COSMOLOGICAL MODEL FREE OF SINGULARITY AND INFLATION BASED ON THE LARGE NUMBERS HYPOTHESIS

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Abstract

It is shown that the new precise formulation of the Large Number Hypothesis (LNH), relating by means of the large number $N_0 = \sqrt{c^5/(2G\hbar H_0^2)}$ = 5.73×10^60 the modern cosmological parameters (age, size, mass, average density, and minimum temperature of the universe) with the corresponding Planck units, allows to determine the time course of these cosmological parameters during the expansion. It was found that the dimensions and mass of the universe increase linearly with time from Planck time $t = t_P$ to the present day, starting from Planck values and increasing $N_0 = 5.73\times10^{60}$ times to now. The amazing result was found that for each discrete time step (beat) with a unit Planck time $\Delta t = t_P$, the size of the universe increases by one Planck length l_P and its mass increases by one Planck mass m_P.

It is shown that the average density of the universe decreases proportionally to the square of time, and starting from the Planck density $\rho_P \sim 10^{96}$ kg m^{-3} decreases $N_0^2 = 3.28\times10^{121}$ times to 9.46×10^{-27} kg m^{-3} in the current epoch. The minimum measurable temperature, which is equal to the Hawking temperature for the universe T_H decreases linearly with time 5.73×10^{60} times, and starting from the Planck temperature $T_P = 10^{32}$ K, it falls to 1.75×10^{-29} K at the present time. It is shown that the found time course of cosmological parameters and the Planck values of the size, mass, average density, and temperature of the universe at the initial moment of the expansion $t = t_P$ follow from the requirement to preserve the Euclidean geometry of space throughout the time of the cosmological expansion.

Therefore, the suggested cosmological model based on the new formulation of LNH is free of singularity because the size and density of the universe remain finite/Planckian in the initial moments of its emergence. Besides, this model conserves the flatness and homogeneity of the universe during cosmological expansion and does not need an inflationary epoch in the early universe.

Keywords: cosmological model, free of singularity, large numbers hypothesis

1. INTRODUCTION.

The question of the origin of the world in which we live has excited humanity since ancient times. In order to explain the origin of the world and man, peoples have created many myths in which the main role is assigned to the gods. It was only after the creation of powerful modern telescopes that it became possible to create a real picture of the scale and structure of the universe. After the creation of General relativity [1], an opportunity was opened to study the origin and evolution of the universe as a whole. It was found that the solutions of Einstein's equations are non-stationary [2, 3], which is why the universe changes its scale and density with time. The discovery of Hubble's law [4], according to which the red shift in the spectrum of distant galaxies is proportional to the distance to the observer, is an experimental confirmation that the distances between galaxies increase with time, i.e., the universe is expanding. Approximating this process back in time, astrophysicists conclude that all the matter of the universe billions of years ago was concentrated in a very small (perhaps even a pointlike) region of enormous density and temperature. The discovery of Cosmic Microwave Background Radiation (CMBR) having a thermal spectrum [5] represents crucial evidence for the expansion of the universe from a small region of high density and temperature. The CMBR was predicted earlier [6] as a result of the universe becoming transparent to photons when its average temperature falls below 3000 K in the epoch of recombination. During the cooling of the photons in the process of the expansion of the universe, the radiation temperature falls to 2.725 K nowadays [7]. Based on measurements of the expansion using Type Ia supernovae and measurements of temperature fluctuations in CMBR, the time that has passed since that event known as the Big Bang is 13.8 billion years [8]. This cosmological model was called the Big Bang, and is accepted by the vast majority of modern astrophysicists. This model offers an explanation for a broad range of observed phenomena, including the abundance of light elements, CMBR, helium abundance, and large-scale structure. However, physics currently lacks a widely accepted theory of quantum gravity that can successfully model the earliest conditions of the Big Bang. By using distant SNeIa as standard candles, the expansion of the universe was found to be accelerating, which acceleration was attributed to the existence of Dark energy Λ with a density several times that of baryonic and dark matter [9, 10]. This variant of Big Bang cosmology is known as the Lambda cold dark matter (ΛCDM) model or Standard model and represents the mainstream of modern cosmology. Below are presented the main stages of the expansion of the early universe according ΛCDM.

