Model of Expansive Nondecelerative Universe and Unified Approach to Fundamental Physical Interactions

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Abstract. The contribution provides the background of the model of Expansive Nondecelerative Universe, rationalizes the introduction of Vaidya metrics allowing thus to localize and quantify gravitational energy. A unifying explanation of the fundamental physical interactions is accompanied by demonstration of some consequences and predictions relating to cosmological problems.

I. Introduction

Starting from the beginning of 80’s, an inflation model of the universe acquired a dominant position in cosmology. Of the main designers of the model, A. Guth and A. Linde should be mentioned. The model has been able to eliminate certain cosmological problems such as a problem of the universe flatness and horizon. At the same time it has open, however, several new questions. There are still significant differences in the calculated values of universe age depending on cosmological theories applied. Inflation model has not been able to precise some important parameters of the universe such as Hubble’s constant or deceleration parameter. It has brought no important knowledge on understanding the gravitation and its relation to the other physical interactions. Moreover, in accordance with some analyses [1], the initial nonhomogenities should not be eliminated but they are rather enhanced within the inflation period.

The mentioned open questions have been a challenge for developing other models of the Universe, one of them being our Expansive Nondecelerative Universe (ENU) model [2]. Here the background of the ENU model is given and its advantages in solving some problems are documented.

It should be pointed out that both the inflation and ENU models exhibit some common features, such as an increase in the universe mass. They differ in a way of the increase. In the inflation model the mass increase is a consequence of its emerging beyond the causal horison due to a deceleration of the Universe expansion caused by gravitational forces. In the ENU model the matter is created simultaneously with the gravitational energy that is negative. The total mass-energy is thus constant and equal to zero which is in accordance with
the laws of conservation. Such an universe can permanently expand with the velocity of light. One of the key differences of the inflation and ENU models concerns the red shift that is constant in ENU but decreasing in the inflation model.

II. Theoretical background

Applying Robertson-Walker metrics to Einstein’s field equations [3], Friedmann’s [4] equations of the universe dynamics are obtained

\[
\left( \frac{da}{dt} \right)^2 = \frac{8}{3} \pi G \rho a^2 - k c^2 + \frac{1}{3} \Lambda a^2 c^2
\]

(1)

\[
2a \left( \frac{a^2}{dt^2} \right) + \left( \frac{da}{dt} \right)^2 = -\frac{8\pi G \rho a^2}{c^2} - k c^2 + \Lambda a^2 c^2
\]

(2)

where \( a \) is the gauge factor, \( \rho \) is the mean density of the universe, \( k \) is the curvature index, \( \Lambda \) is the cosmological term, and \( p \) is the pressure. These corner-stones of ENU are defined as follows

\[
a = c t_c
\]

(3)

where \( t_c \) is the cosmological time,

\[
k = 0
\]

(4)

\[
\Lambda = 0
\]

(5)

Introducing equations (3), (4) and (5) into (1) and (2) has led [4] to

\[
c^2 = \frac{8\pi G \rho a^2}{3} = -\frac{8\pi G \rho a^2}{c^2}
\]

(6)

and at the same time

\[
\epsilon = \rho c^2
\]

(7)

Relations (6) and (7) lead directly to the state equation

\[
p = -\frac{\epsilon}{3}
\]

(8)

The negative sign of the right side documents the negative value of the gravitational energy. Equation (6) can be rewritten as follows

\[
\rho = \frac{3c^2}{8\pi G a^2}
\]

(9)

For a flat universe it holds
\[ \rho = \frac{3m_u}{4\pi \alpha} \]  

(10)

where \( m_u \) is the mass of the universe matter. A comparison (9) and (10) gives

\[ \alpha = c.t_c = \frac{2G m_u}{c^2} \]  

(11)

that manifests the matter creation in time.

Within the first approximation, the density of the gravitational field is described by Tolman’s relation (12)

\[ \epsilon_g = \frac{R_c c^3}{8\pi G} \]  

(12)

in which \( R \) denotes the scalar curvature. Contrary to a more frequently used Schwarzschild metrics (in which \( \epsilon_g = 0 \) outside a body and \( R = 0 \) which prevents from localization of the gravitational energy), in Vaidya metrics \( [5] \) \( R \neq 0 \) and \( \epsilon_g \) may thus be quantified and localized also outside a body. In ENU it holds also

\[ \frac{dm}{dt} = \frac{m}{t_c} \]  

(13)

