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A Model of Accelerated Expansion of the Universe Based on the Idea about a Hypothetical 4-Dimensial Substance with an Inverse Population of Energy Levels

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Abstract

Based on the idea of hypothetical 4-dimensial substance with an inverse population of energy levels, a model of accelerated expansion of the Universe has been developed, which describes Hubble diagrams with great accuracy for type Ia supernovae, quasars and gamma-ray burst sources at the Hubble parameter value of 67.7 km/s/Mpc, coinciding with the value obtained from analysis of inhomogeneities of relic radiation. Calculations at the Hubble parameter value of 73.5 km/s/Mpc, obtained using the ΛCDM model based on the analysis of data on type Ia supernovae and cepheids, differ markedly from the observed data. An explanation of the two values of the Hubble constant is proposed. It is shown that in this model, the magnitude of 13.8 billion years characterizes not the age of the Universe, but the time of propagation of light from those galaxes whose acceleration of removal has a minimal value. Based on the recently discovered curvature of the Universe, estimates are given of the lower limits of its size and lifetime, which turned out to be at least 270 billon years. The probability of transition from the excited state to the underlying energy levels of a hypothetical 4-dimensial substance, as well as the low of increasing energy density as a result of transitions to the underlying levels of this substance, is determined.

Keywords

4-Dimentional Space, Hypothetical 4-Dimensional Substance, 4-Dimensional Spherical Layer, Redshift, Type Ia Supernovae, Quasars, Gamma-Ray Bursts

1. Introduction

As is known [1] [2], when studying the spectra of distant type Ia supernovae, it turned out that the distance to these supernovae, determined by their brightness, is noticeably greater than it was from the redshift estimates. This allowed the authors of these papers to draw conclusions about the accelerated expansion of the Universe and to prove the existence of dark energy associated with antigravity. This exotic property of dark energy still remains, however, misunderstood, despite the many cosmological models currently existing [3]-[12].

In this article, we propose a model of accelerated expansion of the Universe, which is based on the idea of a hypothetical 4-dimensional substance with a reverse population of energy levels. As in [5] [8] [9] [12] in the model under consideration, our Universe is enclosed in a 4-dimensional spherical layer formed in front of an expanding 3-dimensional sphere, inside which there is a source of expansion. "Dark energy", or rather, its source, turns out to be carried outside the Universe. This allows you to abandon the "dark energy" and the association with antigravity. However, unlike [10] [12], the source of expansion has a different nature and geometry. It is assumed that the source is caused by stimulated transitions from upper to lower energy levels, and the 4-dimensional spherical layer is hard. This slows down the increase in the radius of the three-dimensional sphere and has a significant impact on the dynamics of expansion, which leads to agreement with the observed data. All relations are obtained without reference to the standard model of the Universe (ΛCDM model).

It should be noted that, despite the fact that this model in some respects coincides with the Urusovsky model [5], and to a greater extent with the cosmology of Shulman [8], Gogberashvili [9], Potemine [12], differs from them both qualitatively and quantitatively. The main difference is that the dependence of the redshift on the distance to galaxies is obtained without reference to the general theory of relativity, but solely on the basis of the idea of a hypothetical 4-dimensional substance with an inverse population of energy levels.

2. Description of the Model

2.1. Initial Views

The proposed model is based on two postulates. Consider an unlimited 4-dimensional flat Euclidean space with coordinate axes x, y, z, s, filled with some hypothetical substance, relative to which it is assumed that it has some energy levels with inverse population. And although this assumes that the hypothetical substance consists of particles, but these particles, unlike [11], are located inside a 3-dimensional sphere, that is, outside our Universe and their gravitational properties do not matter in this model.

Let it be that in some area of space, due to fluctuations in its characteristics, the release of energy during stimulated transitions from the upper level to the lower one prevails in this area compared to the space surrounding this area. Let's allocate a 4-dimensional volume V_4 in this space, covering the area under consideration, and denote the energy contained in it by the letter Ξ.

The first postulate is that the rate of increase of the energy released in this volume is proportional to the energy itself, as in stimulated transitions from the overlying energy levels to the underlying ones, and is described by the equation

$$\mathrm{d}\Xi/\mathrm{d}t = \kappa\Xi\,, \tag{1}$$

where $\kappa(t)$ is the probability of transition proportional to the inverse population of the lower and upper energy levels of the substance, generally time-dependent. Since the area where more energy is released will increase, the volume covering this area will also increase. In the approximation of a homogeneous energy density ρ_Ξ in a 4-dimensional volume V_4, we reduce equation (1) to the form $\mathrm{d}V_4/\mathrm{d}t = h(t)V_4$, where $h(t) = \kappa(t) - \mathrm{d}\ln\rho_\Xi/\mathrm{d}t$. Since 4-space in this model is assumed to be unlimited, it is quite acceptable to consider the considered 4-dimensional volume as a 4-dimensional ball. Expressing the volume of a 4-dimensional ball in terms of its radius $V_4 = \pi^2R^4/2$ [13], we obtain

$$\mathrm{d}R/\mathrm{d}t = (1/4)h(t)R\,. \tag{2}$$

If $h(t) > 0$, then the radius of the 4-dimensional ball increases.

The second postulate is that in front of the surface of the expanding ball, which is a 3-dimensional sphere, due to the compression of the medium and the phase transition, a hard 4-dimensional spherical layer appears at some point in time, possibly similar to how it is described in [14] and [8] (mechanism the occurrence of the layer does not matter for the results of this work).

The ability to hold waves can be described by some potential. The simplest model of the potential that holds the waves in a 4-dimensional spherical layer is an infinitely deep potential well, the width coinciding with the thickness of the layer. In such a potential model, at any point of a 4-dimensional spherical layer and in any direction, waves propagate with the same velocity equal to the speed of light c and independent of their wavelength. This allows us to determine the time included in the expressions written above through the distance l traversed by these waves: $t = l/c$. The radius of a 4-dimensional spherical volume varies in the general case according to the law

$$R(t) = R_0\exp\left[(1/4)\int_{t_0}^{t} h(t')\,\mathrm{d}t'\right], \tag{3}$$

where t_0 is the moment of formation of a 4-dimensional spherical layer, $R_0 = R(t_0)$. The processes occurring up to the moment t_0 are not considered in this article. **Figure 1(a)** shows the cross sections of this 4-dimensional spherical layer with the plane of the Figure at the moment of occurrence t_0 and at the next two time points t_e and t.

