Open Access Library Journal
2023, Volume 10, e9824
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Optimality of the Evolution of the Universe, the Big Bang Model

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How to cite this paper: Mdzinarishvili, V.V. (2023) Optimality of the Evolution of the Universe, the Big Bang Model. *Open Access Library Journal*, **10**: e9824.
https://doi.org/10.4236/oalib.1109824

Received: January 30, 2023
Accepted: March 28, 202
Published: March 31, 2023

Abstract

This paper deals with the model of the evolution of the Universe proposed by Lemaitre: when the universe expands, the concentration of particles—galaxies declines, and when the universe contracts, the concentration of particles—galaxies increases. The solutions of the corresponding differential equations represent integrals from soliton functions satisfying the Euler-Lagrange equation. This means that the evolution of the universe, which occurs both with its expansion and contraction, is an optimal process. According to the postulate of physics, matter has two forms: substance and field. These forms are in constant competition. It is well known that specific processes are modeled by the systems of Lotka-Volterra. This becomes the reason that the systems of Lotka-Volterra equations are used by the author both in simulating an expanding and contracting Universe. In the epoch of the "radiation era", the field density made a greater contribution to the density of matter than substance. This happened in the early moments of time after the Big Bang. Therefore, when modeling the Big Bang, the field density taking place in the epoch of the "radiation era" is used.

Subject Areas

Modern Physics

Keywords

Physics Postulate, Expansion, Compression, Riccati Equation, Tempo Record, Equilibrium State, Big Bang

1. Introduction

In works devoted to the universe, the optimality of its evolution is noted. However, specific mathematical models, according to which the evolution of the universe takes place, are not given in them (see, e.g. [1]). In the book [2], instead of the optimality of the evolution of the Universe, the term "cosmic wisdom" is applied. In the monograph [3], an attempt is made to create a model of the evolution of the universe based on the diffusion equation; as an optimality criterion, the Hamilton-Jacobi equation is obtained. This monograph allows us to get closer to the real evolution of the universe than any other work. However, we consider that the hydrodynamic model of the universe given in it, cannot describe all the processes (for example, the Big Bang) occurring in the Metagalaxy.

Unlike these studies, the following model of the evolution of the universe is based on the use of G. Lemaitre's research [4], according to which particles—galaxies in the universe are either in the process of approaching (compression of the universe) or in the process of moving away from each other (expansion of the universe). In our opinion, this approach most adequately reflects the real process of evolution of the Universe.

As follows from this approach, at the expansion of the universe, the gas rarefaction consisting of particles of the galaxy occurs, and when the universe is compressed, the average density of the gas, also consisting of particles—galaxies, increases. The expansion and contraction models of the universe shown below are designed for the simulation of both the expansion process and the contraction process of the universe. This approach to the evolution of the universe makes it possible to create an adequate model of the Big Bang.

Let us now turn to the models of expansion and compression of the Universe. As a model of expansion of the Universe, the model of the effect of "closeness" [5] is taken: the closer each galaxy is to other galaxies, the worse it is for them, *i.e.*, the greater the concentration of galaxies, the worse it is for them. Therefore, the term describing the concentration decrease of the galaxies must be proportional to z^2:

$$\frac{\mathrm{d}z_+}{\mathrm{d}t} = \beta_+ z_+ - \mu_+ z_+^2, \tag{1}$$

where z_+ is the density of matter in an imaginary expanding sphere.

Another model simulating the compression of the universe is:

$$\frac{\mathrm{d}z_-}{\mathrm{d}t} = -\beta_- z_- + \mu_- z_-^2, \tag{2}$$

where z_- is the density of matter in a compressing sphere.