Using Vaidya metrics and (13), an interrelationship (14) of scalar curvature and gravitational diameter \( r_{g(m)} \) of a body with the mass

\[ \frac{dm}{dt} = \frac{m}{t_c} \]  

(14)

\[ R = \frac{6G}{r^2 c^2} \left( \frac{dm}{dt} \right) = \frac{6G m}{t_c r^2 c^2} = \frac{3r_{g(m)}}{a r^2} \]  

Introducing (14) into (12) the density of energy \( \epsilon_g \) induced by such a body at a distance \( r \) can be expressed as:

\[ \epsilon_g = \frac{3m_r c^2}{4\pi \alpha r^2} \]  

(15)

Equation (15) can be rewritten as

\[ \epsilon_g = \frac{3E_g}{4\pi \lambda^2} \]  

(16)

where \( E_g \) is the energy of a quantum of gravitational field and \( \lambda \) its Compton’s wavelength

\[ \lambda = \frac{\hbar c}{E_g} \]  

(17)

Substituting \( \lambda \) in (17) for (16) and comparing the result with (15), the expression for an energy quantum is obtained:
where $E_g$ is the quantum of gravitational energy created by a body with the mass $m$ at a distance $r$. Relation (18) is in conformity with the limiting values: the maximum energy is represented by the Planck's energy, the minimum energy equals the energy of a photon with the wavelength identical to the universe dimension ($a = \lambda$).

Gravitational output, defined as an amount of the gravitational energy emitted by a body with the mass $m$ per unit time unit can be derived from (15) as

$$P_g = \frac{d}{dt} \int \epsilon_g \cdot dV \approx -\frac{m \cdot c^3}{a} = -\frac{m \cdot c^2}{t_c}$$

(19)

Gravitational force is a far-reaching force with ostensibly unlimited range. Due to the existence of hierarchic rotational gravitational systems, the range is, however, actually finite. This is a reason for introducing so called “effective gravitational range” $r_{ef(g)}$, i.e. the distance at which the density of gravitational field of a given body is equal to critical density [7]. It follows from (9) and (15) that

$$\frac{3c^4}{8\pi G \cdot a^2} \approx \frac{3m \cdot c^2}{4\pi a \cdot r^2}$$

(20)

and, in turn

$$r = r_{ef(g)} = \left(r_{g(m)} a\right)^{1/2}$$

(21)

where $r_{ef(g)}$ is the effective gravitational range of a body with the gravitational radius $r_{g(m)}$. The present value of the gauge factor is

$$a \approx 1.3 \times 10^{26} m$$

(22)

Based on the above rationalization, it is possible to determine the lightest particle able to exert gravitational influence on its surroundings. The particle has the mass $m_x$ and its gravitational range is identical to its Compton’s wavelength. Stemming from the following relation

$$\left(\frac{2G \cdot m_x \cdot a}{c^2}\right)^{1/2} = \frac{h}{m_x \cdot c}$$

(23)

the mass of the particle is

$$m_x \approx \left(\frac{h^2}{2\pi G \cdot a}\right)^{1/3} \approx 10^{-28} kg$$

(24)

and its Compton’s wavelength
\[ \lambda_x = \frac{\hbar}{m_x c} \cong 10^{-15} m \]  

(25)

In our paper [7] we discussed the advantages and consequences of introduction of \( m_x \) into the dimensionless gravitational constant \( \alpha_g \). Relation (21) allows to determine an amount of dark matter if dimensions of the radiation emitting matter of a corresponding hierarchic rotational gravitational system (galaxies, clusters and superclusters) are known [8].

III. Unification of gravitational and electromagnetic interactions

Field equations of the geometrized electrodynamics can be written as follows [9]

\[ R_{ik} - \frac{g_{ik} R}{2} = \frac{8\pi \varepsilon}{m_c^4} T_{ik} \]  

(26)

where \( T_{ik} \) is the momentum-energy tensor expressed by means the density of electromagnetic energy \( \rho_e c^2 \)

\[ T_{ik} = \rho_e c^2 u_i u_k \]  

(27)

As a metrics of the field of a charged particle, Riemann metrics can be used in the form [9]

\[ ds^2 = \left( 1 - \frac{r_e}{r} \right) c^2 dt^2 - \left( 1 - \frac{r_e}{r} \right)^{-1} dr^2 - r^2 \left( d\theta^2 + \sin^2 \theta d\varphi^2 \right) \]  