The gigantic wave propagation velocity in a 4-dimensional spherical layer in comparison with the velocity of propagation of perturbation waves in the solids known to us suggests that it can be considered as a substance of enormous hardness and elasticity. Waves of disturbances propagate in this hard layer over vast cosmic distances with virtually no loss and attenuation. The thickness of the spherical layer in this model does not exceed half of the Compton wavelength of the electron. Therefore, the space inside a 4-dimensional spherical layer in the cosmic scales available to us can be considered as a 3-dimensional flat space. At

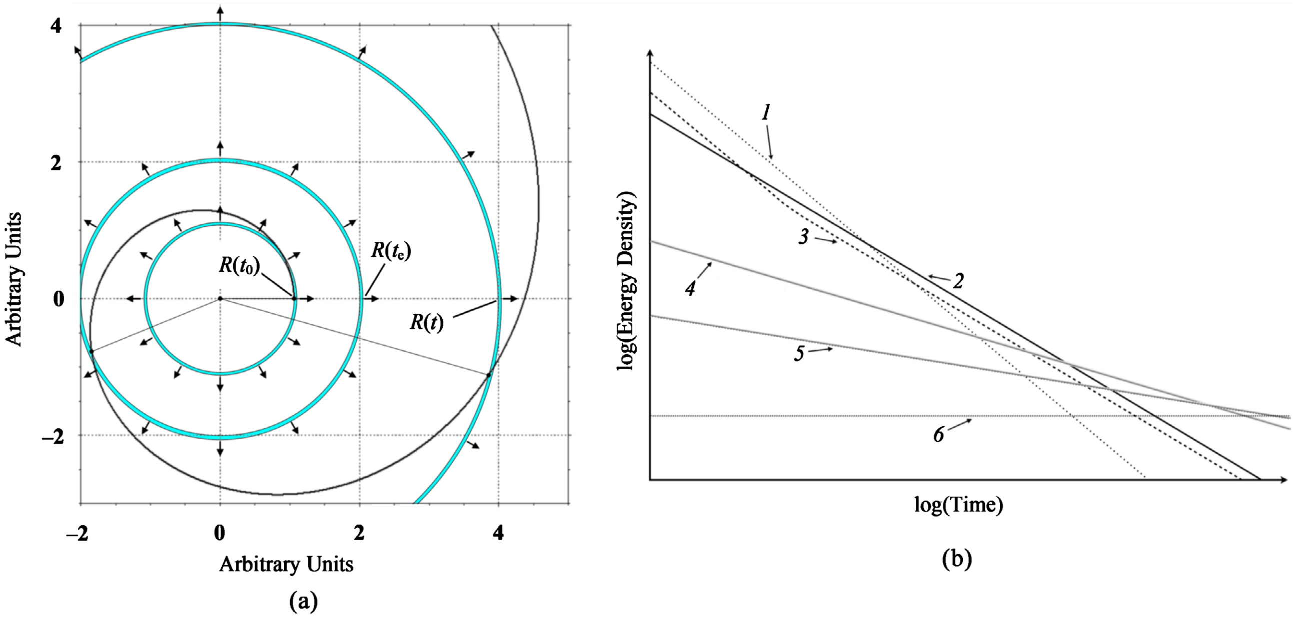

Figure 1. Cross-section by the plane of the drawing of a 4-dimensional ball with a hard spherical layer adjacent to it and the trajectory described by light as the radius of the ball increases. The cross-sections of the spherical layer at times t_0, t_e, t, are represented by concentric circles. The thickness of the 4-dimensional spherical layer is depicted on a greatly enlarged scale (a). The dependence of $\log(\rho_E)$ on $\log t$ (the image is borrowed from [20]) is radiation (1), matter (2), neutrinos (3), cosmic strings (4), domain walls (5), cosmological constant (6) (b).

the same time, the 4-dimensional spherical layer itself in the same scales can be considered as an unlimited plane-parallel layer formed by the mentioned hard substance, in which waves propagate, forming modes that correspond to one or another elementary particle depending on the longitudinal index [15] [16]. A hard spherical layer for these particles and the macro-objects formed by them acts as a vacuum, which does not resist their movement. We emphasize that even such a crude model of the holding potential, as shown in [17] [18] [19], is able to accurately describe both the kinematics and dynamics of relativistic effects.

Thus, in the model under consideration, the Universe we see is enclosed in a thin 4-dimensional spherical layer formed at time t_0 with radius R_0, the inner boundary of which is currently adjacent to the hypersurface of the 3-dimensional sphere of radius R. All the dependencies obtained in this article relate to the moments of time $t \geq t_0$.

Note that the space-time relations between the modes of a 4-dimensional spherical layer are relativistic due to the resonant condition, the fulfillment of which is necessary for each mode [16] [17] [18] [19]. The space itself, both outside and inside the layer, is Euclidean. Relativism refers only to the modes of the layer, which, as mentioned above, form our reality.

2.2. Basic Ratios

It is obvious that the density of the total energy of various modes, *i.e.*, different types of matter in a 4-dimensional spherical layer will decrease as the ball expands and the volume of the layer increases due to its stretching. We concretize the law of this decrease, assuming that the density ρ_E of the total energy of various types of matter in a 4-dimensional spherical layer decreases inversely proportional to the density of the energy released inside the ball, *i.e.*, $\rho_E = \text{const}/\rho_\Xi$. Differentiating in time, we get $\mathrm{d}\ln\rho_\Xi/\mathrm{d}\ln t + \mathrm{d}\ln\rho_E/\mathrm{d}\ln t \equiv 0$. But $\mathrm{d}\ln\rho_E/\mathrm{d}\ln t = -\beta$, where $\beta > 0$ is a constant value [20], **Figure 1(b)**. Then $\mathrm{d}\ln\rho_\Xi/\mathrm{d}\ln t = \beta$ and $h(t) = \kappa(t) - \beta/t$.

During the time scales of the Universe studied in this paper, we consider $\kappa(t) = \kappa = \text{const}$. To calculate Hubble diagrams, it is necessary to determine the rate of relative removal of galaxies, *i.e.*, the rate of removal of the observed galaxy from the galaxy from which the observation is being conducted. To do this, it is necessary to require that the change in radius from the moment of light emission $t_e > t_0$ occurs in such a way that this change depends only on the difference $t - t_e$ and does not depend on the position of t_e with respect to t_0. This requirement can be satisfied by replacing the upper limit of integration $h(t)$ in formula (4) with $t - (t_e - t_0)$. By entering the notation $x = (t - t_e)/t_0$, we get

$$R(x) = M(t_e) R_0 \exp\left\{\frac{\kappa t_0}{4}\left[x - \frac{\beta}{\kappa t_0}\ln(1+x)\right]\right\},$$

where, when replacing t_e with t_0, we get the inner radius of a 4-dimensional spherical layer, which can be referred to as the inner radius of the Universe. At $\beta/(\kappa t_0) \le 1$, the scale factor of the Universe $M \sim R$ increases at each moment of time, and the 4-dimensional spherical layer stretches. In the radiation moment, the radius of the Universe is $R(t_e) = R_0\exp\{(\kappa/4)[t_e - t_0 - (\beta/\kappa)\ln(t_e/t_0)]\}$ and $M(t_e) = R(t_e)/R_0$.