Extrapolation of the expansion of the universe backwards in time using general relativity yields an infinite density and temperature at a finite time in the past [11]. This irregular behavior, known as the gravitational singularity, indicates that general relativity is not an adequate description of the laws of physics in this regime. Models based on general relativity alone cannot fully extrapolate toward the singularity [12]. During the first one second of the universe's existence, violent and dramatic processes took place that formed the structural elements of matter that make up the universe. Gravitational, strong nuclear, and finally weak nuclear interactions are successively separated (freeze out) from the unified interaction [13]. During this first second of the universe's existence, its density and temperature drop by tens of orders of magnitude, and quark-gluon plasma is formed [14]. After that, the quarks and gluons combine, and the hadrons (protons, neutrons, etc.) are formed. From approximately 10^{-37} s to 10^{-33} s, the phase transition caused a cosmic inflation, during which the universe grew exponentially and its volume increased by a factor of at least 10^{78}. The cosmic inflation gives a solution to the flatness problem, where the density of matter and energy is very close to the critical density needed to produce a flat universe, and to the horizon problem connected high homogeneity and isotropy of CMBR. [15]. A few minutes into the expansion, when the temperature falls below 10^9 K the neutrons combine with protons to form helium nuclei in a process called Big Bang nucleosynthesis [16]. This produces one helium nucleus for every 12 hydrogen nuclei (free protons), resulting in a universe that is a little over 8% helium by number of atoms, and 25% helium by mass. About 370 000 years after the Big Bang, neutral hydrogen atoms were formed by the recombination of protons and electrons, and the universe became transparent for the first time. The newly formed atoms hydrogen and helium quickly reach their lowest energy state by releasing photons (photon decoupling), and these photons can still be detected today as CMBR [17]. About 100–150 million years after the Big Bang, the first stars form, and the modern era of galaxies begins. Galaxies, quasars, black holes, star clusters, gas clouds, and other astronomical structures observed today formed over the next billions of years. The dark-energy-dominated era starts about 9.8 billion years into cosmic time, and observations show that the expansion of the universe slowly stops decelerating and gradually begins to accelerate again instead [18]. For a dark-energy-dominated universe, the evolution of the scale factor R is obtained by the solution of the Friedmann equations $R(t)$ = const $\exp(H_0\ t)$, where H_0 is the contemporary value of the Hubble parameter. The description assuming dark energy is used in the current standard model of cosmology, which also includes cold dark matter and is known as the ΛCDM model. In this model, cold dark matter is estimated to make up about 26% of the matter/energy of the universe, while baryonic matter makes up about 5%, and the rest 69%, represents dark energy accelerating the expansion [8].

The main alternative models to Big Bang cosmology are briefly presented below, although modern astrophysical observations do not support them.

According to the Tired Light Hypothesis [19], the increase in redshift in the spectra of galaxies with increasing distance to the observer is due to the loss of photon energy during their journey from the source to the observer. It has been suggested that the reason for the photon energy loss is the Compton scattering of photons, in which the photon energy decreases exponentially with the distance $E_r = E_0 \exp(-r/D_H)$, where D_H is the Hubble distance. According to this hypothesis, the universe is static and not expanding R = const, $\bar{\rho}$ = const. As a result of the Compton scattering of photons on electrons, blurring of distant galaxies should be observed, which is not confirmed by the observations. Besides, the discovery of CMBR [5] represents strong evidence for the expansion of the universe from a small, dense region of high temperature (Big Bang, Hot Universe) and since then Tired Light Hypothesis for a static universe is outside the mainstream of modern cosmology.

The steady-state model [20, 21] asserts that although the universe is expanding, it nevertheless does not change its appearance over time (the perfect cosmological principle), and the universe has no beginning and no end. This required that matter be continually created in order to keep the universe's density from decreasing. The discovery of CMBR in 1965 having a thermal spectrum of an ideal black body with a temperature of 2.72 K is crucial evidence of a hot and dense early universe and rejects the steady-state model, according to which the universe does not change its state in the process of expansion ($\bar{\rho}$ = const, T = const).

Paul Dirac [22] suggested the Large Numbers Hypothesis (LNH), pointing out that the ratio of the age of the universe H^{-1} and the strong time scale $\tau = e^2/(m_e c^3) \sim 10^{-23}$ s is a large number of the order of 10^{40}. Besides, the ratio of electrostatic e^2/r^2 and gravitational forces $Gm_e m_p/r^2$ between proton and electron in a hydrogen atom is of the order of 10^{39} and the ratio of the mass of the observable universe M to the nucleon mass is roughly of the order of 10^{80}. That is to say:

$$\frac{H^{-1}}{\tau} \sim \frac{e^2}{Gm_e m_P} \sim \sqrt{\frac{M}{m_p}} \sim N_D \sim 10^{40} \tag{1}$$

where m_p is the proton mass and $N_D \sim 10^{40}$ is the Dirac large number.