Equation (2) is called the model of "super-closeness". This model is that the close reach galaxy is to other galaxies; the better it is for it, *i.e.*, the greater the concentration of galaxies, the better. ***The* models (1) *and* (2) *are Riccati equations without a free term***; solutions of Equations (1) and (2) have the form

$$z_+ = \frac{1}{4} n_+^2 \mu_+ \int_{t_0}^{t} \operatorname{sech}^2 \left[\frac{1}{2} \mu_+ n_+ \left(t - t_0 \right) \right] \mathrm{d}t, \tag{3}$$

$$z_- = -\frac{1}{4} n_-^2 \mu_- \int_{t_0}^{t} \operatorname{sech}^2 \left[\frac{1}{2} \mu_- n_- \left(t' - t_0' \right) \right] \mathrm{d}t', \tag{4}$$

where $n_+ = \beta_+ / \mu_+$ and $n_- = \beta_- / \mu_-$.

Solutions (3) and (4) satisfy the corresponding Euler-Lagrange optimization equation; this means that the process of expansion and compression of the universe has optimal character.

2. Postulate of Physics

According to the postulate of physics, matter can exist in two states: substance and field. In the universe, the process of transition (transformation) of the substance into field and the process of transition of the field into substance occur in parallel to each other. Figure 1 schematically shows these transitions.

On the scale of the universe, these transformations occur at all levels of the matter. On the level of elementary particles, these transformations are described figuratively by M. A. Tonnelat [5]: "At the end, the experiments in which a quantum of electromagnetic radiation with the energy $E_0 = h\nu_0$ [1] turns into a pair of oppositely charged particles with a common energy $2m_0c^2$, as well as experiments in which the opposite process is observed: transformation of the matter into radiation allows $\left(2m_0c^2 \to h\nu_0\right)$ us to give meaning to the relation $\Delta E = \Delta mc^2$ in the case when as a result of the reaction the mass arises from radiation or, on the contrary, completely disappears and turns into radiation".

On the level of stars, the transformation of matter into a field, i.e. in radiation, takes place in the catastrophic explosion of a star at the end of life. This phenomenon is called the flash of a supernova star. The light component (the brightness of the star) is part of the general, sharply increasing radiation (field) emitted during the explosion of the supernova star.

3. Simulation of Competitive Behavior of Field and Matter in the Universe

Although the density of substance y is many times more than the field density x, for a large mass of the field their competitive behavior becomes real. Soon after the Big Bang, the radiation, i.e. the field made a much larger contribution to the density of matter than the substance. This period is called the "radiation era" [6]. As is known, the competitive behavior of two variables x and y are adequately modeled by the Lotka-Volterra equations, also known as the predator-prey equations.

The report [7] shows that if for two competing variables x and y, satisfying the system of Lotka-Volterra equations predator-prey, the stable

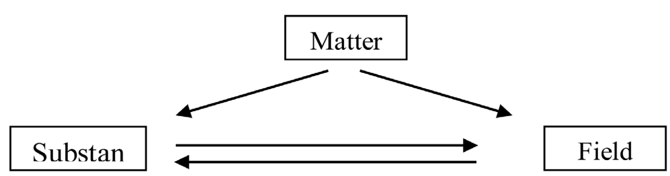

Figure 1. State of matter.

[1] h—Planck's constant, ν_0—frequency of electromagnetic radiation.

$$\begin{aligned} &\frac{\mathrm{d}x}{\mathrm{d}t} = ax - bxy, \quad a, b > 0, \\ &\frac{\mathrm{d}y}{\mathrm{d}t} = cxy - dy, \quad c, d > 0, \end{aligned} \qquad M$$

and the instable

$$\begin{aligned} &\frac{\mathrm{d}x}{\mathrm{d}t} = ax - bxy, \quad a, b > 0, \\ &\frac{\mathrm{d}y}{\mathrm{d}t} = dy - cxy, \quad c, d > 0, \end{aligned} \qquad N$$

for denotation $z = xy$ and the condition according to which the rate of change in the density of matter z is constant, *i.e.*

$$\dot{z}/z = \pm^{2} q = const. \tag{5}$$

the transition from systems M and N to the modified Riccati equation can be carried out [7]

$$\frac{\mathrm{d}z}{\mathrm{d}t} = -^{3}\left(d \mp q\right) z + \frac{bc}{a \mp q} z^{2}.^{2} \tag{6}$$