Since the metric of a 4-dimensional spherical layer changes due to stretching, after normalization by $M(t_e)$ we get the expression

$$R_g(x) = \frac{R(t-t_e)}{M(t_e)} = R_0 \exp\left\{\frac{\kappa t_0}{4}\left[x - \frac{\beta}{\kappa t_0}\ln(1+x)\right]\right\}, \tag{4}$$

which can also be written as $R_g(x) = R_0 M(x)$, where $M(x) = \exp\{(\kappa t_0/4)[x - (\beta/\kappa t_0)\ln(1 + x)]\}$ – scale factor from the moment of radiation. The rate of galaxy removal $V_g = 2\pi V_{gR}$, where $V_{gR} = \mathrm{d}R_g/\mathrm{d}t$, will be described by the formula

$$V_g(x) = \frac{\pi}{2}\kappa R_0\left(1 - \frac{\beta}{\kappa t_0}\frac{1}{1+x}\right)\exp\left\{\frac{\kappa t_0}{4}\left[x - \frac{\beta}{\kappa t_0}\ln(1+x)\right]\right\}. \tag{5}$$

From (5) it can be seen that V_g depends only on the difference between the present moment of time and the moment of light emission and does not depend on the position of the moment of radiation or reception with respect to the moment t_0.

Figure 1(a) also shows the trajectory of light as it propagates in a moving 4-dimensional spherical layer. Let's find the distance that the light travels from the emitter to the receiver, depending on the difference $t - t_e$. To do this, we take into account that at the moment of radiation, the speed of light, taking into account the spatial scale that has already changed by this moment, is equal to the value c obtained in terrestrial laboratories. Since the 4-dimensional spherical layer is stretching, the speed of light along the spherical layer at the time $t_e \le t' \le t$ from the point of view of an observer outside layer, will increase as $c_{sl}(t' - t_e) = cM(t' - t_e)$. The change in the speed of light along the trajectory will be described by the expression

$$c_{tr}(x') = \sqrt{\left[c\mathrm{d}R_g(x')/\mathrm{d}x'\right]^2 + \left[cR_g(x')/R_0\right]^2}, \tag{6}$$

where $x' = (t' - t_e)/t_0$. Since the cosine of the angle between the tangents to the trajectory and to the layer $\cos\alpha(x') = cM(x')/c_{tr}(x')$, then multiplying $c_{tr}(x')$ by $\cos\alpha(x')$ and dividing by the scale factor $M(x')$ we obtain that the speed of light from the point of view of an observer inside the layer is numerically the same as at the moment of radiation, *i.e.*, it is a universal constant. Since $\mathrm{d}D = c_{tr}(x')\mathrm{d}t'$, the time scale does not change. Note that the angle by which the radius of the photon vector rotates during $t - t_e$,

$$\varphi(t) = \pm\int_{t_0}^{t} \mathrm{d}D\cos\alpha(t')/R_g(t' - t_e) + \varphi(t_e),$$

where $\varphi(t_e)$ is the value of the angle at the moment of photon emission. As a result, we get $\varphi(t) - \varphi(t_e) = \pm(c/R_0)(t - t_e)$, *i.e.*, regardless of where the source is located and at what time it emits, the radius vector of the photon $\mathbf{R}$ rotates by the same angle in the same time.

Substituting in (6) $R_g(x')$ and $\mathrm{d}R_g(x')/\mathrm{d}x'$, and integrating by $\mathrm{d}x'$, we obtain the distance that light travels from the source to the receiver during $t' - t_e$

$$D(x) = ct_0\int_0^x \exp\left\{\frac{\kappa t_0}{4}\left[x' - \frac{\beta}{\kappa t_0}\ln(1+x')\right]\right\}\sqrt{1 + \left[\frac{\kappa R_0}{4c}\left(1 - \frac{\beta}{\kappa t_0}\frac{1}{1+x'}\right)\right]^2}\,\mathrm{d}x'. \tag{7}$$

Note that for $t_e = t_0$ (4) and (5), describe the time behavior of the radius and velocity of expansion of a 4-dimensional spherical layer, and (7) is the distance that light has traveled from the moment of formation of the Universe. At this point, the increase in the 4-dimensional volume stops for a moment due to the formation of a hard 4-dimensional spherical layer. Consequently, the rate of expansion of the layer $V(t_0) = 0$. This initial condition is equivalent to the condition $\beta = \kappa t_0$. Then formulas (4), (5) and (7) take the form

$$R_g(x) = R_0\exp\left\{\frac{\kappa t_0}{4}\left[x - \ln(1+x)\right]\right\}, \tag{8}$$

$$V_g(x) = \frac{\pi}{2}\kappa R_0\frac{x}{1+x}\exp\left\{\frac{\kappa t_0}{4}\left[x - \ln(1+x)\right]\right\}, \tag{9}$$

$$D(x) = ct_0\int_0^x \exp\left\{\frac{\kappa t_0}{4}\left[x' - \ln(1+x')\right]\right\}\sqrt{1 + \left(\frac{\kappa R_0}{4c}\frac{x'}{1+x'}\right)^2}\,\mathrm{d}x'. \tag{10}$$

3. Hubble Diagrams

For $x \to 0$, the distance D is proportional to x: $D = ct_0x$, from where we find that

