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WHERE THE MOON WAS BORN?

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Our hypothesis is based on the distribution of approximately circular orbits for terrestrial planets, given by the square law $r_n = r_1 n^2$, where n's are successive integers starting with $n = 3$ for Mercury, reaching $n = 6$ for Mars and $n = 8$ for Ceres, and r_1 is a constant. Quadratic distribution of orbits is a direct consequence of quantized specific angular momentum. An analysis of the planetary masses, volumes and orbital periods of terrestrial planets, as independent observable parameters, makes possible the statement that the orbit with $n = 7$, between Mars and Ceres was the primordial orbit of the Moon. This statement favours a capture theory of the Moon by the Earth. But why the Moon abandoned its orbit and was captured by the Earth remains a problem for further investigation.

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1. *Introduction*

The origin of the Moon, i.e. the question of its formation and primordial orbit where it was born is a long standing problem. The proposed solutions of this problem may be summarized in several models or theories. However, none of them has been definitively accepted. In the following, a short note of each theory is presented. There are five theories with certain physical background but with more or less serious constraints.

1) The fission theory supposes that material of which the Moon was formed has been contained in the Earth. Due to a rapid spinning of the Earth, some its parts have been ejected and later accreted to form the Moon.

2) The capture theory supposes that the Moon was formed somewhere in the solar system and was later captured by the gravitational field of the Earth.

3) The condensation theory assumes that the Moon and Earth condensed at the same time from the nebula that formed the solar system. They were formed in such a way that mutual gravitational interaction made the Moon a satellite of the Earth.

4) The colliding planetesimal theory presumes the interaction of large planetesimals orbiting the Earth with those orbiting the Sun and after their breakup the created debris condensed to form the Moon.

5) The giant impact theory states that a planetesimal whose size was nearly as large as that of Mars struck the Earth, ejecting certain mass which formed a disk of material orbiting around the Earth. A consequent condensation formed the Moon.

Similar many short descriptions (with many more details) of the formation of the Moon may be found on Internet under a title *The Origin of the Moon* and for example an extensive article is that of J. A. Wood: *Moon over Mauna Loa-A Review of Hypoptheses of Formation of Earth's Moon.*

In all these theories, the mechanism of the Moon formation depends on the initial conditions, which are different from one theory to another. Particularly, the mass of the Moon has to be just that which is known to us. But it seems to authors of the present work that all mentioned theories consider too narrow local environments and, therefore, the initial conditions have to be widely different. For example, the fission theory considers only the Earth and its spin and uses the gravitational law. Capture theory does not consider the place of formation of the Moon, but only uses, as the most important physical basis, the gravitational field of the Earth. Similar objections are valid for all other theories.

Among these theories, the giant impact theory is favoured by most astronomers. The main reason for this choice is the analysis of the lunar materials (brought by astronauts) and comparison with terrestrial ones.

In the following section, the common properties of the planets in terrestrial system are considered with the aim to present a regularity of the most important parameters like orbital radii, masses, volumes, densities, orbital periods and angular momenta.

2. The model and analysis of observational data

The authors' previous works on the model have been published in Refs. [1a,b,c,d], and Refs. [1c] and [1d] were reprinted in original form in Ref. [2] (1d at p. 1 – 6 and 1c at p. 7 – 19). The results presented in Ref. [1d] were confirmed and extended in Ref. [3].

It has been found that the distribution of planetary (circular) orbits is given by the square law

$$r_n = r_1 n^2 \, . \tag{1}$$

Such distribution is valid for all subsystems in the solar system, i.e. terrestrial planets, Jovian planets, and systems of main satellites of Jupiter, Saturn and Uranus.

The details may be found in Ref. [1c]. The constant r_1 is system dependent and n is a series of successive integers of orbits, which depends on the particular properties of a system. Distribution of orbits (1) is a direct consequence of the quantization of specific angular momentum J_{ns}

$$J_{ns} = J_n/m_n = v_n r_n \, , \tag{2}$$

where $J_n = m_n v_n r_n$ is the orbital angular momentum of the body at the n-th orbit.

Newton's laws give the speed at the orbit as $v_n = \sqrt{GM/r_n}$ and it follows that

$$J_{ns} = \sqrt{GMr_n} = const \times n \, . \tag{3}$$

G is the gravitational constant and M is the mass of central body. Eq. (1) follows from Eq. (3).

