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THE EFFICIENCY OF TIDAL FRICTION AND THE DENSITY OF THE FLOW OF GRAVITATIONAL ENERGY TRANSMITTED FROM EARTH TO THE MOON

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ABSTRACT

Tides created by the Moon on the Earth are discussed. A tidal wave slows down the rotation of the Earth. The Earth loses 3.3 TJ of kinetic energy every second. Almost all of this energy is converted to heat. However, a small part associated with the angular momentum is transmitted to the Moon. A formula for the efficiency of the transmitted energy is derived. It is proved that the efficiency is equal to the ratio of the following periods: day/month. The flow of energy from the Earth to the Moon is discussed. Its power and density are calculated: the power is equal to 100 GW and the density is equal to 1 mW/m^2. The possibility that this energy is transmitted at the speed of light is discussed. It is shown that in this case the transferred angular momentum would be 17.5 million times less than the observed angular momentum. To reconcile the angular momentum transferred to the Moon with the equations of relativistic dynamics, the energy must be transmitted at a speed exceeding the speed of light by 17.5 million times. Therefore, the author puts forward the hypothesis that energy from the Earth to the Moon is transmitted instantaneously.

Keywords: Tidal friction, angular momentum, energy flow, gravity, spinning of Earth, Moon's orbit, gravity propagation speed.

INTRODUCTION

In 2016, the LIGO Scientific Collaboration and the Virgo Collaboration announced the discovery of burst gravitational waves from the merger of two black holes (Abbott *et al*., 2016). Scientists tried to detect gravitational waves beginning from the second half of the twentieth century, but they did not succeed. The main difficulty is that the power of gravitational radiation is very small. For example, the most powerful gravitational waves in the Solar System are radiated as a result of the interaction of the Sun and Jupiter. The power of this radiation is only 5.3 kW (Misner, 1973). Accordingly, the flux density of this radiation passing near the Earth is negligible. Nevertheless, near the Earth a flow of gravitational energy of 100 GW is constantly flowing. Its density is approximately 1 mW/m^2. The author hopes that these theoretical investigations will attract specialists to study this flow and determine its main parameters, such as the velocity, energy density, and momentum density.

Another problem related to the gravitational waves is the speed of their propagation. According to the general relativity theory, gravity propagates at the speed of light. However, there are other viewpoints. Basing on the study of the motion of the Moon and planets, Laplace claimed that gravity spreads several million times faster than light (Laplace, 1846). The famous physicist Leon Brillouin assumed that gravity can propagate more slowly than light (Brillouin, 1970). Zakharenko developed a model that allows creating a complex system consisting of electric, magnetic, gravitational, and cogravitational subsystems in order to have an estimated speed of gravity propagation many orders of magnitude higher than the speed of light (Zakharenko, 2016, 2017a, 2017b, 2018). The maximum speed can reach 10^{27} m/s. That is, waves of a certain type can almost instantly spread from one edge of the Universe to the other. Füzfa (2016) proposed a method for studying interactions between the magnetic and gravitational subsystems not in space at astronomical distances, but in terrestrial conditions in a laboratory. In 2004, the author examined in detail the differences in the gravitational interaction from the electromagnetic one. For example, there is a law of conservation of the center of mass in a closed system. However there is no analogous law for electric charge. As a result, the author came to the conclusion that the gravity can spread instantaneously if there is a nonlocal connection between the gravitational fields (Yanchilin, 2004).

In this article, the author analyzes a flow of energy from the Earth to the Moon caused by the tidal friction

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Comparing the energy, momentum, and angular momentum transferred by the flow, the author comes to the conclusion that the transmission rate of this energy is 17.5 million times faster than the speed of light. Otherwise, a contradiction arises between the observed angular momentum and the calculated angular momentum. A formula for the efficiency of tidal friction is below derived.

Tidal friction

The Moon is gradually moving away from the Earth because of the action of the tidal friction. The speed of its removal is 3.8 centimeters per year (Murray and Dermott, 1999). If we divide 385 thousand kilometers (the average distance from the Earth to the Moon) by 3.8 cm/year, we will get by about 10 billion years. However, the tidal forces decrease in proportion to the distance cubed. If we extrapolate the movement of the Moon into the past taking into account the growth of the tidal forces, then we will obtain a very interesting result. The Moon was near the Earth approximately 1.6 billion years ago (Kaula, 1968).