To explain the role of the parameters and in the first equation of the system, let us represent the equation in the tempo form:

$$\frac{\frac{\mathrm{d}x}{\mathrm{d}t}}{x} = a - by. \tag{7}$$

It is clear from Expression (7) that the parameter a describes the rate of production of the field density $x = \rho(x)$; parameter b is the weight coefficient for the density of substance $y = \rho(y)$ in Equation (7).

Similarly, to identify the assignment of parameters c and d in the second equation of the system M, we represent this equation in a tempo form:

$$\frac{\frac{\mathrm{d}y}{\mathrm{d}t}}{y} = cx - d. \tag{8}$$

Equation (8) shows that the parameter d characterizes the rate of production (formation) of the density of substance $y = \rho(y)$ and the parameter c is the weighting factor for the field density $x = \rho(x)$.

4. Solution of Equation (6) to Determine Parameter *q*

It should be noted that Equation (6) includes Equation (1) modeling the expanding universe, and Equation (2) modeling the compressing universe; all depends on the choice of coefficients for z and z^2.

Let us now define the parameter q. To this end, the solution of (6) will be sought in the class of generalized functions [8]. Actually, turn to equations

[2]Signs "–" in Formula (6) correspond to the expansion of the universe.

$$\pm\frac{\mathrm{d}\chi}{\mathrm{d}t}=\frac{1}{\psi}, \tag{9}$$

$$\frac{\mathrm{d}\psi}{\mathrm{d}t}=\frac{1}{\chi}\cdot \tag{10}$$

From Equations (9) and (10) it follows that

$$\pm\frac{\mathrm{d}\chi}{\mathrm{d}\psi}=\frac{\chi}{\psi}\Rightarrow\pm\frac{\frac{\mathrm{d}\chi}{\mathrm{d}\psi}}{\chi}=\frac{1}{\psi}\Rightarrow\left(\ln\left|\pm\chi\right|\right)'_{\psi}=\frac{1}{\psi}\cdot \tag{11}$$

If in formula (11) we substitute χ by *z*, and substitute ψ by current time *t*, then denote

$$z=z_0\ell^{t}, \tag{12}$$

(z_0 is the value of matter density in equilibrium state: $a=\frac{bcz_0}{d}e$, and letter *e* denotes the Napier's number, *i.e.*, $e=2.7182\ldots$) with account of (5) we will have

$$\frac{1}{t}=\dot{z}/z=\left(\ln\left|\pm z\right|\right)'_{t}=\ln\ell=\pm q. \tag{13}$$

Expression (13) shows that the parameter q belongs to the class of generalized functions. We divide both sides of Equation (6) by *z*, then with account of (5) we obtain equality

$$\pm q=-d\pm q+\frac{bc}{a\mp q}z.$$

From the last equation we define *z*:

$$z=\frac{d\left(a\mp q\right)}{bc}. \tag{14}$$

According to Relation (13), Expression (14) and notation (12) can be (for $\ell=e$ and for $t=\pm1$) written as follows

$$\ln z_0+t\ln\ell=\ln\left|\frac{d\left(a\mp q\right)}{bc}\right|\Rightarrow e^{1}=\pm\left(\frac{d\left(a\mp q_{1,2}\right)}{bcz_0}\right)\text{ and }e^{-1}=\pm\left(\frac{d\left(a\mp q_{1,2}\right)}{bcz_0}\right). \tag{15}$$