Equation (3) in the form $\sqrt{r_n} = const \times n$ applied to terrestrial planets is graphically presented in Fig. 1. The straight line, obtained by linear regression (without taking the Moon into account), gives the orbital radius for the Moon at $n = 7$ equal to $r_7 = (3.1 \pm 0.1) \times 10^{11}$ m or (2.07 ± 0.07) AU. Data are taken from Ref. [4]. The square roots of orbital radii are plotted as a function of orbital numbers n. Orbits at $n = 1$ and $n = 2$ are empty due to the vicinity of the Sun [1]. One can see that at $n = 3$ is the Mercury (Me) orbit, at $n = 4$ the Venus (V) orbit, at $n = 5$ the Earth (E) orbit, at $n = 6$ the Mars (Ma) orbit, $n = 7$ is empty orbit and at $n = 8$ is the Ceres (Ce) orbit. We put forward the hypothesis that the Moon was born at the orbit n=7 and that it was its primordial orbit. Therefore, in Fig. 1, the marking Moon? associated to the open circle indicates our hypothesis. This means that the Moon should be considered as the penultimate

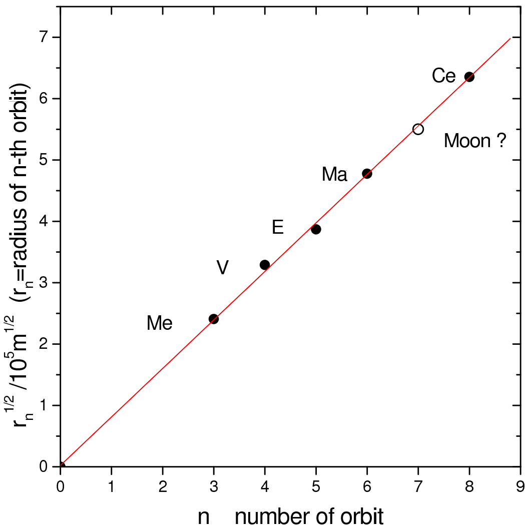

Fig. 1. Square root of orbital radii as a function of orbit numbers.

planet in the terrestrial set of planets. The minor planet-asteroid Ceres together with all asteroids could be regarded as remnants of the ultimate terrestrial planet which has never been formed. However, in our articles in Ref. [1], Ceres has been taken on equal footing with other terrestrial planets. Recently, the observations by NASA's Hubble Space Telescope suggest that Ceres could be a "mini planet" (see, for example on Internet [5], where also the physical parameters are listed).

The hypothesis that the Moon is terrestrial planet formed at the orbit between Mars and Ceres is supported by analysis of some observable parameters of the planets. The logarithm of mass m_n of planets as a function of the number of orbit n is shown in Fig. 2. Data are taken from Ref. [4]. The curve represents a polynomial fit

$$\log m_n = 11.3156 + 6.797\, n - 1.034\, n^2 - 0.0422\, n^3, \tag{4}$$

that at present has no theoretical background, but is useful to point out the general behaviour. The known mass of the Moon located at hypothetical orbit $n = 7$ fits nicely to the function given by Eq. (4)

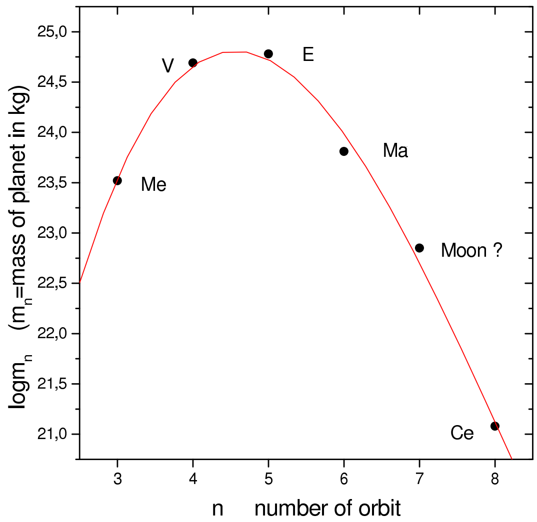

Fig. 2. Logarithm of planetary masses as a function of orbit numbers.