The equations of gravitation are reversible in time. This means that for any orbital motion there may be the reverse motion along the same orbit. However, it is not entirely true. When the planets and satellites are close to each other, they deform each other with their gravitational fields. With this deformation, some of the energy passes into heat. This is an irreversible process. Therefore, any gravitationally bound system gradually evolves towards a decrease in the free energy. The most famous type of irreversible gravitational interaction is the tidal forces. Consider a satellite that rotates around the planet in a circular orbit and one its side faces the planet. For example, one side of the Moon always faces the Earth, and its diameter in the direction of the Earth is slightly larger than in any other direction. The same applies to most satellites of other planets.

Accordingly, the satellite also pulls the planet along the line connecting the planet and the satellite. This forms two tidal humps on opposite sides of the planet. If the spinning of the planet and the revolving of the satellite are not synchronous, then a tidal friction arises. This friction either slows down or accelerates the rotation of the planet.

Consider the Earth-Moon system. The Moon by its gravitational field forms two tidal humps on the Earth, namely on the sublunar and opposite sides. Because the Earth spins around its axis faster than the Moon around the Earth, this hump shifts relative to the Earth-Moon line. Therefore, the Moon forms two new humps on Earth's surface along the Earth-Moon line. These new humps are again shifted due to Earth's spinning and the process is repeated (Darwin, 1898). As a result there are two following effects.

Effect 1. The effect of a running tidal wave is created due to the permanent forming of a tidal hump on the sublunar and opposite sides of Earth. This effect moves against the Earth's spinning and slows it down. Due to the friction, the tidal hump is shifted relative to the Earth-Moon line in the direction of Earth's spinning. Due to this, additional gravitational forces appear that act from two humps towards the Moon. The sublunar hump accelerates the movement of the Moon and the opposite hump slows it down. The sublunar hump is located closer to the Moon and its gravitational action is greater. Therefore, the Moon is gradually accelerating and slowly moving away from the Earth.

Effect 2. As a result of this process, the angular momentum of Earth decreases. On the contrary, the orbital moment of the Moon increases. The Earth gradually transmits the energy of its spinning to the Moon. So the Moon slowly moves away from the Earth. It is worth noting that the Earth transmits towards the Moon only a small part of the kinetic energy lost due to the action of tidal friction. Most of the kinetic energy passes into heat, slightly heating up the Earth.

The Moon, while doing the work on the Earth, including, causing the work of tidal power stations, increases its own energy. Where does this energy come from? It comes from the Earth's spinning. The Earth is gradually slowed down, and its lost kinetic energy is spent on the tidal heating, the work of tidal power stations, and the increase in the gravitational energy of the Moon. Let's calculate the efficiency of this process.

The angular momentum of the entire system is strictly conserved and the kinetic energy decreases. All the lack of kinetic energy passes into heat.

Stationary orbit

Let M, R, V be the mass, radius and equatorial speed of the planet's spinning, and m is the mass of its satellite, v is the speed of its traveling on the orbit, and r is the radius of this orbit. Suppose that the orbit of the satellite is circular and lies in the equatorial plane of the planet. The momentum of the planet J_1 is:

$$J_1 = IMR^2\omega \tag{1}$$

Here ω_1 is the angular velocity of the planet's spinning equal to $\omega_1 = 2\pi/T_1$, where T_1 is the period of the planet's spinning, I is the dimensionless moment of inertia of the planet, its magnitude depends on the mass distribution. The linear velocity of the surface at the equator of the planet is $V = \omega_1 R$. As a result, we get:

$$J_1 = IMRV \tag{2}$$

The orbital moment of the satellite is $J_2 = mvr$. Let us write the law of conservation of angular momentum for a planet and a satellite:

$$J_1 + J_2 = \text{const} \tag{3}$$

Differentiate this expression: $\mathrm{d}J_1 + \mathrm{d}J_2 = 0$. Therefore, $IMR\mathrm{d}V + mr\mathrm{d}v = 0$ results in

$$\mathrm{d}v = -\frac{IMR}{mr} \cdot \mathrm{d}V \tag{4}$$

The kinetic energy of rotation of the planet K_1 is equal to:

$$K_1 = IMR^2 \frac{\omega_1^2}{2} = IM\frac{V^2}{2} \tag{5}$$

The kinetic orbital energy of the satellite K_2 is:

$$K_2 = \frac{mv^2}{2} \tag{6}$$

Write the expression for the energy in a differential form:

$$\mathrm{d}K_1 + \mathrm{d}K_2 < 0 \tag{7}$$

This inequality means that, due to tidal friction, the total kinetic energy of the system decreases. Substituting K_1 (5) and K_2 (6) in (7), we obtain:

$$IMV\mathrm{d}V + mv\mathrm{d}v < 0 \tag{8}$$

Substitute $\mathrm{d}v$ from equation (4): $IMV\mathrm{d}V - mv\mathrm{d}V\frac{IMR}{mr} < 0$, divide by $IMR\mathrm{d}V$ and therefore

$$\left(\frac{V}{R} - \frac{v}{r}\right) \cdot \mathrm{d}V < 0 \tag{9}$$

Taking into account that the angular velocity of the orbital rotation of the satellite ω_2 around the planet is equal to $\omega_2 = v/r$, we obtain:

$$(\omega_1 - \omega_2) \cdot \mathrm{d}V < 0 \tag{10}$$

We have got a clear result. The direction of energy transfer depends only on the angular velocity of the planet's spinning ω_1 and the angular velocity of the satellite's motion along the orbit ω_2. If $\omega_1 > \omega_2$, then $\mathrm{d}V < 0$. In this case, the speed of the planet's spinning decreases, and the kinetic energy is transferred from the planet to the satellite. In other words, if a day on the planet $T_1 = 2\pi/\omega_1$ is shorter than a month $T_2 = 2\pi/\omega_2$, then the planet's spinning speed will decrease. The energy of the satellite will increase, and it will gradually move to a higher orbit. A similar process occurs in the Earth-Moon system, in which a day is 27 times shorter than a month, and the Moon is removed by 3.8 centimeters per year.

If $\omega_1 < \omega_2$, then $\mathrm{d}V > 0$, and the planet's spinning speed increases. The kinetic energy is transferred from the satellite to the planet. In this case, the tidal wave created by the satellite on the planet, outruns the planet's spinning and as a result accelerates the planet. Orbital energy of the satellite, on the contrary, decreases, and it is gradually "falling" on the planet. This scenario is realized for the Martian satellite Phobos.

It follows from equation (10) that there exists a special orbit for each planet, which is called stationary orbit. On it, an orbital period of a satellite is exactly equal to a period of the planet's spinning around its axis. For Earth, such an orbit is also called geostationary. The satellites on it move so that they as if "soar" all the time over the same place.

The stationary orbit is unstable. If we slightly increase it, then the irreversible process of removing the satellite from the planet will begin. The higher its orbit, the longer the period of motion along it and, consequently, the tidal wave created by it on the planet will move faster along it in the opposite direction, slowing its rotation. If we slightly reduce the orbit of a satellite in a stationary orbit, then, on the contrary, the irreversible process of its fall will begin.

It should be noted that Mars, Jupiter, Uranus and Neptune have satellites below the stationary orbit. In the future, such satellites will fall on their planets. The time of their existence is estimated in tens of millions of years.

Efficiency of tidal friction

Calculate the efficiency of tidal friction. Let us find out which part of the energy of the planet's spinning is transferred to the satellite (for example, from the Earth to the Moon), and which part is lost in the form of heat.

In the planet-satellite system, the "funder" of energy is always a body with the greater angular velocity of rotation (10). It follows from equation (6): $\mathrm{d}K_2 = mv\mathrm{d}v$. Taking into account equation (4), we obtain $\mathrm{d}K_2 = -mv\frac{IMR}{mr} \cdot \mathrm{d}V$. From the equation (5): $\mathrm{d}K_1 = IMV\mathrm{d}V$ and $\mathrm{IM}\mathrm{d}V = \frac{\mathrm{d}K_1}{V}$, and therefore $\mathrm{d}K_2 = -mv\frac{R\mathrm{d}K_1}{mrV} = -\frac{vR}{rV} \cdot \mathrm{d}K_1$ resulting in