Based on the ratios (1), he proposed that, as a consequence of causal connections between the macro and microphysical worlds, the gravitational constant G decreases linearly with time G = const t^{-1}. Besides, according to the original formulation (1) of Dirac LNH, the mass of the universe should increases quadratically with time M = const t^2. Therefore, the average density of the universe $\bar{\rho}$ is:

$$\bar{\rho} = \frac{M}{V} = \frac{const.t^2}{const.t^3} = const\ t^{-1} \tag{2}$$

Other alternative models of the Big Bang are known, such as modified Newtonian dynamics, entropic gravity, bimetric gravity, scale invariance of empty space, decaying dark matter, etc. Although most of these models have been rejected by observations, they have historical value in the search for an adequate cosmological model.

A new precise formulation of LNH has been found in [23] connecting cosmological parameters and Planck units. The large number $N_H = \sqrt{c^5/(2G\hbar H^2)}$ connects cosmological parameters (mass of the Hubble sphere, Hubble distance, age of the universe, density of the universe, and minimal measurable temperature of the universe) and the respective fundamental ultramicroscopic properties of matter (Planck mass, Planck length, Planck time, Planck density, and Planck temperature):

$$\frac{M_H}{m_P} = \frac{cH^{-1}}{l_P} = \frac{H^{-1}}{t_P} = \sqrt{\frac{\rho_P}{\bar{\rho}}} = \frac{T_P}{T_H} = \frac{m_P}{m_H} = \sqrt{\frac{M_H}{m_H}} = \sqrt{\frac{c^5}{2G\hbar H^2}} = N_H \tag{3}$$

where $$m_P = \sqrt{\frac{\hbar c}{2G}}, l_P = \sqrt{\frac{2G\hbar}{c^3}}, t_P = \frac{l_P}{c} = \sqrt{\frac{2G\hbar}{c^5}}, \rho_P = \frac{3}{16\pi}\frac{c^5}{\hbar G^2}, T_P = \frac{m_P c^2}{k_B} = \sqrt{\frac{\hbar c^5}{2Gk_B^2}} \tag{4}$$

are precise values of the Planck units (mass, length, time, density, and temperature) recalculated with a definition of Planck mass as a mass whose Compton wavelength and gravitational radius are equal. These values are very close to standard Planck units obtained from Max Planck by dimensional analysis [24]. M_H is the mass of the Hubble sphere, $t = H^{-1}$ – age of the universe, cH^{-1} – Hubble distance, $\bar{\rho} = \rho_c$ – density of the universe, T_H – lowest limit of measurable temperature equal to Hawking temperature for a black hole having the mass of the Hubble sphere, m_H – minimal measurable mass/energy close to the graviton mass. At the present moment $t = t_0$, the Hubble parameter H has a value of H_0 = 68 km/s Mps = 2.3×10^{-18} s^{-1} [8], and the large number $N(t_0) = N_0 = \sqrt{c^5/(2G\hbar H_0^2)} = 5.73\times10^{60}$.

These amazing connections between the microworld and the megaworld are very interesting and exciting because they show that the world is structured from the deepest (Planckian) level to the largest (cosmological) level. It remains an open issue as to the reason for the existence of these deep but unclear connections. In the next sections, we will show that the reason for the appearance of these connections is rooted in the very genesis and development of the universe from the quantum vacuum—the Hot Big Bang free of singularity and inflation.

2. COSMOLOGICAL MODEL BASED ON THE LARGE NUMBERS HYPOTHESIS.

First, we will try to reveal the physical meaning of the large number N_H connecting cosmological parameters and Planck units. We will then find the time course of the size, mass, density, and temperature of the universe from the earliest moments after the Big Bang (Planck era) to the present day. From equation (3) we find:

$$N_H = \sqrt{\frac{c^5}{2G\hbar H^2}} = \frac{1}{Ht_P} = \frac{t}{t_P} \tag{5}$$

Therefore, the mysterious large number N_H represents the age of the universe in Planck time units (t_P = 7.59×10^{-44} s). Due to the quantization of time, it does not take continuous values, but grows with a step t_P. Obviously, at the initial moment of the expansion $t = t_P$ the number N_H takes a minimal value $N_H = 1$, at the next moment $t = 2t_P$, $N_H = 2$, and increasing proportionally to the time t reaches a value $N_0 = \sqrt{c^5/(2G\hbar H_0^2)}$ = 5.73×10^{60} in present time. In other words, it can be said that the large number N_H connecting the cosmological parameters to the corresponding Planck units represents the number of beats of the "cosmological clock" from the Big Bang to the moment $t \sim H^{-1}$. It follows from (3) that the large number N_H also determines the size and mass of the universe: $N_H = cH^{-1}/l_P$ and $N_H = M_H/m_P$ in the moment $t \sim 1/H$ in Planck units.