The next parameter of terrestrial planets is their volume. According to the available data [4], the volume dependence on the number of orbit n is shown in Fig. 3. A polynomial fit to the experimental points is given by

$$\log V_n = 7.968 + 6.569\, n - 0.999\, n^2 + 0.0413\, n^3. \tag{5}$$

Using Eqs. (4) and (5), it follows that

$$\log \rho_n = 3.3467 + 0.227\, n - 0.3564\, n^2 + 0.00092\, n^3. \tag{6}$$

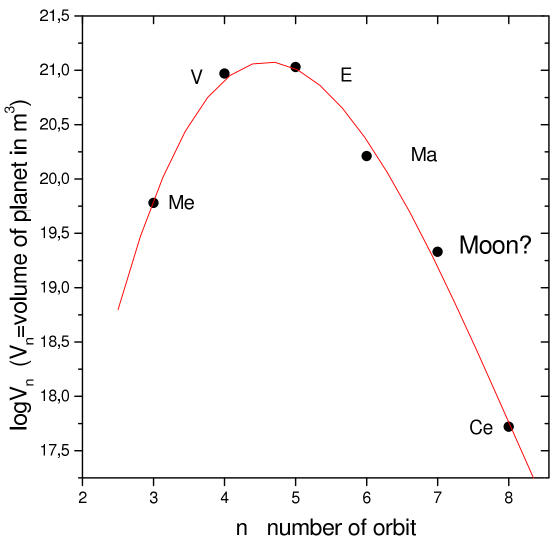

Fig. 3. Logarithm of planetary volumes as a function of orbit numbers.

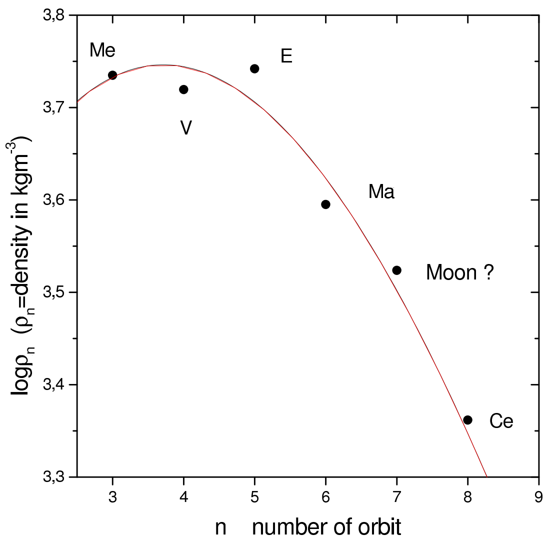

Fig. 4. Logaritm of planetary densities as a function of orbit numbers.

Figure 4 shows a good agreement of tabulated values for densities given in Refs. [4] and [5] with values calculated by Eq. (6).

The last parameter considered here is the orbital period T_n of planets. According to the Kepler's third law, the period of revolution is $T_n = 2\pi/\sqrt{GM} \times \sqrt{r^3}$, and using Eq. (3) it follows that

$$T_n^{1/3} = const \times n\,. \tag{7}$$

The third root of observational orbital periods as the function of the number n of orbits is a linear function presented in Fig. 5. Equation (7) may be undestood as the quantum presentation of the Kepler's third law.

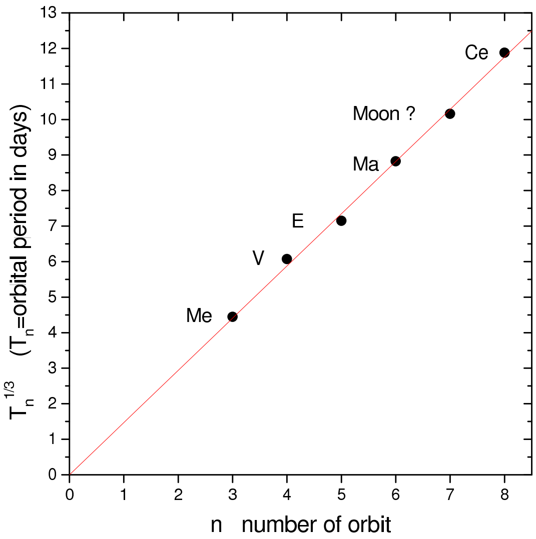

Fig. 5. Third root of orbital periods as a function of orbit numbers.

Linear regression without the Moon gives $T_n = \left[(1.47\pm0.01)\,n\right]^3$. Consequently, for $n = 7$, the orbital period of Moon around the Sun is thought to have been (1089 ± 23) days.