$$\mathrm{d}K_2 = -\mathrm{d}K_1\frac{\omega_2}{\omega_1} \tag{11}$$

If $\omega_1 > \omega_2$ (the planet revolves faster than the satellite), then $|\mathrm{d}K_2| < |\mathrm{d}K_1|$. This means that energy can only pass from the planet to the satellite. For $\mathrm{d}K_2 < 0$, the following necessary condition is fulfilled:

$$\mathrm{d}K_1 + \mathrm{d}K_2 < 0 \tag{12}$$

This means that part of the kinetic energy passes into heat. The transfer of energy from a slowly rotating

orbiting satellite to a rapidly rotating planet is impossible. In this case inequality (12) is violated. And, therefore, additional energy is needed to implement such a process.
If the satellite rotates faster than the planet (for example, as Phobos relative to the Mars), then in this case $\omega_2 > \omega_1$. Accordingly, the kinetic energy of the planet grows, and the orbital energy of the satellite decreases. The satellite is slowly "falling" on the planet.

So, if in the system the energy is released in the form of heat, the state of this system will change. The system will tend to a stable state with minimal energy. A stable state has been achieved, for example, in the Pluto-Charon system. The same side of Charon always faces Pluto (like one side of the Moon faces the Earth). This satellite also rotates around Pluto at an angular velocity equal to the speed of Pluto's spinning. That is, the same side of Pluto also faces Charon. It is clear that such a state of the system is not accidental. Apparently, earlier Charon was in another orbit, but due to of tidal friction it gradually moved to the modern orbit.

It is clear from equation (11) that the efficiency of tidal friction depends only on the ratio of the frequencies of rotation of the satellite and the planet. For example, in the Earth-Moon system ω_1/ω_2 = month/day ≈ 27, therefore less than four percent of the Earth's spinning energy is used to increase the orbital energy of the Moon, and the rest is radiated as heat dQ inside the Earth and on its surface. Let's do the calculations. According to the law of conservation of energy

$$\mathrm{d}K_1 + \mathrm{d}K_2 + \mathrm{d}Q = 0 \tag{13}$$

Introduce the following definition of the efficiency of the tidal friction. This value is equal to the ratio of the received energy to the transmitted energy. If $|dK_2| < |dK_1|$ (energy is transferred from the planet to the satellite), then

$$\text{Efficiency} = \frac{|\mathrm{d}K_1| - \mathrm{d}Q}{|\mathrm{d}K_1|} = \frac{|\mathrm{d}K_2|}{|\mathrm{d}K_1|} = \frac{\omega_2}{\omega_1} \tag{14}$$

$$\text{Efficiency} = \frac{\omega_2}{\omega_1} \tag{15}$$

If $|\mathrm{d}K_2| > |\mathrm{d}K_1|$ (energy is transferred from the satellite to the planet), then

$$\text{Efficiency} = \frac{|\mathrm{d}K_2| - \mathrm{d}Q}{|\mathrm{d}K_1|} = \frac{|\mathrm{d}K_1|}{|\mathrm{d}K_2|} = \frac{\omega_1}{\omega_2} \tag{16}$$

$$\text{Efficiency} = \frac{\omega_1}{\omega_2} \tag{17}$$

So, in all the cases, the efficiency of the energy transfer process is equal to the ratio of frequencies. The efficiency tends to one hundred percent if $\omega_1 = \omega_2$. However, in this case there is no transfer of energy. If the frequencies are very different from each other, the bulk of the transmitted energy is expended on the tidal heating and only a small part is transferred to another body. That is, the process of transferring the rotation energy is always accompanied by a dissipation of energy and consequently, an increase in entropy. This is an irreversible process.

The efficiency of tidal friction can be expressed in terms of the ratio of periods. If a period of the planet's spinning T_1 (stellar day) is less than a period of revolution of satellite T_2 (stellar month), then the satellite moves away from the planet and the energy transfer efficiency is equal to

$$\text{Efficiency} = \frac{T_1}{T_2} \tag{18}$$

The sidereal (stellar) lunar month is shorter than the usual (synodic) month and is equal to 27.3 days. Therefore, the efficiency of transferring tidal energy from the Earth to the Moon is 1/27.3 = 3.7%. If a period of the planet's spinning T_1 is greater than the period of revolution of the satellite T_2, the satellite approaches the planet and the transmission efficiency of the energy is