$x = D/(ct_0)$. Substituting this expression into formula (9) for $V_g(x)$, which for small x has the form $V_g(x) = (\pi/2)\kappa R_0 x$, we obtain Hubble's law $V_g(D) = H_0 D$, where $H_0 = (\pi/2)\kappa R_0/(ct_0)$ is the Hubble constant. By expressing κ through the Hubble constant $\kappa = (2/\pi)H_0 ct_0/R_0$, respectively, we obtain

$$R_0(x) = R_0 \exp\left\{\frac{H_0 t_0}{2\pi}\frac{ct_0}{R_0}\left[x - \ln(1+x)\right]\right\}, \tag{8a}$$

$$V_g(x) = cH_0 t_0 \frac{x}{1+x}\exp\left\{\frac{H_0 t_0}{2\pi}\frac{ct_0}{R_0}\left[x - \ln(1+x)\right]\right\}, \tag{9a}$$

$$D(x) = ct_0 \int_0^x \exp\left\{\frac{H_0 t_0}{2\pi}\frac{ct_0}{R_0}\left[x' - \ln(1+x')\right]\right\}\sqrt{1+\left(\frac{H_0 t_0}{2\pi}\frac{x'}{1+x'}\right)^2}\,\mathrm{d}x'. \tag{10a}$$

Note that it follows from the results obtained above that it is impossible to calculate the red shift through an increase in wavelength due to the stretching of space. Indeed, due to the fact that the 4-dimensional spherical layer is stretching, the wavelength λ_0 of the emitting source, during propagation from the source to the receiver, increases as $\lambda = \lambda_0 R_g(x)/R_0$ and, if we define the redshift as $z = \lambda/\lambda_0 - 1$, we get that $z = R_g(x)/R_0 - 1$. This dependence contradicts the data of redshift observations. For example, at a small distance at which $R_g(x)/R_0$ is a quadratic function of the distance $R_g/R_0 \approx 1 + H_0 D^2/(4\pi cR_0)$, a redshift dependence z on D of the form $z = H_0 D^2/(4\pi cR_0)$ is obtained, in contrast to the observational data, which show that it is linear in D and has type $z = H_0 D/c$ (see also below).

It is also impossible to calculate the redshift using the formula of the relativistic Doppler effect. As shown in [21], it occurs only between the modes of a 4-dimensional spherical layer due to the motion of the modes excited in it relative to each other, in other words, due to the difference in the slopes of the wave vectors of the waves forming these modes with respect to each other. The stretching of a 4-dimensional spherical layer cannot lead to the appearance of an angle of inclination with respect to the normal of the layer. Otherwise, an increase in the radius of a 4-dimensional spherical layer would lead to spontaneous acceleration of bodies at rest with respect to the normal to the layer in the Universe.

Since the space of the 4-dimensional spherical layer under consideration is Euclidean, in this model it is natural to assume that the frequency of the received light is determined in the same way as for sound in the case when the receiver is not moving and the source is moving away at a speed of V [22], *i.e.* as $\nu(t) = \nu(t_e)/(1 + V/c_s)$. Here c_s is the speed of sound. Then in our case, the redshift $z = [\nu(t_e) - \nu(t)]/\nu(t)$ will be described by the formula

$$z(x) = \frac{V_g(x)}{c} = H_0 t_0 \frac{x}{1+x}\exp\left\{\frac{H_0 t_0}{2\pi}\frac{ct_0}{R_0}\left[x - \ln(1+x)\right]\right\}. \tag{11}$$

The set of formulas (10a) and (11) sets the dependence $D(z)$ in parametric form. Thus, in the model under consideration, to describe the expansion of the Universe, it is necessary to know three parameters: H_0, t_0 and R_0.

Let's find H_0 first. As it was shown above at small distances to galaxies $V_g(x) =$

$V_g(D) = H_0 D$. This is equivalent to the fact that $z = H_0 D/c$. We express $D(z)$ in terms of the distance module μ using the well-known ratio $D = 10^{\mu/5-5}$ [23], where D is calculated in Mpc: $\mu(x) = 5\lg D(x) + 25$. Then, at small distances to galaxies $\mu = 25\,[1 + \lg(cz/H_0)]$. The dependence of μ on $\lg z$ is linear. Let's compare it at different values of H_0 with the dependencies given in [1] (the results of calculation and fitting to them were used). In **Figure 2(a)** shows data from this work and linear dependencies at $H_0 = 40$; 67.7 and 100 km/s/Mpc. It can be seen that there is a strong dependence on H_0, and the best match occurs at $H_0 = 67.7$ km/s/Mpc, which practically coincides with the value of the Hubble constant $H_0 = 67.74$ km/s/Mpc (2.19×10^{-18} c^{-1}), determined by the parameters of the relic radiation [24] (latest data 67.9 ± 1.5 [25] and 67.6 ±1.1 [26]). The same result is obtained from the results of comparing calculations at small z for this model with the data presented by Perlmutter in [2]. In further calculations, the value of the Hubble constant $H_0 = 67.7$ km/s/Mpc will be used.

Thus, to describe the expansion of the Universe, it is necessary to define two more parameters. As mentioned above, these are t_0 and R_0. However, it is more convenient to use the product $T_0 = ct_0$, expressed in Mpc, and the ratio T_0/R_0. In this paper, these parameters were determined by comparing the dependences calculated by the formulas (10a, 11) of the distance modulus as a function of the redshift with varying T_0 and T_0/R_0 with observations of supernovae Ia. As a result of this comparison, it was found that for these radiation sources $T_0 = 8500$ Mpc, and $T_0/R_0 = 3.8$. The results of calculations for the specified values of the parameters T_0 and T_0/R_0 and the data of observations of type Ia supernovae presented by Perlmutter in [2] are shown in **Figure 2(b)**. Since in [2] the dependences of the absolute distance modulus (absolute brightness) m on z are given, then in the calculations, μ was expressed in terms of m: $\mu = \text{m} - \text{M}^0$, where $\text{M}^0 \approx -19.25$ [27]. Then $\text{m} = 5\lg D(x) + 5.75$. At $H_0 = 67.7$ km/s/Mpc, we obtain a