3. *Conclusion*

The analysis of observational data of terrestrial planets using the model of quantized orbits, presented in this work, enables one to assume that the Moon was born at the orbit denoted by $n = 7$, i.e. at the orbit between Mars and Ceres at orbital radius 3.1×10^{11} m (2.07 AU), with the orbital period of 1089 days.

Presently, the Moon is the Earth's satellite. Therefore, it has not had a significant change in its mass in the transfer from its initial orbit to the orbit around Earth. This statement favours the unpopular capture theory of the Moon by Earth's gravitational field. The physical laws of conservation of angular momentum and kinetic energy do not permit a simple transition from the seventh orbit to the fifth orbit of the Earth. However, the physical laws could be satisfied if the push-pull tidal theory is employed in the process of capture of the Moon by the Earth [6]. Tidal effects and the capture of Moon are also presented in Ref. [7].

The problem is: why the Moon started its travel from its primordial orbit? It is well known that Kirkwood gaps appear at Jupiter's main resonances 2:1, 3:1 and 4:1. If the Moon was located at orbit $n = 7$, then the orbital periods $T_{\rm Moon} = 1089$ days and $T_{\rm Jupiter} = 4333$ days define the ratio 4333/1089=3.98 which is close to 4:1. Close to the Jupiter resonance 4:1 is the Earths resonance 1:3, because the corresponding ratio $T_{\rm Earth}/T_{\rm Moon} = 365/1089 = 0.335$ is close to $1/3$. Perhaps the interaction of the Moon at orbit $n = 7$ with Jupiter and Earth forced the Moon to abandon its original orbit and to begin its travel. However, the conservation laws require a third body to absorb the excess energy and angular momentum. Maybe an additional interaction of the Moon with Mars is necessary to understand the dynamics of the Moon's voyage to Earth. However, this has to be the subject of further investigations and here has to be understood only as an idea without firm arguments. What we like to point out in this work is the following question: How is it possible that whichever of the existing theories mentioned in the introduction could give the present parameters of the Moon which are of a reasonable behaviour compared to relevant physical properties of other terrestrial planets. We modestly think that it is very unlikely that processes in creation of the Moon according to the existing models could fulfil this requirement. For example, according to the giant impact theory, a planetesimal of the order of size of Mars struck off-center the young Earth. After collision, the total mass was finally divided into two masses with deliberated energy and some mass is lost in space. However, the Earth was born in the solar nebula at the same time as other terrestrial planets and pressumably the Moon, too. The quantization of orbital radii and specific angular momenta of terrestrial planets suggest that giant cataclismic impact should be revised. Recently, the exploration of the Moon by NASA confirmed that the signs of water were found at the bottom of the crater Cabeus and, moreover, water was found in minerals and in all sorts of places. Also it is suspected that that blocks or sheets of ice exist under surface in the depths of the Moon [8,9]. All this means that Moon contains volatile materials what is not in accord with the theory of giant impact. Perhaps the combination of capture theory and a weak almost tangential impact of the Moon with Earth could be a favourable explanation for the origin of the Moon. Obviously, this is only a hypothesis, which requires further investigations.

In conclusion, we argue that the Moon was born at the orbit located between Mars and Ceres in a definite order with all terrestrial planets. This is our answer to question given in the title of this work.

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GDJE JE NASTAO MJESEC?

Naša se postavka zasniva na približnoj raspodjeli kružnih staza zemaljskih planeta, koja je dana kvadratnim zakonom $r_n = r_1 n^2$, gdje su n-ovi uzastopni cijeli brojevi počevši od $n = 3$ za Merkur, sa $n = 6$ za Mars i $n = 8$ za Ceres, a r_1 je konstanta. Kvadratna raspodjela staza je izravna posljedica kvantizacije specifičnog momenta impulsa. Analiza neovisnih podataka opažanja, tj. masa planeta, njihovih volumena i staznih perioda čini mogućom tvrdnju da je staza s $n = 7$, između Marsa i Ceresa, bila prvotna staza Mjeseca. Ova tvrdnja podupire teoriju Zemljinog uhvata Mjeseca. Zašto je Mjesec napustio svoju prvotnu stazu i kako je uhvaćen Zemljom ostaje kao zadatak daljnjih istraživanja.