$$\text{Efficiency} = \frac{T_2}{T_1} \tag{19}$$

How much energy does the Earth lose every second?
How much energy is radiated within the Earth because of tides? It is easy to calculate this using formula (18) and knowing the speed of removal of the Moon. When a body of mass m moves along its orbit, its total orbital energy E (kinetic and potential) depends only on the value of the large semiaxis a:

$$E = -\frac{1}{2}\frac{GMm}{a} \tag{20}$$

Here M is the mass of the central body, $G = 6.67 \times 10^{-11}$ $\mathrm{kg^{-1}m^3s^{-2}}$ is the gravitational constant. Coefficient ½ appears because the average kinetic energy is half the average potential energy and has an opposite sign. If the semimajor axis increases by Δa, the orbital energy will increase by ΔE:

$$\Delta E = \frac{1}{2}\frac{GMm}{a^2}\Delta a \tag{21}$$

Earth's mass is $M = 6 \times 10^{24}$ kg, the mass of the Moon $m = 7.35 \times 10^{22}$ kg, the semimajor axis of the lunar orbit $a = 3.85 \times 10^8$ m. Substituting the values of the quantities, we get that the Earth transmits 3.8×10^{18} J of energy per year to the Moon. A year has approximately 31.5 million seconds. Therefore, the transmitted power is 1.2×10^{11}W.

To find out how much energy the Earth loses as a result of the lunar tides every second, the power of the transmitted energy must be divided by the efficiency (18). That is, we must multiply this power by the sidereal lunar month expressed in terrestrial stellar days: 1.2×10^{11} W × 27.3 =

3.3×10^{12} W. Earth loses 3.3 TJ of energy every second because of the Moon's influence. Almost all this energy goes into heat. By virtue of the law of conservation of the angular momentum, only 1/27.3 part cannot go into heat and is transmitted to the Moon, increasing its orbital moment. If we subtract from 1.2×10^{11} W the energy transferred to the Moon, then we will find out how much kinetic energy of the Earth is consumed by the tides and eventually turns into heat:

$$(3.3 - 0.12) \times 10^{12}\ \text{W} \sim 3.2 \times 10^{12}\ \text{W} \qquad (22)$$

Approximately 3.2 TJ of the kinetic energy of the Earth is spent on tidal friction every second and eventually turns into heat. Munk and Macdonald (1960) give a value of 2.7 TW.

Density of the flow of gravitational energy from the Earth to the Moon

So, the Earth slows down its own spinning because of the gravitational impact of the Moon. Every second the Earth loses about 3.3 TJ of its kinetic energy. Almost all this energy is spent on tidal heating, and only 3.7% is transferred to the Moon (18). The power with which the Earth transmits energy to the Moon is 1.2×10^{11} W. The total area of the Earth is 510 million km^2. The area of the Earth's cross-section is 4 times smaller: 126 million km^2. If we divide the power by the cross-sectional area, we get the energy flux: 1 mW/m^2. Such a flow of energy continuously flows from the Earth to the Moon. The Earth loses its energy, and the Moon receives it. The area of the Moon is about 13.5 times smaller than the Earth's area. Therefore, the energy flux density near the Moon is approximately 13.5 mW/m^2.

It is known that energy conserves. In addition, the law of conservation of energy is of a local nature. In his lectures on physics, Feynman devoted a whole paragraph to the local character of conservation laws. Here is what he wrote (Feynman *et al*., 1977):

"Very early in Volume I, we discussed the conservation of energy; we said then merely that the total energy in the world is constant. Now we want to extend the idea of the energy conservation law in an important way – in a way that says something in *detail* about how energy is conserved. The new law will say that if energy goes away from a region, it is because it *flows* away through the boundaries of that region. It is a somewhat stronger law than the conservation of energy without such a restriction."