From the Relation (15) we obtain following formulas

$$\left.\begin{aligned}
e&=+\frac{d\left(a-q_1\right)}{bcz_0}\Rightarrow q_1=a-\frac{bcz_0e}{d},\\
e&=+\frac{d\left(a+q_2\right)}{bcz_0}\Rightarrow q_2=\frac{bcz_0e}{d}-a,\\
e&=-\frac{d\left(a-q_1\right)}{bcz_0}\Rightarrow q_1=\frac{bcz_0e}{d}+a,\\
e&=-\frac{d\left(a-q_2\right)}{bcz_0}\Rightarrow q_2=\frac{bcz_0e}{d}+a.
\end{aligned}\right\} \tag{16}$$

$$\left.\begin{aligned} e^{-1} &= +\frac{d\left(a-q_1'\right)}{bcz_0} \Rightarrow q_1' = a-\frac{bcz_0}{de}, \\ e^{-1} &= +\frac{d\left(a+q_2'\right)}{bcz_0} \Rightarrow q_2' = \frac{bcz_0}{de}-a, \\ e^{-1} &= -\frac{d\left(a-q_1\right)}{bcz_0} \Rightarrow q_1' = \frac{bcz_0}{de}+a, \\ e^{-1} &= -\frac{d\left(a-q_2\right)}{bcz_0} \Rightarrow q_2' = \frac{bcz_0}{de}+a. \end{aligned}\right\} \tag{17}$$

Root q_2' (17) is not suitable, because it corresponds only to the compressing or only to the expanding universe: $z = z_0 e^{q_2' t} \to \infty$ for $t \to \infty$ or $z = z_0 e^{-q_2' t} \to 0$ for $t \to \infty$.

From the first expression it follows that the density of matter tends to infinity.

Root q_1 (16) can be used in modeling the expanding universe for $\frac{bcz_0}{d}e > a$, and in the modeling of a compressing Universe for $a > \frac{bcz_0}{de}$. In Equation (6), the parameter q implies root q_1. Consequently, the density of matter corresponding to the root q_1 will be written as follows

$$z = z_0 e^{q_1 t}. \tag{16a}$$

Thus, for a constant rate (5) of change of the matter density $z\left(z = xy\right)$, formula (16a) determines the total density of the field x and the substance y in the form of an exponential function, consisting of the production of the current time *t*, difference $q_1 = a - \frac{bcz_0}{d}e$ characteristic of the relationship between the weight coefficients of the field (*a*, *d*), the substance (*b*, *c*) and the value of the total density of the matter in the equilibrium state $z_0 = \frac{a_0 d_0}{b_0 c_0 e}$ where the parameters a_0, b_0, c_0, d_0 correspond to the equilibrium state of the parameters a, b, c, d, for which equality $a - \frac{bcz_0}{d}e = 0$ holds.

Consequently, for an expanding universe, *i.e.* for the Equation (1), the parameters β_+ and μ_+ are defined as follows

$$\left\{\begin{aligned} &\beta_+ = -\left(d+q\right) = -d-a+\frac{bcz_0}{d}e > 0 \Rightarrow \frac{bcz_0}{d}e > a+d, \\ &\mu_+ = \frac{bc}{a-q} = \frac{bc}{a+\frac{bcz_0}{d}e-a} = \frac{d}{z_0 e} > 0. \end{aligned}\right. \tag{18}$$

For a shrinking universe, *i.e.* for Equation (2), the parameters β_- and μ_- are found from expressions

$$\left\{\begin{aligned} &\beta_- = q-d = a-\frac{bcz_0}{de}-d > 0 \Rightarrow a-d > \frac{bcz_0}{de}, \\ &\mu_- = \frac{bc}{a+q} = \frac{bc}{a+a-\frac{bcz_0}{de}} = \frac{bcde}{2ade-bcz_0} > 0 \quad \text{for } 2ade > bcz_0. \end{aligned}\right. \tag{19}$$

As long as we have inequality $ade > bcz_0 + d^2e$, then condition $2ade > bcz_0$ is in excess; its realization occurs automatically.