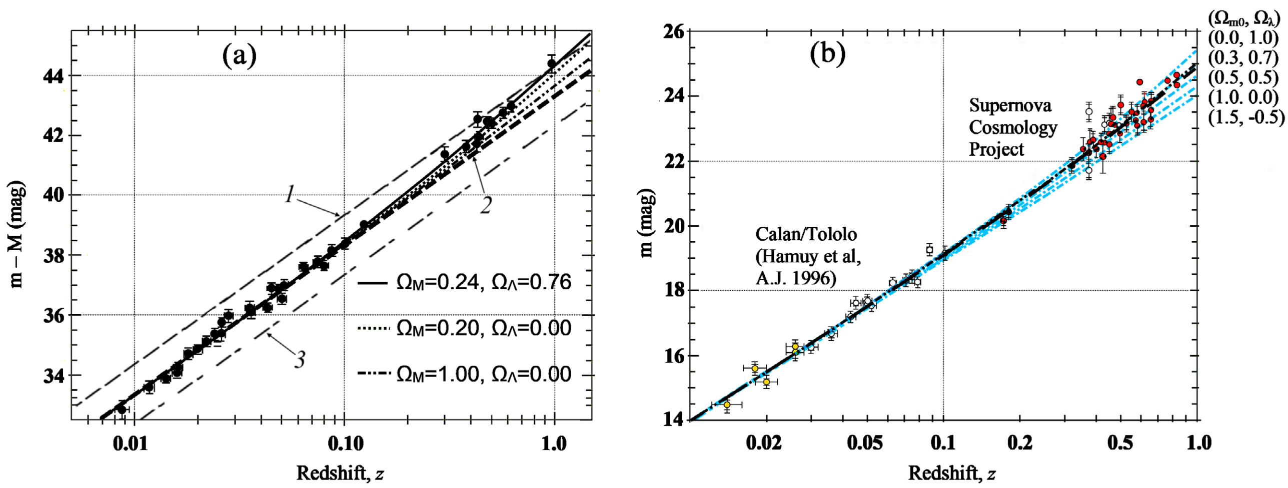

Figure 2. Comparison of calculation results by linear formulas at $H_0 = 40$ (1); 67.7 (2) and 100 km/s/Mpc (3) with the observed data [1]. The deviation of the observed data from the linear dependence is clearly visible (a). The results of calculations using the obtained formulas (10a, 11) (bold dashed line) of the distance modulus as a function of the redshift at $H_0 = 67.7$ km/s/Mpc and the specified values of the parameters T_0 and T_0/R_0 and observations of type Ia supernovae presented by Perlmutter in [2] (b).

dependence m on lg$z$ that coincides with the dependence approximating the data of observations of type Ia supernovae at $\Omega_{m0} = 0.3$ and $\Omega_\lambda = 0.7$ calculated on the basis of the ΛCDM model.

The value H_0, which appears in the formulas obtained, is the Hubble parameter at a small z, *i.e.*, at a small distance from the light source and a small time for which light passes from the moment of radiation to the receiver. Now let's find out how the Hubble parameter changes with the distance to the source. It follows from (9a) that the local D value of the Hubble parameter $H = \mathrm{d}V_g/\mathrm{d}D = (\mathrm{d}V_g/\mathrm{d}x)/(\mathrm{d}D/\mathrm{d}x)$. Differentiating (9a) and (10a) by x, we obtain

$$H(x) = H_0\left(1+\frac{H_0T_0}{2\pi c}\frac{T_0}{R_0}x^2\right)\Bigg/\left[(1+x)^2\sqrt{1+\left(\frac{H_0T_0}{2\pi c}\frac{x}{1+x}\right)^2}\right].$$

Together with the expression for $D(x)$, we have a dependence H on D, from which it follows that with increasing D, the Hubble parameter first decreases, and then, after passing the minimum at $D \approx 8.24$ Gpc, it begins to increase. When $D\to\infty$ ($x\to\infty$)

$$\lim_{x\to\infty} H(x) = \frac{(H_0T_0)^2}{2\pi cR_0}\Bigg/\sqrt{1+\left(\frac{H_0T_0}{2\pi c}\right)^2} = 75.08 \text{ km/s/Mpc}.$$

This limit value falls within the range of values $H = 73.48 \pm 1.66$, *i.e.*, $71.82 \le H \le 75.14$ km/s/Mpc, obtained by the Riess team [28]. It also practically does not differ from the value $H = 75.1 \pm 2.3$ (stat) $\pm$ 1.5 (sys) km/s/Mpc obtained in [29].

For a more detailed analysis of the obtained result, let us consider the behavior of the curve calculated from the model under consideration, describing the Hubble diagram in a wider range of redshifts than has been done so far, **Figure 3**.

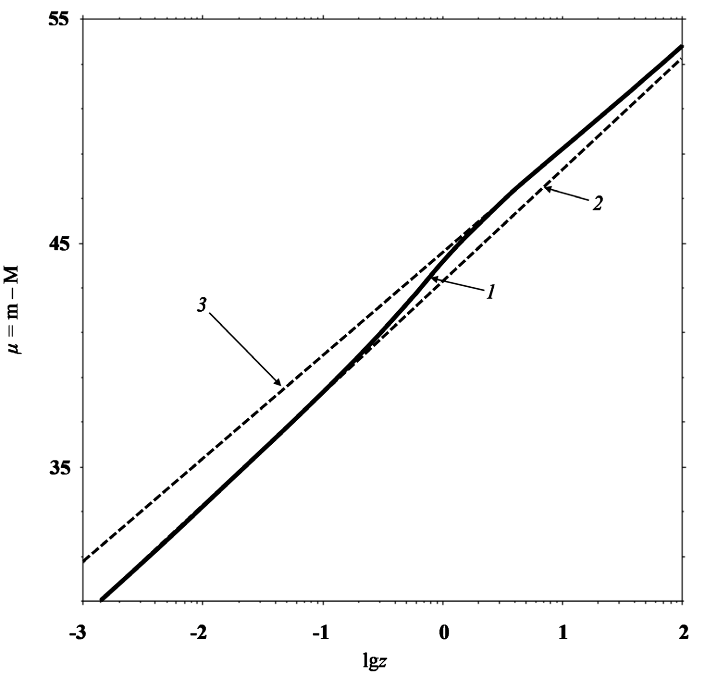

Figure 3. A feature of the behavior of the distance module depending on the redshift.

It can be seen that in the range of values of $z \sim 1$ there is a feature in the behavior of the distance module (curve 1), which sheds light on the appearance of different values of the Hubble constant. For small values of $z \sim 0.01$, the dependence is steeper, $d\mu/d\lg z = 5.0$ (line 2). Then, for values of $z > 3$ there is a bend in the region $z \sim 1$, and a transition to the less steep part of the curve $d\mu/d\lg z = 4.61$ (line 3).

Let's find out which values of the Hubble constant correspond to these slopes of the tangents to the curve. To do this, we express the derivative $d\mu/d\lg z$ in terms of H_0 and the local value $H = dV_g/dD$: $d\mu/d\lg z = d(5\lg D + 25)/d\lg z = 5(cz/D)/(dV_g/dD)$. But, as shown above, $cz/D = H_0$. As a result, we get that $H = 5H_0/(d\mu/d\lg z)$. At $H_0 = 67.7$ km/s/Mpc, $H = 5H_0/4.61 = 73.4$ km/s/Mpc, *i.e.*, the value given by Riess [28].

