

Possible source of the hot Universe^{*,**}

L. V. Verozub^{a,1,**}

^a*Kharkiv University, Kharkiv, Ukraine*
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Abstract

It is shown that the gravitational mass-energy defect could be the main cause of Big Bang energy and triggering inflation in the newborn Universe. The results were obtained on the basis of modified classical Einstein equations, which is caused by the need to take into account an important mathematical fact that Einstein could not have known in his time.

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1. Introduction

The most likely reason for the formation of a visible expanding universe is its spontaneous appearance as a point-like object as a result of the instability and fluctuations of the vacuum [1, 2, 3].

However, the fundamental law of conservation of energy prohibits the appearance of an observable matter in the Universe "from nothing". On a macroscale, we can assume that the total energy of the Universe is $E = E_0 - E_b$, where E_0 is the gravitational binding energy. Therefore, contradictions with the law of conservation of energy can be avoided if the total energy of the Universe is zero. The hope for this has been repeatedly expressed, for example, by Høging and Zeldovich. The main reason preventing the solution of this question quantitatively is the absence of a correct expression for the gravitational energy in general relativity.

The only, more or less rigorous basis for this hope is the result of Landau and Lifshitz [8], who, on the basis of the pseudo-tensor of the energy-momentum proves this fact within the framework of GR for a particular model and for

*This document is a collaborative effort.

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*Leonid Verozub

**Principal corresponding author

Email address: leonid.v.verozub@univer.kharkov.ua (L. V. Verozub)

¹Kharkiv University, UA.

a particular coordinate system. However, no one has proved that this result does not depend on the choice of the coordinate system, and therefore puts the conclusions into question.

In addition, it is not clear what the meaning of the equality $E = 0$ has for a spatially infinite universe.

Another possibility is being explored here. The law of conservation of energy does not prohibit the appearance of any mass. It only requires that the inert mass formed in some way, which is inevitably accompanied by the gravitational binding energy, must immediately be released in the form of kinetic energy and radiation.

The correct expression for the gravitational binding energy can be obtained based on the modified Einstein equations. This modification is not a fantasy of the author. It is necessary in order to bring into agreement with an important mathematical fact that the creator of general relativity may not have known in his time.

2. Projectively invariant bimetric equation of gravitation

2.1. General Properties

The need to modify the Einstein equations follows from the fact that mathematicians discovered many years after the appearance of the classical Einstein equations.

All Christoffel symbols $\bar{\Gamma}_{\beta\gamma}^{\alpha}(x)$ obtained by the transformations

$$\bar{\Gamma}_{\beta\gamma}^{\alpha}(x) = \Gamma_{\beta\gamma}^{\alpha}(x) + \delta_{\beta}^{\alpha} \phi_{\gamma}(x) + \delta_{\gamma}^{\alpha} \phi_{\beta}(x), \quad (1)$$

where $\phi_{\beta}(x)$ are an arbitrary differentiable vector-function, describe the same gravitational field because the geodesic equations remain invariant under this transformation[13].

This is most easily seen if the geodesic equation is written as

$$\ddot{x}^{\alpha} + (\Gamma_{\beta\gamma}^{\alpha} - c^{-1}\Gamma_{\beta\gamma}^0 \dot{x}^{\alpha}) \dot{x}^{\beta} \dot{x}^{\gamma} = 0 \quad (2)$$

where points denote differentiation with respect to $t = x^0/c$, c is speed of light.

However, Einstein's equations are not invariant with respect to such transformations[14] because, for example, the Ricci tensor is transformed under (1) as follows

$$\bar{R}_{\alpha\beta} = R_{\alpha\beta} - \phi_{\alpha\beta}, \quad (3)$$

where $\phi_{\alpha\beta} = \phi_{\alpha;\beta} - \phi_{\alpha}\phi_{\beta}$, and $\phi_{\alpha;\beta}$ is a covariant derivative of ϕ_{α} with respect to x^{β} .

Transformation (1) induces some mapping $g_{\alpha\beta} \rightarrow \bar{g}_{\alpha\beta}$ of the metric tensor $g_{\alpha\beta}$ [13]. Consequently, such transformations should be some gauge transformations in any theory based on the hypothesis of motion of free test particles alone geodesic lines. Only objects that are projectively (geodesically) invariant can have physical meaning in such theory.

2.1 General Properties

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In paper [9] a theory in which geodesic mappings play a role of gauge transformations is considered.

The only projectively invariant object which can be created by Christoffel symbols is the Thomas symbols

$$\Pi_{\alpha\beta}^{\gamma} = \Gamma_{\alpha\beta}^{\gamma} - (n+1)^{-1} \left[\delta_{\alpha}^{\gamma} \Gamma_{\beta} + \delta_{\beta}^{\gamma} \Gamma_{\alpha} \right] \quad (4)$$

where $\Gamma_{\alpha} = \Gamma_{\alpha\beta}^{\beta}$.

However, $\Pi_{\alpha\beta}^{\gamma}$ is not a tensor. A tensor object can be formed only within the framework of a bimetric theory. It is of the form [9]:

$$B_{\beta\gamma}^{\alpha} = \Pi_{\beta\gamma}^{\alpha} - \overset{\circ}{\Pi}_{\beta\gamma}^{\alpha}, \quad (5)$$

where

$$\overset{\circ}{\Pi}_{\alpha\beta}^{\gamma} = \overset{\circ}{\Gamma}_{\alpha\beta}^{\gamma} - (n+1)^{-1} \left[\delta_{\alpha}^{\gamma} \overset{\circ}{\Gamma}_{\beta} + \delta_{\beta}^{\gamma} \overset{\circ}{\Gamma}_{\alpha} \right] \quad (6)$$

and $\overset{\circ}{\Gamma}_{\alpha} = \overset{\circ}{\Gamma}_{\alpha\beta}^{\beta}$, are the Thomas symbols in Minkowski space in a coordinate system used.