(28)

where \( r_e \) is the electromagnetic radius

\[ r_e = \frac{2e^2}{m_c} \]  

(29)

Monopole radiation of a charged body can be described by Vaidya metrics [9] as

\[ ds^2 = \left( 1 - \frac{2e}{m_e r c^2} \frac{dc}{dt} \right) c^2 dt^2 - \left( 1 + \frac{2e}{m_e r c^2} \frac{dc}{dt} \right) \left( d^2 x + d^2 y + d^2 z \right) \]  

(30)

Density of electromagnetic field energy \( \epsilon_e \) obtained from (26) can be written as

\[ \epsilon_e = -\frac{m_e^4 R}{8\pi c} \]  

(31)

where \( R \) is the scalar curvature that, using (30), adopted the form

\[ R = \frac{6}{r^2 c^2} \frac{dc}{dt} = \frac{6e}{m_e r c^2} \]  

(32)

Introducing (32) into (31), relation (33) identical to (15) is obtained and this identity can be taken as an evidence of the unity of gravitational and electromagnetic interactions.
\[ \epsilon_e = -\frac{3m_e c^2}{4\pi \alpha r^2} \]  \hspace{1cm} (33)

In the initial period of the universe expansion \( t \approx 10^{-44} s; T \approx 10^{32} K \) all the fundamental interactions were unified. Two factors are worth keeping in mind when evaluating unification of the interactions:

1) energy - mass at the time of unification/separation,
2) range typical for a given kind of interaction.

The value of energy-mass is identical for unification of all physical interactions. It holds \( m_{gPc} \) is the Planck’s mass

\[ m_g = m_{Pc} = \left( \frac{\hbar c}{G} \right)^{1/2} \approx 10^{19} \text{GeV} \]  \hspace{1cm} (34)

Since both gravitational and electromagnetic interactions are of far-reaching nature, a question of dimension limit does not play any important role in their unification.

IV. Unification of gravitational and strong interactions

Binding energy \( E_s \) of two quarks increases with the square of their distance. This phenomenon is expressed in [9 - 11] as follows

\[ E_s = \frac{\hbar c}{a} \frac{r^2}{l_{Pc}^2} \]  \hspace{1cm} (35)

where \( l_{Pc} \) is the Planck’s distance

\[ l_{Pc} = \left( \frac{G \hbar}{c^3} \right)^{1/2} \approx 10^{-35} m \]  \hspace{1cm} (36)

There are authors proposing a linear dependence of \( E_s \) on \( r \). However, relation (35) is in good accordance with asymptotic freedom for limiting cases. When

\[ r = l_{Pc} \]  \hspace{1cm} (37)

the energy reaches the minimum possible value

\[ E_s = \frac{\hbar c}{a} \]  \hspace{1cm} (38)

i. e. the energy of a photon with the maximum wavelength \( a \). On the other hand, if

\[ r = a \]  \hspace{1cm} (39)

then
\[ E_s = m_U c^2 \] (40)

that represents the maximum energy. At a typical distance

\[ r \approx 10^{-15} m \] (41)

the energy value is

\[ E_s \approx 10^{-11} J \] (42)

This value is very close to the kinetic energy of \( \pi^+ \) mesons (200 MeV) at their scattering on protons followed by the formation of resonance.

Unification of gravitational and strong interactions is conditioned by the following equality

\[ \frac{G m^2}{r} = \frac{\hbar c}{a} \cdot \frac{r^2}{r_c} \] (43)

It stems from (34) and (43) that

\[ r = \lambda_x = \frac{\hbar}{m_x c} \approx 10^{-15} m \] (44)

The value of \( m_x \) is given in (24). Calculated limiting distance (44) actually correspond to a real range of the nuclear forces that, in turn, can be understood as an evidence of unification of the gravitational and strong interactions.

Based on (24), (35) and (44), a time dependent decrease in the energy of strong interactions can be obtained as

\[ E_s \approx a^{-1/3} \approx t_c^{-1/3} \] (45)

At present, the typical value of this energy is about 100 MeV. The magnitude of binding energy of an electron in atom is 1 eV. Based on (45), the values of nuclear strong interaction and electron binding energies should approach in time

\[ t \approx 10^{34} \text{ years} \] (46)

This result of ENU is in good agreement with the time of baryonic matter disintegration predicted by the GUT theory.