Since $t = H^{-1}$, it follows from equation (5) that at the initial moment of the emerging of the universe $t = t_P$, $H = t_P^{-1} = \sqrt{c^5/(2G\hbar)}$. Substituting into equation (3), we get that at this moment $N_H = 1$, the initial mass of the universe $M_H = m_P$ =1.54×10^{-8} kg, the size/radius $R = cH^{-1} = l_P$ = 2.28×10^{-35} m, the density $\bar{\rho} = \rho_P$ = 3.1×10^{95} kg m^{-3}, the temperature of Hawking radiation $T_H = T_P$ = 10^{32} K, and the minimal possible mass/energy $m_H = m_P$ = 1.54×10^{-8} kg.

From (3) and (4), we find:

$$cH^{-1} = R = N_H l_P = \frac{t}{t_P} ct_P = ct \tag{6}$$

Therefore, the universe expands with the speed of light c, and its size increases proportionally to time, starting from Planck length at Planck time and reaching cH^{-1} = 13.8 billion light years in present time, i.e., increasing N_0 = 5.73×10^{60} times.

We find from equations (3), (5), and (4):

$$M_H = N_H m_P = \frac{m_P}{t_P} t = \frac{c^3}{2G} t = \frac{c^3}{2GH} = 2.02\times10^{35}\, t \tag{7}$$

Apparently, the mass of the universe increases proportionally with time, starting from the Planck mass m_P at the Planck time t_P and reaching 8.8×10^{52} kg at the present time, i.e., increasing of N_0 = 5.73×10^{60} times.

The mass growth rate of the observable universe is determined by (8):

$$\dot{M} = \frac{dM}{dt} = \frac{m_P}{t_P} = \frac{c^3}{2G} = 2.02\times10^{35}\ \text{kg s}^{-1} \tag{8}$$

Since the mass of the Sun is 2×10^{30} kg, it can be said that the mass of the observable universe is increasing at a constant rate of 10^5 solar masses per second. This result is close to that obtained in [25] by dimensional analysis.

The relative increase in the mass of the universe is determined by equation (5):

$$\frac{\dot{M}}{M} = \frac{c^3/2G}{M} = \frac{c^3/2G}{c^3/2GH} = H = 2.3\times10^{-18}\ \text{kg s}^{-1}/\text{kg} \tag{9}$$

In the modern stage of expansion of the universe, the relative increase in its mass is only 2.3×10^{-18} s^{-1}, but in the early universe this increase was much faster and reached $1/t_P$ = 1.32×10^{43} s^{-1} at Planck time, i.e., 5.73×10^{60} larger than the modern one.

From equations (3), (5), and (4), we obtain the equation (11) for the average density of the universe at time t:

$$\bar{\rho} = \frac{\rho_P}{N_H^2} = \frac{\rho_P}{(t/t_P)^2} = \frac{\rho_P t_P^2}{t^2} = \frac{3}{8\pi G}\frac{1}{t^2} = 1.79\times10^{9}\, t^{-2} \text{ kg m}^{-3} \tag{10}$$

Replacing $t \sim H^{-1}$ in (10) we find:

$$\bar{\rho} = \frac{3}{8\pi G} H^2 = \rho_c \tag{11}$$

This equation shows that the density of the universe always remains equal to the critical one and decreases with the square of time, starting from Planck density $\bar{\rho} = \rho_P$ = 3.1×10^{95} kg m^{-3} at Planck time and decreasing to 9.46×10^{-27} kg m^{-3} in present time, i.e., falling N_0^2 = 3.28×10^{121} times! Therefore, according to the new formulation (3) of LNH, the density of the universe is always equal to the critical one, and the global geometry of the universe remains Euclidean in the process of cosmological expansion.

On the other hand, the original formulation of Dirac LNH is not capable of providing Euclidean geometry of the space during the expansion because of the linear decreasing of density (2) and the quadratic decreasing of critical density ρ_c.

From equations (3), (5), and (4), it follows that the temperature of Hawking black hole radiation is:

$$T_H = \frac{T_P}{N_H} = \frac{T_P}{t/t_P} = \frac{T_P t_P}{t} = \frac{\hbar}{k_B}\frac{1}{t} = 7.64\times10^{-12}\, t^{-1} \text{ K} \tag{12}$$

Equation (12) shows that the Hawking temperature for the universe decreases proportionally with time, starting from the Planck temperature $T_H = T_P = 10^{32}$ K at the Planck time and decreasing to a recent value of 1.75×10^{-29} K, i.e., falling N_0 = 5.73×10^{60} times. It has been found [26] that the Schwarzschild radius of the observable universe $R_S = 2GM/c^2$ is equal to the Hubble distance. Therefore, the universe has black hole properties and could be considered a hypermassive black hole with very low density at the present time.