The simplest bimetric geodesic-invariant generalization of Einstein's vacuum equations is [9]:

$$\nabla_{\alpha} B_{\beta\gamma}^{\alpha} = B_{\beta\delta}^{\epsilon} B_{\epsilon\gamma}^{\delta}. \quad (7)$$

The symbol ∇_{α} denotes a covariant derivative in Minkowski space with respect to x^{α} .

These equations have similarities to vacuum equations of classical electrodynamics in Minkowski space:

$$\mathcal{F}_{\alpha;\gamma}^{\gamma} = 0, \quad \mathcal{F}_{\alpha\beta} = \partial_{\alpha} A_{\beta}(x) - \partial_{\beta} A_{\alpha}(x),$$

which are invariant relative to mappings of 4-potentials: $A_{\alpha} \rightarrow A_{\alpha} + \phi(x)_{\alpha}$. However, eqs. (7) contains the right-hand side which expresses self-interaction of gravitation.

When we select the covariant gauge conditions in the form $Q_{\alpha} = \Gamma_{\alpha\beta}^{\beta} - \overset{\circ}{\Gamma}_{\alpha\beta}^{\beta} = 0$, equations (7) coincide with the classical vacuum Einstein equations $R_{\alpha\beta} = 0$. In other words, the classic vacuum Einstein's equations are equations (7) at the gauge conditions $Q_{\alpha} = 0$.

These equations lead to the same results that Einstein's equations at the distances r from a gravity center which is much larger of the Schwarzschild radius r_g of the central mass [15]. However, gravity properties become quite different when the distance approaches r_g . Instead of the classic Newtonian an expression for force F acting on a rest test mass m at rest we obtain:

$$F = -\frac{mMG}{r^2} \left(1 - \frac{r_g}{f} \right) \quad (8)$$

where $r_g = 2GM/c^2$ is the Schwarzschild radius of a dot mass M .

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A singularity in the center is missing in this model. The gravitational force decreases within the Schwarzschild radius, and eventually tends to zero along with the distance from the center.

The weakness of the gravitational field inside the Schwarzschild radius leads to the possibility of the existence of cold stable supermassive objects without an event horizon, which are an alternative to supermassive black holes in the centers of galaxies [14, 13, 15]. This modification of the classic Newtonian law is also consistent with recent observations. Observation of gravitational waves during the merging of supermassive objects do not allow us to identify the nature of the objects.

The existence of supermassive objects without event horizon also does not contradict the result obtained with Event Horizon Telescope (EHT) collaboration observations [19] Remarkable result Event Horizon Telescope (EHT) demonstrates the existence of supermassive objects in the centers of galaxies, but it still does not make it possible to uniquely establish their nature.

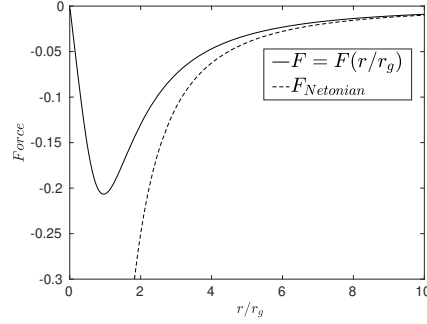


Figure 1: The force acting rest-particle closes the Schwarzschild radius in arbitrary units.

2.2. Gravitational event horizon

In this paper, we start from a standard cosmological principle. However, the physical meaning of the existence of the Minkowski space along with the Riemannian space in equations (7) requires serious justification.

This problem is considered in [10] in detail, and in Section 6 briefly. In present Section, we simply postulate that Riemannian and Minkowskian geometry are, at least locally, two physically equivalent possibilities.

According to this, we can consider the motion of a test particle in Minkowski space by a Lagrangian $L(x, \dot{x})$, or equivalent in space-time with line element $ds = (g_{\alpha\beta}(x)dx^\alpha dx^\beta)^{1/2}$, which is connection with L by relation

$$ds = -(mc)^{-1} dS(x, dx)$$

where S is the action $S = \int L(x, \dot{x}) dt$.

The most important consequence of the equations of gravitation under consideration for cosmology is that for any observer, the influence of the Universe gravity to remote objects is mainly limited by some distance R_g .

The Lagrangian, which is invariant with respect to mapping $t \rightarrow -t$ and describes the motion of test particles in the the spherically symmetric field of a mass M in Minkowski space has the form:

$$L = mc[A(r)\dot{r}^2 + B(r)(\dot{\theta}^2 + \sin^2 \theta \dot{\varphi}^2) - c^2 C(r)]^{1/2} \quad (9)$$

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The solution of the equations (5) at the conditions

$$\lim_{r \rightarrow \infty} A(r) = 1, \lim_{r \rightarrow \infty} (B(r)/r^2) = 1, \lim_{r \rightarrow \infty} C(r) = 1 \quad (10)$$

is given by :

$$\begin{aligned} C &= 1 - r_g/f, f = (r^3 + r_g^3)^{1/3}, B = f^2, \\ A &= r^4/f^4 C, r_g = 2GM/c^2 \end{aligned} \quad (11)$$

In [9, 10] was shown that the equations of motion of a test particle resulting from this solution do not change if A, B, C are functions not only of r , but also of time t . Since the equations of motion determine the properties of the field, this means that spherically symmetric solution is static. This proves the analog of the Birkhoff theorem. However, this is not surprising since Einstein's vacuum equations are equations (7) at the gauge defined by the condition $Q_\alpha = 0$. In other words, in the gauge used, these equations are equivalent to the system

$$R_{\alpha\beta} = 0$$

$$Q_\alpha = 0.$$

The solution (11) is valid for any spherically symmetric substance, therefore it is correct inside the spherical hollow shell as well. Gravitational field is absent here since $M(r) = 0$, and the space-time is pseudo-Euclidean. Consequently, the matter of the spherical shell does not affect the gravity inside the shell. This important conclusion will be used hereafter.