It should be noted that the use of the value of the Hubble constant obtained by Riess *et al.* leads in this model to a mismatch with the observational data. To verify this, let us turn to the observational data [2]. At $H_0 = 67.7$ km/s/Mpc, $T_0 = 8500$ Mpc, $T_0/R_0 = 3.8$, the dependence of m on z coincided with the dependence obtained in ΛCDM at $\Omega_{m0} = 0.3$ and $\Omega_\lambda = 0.7$ based on observations of type Ia supernovae, **Figure 2(b)**. At $H_0 = 73.48$ km/s/Mpc, the dependence of m on z is lower by approximately 0.2 - 0.3 mag. A similar picture is obtained when using the data presented by Riess *et al.* [1].

To confirm the obtained values of H_0, T_0, and T_0/R_0, comparisons were made with the combined observations of type Ia supernovae, which extend up to $z = 1.4$ [30], as well as with observations of quasars [31] and gamma-ray bursts at z values extending up to 6.6 [32] [33]. The results of calculations based on the obtained distance modulus formulas depending on the redshift and the data of combined observations of type Ia supernovae, quasars and gamma-ray bursts at the specified values of the parameters T_0 and T_0/R_0 are presented in **Figure 4** below.

It can be seen that the Hubble diagrams calculated using this model coincide with the observed diagrams, while the diagrams calculated using the ΛCDM model differ observed diagrams, while the diagrams calculated using the ΛCDM model differ significantly from them at large z, which is also confirmed by the results of studies conducted in [34].

4. Discussion of the Results

Based on the results obtained, we conclude that the moment of formation of a hard spherical layer on the time scale of the Universe we observe is $t_0 = T_0/c = 27.7$ billion years (8.74×10^{17} s), $H_0 t_0 = 1.92$, and the initial inner radius of a 4-dimensional spherical layer, *i.e.*, the inner radius of the Universe, $R_0 = T_0/3.8 = 2.24$ Gpc. The probability of transition from the excited state to the underlying energy levels of a 4-dimensional hypothetical substance is $\kappa = 5.31 \times 10^{-18}$ s^{-1}, and $\beta = \kappa t_0 \approx 4.64$. Having determined β and using the equation $d\ln\rho_\Xi/d\ln t = \beta$, we come to the conclusion that the energy density as a result of transitions to the

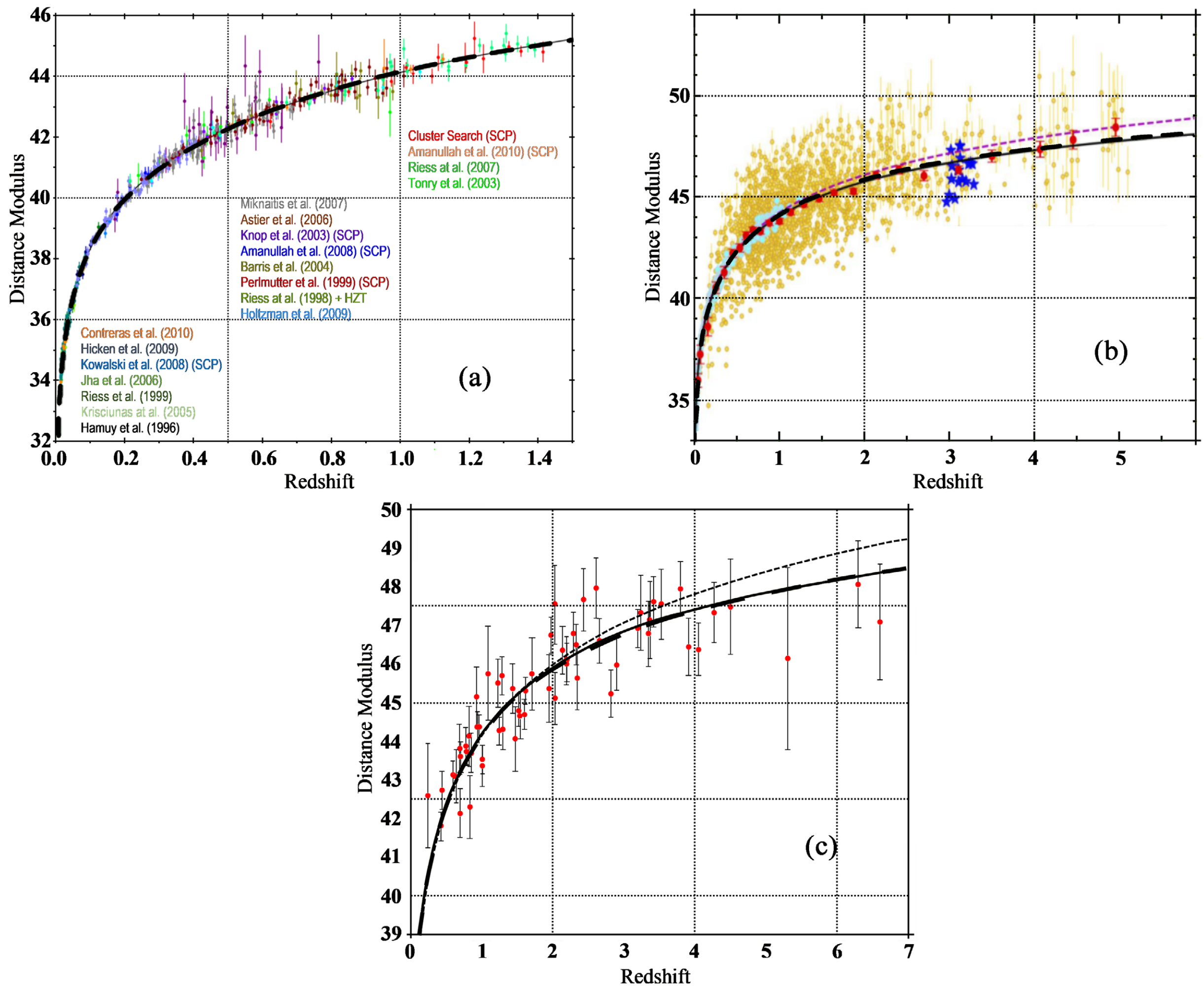

Figure 4. Hubble diagram based on observations of type Ia supernovae (Figure taken from article [30]). The solid line represents the best fit within the framework of the standard ΛCDM model of a flat Universe (a). Hubble diagram constructed from quasar observations. A solid line is the best approximation, a dashed line with small strokes is the result of fitting at $z < 1.4$ according to the standard ΛCDM model of a flat Universe with $\Omega_M = 0.31 \pm 0.05$ and extrapolated to higher redshifts (the Figure is taken from the article [31]) (b). The Hubble diagram constructed from observations of gamma-ray bursts. The dotted line is constructed by calculation within the framework of the standard ΛCDM model of a flat Universe with $\Omega_{m0} = 0.27$ and $w_0 = -1$. The solid line is the best approximation at $\Omega_{m0} = 0.27$ and $w = w_0 + w'z$, where $w_0 = -1.4$, $w' = \mathrm{d}w/\mathrm{d}z = 1.3$, (the Figure is taken from [32] and Schaefer's presentation [33]) (c). In all Figures, a bold dashed line is a calculation based on the formulas of the proposed model.

underlying levels inside the 4-dimensional ball increases in time according to the law $\rho_\Xi(t) = \rho_\Xi(t_0)(t/t_0)^{4.64}$.