As mentioned above, it follows from equation (5) that the large number N_H is a positive integer that defines the age of the universe in Planck time units, i.e., $t = N_H t_P$. That is, cosmic time is discrete and increases by $\Delta t = t_P$ at each tick of the cosmological clock. From equation (6), we find that for a time interval $\Delta t = t_P$, the size of the universe increases by $\Delta R = c\Delta t = ct_P = l_P$, i.e., with 1 Planck length. From (7), we find that for a time interval $\Delta t = t_P$ the mass of the universe increases by $\Delta M_H = \frac{m_P}{t_P}\Delta t = m_P$. It is amazing that for each discrete step (beat) of cosmological time by one Planck time unit $\Delta t = t_P$ = 7.59×10^{-44} s, the size of the universe increases by one Planck length $\Delta R = l_P$ = 2.28×10^{-35} m, and the mass increases by one Planck mass $\Delta M = m_P$ = 1.54×10^{-8} kg. This striking result provides further support for the suggested model.

The time course of these cosmological parameters during the expansion is shown in Fig. 1.

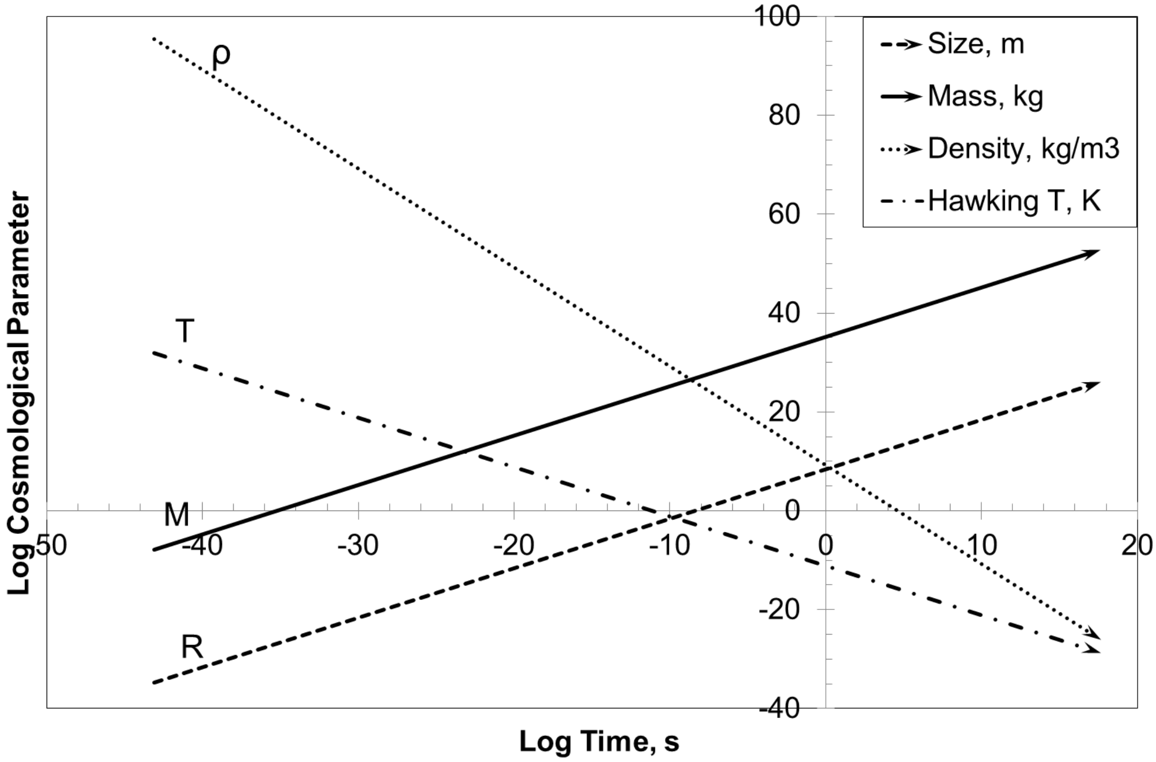

Fig. 1 Time course of cosmological parameters during the expansion.