A projectively invariant generalization of Einstein's equations in the presence of matter can also be obtained [9]. We do not use them, since their validity by comparison with observations is difficult to verify.

It is easy to see that the main peculiarity of this solution is that functions A, B , and C tend to their values in the Minkowski space ($A = 1, B = r, C = 1$) at $r/r_g \rightarrow 0$, i.e., when the matter radius is much less than the Schwarzschild radius.

Consider when this condition can be satisfied.

For this, we must take into account that the radius of a homogeneous sphere, which is equal to the Schwarzschild radius of the matter contained in it, is

$$R_g = c\sqrt{\frac{3}{8\pi G\rho}} \quad (12)$$

where ρ is the density.

Radius R of a mass becomes less than R_g in two cases:

1. This happens at densities of the order of $10^4 \div 10^5 \text{ g/cm}^3$. For example, for density of 10^5 g/cm^3 , R_g is equal in order to the radius of the Sun. In such cases, due to the weakness of gravity inside R_g , the substance may have a huge mass [14, 15, 16, 13]. Such configurations are candidates for supermassive objects in the centers of galaxies.

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2. At a very low average density of the visible Universe, the distance to the object becomes less than the Schwarzschild radius of the matter contained in it already at $R > 10^{28} \text{cm}$.

More information can be obtained if we consider the force $F = m\ddot{r}$ (or acceleration \ddot{r}) acting on a test particle of mass m as a function of the distance r from the observer. For a free radial motion of a test particle Lagrangian (9) is: $L = -m c (c^2 C - A\dot{r}^2)^{1/2}$. It has the energy integral

$$\frac{cC}{(c^2 C - A\dot{r}^2)^{1/2}} = \bar{E} \quad (13)$$

where $\dot{r} = dr/dt$, $\bar{E} = E/mc^2$ and E is the energy of the particle. This equation gives the velocity $v = \dot{r}$ as a function of r :

$$v^2 = c^2 \frac{C^4 f^4}{r^4} \left(1 - \frac{C}{\bar{E}^2} \right) \quad (14)$$

For parameter \bar{E} three variants are possible: $\bar{E} > 1$, $\bar{E} < 1$ and $\bar{E} = 1$. However, only $\bar{E} = 1$ is consistent with observations.

Indeed, the distance to nearby galaxies satisfies inequality $r \gg r_g$ where $r_g = 2GM/c^2$ and $M = 4/3\pi\rho r^3$. At this condition, $f \approx r$, and $C = 1 - r_g/r$. Consequently, we obtain from (14) that

$$v = Hr,$$

where

$$H = \sqrt{(8/3)\pi G\rho} = 1.8 \cdot 10^{-18} \text{s}^{-1}$$

at $\rho = 6 \cdot 10^{-30} \text{g/cm}^3$. This is consistent with the observations.

If $\bar{E} \neq 1$, then equation (14) does not lead to the Hubble law since v does not tend to zero when $r \rightarrow 0$. For this reason, we set $\bar{E} = 1$.

With eq. (14) we can obtain a graph of the acceleration $a = vdv/dr$ as a function of the distance to a test particle.

It is very useful to compare the acceleration of a free test particle close a point mass M and this value in the Universe close distance of 10^{28}cm , which are given in fig 3 and 4.

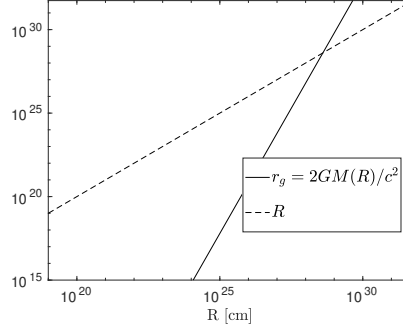


Figure 2: $r_g(R)$ vs. the distance R

²In this paper, we assume that the average density of the visible Universe is equal to $6 \cdot 10^{-28}$ since this value leads to satisfactory agreement between our theoretical Hubble diagram and the observed one[9].

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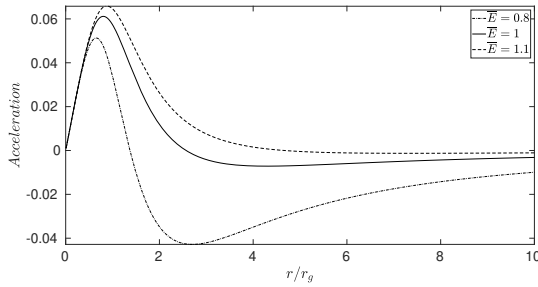


Figure 3: Acceleration (arbitrary units) of free-falling test particles to a central point mass M as the function of the distance from the mass in the Schwarzschild radius's. The value \bar{E} is the dimensionless energy E/m .

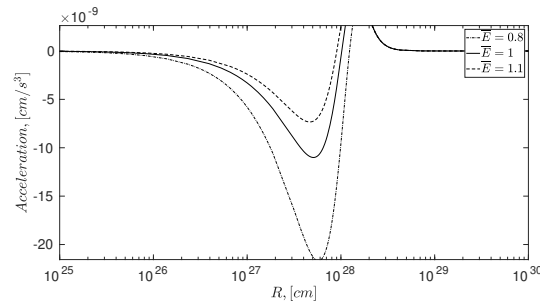


Figure 4: Acceleration of test particles in the Universe at the distance vicinity of $R = 10^{28} \text{ cm}$.