V. Unification of gravitational and weak interactions

The cross section \( \sigma \) of weak interaction can be expressed as [12, 13]

\[ \sigma \approx \frac{g^2 E^2}{(m_c)^2} \] (47)
where $g_F$ is the Fermi’s constant, $E_w$ is the energy of weak interactions that, based on (47), can be formulated by relation

$$E_w \approx \frac{r \hbar^2 c^2}{g_F}$$ (48)

where $r$ represents the effective range of weak interactions related in a limiting case to the mass $m_{ZW}$ of vector bosons Z and W

$$r = \frac{\hbar}{m_{ZW} c}$$ (49)

The maximum energy of weak interaction obtained from (48) and (49) is then given as

$$E_{w,\text{max}} \approx m_{ZW} c^2$$ (50)

Equations (48), (49) and (50) lead to an expression for the mass of the bosons Z and W

$$m_{ZW}^2 \approx \frac{\hbar^2}{g_F c} \approx (100 \text{GeV})^2$$ (51)

giving the value that is in good agreement with the known actual value.

When unifying gravitational and weak interactions, it must hold

$$\frac{G m^2}{r} = \frac{\hbar^2 c^2 r}{g_F}$$ (52)

Using (34) and (52) the value of limiting range of weak interactions is obtained

$$r = \lambda_{ZW} = \frac{\hbar}{m_{ZW} c} \cong 10^{-18} \text{m}$$ (53)

that proves the unity of gravitational and weak interactions.

VI. Formation of solar antineutrinos from the viewpoint of ENU

Stemming from one of the most significant achievements of the ENU model - localization of gravitational energy - and based on the knowledge on weak interactions some consequences related to the Sun occurring processes can be drawn. It should be pointed out that the essence of the following discussion is to be taken as a scientific hypothesis rather than the definite conclusions.

The gravitational energy output of a body with the mass $m$ is established by relation (19). This energy is negative. Due to the conservation laws validity, a corresponding amount of energy-matter must be created. In the case of the Sun it represents
Due to the chemical composition of the Sun it appears justifiable to assume that a significant part of the matter created are represented by neutrons. Owing to the weak interactions, neutrons undergo a decay to protons, electrons and antineutrinos:

\[ n \rightarrow p^+ + e^- + \nu \]  

(55)

Based on the fact that the rest mass of the neutron exceeds the proton mass about on the mass of two electrons and the mass of antineutrinos (as well as neutrinos) can be omitted, analysing relation (55) in a more detail, the law of energy conservation leads to a conclusion that each process (55) is accompanied by an energy release of about 0.5 MeV. Taking the whole Sun into account, the energy output totalled to

\[ P = \frac{m_S c^2}{c} m_n. m_e. c^2 \approx 2 \times 10^{26} W \]  

(56)

where \( m_n \) and \( m_e \) are the mass of neutron and electron, respectively. The result in (56) is in excellent agreement with the assessed actual radiation energy output that is

\[ P \approx 4 \times 10^{26} W \]  

(57)

A number of antineutrinos being formed per 1 second via the neutron decay (55) is given as

\[ N_\nu = \frac{m_S}{c m_n} \approx 10^{39} s^{-1} \]  

(58)

It is worth emphasizing that the neutrinos/antineutrinos formation can occur both inside the Sun and in its environment (solar corona).

The present hypothesis casts in no case any doubt on the existence of thermonuclear processes inside the Sun. At the given conditions they must proceed. It is, however, possible that simultaneously also the creation occurs and its effect may be related to the known deficit of solar neutrinos. In addition, the question concerning the solar corona temperature can be answered from the presented viewpoint.

VII. ENU model and wave function of the universe

Based on (18) when

\[ m = m_U \]  

(59)
the energy of gravitational quanta of the universe is obtained \([12]\)

\[|E_g| = \left( \frac{\hbar^3 c^7}{G a^2} \right)^{1/4} \tag{61} \]

Expressing (61) by wave function

\[E_g \Psi_g = \imath \hbar \frac{d\Psi_g}{dt} \tag{62} \]

where

\[\Psi_g = e^{-\imath \omega t} \tag{63} \]

and at the same time

\[\omega = \frac{c}{(t_{pc} t_c)^{1/2}} = (t_{pc} t_c)^{-1/2} \tag{64} \]

where \(t_{pc}\) is the Planck’s time. It follows from (63) and (64) that

\[\Psi_g = e^{-\imath (t_{pc} t_c)^{-1/2} t} \tag{65} \]

i.e. the wavefunction is dependent on cosmological time. Further, the expansion of the Universe is associated with a decrease in the frequency of gravitational waves. The rate of the expansion is in ENU constant, wave function \(\Psi_g\) will vary due to the uncertainty principle. Such fluctuations must cause fluctuations of relict radiation. The mentioned nonhomogenities will increase in time and have given rise to the present galaxies, clusters and superclusters.