According to the Standard cosmological model, all the mass/energy of the universe remained unchanged in the expansion process, and at the beginning of the Big Bang, it was concentrated in a single point region, resulting in a singularity associated with infinite values of the density and temperature of the universe. In our suggested model, the singularity is avoided because the mass of the universe at the initial moment of expansion (Big Bang) $t = t_P = 7.59\times10^{-44}$ s is equal to the Planck mass m_P, the size of the universe is equal to the Planck length l_P, and density and temperature are equal to the Planck density ρ_P and Planck temperature T_P, respectively. Thus, the size of the universe remains extremely small but still finite, and the density is enormous but also finite. Therefore, the model is free of singularity. The total density of the universe remains equal to the critical density of the universe $\rho_c = 3H^2/(8\pi G)$, and the geometry of the universe remains asymptotically flat (Euclidean) during cosmological expansion. Because of the random nature of quantum processes, the entry of new mass from the physical vacuum into the expanding universe proceeds practically homogeneously throughout its volume, it follows that the distribution of matter remains homogeneous during the expansion, and the currently registered CMBR is highly homogeneous and isotropic. Therefore, there is no need to introduce an inflationary epoch to ensure the flatness of space, and the homogeneity and isotropy of CMBR, and the model is free of inflation.

3. CONSERVATION OF THE CRITICAL DENSITY OF THE UNIVERSE DURING THE EXPANSION SUPPORTS THE LARGE NUMBERS HYPOTHESIS SCENARIO.

In [26] it was shown that if the experimentally established fact [27] that the average density of the universe is close to critical $\bar{\rho} = 3M/(4\pi R^3) \approx \rho_c = 3H^2/(8\pi G)$ is valid for the *entire* period of the cosmological expansion, it follows that the mass of the observable universe M is determined by Eq. (13):

$$M = \frac{H^2\ R^3}{2G} = \frac{c^3}{2GH} = \frac{c^3}{2G}t \qquad (13)$$

where G is the Newtonian gravitational constant, c – the speed of light in a vacuum, H – the Hubble parameter, and $R \sim c/H$ – the size of the observable universe.

The equation (13) has also been found by means of dimensional analysis [28] and is close to the Hoyle equation for the mass of the universe [20] found in the framework of the steady-state model. Obviously, in order to keep the density of the universe equal to the critical one (as a result of which the geometry of the universe remains Euclidean) throughout the expansion time, it is necessary that the mass of the observable universe increases in proportion to cosmological time.
From equation (13), one can determine the mass of the observable Universe at the initial moment of expansion, i.e., Planck time $t = t_P$:

$$M(t_P) = \frac{c^3 t_P}{2G} = \sqrt{\frac{c\hbar}{2G}} = m_P = 1.54\times10^{-8}\text{ kg} \quad (14)$$

That is, at the initial moment of the universe's expansion t_P, its mass was equal to the Planck mass. The size of the universe at time t_P was $R(t_P) = ct_P = l_P$, i.e., on the order of the Planck length $l_P = \sqrt{2G\hbar/c^3} = 2.28\times10^{-35}$ m. Therefore, the density of the universe was:

$$\bar{\rho}(t_P) = \frac{3m_P}{4\pi l_P^3} = \frac{3}{16\pi}\frac{c^5}{\hbar G^2} = \rho_P = 3.1\times10^{95}\text{ kg m}^{-3} \quad (15)$$

That is, at the initial moment of Planck time $t_P \sim 10^{-43}$ s, the universe was a mini black hole (Planck particle, planckion) having Planck mass, Planck size, and Planck density [29].
The Hawking temperature [30] for a black hole having mass m_P is:

$$T_{BH} = \frac{hc^3}{8\pi G k_B m_P} = 5\times10^{31}\text{ K} \sim T_P \quad (16)$$

where $k_B = 1.38\times10^{-23}$ J K^{-1} is the Boltzmann constant.

Therefore, the Hawking temperature of the universe at Planck time is of the order of Planck temperature $T_P \sim 10^{32}$ K.