A comparison of graphs 3 and 4 shows that they have similar features, since in both cases, accelerations are considered in the area where the equality $r/r_g = 1$ holds.

Two conclusions can be made from figure 4.

1. The Schwarzschild radius R_g becomes more than R at $R > 1.5 \cdot 10^{28} \text{ cm}$. Before this, at $R = 6 \cdot 10^{27} \text{ cm}$, the acceleration change sign, in analogy with the particle free falling to a point mass (fig 2). If $R > 6 \cdot 10^{27} \text{ cm}$, the acceleration is positive. Hence, for sufficiently large radius R the gravitational force gives rise to an acceleration of remote galaxies.

This is a natural explanation of the observed acceleration of the expanding Universe, which is confirmed by the satisfactory coincidence of the theoretical and the real Hubble diagram [9]. Besides, in the next section, additional justification for this statement provides by calculating the deceleration parameter.

2. At $R > 10^{28} \text{ cm}$, gravitational force $F = m\ddot{R}$ affecting the particles, quickly tends to zero when R tends to the infinity. The reason for the fact is that the ratio R/R_g tends to zero when R tends to infinity. Consequently, the gravitational influence on galaxies at large distance R caused mainly by the matter insider of the sphere of the radius R_g which typically, the Schwarzschild radius is small compared with the dimensions of celestial objects. That is,

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almost always the condition $r \gg r_g$ is executed. Therefore, for comparison with observations in most cases only the expansion of functions $A(x)$, $f(x)$, and $C(x)$ in a Taylor series in powers of $\phi = r_g/r$ are of interest.

Accurate to terms of second order with respect to ϕ these functions are of the form:

$$C = 1 - \phi, \quad B = r^2, \quad A = 1 + \phi + \phi^2 \quad (15)$$

Therefore, in a first approximation, the line element ds^2 of the field in the rest frame coincides with the commonly used expression in general relativity:

$$ds^2 = (1 - \phi) dx^0{}^2 - (1 + \phi) dr^2 - r^2[d\theta^2 + \sin^2 \theta d\varphi].$$

And to this accuracy all observed effects, of course, will be the same as in the general theory of relativity.

This shows that the observed effects differ from the results that follow from the Einstein equations only when the Schwarzschild radius is approached

... h can be called "a gravitational event horizon".

Thus, the solution of the gravitational equations under consideration are valid in the infinite Universe due to the peculiarity of the gravitational force and the fact that the functions A , B , and C tend to their values in the Minkowski space at distances shorter than the Schwarzschild radius.

For this reason, only the mass of the Universe within a radius of R_g has a physical meaning for studying the history of the Universe.

2.2.1. Deceleration parameter

Calculation of the deceleration parameter is an important method for checking the relativistic expression used above for the speed and acceleration of a test particle in the expanding Universe.

The acceleration as a function of the distance is $g = v'(r)v(r)$ where the velocity v is given by (14). It allows us to find the value of the deceleration parameter:

$$q = -\frac{\ddot{r} \cdot r}{v^2}.$$

The fig. 5 shows q as a function of the distance of an object from the observer.

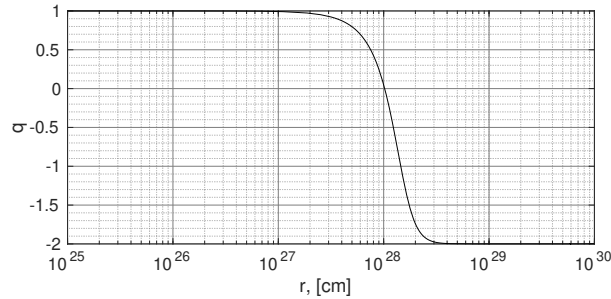
This graph shows that the observed value of present-day $q_0 \approx -0.55$ [18, 20] corresponds to the geometrical distance of the remote objects of about 10^{28} cm . It is consistent with fig. 4 that shows the acceleration of distance objects.

Physical meaning of the bimetricity

In Einstein's classical theory, coordinates play a twofold and difficultly compatible role. On the one hand, coordinates are only a way to parameterize

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Figure 5: *Parameter q vs. distance to the object.*

events, that is, points in space-time. From this point of view, they are completely arbitrary. On the other hand, they play the role of gauge transformations.

However, the equations of motion of test particles admit invariance with respect to projectively (geodesic) metrics (??), and due to this fact, the equations defining a space-time metric must also be invariant with respect to these transformations.

A projectively invariant generalization of Einstein's equations seems to be possible only within the framework of some bimetric theory of gravity.

Rosen [11] was the first to recognize the need for introducing Minkowski space into theory. The possibility of considering Einstein's equations in flat space was also considered by some authors after the paper of Tiring[12].

The physical meaning of bimetrism used in the present paper is based on ideas going back to Poincaré, who realized that there is a strange situation: In order to characterize the properties of the geometry of space, we must know the properties of measuring instruments, and in order to characterize the properties of instruments, we must know the geometric space properties. In the modern interpretation, this can be summarized as follows: The physical, operational sense has only the aggregate "space-time geometry + properties of measuring instruments" 10. In this form, this fact has never been realized in physics.

However, a step in its implementation can be made if we notice that it is the reference frame used by the observer is the measuring tool that is necessary to establish the geometric properties of space-time. Therefore, it should be assumed that the following statement is true: Only the combination "space-time geometry + properties of the reference frame used" has physical meaning.

Of course, by reference frame we mean here not a coordinate system, but a physical device consisting of a reference body and a clock attached to it.

Remembering all the above, we now consider a classical field \mathcal{F} in an inertial reference system (*IRF*), where space-time according to experience is Minkowski space. The world lines of the particles of mass m moving under the action of the field \mathcal{F} form the reference body of a non-inertial reference which can be named the proper reference frame (*PRF*) of the field \mathcal{F} .