Thus, the energy lost by the Earth is not transmitted to the Moon instantaneously. This energy must travel from Earth to the Moon. Energy flows from the sphere that surrounds the Earth, and flows into the sphere around the Moon. This flow of energy must flow through any plane that separates the Moon and the Earth. If we believe that energy cannot be transmitted faster than light, then in the space between the Earth and the Moon there is a lot of energy all the time. The distance to the Moon is 385 thousand km. Light travels this distance in 1.3 seconds. We can conclude that in the space between the Earth and the Moon there are always 1.2×10^{11} W $\times$ 1.3 s = 1.6×10^{11} J of energy. In what form is this energy? There are only 4 types of interaction: nuclear, weak, electromagnetic and gravitational. Nuclear forces operate only at short distances. It is unlikely that a neutrino stream flows from the Earth to the Moon. The neutrino almost does not interact with matter, and the neutrino flux would pass through the Moon like light through a thin transparent glass. Can the energy be transmitted by electromagnetic radiation? In this case, we could screen this radiation. So we have only one possibility. The flow of energy from Earth to the Moon has a gravitational nature. We have two problems.

1. Is there a formula for describing this flow in the modern theory of gravitation? On what parameters do the power of the stream and the density of its energy depend? In electrodynamics, there are formulas for the energy density and for the energy flux. But in general relativity, there are no formulas for the energy of a gravitational field because a gravitational field in a small region of space can be eliminated by the transformation of coordinates. Therefore, I think that in the modern theory of gravity, there are no formulas for describing the flow of energy from the Earth to the Moon. In my opinion, general relativity is not able to describe either the power of such flows or the density of gravitational energy in them. If I am wrong, then let experts on gravity correct me. Let they offer a formula for describing such flows and explain which parameters determine the power and density of energy in them. It can be noted that similar energy flows occur near planets that have satellites.

2. Is it possible to detect this energy flow using modern physical devices? I think no. I do not know what kind of devices should be capable of detecting this flow. Suppose in the future there will be devices capable of detecting this stream. While detecting a flow, we slightly reduce its power, that is, we screen gravity. I think it is impossible. Therefore, the stream cannot be detected. But if the flow cannot be detected, is it possible to assert that this flow exists? I think no. So we can conclude that there is no flow of energy from the Earth to the Moon. Therefore, the energy that the Earth loses is transmitted instantly from the Earth to the Moon.

Such a conclusion contradicts the theory of relativity. It should be emphasized that the theory of relativity has been tested in numerous experiments, and its equations are used in engineering calculations in the construction of accelerators, particle detectors, and so on. Therefore, there is no doubt about the truth of the theory of relativity.

Nevertheless, the theory of relativity is checked only in the field of electromagnetic phenomena. Gravitation does not apply to electromagnetism, therefore the principles of the theory of relativity may not be fulfilled for gravitational phenomena. It can be noted that Feynman suggested in his lectures on physics that the principle of relativity might turn out to be incorrect (Feynman *et al.*, 1963): "Today we say that the law of relativity is supposed to be true at all energies, but someday somebody may come along and say how stupid we were."

Speed of gravity propagation

Suppose that the energy from the Earth to the Moon is transmitted at the speed of light. What conclusions will follow from this? As we have already explained, the Earth transmits 3.8×10^{18} J of energy to the Moon per year. This follows from (21). Consequently, according to Einstein's formula, every year the Earth loses mass ΔM:

$$\Delta M = \frac{\Delta E}{c^2} = 42\,\text{kg} \tag{23}$$

Here c is the speed of light. Mass ΔM together with energy is transmitted to the Moon. In addition, together with energy and mass, momentum p is transmitted, which is equal to:

$$p = \Delta M \times c = 1.26 \times 10^{10}\ \text{kg}\times \text{m/s} \tag{24}$$

In addition, the Earth transmits the angular momentum ΔJ to the Moon. The angular momentum is strictly conserved. This is one of the main laws of conservation in physics associated with the isotropy of space. A value of the angular momentum depends on the chosen frame of reference. We calculate the angular momentum in the frame of reference connected with the center of the Earth. Therefore, knowing a value of the transmitted momentum, we can estimate the maximum value of the momentum transfer $\Delta J_{\max}$. To do this, a momentum p must be multiplied by the radius of the Earth $R = 6.4 \times 10^6$ m:

$$\Delta J_{\max} = 8 \times 10^{16}\ \text{kg}\times \text{m}^2/\text{s} \tag{25}$$