Although the mechanism of the linear increase in the mass of the universe is currently unknown, it is most likely that the newly created mass in the universe enters from the physical (quantum) vacuum and is distributed uniformly throughout the universe due to the random nature of the quantum processes. It is known that the energy of quantum vacuum associated with zero-point energy is ~ 10^{120} times larger than dark energy [31, 32], i.e., of the order of magnitude of the Plank density $\rho_P c^2 \sim 10^{112}$ J/m^3. Zero-point energy is a real physical quantity and manifests itself in a number of physical phenomena such as the Casimir effect [33], the Lamb shift [34], and vacuum birefringence [35]. Therefore, it seems plausible to assume that, as a result of some disturbance or disturbance of equilibrium/symmetry of the vacuum, a space-time cell of Planck size will break away from the quantum vacuum and become the seed of our expanding universe. This Planck particle (the lightest black hole) is joined by a new Planck particle from the quantum vacuum for each tick of cosmological time of duration $\Delta t = t_P \sim 10^{-43}$ s, and thus the mass of the universe increases by ~ 100,000 solar masses per second from its emergence until now. Due to the statistical nature of quantum transitions of matter from the physical vacuum into the expanding universe, the distribution of matter in the early moments of its existence, when the number of particles was small, deviated significantly from the homogeneous one. Under the influence of gravity, these early fluctuations in the density of the universe grew into large-scale concentrations of matter, from which galaxies, galactic clusters, and superclusters arose. Obviously, the requirement to keep the density of the universe close to the critical one during cosmological expansion supports the time course of the physical parameters of the universe (mass, size, density, and temperature) obtained by means of the new precise formulation of the LNH. Therefore, the suggested cosmological model based on the new formulation of LNH is free of singularity because the size and density of the universe remain finite/Planckian in the initial moments of its emergence. Besides, this model conserves the flatness and homogeneity of the universe during cosmological expansion and does not need an inflationary epoch in the early universe. Within the framework of the suggested model, the question of the existence and properties of our universe before the moment t_P is dropped due to the fact that space and time are quantized and there is no smaller time interval than t_P and no smaller spatial region than l_P. Our universe simply did not exist before the moment t_P, and the universe emerged by a quantum jump when the matter m_P from the physical vacuum entered a region of size l_P for a time interval t_P.

Since, due to the random nature of quantum processes, the entry of new mass into the expanding universe proceeds practically homogeneously throughout its volume, it follows that during their formation and youth, galaxies had many times less mass than the modern one. Indeed, the Hubble ultra-deep field shows that distant young galaxies are significantly smaller than modern ones [36]. The larger size of modern galaxies is explained in the Standard cosmological model by the merger of smaller galaxies as a result of collisions between them over billions of years. Although such processes are observed, they are unlikely to be common enough in the universe to explain the large size of modern galaxies [37]. According to the suggested Big Bang model based on the large numbers hypothesis, not only the mass of the universe but also the masses of galaxies M_G increase linearly with time M_G = const.t, i.e., $M_G(0)/M_G = t_0/t$. Therefore, if a galaxy 200 million years old had a mass M_G, its mass now would be $M_G(0) = 1.38\times10^{10}/2\times10^{8}\ M_G = 69\ M_G$, i.e., 69 times larger. This is one of the first pieces of evidence in support of the new cosmological model with increasing mass of the universe.

Another way is to attempt to directly detect the influx of new mass/energy into the universe. According to equation (10), the relative increase in the mass of the universe in the current epoch $\dot{M}/M = H = 2.3\times10^{-18}$ kg s^{-1}/kg. The equivalent amount of energy created in 1 s in 1 kg mass will be:

$$\frac{\dot{E}}{M} = \frac{\dot{M}c^2}{M} = Hc^2 = 0.207 \text{ J s}^{-1}\text{ kg}^{-1} = 0.207 \text{ W kg}^{-1} \tag{17}$$

But this mass/energy is created randomly and therefore homogeneously throughout the volume of the entire universe, and therefore this energy will primarily flow into interstellar and intergalactic space. Bearing in mind equation (17), and also that the average density of the universe is close to the critical $\bar{\rho} = \rho_c = 9.46\times10^{-27}$ kg m^{-3}, the amount of energy that is created in 1 s in 1 m^{-3} can be determined at any point in the observable universe:

$$\frac{\dot{E}}{V} = \frac{\dot{E}\bar{\rho}}{M} = Hc^2\rho_c = 1.96\times10^{-27} \text{ W m}^{-3} = 1.22\times10^{-8} \text{ eV s}^{-1}\text{ m}^{-3} \tag{18}$$

This is an extremely low value of energy flow and is beyond the capabilities of modern experiments. However, if the vacuum energy enters the observable universe in the form of mini black holes (Planck particles) with mass $m_P = 1.54\times10^{-8}$ kg and density $\rho_P = 3.1\times10^{95}$ kg m^{-3}, according to [Hawking, 1974] they will evaporate for a time $t_{ev} = 5.12\times10^3\pi G^2M^3/(\hbar c^4) \sim 10^{-40}$ s and release their energy in the form of gamma quanta. In such a case, it would be possible, by means of suitable highly sensitive instruments, to register this emission.

4. CONCLUSIONS AND DISCUSSIONS.

It is shown that the new precise formulation of the LNH, relating by means of the large number $N_0 = \sqrt{c^5/(2G\hbar H_0^2)} = 5.73\times10^{60}$ the modern cosmological parameters (age, size, mass, average density, and Hawking temperature of the universe) with the corresponding Planck units, allows to determine the time course of these cosmological parameters during the cosmological expansion. It has been shown that:

1. The size of the universe is increasing at the speed of light $R = cH^{-1} = N_H l_P = ct$. At the beginning of the expansion $t = t_P = 7.59\times10^{-44}$ s, the size of the universe was equal to the Planck length $l_P = 2.28\times10^{-35}$ m, and growing linearly with time, it reached $cH^{-1} = 1.3\times10^{26}$ m = 13.8 billion light years in present time, i.e., increasing by $N_0 = 5.73\times10^{60}$ times.