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If an observer in a *PRF* of the field \mathcal{F} is at rest, his world line coincides with the world line of some point of the reference body. It is obvious for the observer that the accelerations of the point masses forming his reference body are equal to zero in non-relativistic and relativistic meaning. That is, if the line element of space-time in an inertial reference frame is denoted by $d\sigma$ and $u^\alpha = dx^\alpha/d\sigma$ is the field of 4- velocities of the point masses forming the reference body, then the absolute derivative of u^α is equal to zero: ³

$$Du^\alpha/d\sigma = 0. \quad (16)$$

(We mean that an arbitrary coordinate system is used.)

The same should occur in the *PRF* used. That is, if the line element of space-time in the *PRF* is denoted by ds , the 4-velocity vector $\zeta^\alpha = dx^\alpha/ds$ of the point-masses forming the reference body of the *PRF* should satisfy the equation

$$D\zeta^\alpha/ds = 0 \quad (17)$$

The equation (17) uniquely determines the fundamental metric form in *PRFs*.

Indeed, the differential equations of these world lines are at the same time the Lagrange equations describing, in Minkowski space, the motion of the point masses forming the reference bodies of the *PRF*. The eq. (17) can be derived from a Lagrange action S by the principle of the least action. Therefore, the equations of the geodesic lines can be obtained from a line element $ds = k dS$, where k is a constant, $dS = \mathcal{L}(x, \dot{x})dt$, and $\mathcal{L}(x, \dot{x})$ is a Lagrange function describing, in Minkowski space, the motion of identical point masses m forming the body reference of the *PRF*. The constant k is equal to $-(mc)^{-1}$, as follows from the analysis of the case when the frame of reference is inertial, when $\mathcal{L}(x, \dot{x}) = -mc ds$ at the signature (+ - - -).

Thus, if we proceed from relativity of space and time in the Berkeley-Leibniz-Mach-Poincaré (BLMP) sense, then the line element of space-time in *PRFs* can be expected to have the following form [9]

$$ds = -(mc)^{-1} dS(x, dx). \quad (18)$$

For example, if the field \mathcal{F} is electromagnetic, then the space-time in such reference frames is Finslerian[9, 10]. And the space-time in the reference frames comoving to an isentropic ideal fluid is conformal to the Minkowski space.

In the case of gravity, we proceed from Thirring's assumption that gravity is described by a tensor field $\psi_{\alpha\beta}(x)$ and the Lagrangian describing the motion of test particles has the form

$$L = -mc[g_{\alpha\beta}(\psi) \dot{x}^\alpha \dot{x}^\beta]^{1/2}.$$

Then it is obvious from () that space-time in the *PRF* is Riemannian with a linear element of the form

³WE USE NOTATIONS AND DEFINITIONS, FOLLOWING THE LANDAU AND LIFSHITZ BOOK [8].

$$ds = (g_{\alpha\beta}(x)dx^\alpha dx^\beta)^{1/2}$$

This conclusion leads to the possibility of a double interpretation of gravity. Gravity can be considered as physical field ψ in inertial reference frames and manifests itself as curvature in its own reference frames (*PRFs*) of this field.⁴

In the present paper, the description of gravity in Minkowski space is used since only in this case we can get a correct expression for the field energy.

3. The energy of the gravitational field

3.1. Motivation

The correct expression for the energy of the gravitational field can be obtained directly from the equation for the gravitational force:

$$F = -\frac{mMG}{r^2} \left(1 - \frac{r_g}{f}\right) \quad (19)$$

for a spherically symmetric field.

We define the potential of the force F as $U(r) = \int_0^r \frac{F(r')}{m} dr'$.

Double differentiation of function $U(r)$ gives

$$U'' = -\frac{2U'}{r} - \frac{2G^2M^2}{c^2 f^4}.$$

Now denote

$$t_{00} = \frac{GM^2}{2\pi f^4}.$$

As a result, we obtain that function $U(r)$ satisfies the differential equation

$$\nabla^2 U = -4\pi\bar{\rho} \quad (20)$$

where $\bar{\rho} = t_{00}/c^2$.

This equation has a clear physical meaning. This is the Poisson equation for spherically symmetric field, in which $\bar{\rho}$ is the mass density of the gravitational field created by the mass M . In the absence of another matter, only the density of the gravitational field can lead to the fact that the potential will differ from zero.

The result obtained can also be written as

⁴1) The question: "Where is this inertial reference frame ?" does not make sense, since the properties of the reference system do not have a physical meaning in themselves. In the concrete, we can imagine that we are in an inertial reference frame and consider the gravity of the Universe as a physical field in Minkowski space, but we can also assume that we are in the reference frame comoving to the radial flow of galaxies and consider space-time as Riemannian.

$$t_{00} = \kappa \frac{r_g^2}{2f^4} \quad (21)$$

where $\kappa = \frac{c^4}{4\pi G}$.
This gives

$$\int t_{00} dV = Mc^2$$

Thus, the energy of a point mass is finite and equal to the expected value.

In addition, it should be noted also that the integration of density t_{00} over the volume of the visible Universe gives the correct value of its mass $\sim 10^{56}g$.

For this reason, we can consider (21) as the density energy of the gravitational field of the mass M .

4. Gravitational mass-energy defect

Since we proceed from the law of gravitation, which does not have a singularity, it is natural to think that the expansion of the visible Universe began with a radius of zero, i.e. from a point mass.

If there is a gravitational event horizon, then the inert part of this mass was equal in order of magnitude to the mass of the visible universe.

No macroscopic mass can be created without the gravitational binding energy, so the internal energy must have the form

$E = E_0 - E_b$ where $E_0 = M_0c^2$, M_0 is inert mass of the created mater, E_b - is the gravitational binding energy.

