the Moon and the planets. Modern theories of the formation of planets cannot explain such a large number of meteorites that appeared so late (Gomes, 2005). According to the eruptive hypothesis, the heavy meteorite bombardment of the Moon was caused by the fall of bodies that separated from the Earth together with the Moon and moved to near-Earth orbits before falling to the Moon.

There are about 1000 asteroids with a size of more than 1 km, which approach Earth. They are usually called near-Earth objects. It is not entirely clear how these asteroids hit their orbits. There are hypotheses that these are either comets or asteroids from the main belt (Morbidelli *et al*., 2002). From a new point of view, near-Earth objects are bodies that were ejected from the Earth as a result of volcanic activity. Most of these bodies were thrown out with the Moon, but some of the near-Earth objects may have been thrown away not so long ago: 100-200 million years ago. This can be verified by examining the substance of these objects in the terrestrial laboratory.

Since the 19th century, scientists regularly find organic substances in the carbonaceous chondrites, including amino acids, purine and pyrimidine bases, fatty acids and lipids. All these findings are described in detail in the monograph (Nagy, 1975). Some scientists claim that already in 1975 it was possible to conclude that meteorites contain fossilized remains of organisms at least of the bacterial level of organization (Rozanov, 2009). Thanks to modern microscopes, scientists observe formations in some meteorites, which coincide in form with ancient petrified organisms (Rozanov, 2010). Some scientists claim that they found petrified diatoms in a meteorite and, based on this, conclude that life on Earth was brought from space (Wickramasinghe *et al*., 2013). From a new point of view, all the meteorites containing fossils were ejected from the Earth as a result of volcanic activity. Therefore, the author proposes to double-check the age of meteorites, in which fossils are found.

CONCLUSION

It is widely believed that the tides created by the satellite on the planet increase the eccentricity of the orbit. It is difficult to agree with this. First, the eccentricities of the orbits of regular satellites are small. Second, a simple analysis shows that a wave of variable speed and height dissipates more energy than a wave of constant speed and height. Therefore, the efficiency of energy transfer is lower for an elliptical orbit than for a circular one. The higher the eccentricity, the lower the efficiency. Accordingly, any elliptical orbit will be rounded off by tidal friction. Now the eccentricity of the lunar orbit is quite high: 0.055. Consequently, in the past the Moon moved in a more elliptical orbit, and in the distant past the Moon moved in a highly elliptical orbit. In addition, the Moon's orbit never coincided with the equatorial plane of the Earth. Therefore, we can conclude that all hypotheses of the origin of the Moon, which include the accretion process, are incorrect. This also applies to the hypothesis of the giant-impact, which includes the process of accretion of the Moon from a substance knocked out of the Earth. Therefore, the author put forward the eruption hypothesis of the origin of the Moon as a result of ejection from the Earth. This hypothesis is consistent with the modern orbit of the Moon. In addition, the new hypothesis explains all the most intriguing features of the Moon: low density, the absence of iron and iron core, the same isotopic composition with the Earth, large reserves of water in the form of ice. The eruption hypothesis also explains the origin of near-Earth objects and the origin of the late heavy bombardment. The late heavy bombardment of the Moon is the fall of bodies on the Moon that had been erupted together with the Moon from the Earth. Near-Earth objects are volcanic bombs, mostly ejected together with the Moon from the Earth. However, some of these objects could have been erupted out much later: 100–200 million years ago. This assumption can be checked and clarified if to research a substance of asteroid crossing the Earth's orbit. From a new point of view, meteorites containing fossils were ejected from the Earth. Thus, fossils in meteorites are of terrestrial origin and therefore are not proof of the panspermia hypothesis. The author proposes to carefully check the age of meteorites, which contain fossils. If in a meteorite, fossilized diatoms are indeed found, then the age of the substance of this meteorite should be several hundred million years.

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