2. The mass of the universe is increasing at a rate of $\dot{M} = c^3/(2G) = m_P/t_P = 2.02\times10^{35}$ kg s^{-1}, i.e., 10^5 solar masses per second. It is amazing that for every tick of the "cosmological clock" $\Delta t = t_P$, the size of the universe increases by one Planck length, and the mass of the universe increases by one Planck mass. At the beginning of the expansion $t = t_P = 7.59\times10^{-44}$ s, the mass of the universe is equal to the Planck mass $m_P = 1.54\times10^{-8}$ kg, and after growing $N_0 = 5.73\times10^{60}$ times, it currently reaches 8.8×10^{52} kg

3. The global density of the universe decreases with the square of time $\bar{\rho} = 3t^{-2}/(8\pi G)$ = 1.79×10^{9} t^{-2} kg m^{-3}. Thus, at the initial moment $t = t_P$ the density of the universe was equal to the Planck density ρ_P = 3.1×10^{95} kg m^{-3}, and decreasing to 9.46×10^{-27} kg m^{-3} in present time, i.e., falls N_0^2 = 3.28×10^{121} times.

4. The temperature of Hawking radiation for the universe $T_H = \hbar t^{-1}/k_B$ = 7.59×10^{-12} t^{-1} decreases linearly with time from T_P ~ 10^{32} K at the initial moment t_P to 1.75×10^{-29} K in present time, i.e., it falls by N_0 = 5.73×10^{60} times.

In this way, it turns out that at the initial moment of expansion $t = t_P$ = 7.59×10^{-44} s, the universe was a Planckian black hole with mass m_P = 1.54×10^{-8} kg, dimensions l_P = 2.28×10^{-35} m, density ρ_P = 3.1×10^{95} kg m^{-3}, and temperature T_P = 10^{32} K. Therefore, the suggested cosmological model could be regarded as a variant of the hot Big Bang starting from the Planckian state (mass, size, density, and temperature) free of the singularity inherent of the Standard cosmological model. In the process of cosmological expansion, the size and mass of the universe increase, and the Hawking temperature decreases linearly with time, while the density decreases with the square of time. The total density of the universe remains equal to the critical density throughout the expansion process, as a result of which the geometry of the universe remains flat (Euclidean) and there is no need for an inflationary epoch.

Although the mechanism of the linear increase in the mass of the universe is still unknown, it is most likely that the newly created mass in the universe enters from the physical (quantum) vacuum and is distributed uniformly in the universe due to the random nature of the quantum processes. Thus, the distribution of matter remains practically homogeneous, and there is no need for an inflationary epoch to homogenize the universe. In any case, it is hardly a coincidence that for each discrete time step (tick) of time increase by a unit Planck time $\Delta t = t_P$, the size of the universe increases by one Planck length, and its mass increases by one Planck mass. Possibly, these masses enter from the physical quantum vacuum in the form of mini black holes with masses m_P ~ 10^{-8} kg. Such Planckian black holes explode and release their energy E_P = $m_P c^2$ = 1.39×10^{9} J in time t_P ~ 10^{-40} s as gamma quanta [33].

The main difference between the suggested model and the Standard cosmological model is that, according to the latter, the entire mass/energy of the universe remains unchanged in the process of expansion, and at the beginning of the Big Bang, it was concentrated in a point region with infinite density and temperature. In our suggested model, the singularity is avoided because the mass of the universe at the initial moment of expansion (Big Bang) $t = t_P$ = 7.59×10^{-44} s is equal to the Planck mass m_P, the size of the universe is equal to the Planck length l_P, and density and temperature are equal to the Planckian ones. Thus, the size of the universe remains extremely small but finite, and the density is enormous but also finite, and the model is free of singularity. The mass of the universe increases linearly at a rate $\dot{M} = c^3/(2G) = m_P/t_P$ = 2.02×10^{35} kg s^{-1} = const. The influx of mass/energy into the universe from the physical vacuum at a rate of one Planck mass per Planck unit time ensures that the density of the universe is maintained equal to the critical and the geometry remains flat (Euclidean) during the expansion. The random nature of quantum processes ensures the uniform distribution of Planck particles arriving from the physical vacuum in the universe. Therefore, there is no need to speculatively introduce an inflationary epoch to solve the horizon problem, and the model is free of inflation.

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