Let us consider what form the gravitational field of the above-mentioned point mass in radius R .

From (21) we have

$$E_{in} = \int_0^R t_{00}(r) dV = M_0c^2 \left(1 - \frac{r_g}{f(R)} \right) \quad (22)$$

where $r_g = 2GM_0/c^2$ and $f = (r_g^3 + R^3)^{1/3}$.

The field energy includes inert rest energy. Therefore, this formula is essentially the sum of the energy of the inertial mass and the binding gravitational energy and is therefore nothing more than the equation $E = E_0 - E_b$ for a newborn observable universe .

The field energy outside the radius R is

$$E_{out} = \int_R^{\infty} t_{00}(r) dV = M_0c^2 \frac{r_g}{f}$$

Therefore, the total value of this energy of a point mass is equal to M_0c^2 . It is this energy that is the conserved quantity. Therefore, since M_0c^2 is less than E_{in} , the gravitational binding energy should immediately be released from the

radius P in the form of kinetic energy and radiation. Apparently, this is the physical reason for the expansion of the Universe.

In this case, when the radius R increases and E_{in} decreases, the energy E_{out} increases in accordance with the requirement to conserve the total energy.

It should also be noted that the growth of E_{in} continues up to a radius corresponding to the observed mass of the Universe.

It should be noted that such a model of the expansion of the universe is not unique and can occur anywhere in an infinite homogeneous and isotropic universe. However, we have no physical reason to discuss such a phenomenon as the birth of the universe as a whole. We can only talk about that region of the universe that is accessible to observation.

Thus, the fulfillment of the law of conservation of energy does not need zero energy of the Universe. The conserved quantity is the total energy of the newborn universe, and the gravitational binding energy is a mass-energy defect that is immediately removed from the internal energy to conserve total energy.

It is very important that the model under consideration can be compared with observations since we know the density ρ_γ of the cosmic microwave radiation and the corresponding redshift. The density is $\rho_\gamma = 2 \cdot 10^{-13} \text{ erg/cm}^3$, and redshift is $z \approx 10^3$.

Figure 7 shows the dependence of the radiation density E_b/V in the volume V due to the gravitational mass-energy defect on the radius R of the expanding Universe.

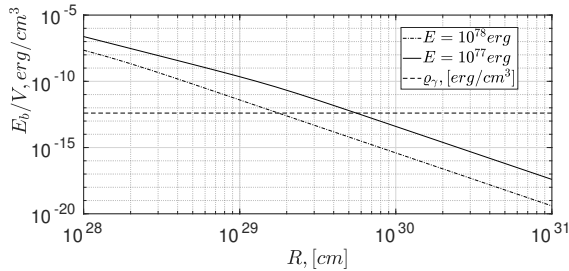


Figure 6: The energy density of the radiation as the function of the Universe radius.

We see that the radiation density due to the gravitational mass-energy defect is $2 \cdot 10^{-13} \text{ erg/cm}^3$ at the radius $\sim 5 \cdot 10^{29} \text{ cm}$.

This distance is consistent with the graph in Fig.4 where the acceleration of the particles is shown.

In addition, we can also find the relationship between the geometric distance from the observer and the redshift z . It is obtained with a formula obtained in [9]:

$$z = \left(C(r)^{-1} \frac{1 + v(r)/c}{1 - v(r)/c} \right)^{1/2} - 1 \quad (23)$$

where $C(r) = 1 - r_g/(r_g^3 + r^3)^{1/3}$ and $v(r)$ is the recession velocity in Minkowski space at zero-density and pressure.

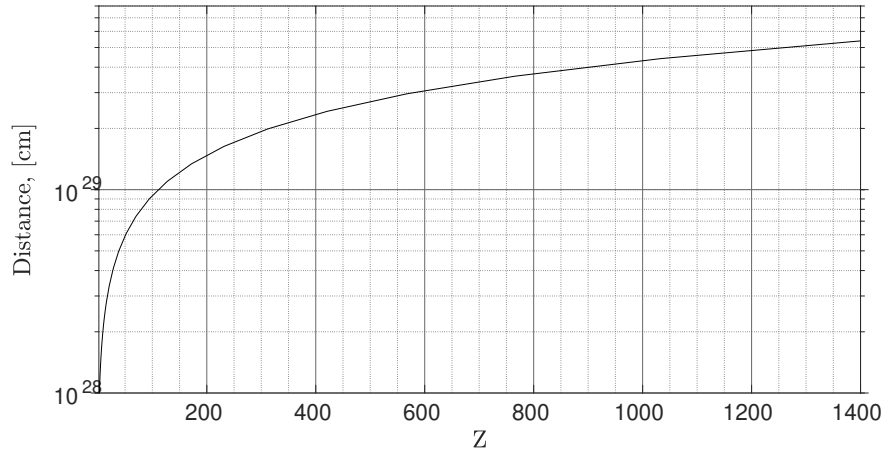


Figure 7: R vs. z

It can be seen from figure 8 that the distance $r \approx 5 \cdot 10^{29} \text{ cm}$ corresponds to the $z = 10^3$ which is CMBR density. This is consistent with observations.

It should be noted that all calculations in this model use a single parameter - the average density of the visible universe.

5. Direct evidence for inflation

Although the model of inflationary cosmology is almost generally accepted, the nature of the inflaton remains unclear. Therefore, it is not surprising that attempts have been made to explain inflation without the need to use hypothetical fields, and to obtain inflation as a consequence of the properties of space-time in modified versions of the Einstein equations [23, 21, 22, 25, 24].

However, the triggering of inflation could also be the result of a gravitational mass-energy defect in the newborn Universe.

Let us find the dependence of the radius of the spherically symmetric mass E/c^2 on time during its expansion, due to the gravitational mass-energy defect.