The experimental value of the fluctuation based anisotropy \(A\) is

\[A = \frac{\Delta T}{T} \cong 10^{-5} \tag{66} \]

Given the interrelationship between temperature and energy, it must hold

\[\Delta E \cong 10^{-5} E \tag{67} \]

and if uncertainty of time is identified with cosmological time

\[\Delta t = t_c \tag{68} \]

then the Heisenberg’s equation of uncertainty can be, based on (66), (67) and (68), written as
and relations (62), (65) and (69) lead to the time when fluctuations or anisotropy appeared and developed

$$t_{c(A)} \approx 10^{10} t_{Pc} \approx 10^{-33} s$$

(70)

Since in the primordial period of the universe

$$T \approx a^{-1/2} \approx t_{c}^{-1/2}$$

(71)

in the time about $10^{-33} s$, temperature of the universe based on ENU was

$$T \approx 10^{26} K$$

(72)

which is in excellent agreement with the value calculated in [14].

If all the above rationalizations stemming from ENU model are correct, then the equivalence (73) must hold.

$$|\Sigma E_g| = m_U. c^2$$

(73)

Further, the validity of (73) will be checked. Hawking found [15] a close relationship between gravitation and thermodynamics. Using Stefan-Boltzmann law the following relation can be written

$$\int \frac{4 \pi T^4}{c} dV \approx M_U. c^2$$

(74)

Substitutions

$$T \approx \frac{|E_g|}{k}$$

(75)

$$k^4 \approx \sigma. h^3. c^2$$

(76)

and the subsequent integration over whole volume of the universe (that is confined by a causal horizon) taken (11) into account leads directly to (73).

Similarly the validity of relation

$$|\epsilon_g| = \epsilon_{cr}$$

(77)

where $\epsilon_{cr}$ is the critical density of the universe matter can be proved.

VIII. Time of the anisotropy creation

$$10^{-5} E_t \approx h$$

(69)
Probably it is not a pure coincidence that the gravitational influence of vector bosons X and Y started just at the time of anisotropy creation

\[ t_{c(A)} \approx 10^{-33} \text{s} \] (78)

Because of the mass of hypothetical particles mentioned in (24) is just of the order \(10^{15} - 10^{16} \text{ GeV\)} it may be concluded that their appearance and, in turn, their gravitational impact are the very reasons having caused both the value of the anisotropy and the time of its creation. If the introduction of anisotropy \(A\) (66) is followed by a subsequent modification of (70) into the form

\[ a_{(A)} \approx \frac{l_P}{a_{(A)}} \] (79)

where \(a_{(A)}\) is the gauge factor at a cosmological time \(t_{c(A)}\) from (78), then (24) is transformed to

\[ a_{(A)} \approx \frac{\hbar^2}{G_m} \] (80)

where \(m_{XY}\) is the mass of vector bosons X and Y expressed from (79) and (80) as

\[ m_{XY} \approx (A)^{2/3}m_{Pc} \] (81)

Thus a degree of accuracy in an anisotropy \(A\) measurement will help to determine the mass of the vector bosons X and Y.

IX. Conclusions

It is becoming still more and more obvious that solution of several problems of cosmology and astrophysics depends of the ability of researchers to localize gravitational energy. In this area three main streams of opinions can be identified: 1) gravitational field energy is localizable but a corresponding “magic“ formula for its density is to be found; 2) gravitational energy is nonlocalizable in principle; 3) gravitational energy does not exist at all since the gravitational field is a pure geometric phenomenon. It seems that solution of this enigma lies in metrics applied. It has stemmed from the starting points of the ENU model that a metrics involving changes in matter due to its permanent creation must be used. Vaidya metrics [5] has met the requirements of the ENU model and its utilization allowed to offer answers to many questions, explain some known facts in independent ways, correct some opinions or demonstrate their limitations and predict deep mutual interrelationships of natural phenomena. In addition to theoretical approach present in this contribution, we proposed a procedure for the experimental determination of gravitational field energy [16]. Based on the up-to-date knowledge we are convinced that the time is ripe to accept the idea of localizability of gravitational field energy,
develop adequate mathematic tools and take advantage this opportunity to look at old problems from new viewpoints.

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