Let us now find out how the acceleration of receding galaxies behaves depending on the time of propagation of light from the galaxies. The rate of removal of galaxies, as it was found out above, is given by the formula (9). Using this formula, we obtain a formula for accelerating the receding galaxies

$$a_g(x) = \frac{\mathrm{d}V_g}{\mathrm{d}t} = \frac{cH_0}{(1+x)^2}\left(1 + \frac{H_0T_0}{2\pi c}\frac{T_0}{R_0}x^2\right)\exp\left\{\frac{H_0T_0}{2\pi c}\frac{T_0}{R_0}\left[x - \ln(1+x)\right]\right\}.$$

Figure 5 shows the dependence of the acceleration of receding galaxies on $t - t_e = xt_0$. It can be seen from the Figure that during the transition from nearby

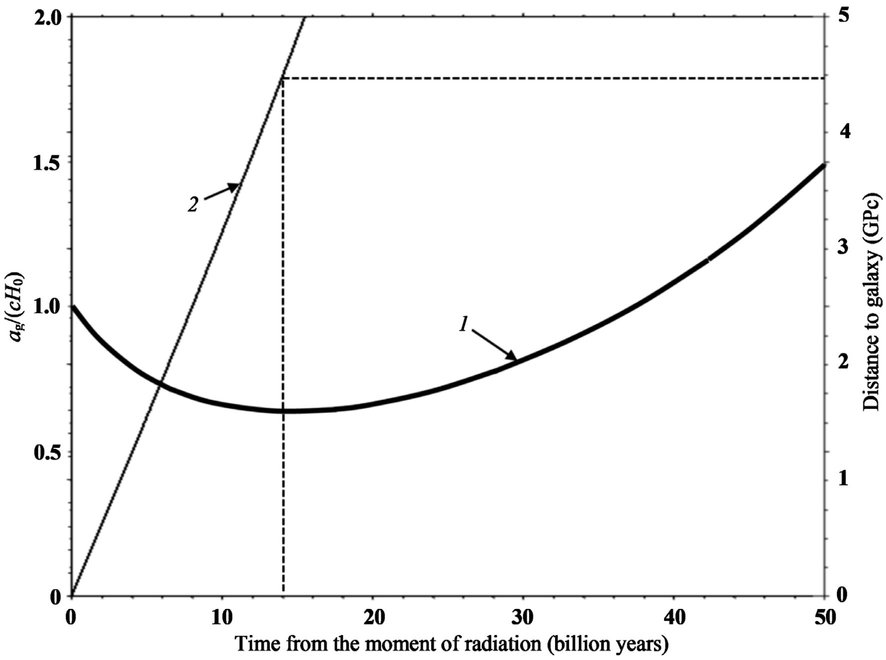

Figure 5. Acceleration of receding galaxies (1) and the distance to them (2) depending on the time elapsed from the moment of light emission by the galaxy to the present moment.

galaxies to more distant ones, the rate of removal first slows down (curve 1), then, in the region of $t = 6$ - 7 billion years, the deceleration decreases. At a value of $t - t_e \approx 14$ billion years ($D_g \approx 4.5$ Gpc (curve 2)), the acceleration drops to a minimum value, and starting from the moment of time ≈14 billion years away from the present moment, the acceleration begins to increase monotonically.

This means that in the considered model of the Universe, 14 billion years characterize not the age of the Universe, but the moment in time when the acceleration of receding galaxies has a minimum value.

The lower bound of the age of the Universe from the moment of formation of the 4-dimensional spherical layer according to this model can be estimated from the data on the red shift of distant galaxies. If their z is known, then considering the moment of galaxy formation equal to t_e, we can find $x(z)$ and estimate the lower bound of the age of the galaxy $T_g = t - t_e$ using the ratio $T_g = x(z)t_0$. These distant galaxies are the galaxy GN-z11 [35], for which the value $z = 10.957$ has recently been determined with an error of 0.001 [36], and the protogalaxy UDFj-39546284 with $z = 11.9$ [37], which is considered very young, because intense star formation occurs in it. The indicated z values, as can be seen from **Figure 6(a)**, correspond to the age of galaxies at least 86-90 billion years (curve 1) and to the distance to these galaxies is $D_g \approx 80$ Gpc (curve 2).

If the age of the Universe was equal to the age of these galaxies, then the length of the equator of the 3-dimensional sphere L_e would be, as can be seen from **Figure 6(a)** (curve 3) ≈ 115 Gpc. This value is comparable to the distance to these galaxies, and the curvature of a 3-dimensional sphere, to which a 4-dimensional spherical layer adjoins, should appear in the observations of objects