Consider a test particle located on the edge of the expanding spherical mass M . The desired dependence is determined by the change in the force acting on this particle by the substance of the mass M in the process of the sphere expansion.

External matter does not affect this due to the supposed homogeneity and isotropy of the Universe, as well as due to the existence of the gravitational event horizon.

To avoid doubts about the correctness of the result obtained by numerical methods, we consider the solution of this problem in two different ways.

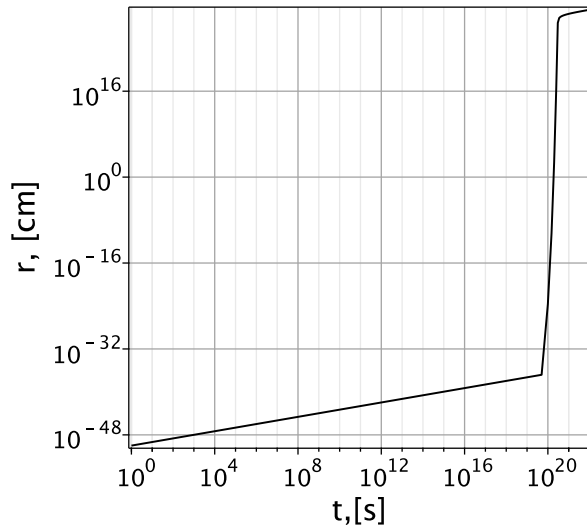


Figure 8:

1. The Lagrangian for the motion of a particle during its radial expansion of mass M in Mikowski space has the form (9)

$$L = -mc(Cc^2 - A\dot{r}^2)$$

where C and A (11) are the functions of the distance r from the mass center. The corresponding particles motion equation is

$$\ddot{r} = -c^2 \frac{C'}{A} + \left(\frac{C'}{C} - \frac{A'}{2A} \right) \dot{r}^2.$$

Sometimes, the solution of this equation it is easy all obtained by the expression for the velocity (14) which follows from an integral of motion considered in section 2 :

$$\dot{r}^2 = c^2 \frac{C^4 f^4}{r^4} \left(\frac{r_g}{f} \right). \quad (24)$$

The speed and acceleration do not have a singularity in the mass center, they tend to zero together with distance r . The dependence of r on t can be found both for the expansion of mass from zero radius, and for history back in time, starting from the radius of the visible Universe was approximately $1 \cdot 10^{-100} \text{ cm}$. Figure 9 shows this solution.

2. Of course, the above method does not allow us to take into account the influence of pressure, since we are dealing with a dust-like model of the Universe

The expansion of the Universe as a function of time, taking into account pressure inside the mass M , can also be obtained by another method.

It was shown in [15] that the motion of macroscopically small elements of an isentropic fluid ("particles") of a mass m is described by the following Lagrangian⁵,

$$L_{fl} = -mc\chi (\eta_{\alpha\beta} dx^\alpha dx^\beta)^{1/2} \quad (25)$$

where $\eta_{\alpha\beta}$ is metric tensor of Minkowski space in coordinate system used,

$$\chi = \frac{w}{\rho c^2},$$

w is the enthalpy per unit volume, $\rho = mn$, n is the particle number density.

This means that macroscopically small elements of the isentropic fluid move along the geodesic lines of the Riemannian space with a line element $ds = (mc)^{-1}dS$ where $S = \int L_{fl}(x, \dot{x})dt$, i.e.,

$$ds = (G_{\alpha\beta}(x) dx^\alpha dx^\beta)^{1/2}$$

where $G_{\alpha\beta} = \chi^2 \eta_{\alpha\beta}$.

This space-time is conformal to the Minkowski one.

This result allows us to study the properties of a fluid by studying the motion of its elements instead of studying the streamlines obtained by solving the complex relativistic Euler equations.

For a radial motion in the expanding Universe in Minkowski space we have:

$$L_{lf} = -mc\chi(r) (c^2 - \dot{r}^2)^{1/2}$$

The enthalpy of a fluid is $W = E + pV$ where $E = \rho_0 c^2 - E_{gr}$, $\rho_0 = mn$, and p is the pressure. Consequently,

$$\chi = 1 - \frac{E_{gr}}{\rho_0 c^2} + \frac{P}{\rho_0 c^2}$$

and the above Lagrangian yields the following equation of the radial motion of "particles" at the Universe expansion:

$$\ddot{r} = -c^2 \frac{\chi'(r)}{\chi(r)} \cdot \left(1 - \frac{\dot{r}^2}{c^2}\right). \quad (26)$$

In order to solve this equation, we can sometimes use an integral of the motion

$$\frac{mc^2 \chi}{[1 - (\dot{r}/c)]^{1/2}} = Const. \quad (27)$$

⁵This approach is inspired by the existence of an effective numerical solution of problems of hydrodynamics [16, 17], known as Smoothed Particle Hydrodynamics (SPH). In this method, a fluid is considered as composed by finite number of particle. These particles move under the action of inter-particle forces which mimic effects of pressure, viscosity, and so on. Due to the replacement of integration by summation over number of particles, continual derivatives become the time derivative along the particle trajectory, and as a result, the motion of particles governed by ordinary differential equations of classical mechanics.

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that yields the following equation of the motion of macroscopic small element (“particle”) of the isentropic fluid

$$\left(\frac{\dot{r}}{c}\right)^2 = 1 - \frac{\chi^2}{\bar{E}^2} \quad (28)$$

where $\bar{E} = E/mc^2$ and E is the energy of the “particle”.

Since Hubble’s law in the absence of pressure must be satisfied, the constant \bar{E} must be equal to 1 in vacuum.

Below graphs of the solutions $r = r(t)$ of equation (26) are given at $p = 0$.