5. Determination of the Current Density in the Expanding and Contracting Universe

The solution of Equations (1) and (2) have the form:

$$z_+ = \frac{n_+}{1+e^{-\mu_+ n_+(t-t_0)}}, \tag{1a}$$

$$z_- = -\frac{n_-}{1+e^{\mu_- n_-(t'-t'_0)}}. \tag{2a}$$

In these formulas, the moment of "creation of the world" is t_0, and the moment of compression of the universe is t'_0.

At first glance, it may seem that Formula (2a), incorrectly describes the change in the density z_- of matter in the universe when it is compressed, since negative density has no physical meaning. However, upon careful consideration of Formula (2a), it becomes clear that the parameter β_- is negative, that is $\beta_- = \frac{bcz_0}{de} - (a-d) < 0$ and therefore, the ratio $n_- = \beta_- / \mu_-$ is also negative, so Formula (2a) must be written in the following form

$$z_- = \frac{n_-}{1+e^{-\mu_- n_-(t'-t'_0)}}. \tag{3a}$$

Formula (2a) correctly models the change in the density of matter in the universe during its contraction.

6. Model of the Big Bang in the Universe

In the radiation era the field density is determined by the formula [6]

$$x = \frac{3}{32\pi æ t^2}. \tag{20}$$

The time t is given in seconds.

The density of matter in the universe is determined by the expression (16a)

$$z = z_0 e^{\left(a - \frac{bcz_0}{d}e\right)t}, \tag{21}$$

where the parameters a, b, c, d satisfy "predator-prey" systems M and N. Since in the early moments of time the strong inequality must hold

$$a \gg \frac{bcz_0}{d}e,$$

instead of Expression (21), we obtain a simplified formula

$$z = z_0 e^{at}. \tag{22}$$

As in the early moments of time after the Big Bang the field made much larger contribution to the matter density than the substance, the weight coefficient b in the first equation of the system M is approximately equal to zero, *i.e.* $b \approx 0$.

Proceeding from this, the first equation of the system M will take the form:

$$\frac{\frac{\mathrm{d}x}{\mathrm{d}t}}{x} = a .$$

The solution of the last equation is written as $\ln x = a\int_0^t \mathrm{d}t$.

If in the last equation we take into account x according to (20), we will have

$$at = \ln K - \ln t^2 , \tag{23}$$

where $K = \frac{3}{32\pi æ}$.

In Formula (22) substitution of value at found from (23), will give

$$z = z_0 e^{\ln K} \cdot e^{-\ln t^2} .$$

The volume occupied by matter M^* in the universe during the Big Bang is

$$V = V_0 e^{\ln t^2} , \tag{24}$$

where

$$V_0 = \frac{M^*}{z_0 e^{\ln K}} = const.$$

Formula (24) shows that as a result of the Big Bang the volume of matter in the universe grows exponentially-logarithmically; it adequately reflects the exponential-logarithmic expansion of the Universe that occurs during the Big Bang. On the basis of physical considerations, in the Formula (24), the current time $\pm \boldsymbol{t}$ must satisfy the initial condition $\pm \boldsymbol{t_0} = \mathbf{1}$.

In the course of time, the contribution of the density of matter to the density of matter increases. In quantitative terms, this increase is appropriately reflected by an increase of the value of coefficient b in the first equation of the system M. In addition, the process of expansion of the universe slows down, because the difference $a - \frac{bcz_0}{d} e$ decreases. Such development of scenario is actually observed.

7. Result and Conclusion

The main result of this work is to obtain Formulas (1a) and (2a) that allow determining the density of matter in an expanding and contracting Universe. Thanks to the use of the model of competitive behavior of matter and field, it became possible to obtain expressions that imitate both the expansion and contraction of the universe. This approach made it possible to create an adequate model of the evolution of the universe, as well as to obtain a mathematical model of the Big Bang.

Conflicts of Interest

The author declares no conflicts of interest.

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