Now we will calculate an angular momentum ΔJ transmitted from the Earth to the Moon for a year. The orbital angular momentum of the Moon J_2 is

$$J_2 = m\sqrt{GMa} \tag{26}$$

G is the gravitational constant. We neglect the elliptical form of the lunar orbit, whose eccentricity is 5%. We will take the differential of (26) and obtain:

$$\Delta J_2 = \frac{1}{2} m \sqrt{\frac{GM}{a}}\ \Delta a \tag{27}$$

The square root in this equation is the orbital velocity of the Moon equal to 1 km/s, Δa = 3.8 cm/s, the Moon mass $m = 7.35 \times 10^{22}$ kg. Substituting these numbers in (27), we obtain:

$$\Delta J_2 = 1.4 \times 10^{24}\ \text{kg}\times \text{m}^2/\text{s} \tag{28}$$

We see that angular momentum transmitted from the Earth to the Moon (28) per year exceeds the maximum possible angular moment (25) by 17.5 million times. To increase the maximum possible angular momentum by 17.5 million times, we must assume that the speed of energy transmission exceeds the speed of light by 17.5 million times. Assuming that the energy is transmitted at the speed of light, we have come to a contradiction. To better understand the essence of this contradiction, we will express it in the form of a formula.

If energy ΔE is transmitted from the Earth to the Moon, the maximum possible angular momentum transfer is:

$$\Delta J_{\max} = \frac{\Delta E}{c^2} V_{gr} R \tag{29}$$

V_{gr} is the propagation speed of gravitational energy. Substituting ΔE from (21) we obtain:

$$\Delta J_{\max} = \frac{1}{2}\frac{GMm}{c^2 a^2} V_{gr} R \Delta a \tag{30}$$

Divide equation (27) by equation (30): $\dfrac{\Delta J_2}{\Delta J_{\max}} = \sqrt{\dfrac{GM}{a}}\,\dfrac{c^2 a^2}{GMV_{gr}R}$ and therefore $\dfrac{\Delta J_2}{\Delta J_{\max}} = \sqrt{\dfrac{a}{GM}}\,\dfrac{c^2 a}{V_{gr}R}$ resulting in

$$\frac{\Delta J_2}{\Delta J_{\max}} = \frac{c^2 a}{V_{orb} V_{gr} R} \tag{31}$$

V_{orb} is the orbital velocity of the Moon equal to 1 km/s. If we assume that $V_{gr} = c$, then the angular momentum received by the Moon will be seven orders of magnitude higher than the maximum possible angular momentum because $c >> V_{orb}$ and $a >> R$. If we assume that $\Delta J_{\max} \approx \Delta J_2$, then:

$$\frac{V_{gr}}{c} = \frac{c}{V_{orb}} \times \frac{a}{R} \approx 1.8 \times 10^7 \tag{32}$$

Assuming that the energy from the Earth to the Moon is transmitted at the speed of light we have come to a contradiction.

CONCLUSION

We have considered such a well-known phenomenon as the lunar tides. The Moon forms a tidal wave that move against the Earth's spinning. As a result, the Earth slows down its rotation and loses its kinetic energy. The bulk of this energy passes into the energy of the tides and then goes into heat. But a small part connected with the angular momentum of the Earth is transmitted to the Moon. As a result, the orbital energy of the Moon increases and its orbital angular momentum also increases. The lost moment of the Earth's momentum is transmitted to the Moon and thus the total angular momentum in the system conserves. We obtained a simple formula for the efficiency of this process. The energy transfer efficiency is always equal to the ratio of the periods. In the case of the Earth and the Moon, this efficiency equals the ratio of the stellar day to the stellar month and is only 3.7%.

Exploring the energy transmitted from the Earth to the Moon we discovered a problem. By transmitting to the Moon a relatively small amount of energy, the Earth transmits a sufficiently large 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 the angular momentum. To provide the observed increase in the orbital angular momentum of the Moon, the Earth must transmit energy at a speed of 17.5 million times greater than the speed of light. We also encountered a problem when trying to understand kind of nature of the flow of transmitted energy. Trying to solve these problems the author suggested that the theory of relativity ends where gravity begins. In this case, a simple solution of the problem appears: the energy from the Earth to the Moon is transmitted instantaneously.

Unfortunately, the problem of energy transfer from the Earth to the Moon has never been discussed in the scientific literature. I mean that the nature of the flow of transmitted energy was not discussed and its parameters, such as power, density and speed were not discussed. Therefore, the author hopes that this article will attract specialists in gravitation and gravitational radiation to discuss and solve this problem.

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