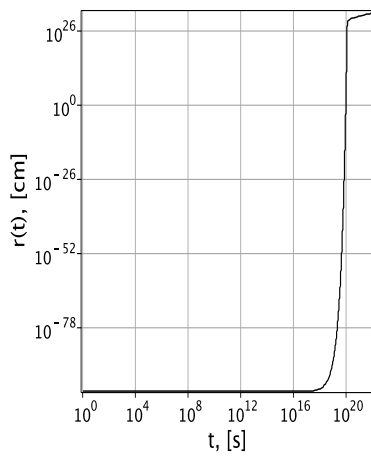


Figure 9: The Universe radius $r(t)$ starting for the initial conditions: $r(0) = 10^{-100}cm$. and $\dot{r}(0) = 0$.

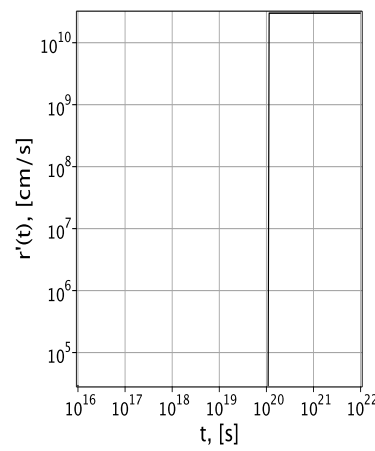


Figure 10: The Universe velocity $\dot{r}(t)$ for the initial condition: $r(0) = 10^{-100}cm$. and $\dot{r}(0) = 0$.

It should not be thought that there was a singularity before the exponential expansion, since all the equations of motion of the test particles give zero velocity when radius of the Universe tends to zero.

It should be noted that the above-obtained graphs of evolution of the radius of the expanding universe can be obtained in another way. The solution (11) of equations (7), in Minkowski space, which is similar to the solution of Schwarzschild in GR, allows you to get the distribution of velocities $v(r)$ and accelerations $w = vdv/dr$ at an arbitrary radius r . The solution of the differential equation $dr/dt = v(r)$ with the initial condition $r(0) = r_0$ close to $r_0 = 0$ gives the evolution of the geometric radius of the visible universe. It is similar to that obtained on the graph above.

5.1. The time and energy before inflation

The purpose of this paper is to show that the gravitational mass-energy defect is a likely cause of the Big Bang energy.

5.1 The time and energy before inflation

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There are at least two consequences of the considered model, which can help further study the structure of the substance before inflation and study its results.

1) Time t on the graphs is not of course physical time. Physical time is measured by the length of its own world line of particle motion. When the particles of the newborn Universe move radially, the proper time is $\tau = ds/c$ where ds is the line element

$$ds = \left(C - A \left(\frac{v}{c} \right)^2 \right)$$

where A , C and the velocity v are given above in this Section. The dependency τ on t is given by fig. 12.

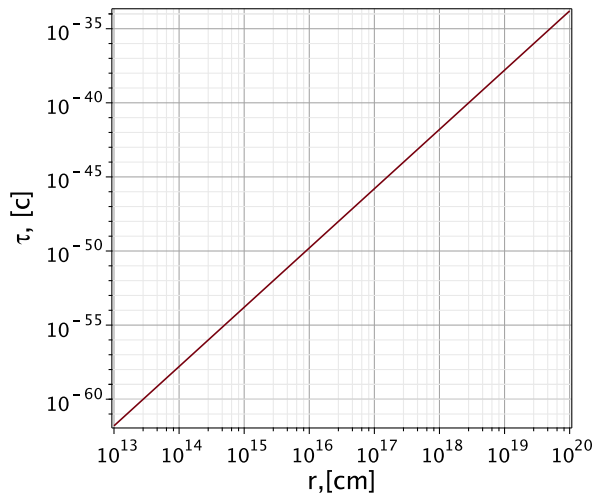


Figure 11: The proper time τ vs. radius r

It is very interesting that these results are consistent with well-known results obtained on the basis of General Relativity, except for the absence of singularity at the time of the birth of the Universe.

2) In the model of the dynamics of the universe considered here, the energy of the newborn Universe is quantity determined by the Schwarzschild radius R_g , which in turn is given by the average density ρ of the visible Universe.

The energy released is the gravitational binding energy, which, unlike GR, can be found for any radius r of the

Figure 13 shows the dependence of the density of released energy on the radius of the Universe on the radius r before inflation. This is important information for assumptions about the structure of matter, from the Planck era to the time of inflation.

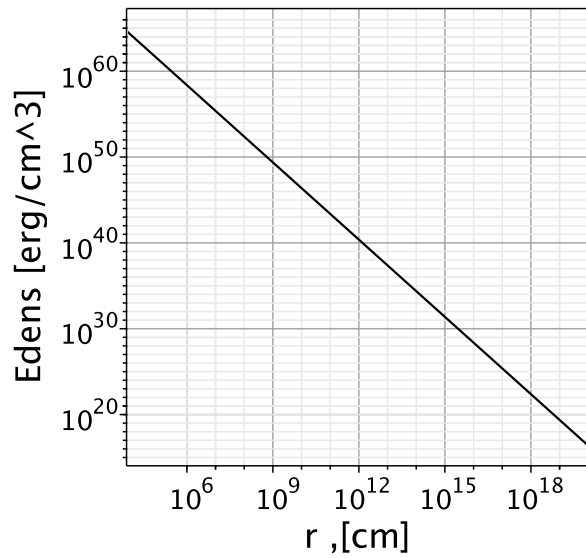


Figure 12: *Energy released vs. radius r*

6. Conclusion

Thus, we have a reason to think that the main cause of the Big Bang, the hot Universe, and the triggering inflation was the gravitational mass-energy defect of the newborn point mass, which is contained within radius R_g .

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