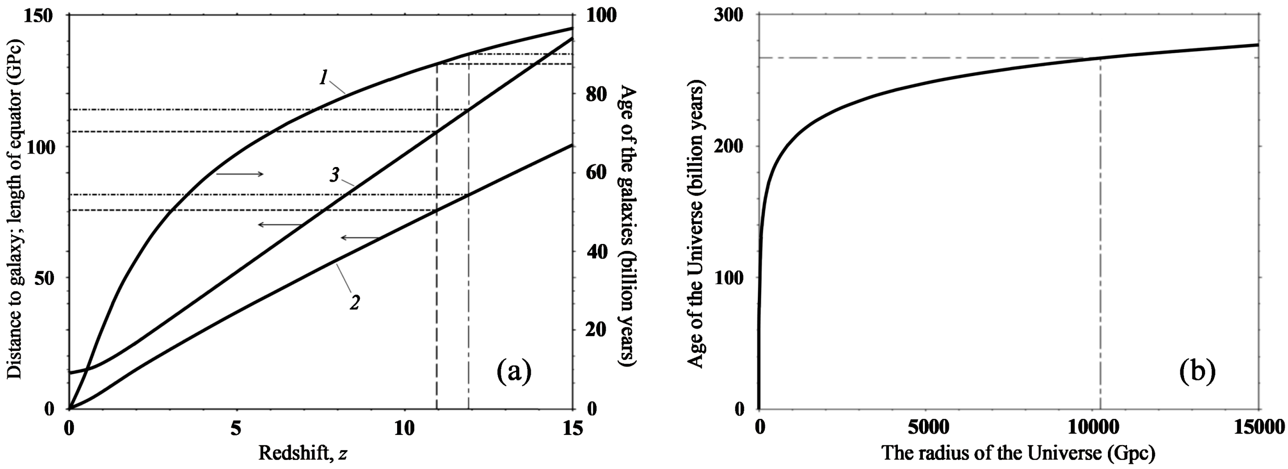

Figure 6. The dependences on the redshift of the age of the galaxy (curve 1) and the distance to it (curve 2), as well as the dependence of the length of the equator of the 3-dimensional sphere (curve 3) on the age of the Universe, which is calculated under the assumption that the age of the Universe coincides with the age of the galaxy (the left vertical line corresponds to the galaxy GN-z11, the right one is for the galaxy UDFj-39546284) (a); the dependence of the age of the Universe on its inner radius (the value of the radius corresponding to the vertical line was estimated from the data on the curvature of the Universe) (b).

at such distances. But even with such big red shifted, we see a flat Universe.

However, it has recently been discovered that the Universe has a positive curvature basis equal to 4% [38]. Moreover, the confidence level is 99%. This discovery was made on the anomalies in the distribution of relic radiation. Since the dependence of the redshift of the relic radiation on the distance to the place from where it came from is unknown, we estimate the lower bound of the inner radius of the Universe based on the measured redshift of the galaxies GN-z11 and UDFj-39546284 and the distance to them D_g calculated above according to the considered model.

To do this, consider the equatorial section of a 3-dimensional sphere and draw a straight tangent to the circle of the section. The ratio of the deviation δ from the straight line to the distance D_g from the point of contact of the circle and the straight line must satisfy the condition $\delta/D_g < \varepsilon\Omega_K$, where $\Omega_K = 0.04$ the curvature of the Universe found in [38], ε is a small value. It is necessary to put ε no more than 0.1 so that the curvature of the Universe at distances corresponding to the galaxies mentioned above is imperceptible. On the other hand, $\delta = R_U - [(R_U)^2 - (D_g)^2]^{1/2}$, where R_U is the inner radius of the Universe. Solving this equation with respect to R_U, and using the inequality written above, we obtain an estimate for the lower bound of the inner radius of the Universe

$$R_U > \frac{1+\varepsilon^2\Omega_K^2}{2\varepsilon\Omega_K} D_g \approx \frac{D_g}{2\varepsilon\Omega_K}.$$

As a result, we have $R_U > 10{,}000$ Gpc, and the corresponding age of the Universe T_U should be at least 270 billion years, Figure 6(b).

This is consistent with the observational data, in which it was found that the birth of low-metal stars and even entire galaxies occurs in the Universe during its entire lifetime [39]. Based on these data, the opinion arose that at this stage there is no reason to assert anything about the age of the Universe [40]. Moreover, it was suggested that the observations of recent years, indicating the continued origin of stars and galaxies, provide the basis for the assertion of the eternal existence of the Universe. Of course, within the framework of the proposed model, there is no reason to agree with such an assumption. However, the above estimate of the lower bound of the age of the Universe suggests that 270 billion years, compared with the accepted age of the Universe in standard cosmology, equal $t_0 \approx 14$ billion years, can be conditionally accepted as an infinite lifetime.

5. Conclusions

This article considers a model of accelerated expansion of the Universe based on the idea of a hypothetical 4-dimensional substance with an inverse population of energy levels. A theoretical model of the expanding Universe has been developed. The analytical dependence of the redshift on the distance to the galaxies is derived. At the Hubble constant H_0 = 67.7 km/s/Mpc, it coincides with great accuracy with the dependencies describing the Hubble diagrams for type Ia supernovae, quasars and gamma-ray bursts, which are best adapted to the observed data. At the same time, the use in this model of the Hubble constant H_0 = 73.48 km/s/Mpc obtained by Riess *et al.* does not provide agreement with the observed data.

An explanation of two values of the Hubble constant is proposed. It is shown that the Hubble constant first decreases with increasing distance to galaxies. Then, after passing a minimum at a distance of about 8 Gpc, it begins to increase. Passes in the range of $z \sim 1$ values the value of 73.5 km/s/Mpc, represented by the Riess group. Then it reaches the limit value of 75.08 km/s/Mpc, which practically coincides with the value H_0 = 75.1 ± 2.3 (stat) ± 1.5 (sys) km/s/Mpc obtained in the work of Schombert *et al.*

It is shown that in the considered model of the Universe, 14 billion years characterizes not the age of the Universe, but the moment of time when the acceleration of receding galaxies has a minimum value.

Based on the recently discovered curvature of the Universe, it is shown that the age of the Universe is at least 270 billion years. This is consistent with the conclusions from studies of the birth of low-metal stars.

The probability of transition from the excited state to the underlying energy levels of a hypothetical 4-dimensional substance $\kappa = 5.31 \times 10^{-18}\ \text{s}^{-1}$ is determined, as well as the law of increasing energy density inside a 4-dimensional ball $\rho_\Xi(t) = \rho_\Xi(t_0)(t/t_0)^{4.64}$ as a result of transitions to the underlying levels of an hypothetical 4-dimensional substance.

It will be interesting to compare the obtained dependencies describing the Hubble diagram with the dependencies that will be obtained on the basis of statistical processing of new data obtained using the James Webb Space Telescope. If the dependences obtained in this work are confirmed at a redshift greater than ten, then with a high degree of confidence it will be possible to assert that our

Universe is really enclosed in a 4-dimensional spherical layer having a thickness equal to half the Compton wavelength of an electron and possessing gigantic hardness and strength. Since relativistic laws are conditioned by the resonance condition for the deformation modes of this layer, the covariance of physical processes, and, consequently, the properties of our world are conditioned by the characteristics of this layer and the hypothetical 4-dimensional substance. As follows from the results of this work, in order to determine their characteristics that are not yet known, further research of objects of the Universe remote over vast cosmic distances is required.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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