A QUIET COSMOLOGY AND HALO AROUND VISIBLE UNIVERSE

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Abstract

A modification of the general relativity theory is presented. This modification does not introduce new fields (or miraculous events like in "Big Bang + Inflation" scenario), but takes into account the effect of spacetime stretching along with classical curvature. The modification is especially important when global spacetime curvature is close to zero, which is the case in our universe. Exact analytical solution of the modified equations (without any fitting parameters) shows good quantitative agreement with cosmological observations (SnIa, SDSS-BAO). According to this solution, our universe was born in infinite past from small fluctuation and will continue stable expansion until Tmax about 38 billion years. In connection with this solution, it is concluded that visible universe is surrounded by halo of ultralight dark matter particles. Mass of these particles is estimated.

Key Words: modification of general relativity; spacetime curvature; spacetime stretching (divergency); exact analytical solution; comparison with cosmological observations; ultralight dark matter particles; halo around visible universe.

Introduction

The cosmological data (Riess et al. 1998, 2004; Perlmutter et al.1999) about accelerated expansion of the universe lead to the well known problems, which are broadly discussed [Sahni & Starobinsky 1999, 2006; Weinberg 2000; Padmanabhan 2003; Coule 2005; Chernin 2008; Lukash & Rubakov 2008; Shfieloo, Sahni & Starobinsky 2009; Cai et al. 2009]. Particularly striking is the problem with the cosmological constant. Comparison with cosmological observations shows that corresponding nondimensional constant is more than hundred orders smaller than can be predicted in the frames of classical general relativity (GR). In our opinion, such situation means that some important physical mechanism is missing in the classical GR. In this letter we present twofold approach to this problem. The first informal part gives an insight into the core of GR and direction for its modification. This modification of GR takes into account the effect of production (absorption) of particles by the vacuum. The second part contains an exact solution of modified equations, comparison with experimental data and new predictions.

1. Trivialisation in general relativity.

The first part of our approach can be sketched as follows:

$$GR \rightarrow [TT \rightarrow MTT] \rightarrow MGR \qquad 1$$

It starts with a trivialisation of GR. It means reducing GR to a trivial or toy theory (TT), which retain the essence of GR, but has only small number of simple factors. After that, we look for an additional simple factor, absent in GR, add it to TT and obtain its modification (MTT). The next step is retrivialisation of MTT, leading to modification of general relativity (MGR), which can be tested by the data. In this way, the most creative part of the work can be done on the level of TT without all the complications of the full theory.

So, how we make the first step in (1) for the indicated above problem ? We know that the vacuum creates and absorbs particles. The essential point of GR, in our understanding, is that process of bending of such creative (busy) vacuum requires some energy. This is especially important if we want to make a step (see below) from classical GR towards quantum gravity. From this point of view, a natural trivialisation of GR is to write equation (temporary forget about tensor fields and cosmological constant):

$$R = k\varepsilon \qquad 2$$

Here R is the scalar curvature, k is constant and ε is energy density. In classical GR we have only two dimensional constants: gravitational constant G and speed of light c. Dimensionally, we can write $k = \alpha G_*$, where α is nondimensional constant and $G_* = Gc^{-4}$. Equation (2) represents a balance of energy. That is the first step in (1).

For the next step in (1), we know that the global structure of our Universe is such that R is very close to zero. In this situation (2) spells disaster. Energy should go somewhere. It means collapse to singularity or/and disintegration of the universe. But, naively speaking, it exist for a long time and, as a whole, seems to be doing OK. Can we modify (2) and save our universe without introducing additional unknown fields (using Occam's razor)?

Yes, we can. The idea came from the dynamics of distributed sources-sinks (DoDSS) [Novikov 2003, 2005b, 2006]. In (Novikov 2003) it is explained that DoDSS, in turn, is related to the exact general analytical solution for the (1+1)-dimensional Newtonian gravity (again trivialisation!). In this case the relative acceleration of two particles is the Lagrangian invariant (Novikov 1969). Note, that the (1+1)-dimensional and (2+1)-dimensional universes (without the indicated below σ-effect), sadly, are collapsing for any initial conditions (Novikov 1969). The Lagrangian invariant of DoDSS is divergency σ (see definition below in (4)). The divergency is associated with stretching, which can take place even when $R = 0$ and this is actually the case in present epoch.

Let us stress: if something (busy vacuum) is not easy to bend, one can expect a reaction to stretching.

So, for the creative vacuum, σ can contribute to the energy balance. Dimensionally, we can add in equation (2) terms (characteristic for DoDSS [Novikov 2003, 2005b, 2006]) $\beta d\sigma/ds + \gamma\,\sigma^2$, where β, γ are nondimensional constants and d/ds is the full (substantial) derivative. In such MTT universe is potentially safe! The importance of σ also follows from the fact that it is the only dynamical characteristic of the media, which enters into the balance of the proper number density of particles n: $dn/ds + \sigma n = q$, where q is the rate of particle production (or absorption) by the vacuum. So, if n is constant (see exact analytical solution (5) below) or changing slowly, than the σ-effect is, certainly, very important in quantum cosmology. This is the second step in (1), which is connected with DoDSS.

2. Modified general relativity

The final step in (1) is retrivialisation from MTT to MGR. This is a step leading to modified equation of GR (Novikov 2006):

$$R_i^k - \frac{1}{2}\delta_i^k R = 8\pi G_* T_i^k + \lambda_N \delta_i^k,\ T_i^k = w u_i u^k - \delta_i^k p,\ w = \varepsilon + p, \qquad 3$$

$$\lambda_N = \lambda_0 + \beta\frac{d\sigma}{ds} + \gamma\sigma^2,\ \sigma = \frac{\partial u^k}{\partial x^k} + \frac{1}{2g}\frac{dg}{ds},\ \frac{d}{ds} = u^k\frac{\partial}{\partial x^k} \qquad 4$$

Here R_i^k is the curvature tensor, p, ε and w are pressure, energy density and heat function, respectively, u^k - components of velocity (summation over repeated indexes is assumed from 0 to 3, $x^0 = \tau = ct$), λ_0 is the cosmological constant and g is the determinant of the metric tensor. With $\beta = \gamma = 0$ we recover the classical equation of GR.

Some exact analytical solutions of (3)-(4) where obtained in (Novikov 2006). On the basis of these solutions, it was concluded that the effect of spacetime stretching (σ) explains the accelerated expansion of the universe and for negative σ (collapse) the same effect can prevent formation of singularity.

The natural next step is quantitative comparison with cosmological data and choice of nondimensional constants β and γ. Let us consider equations for the scale factor $a(\tau)$ in homogeneous isotropic universe (Eq. (8,9) in [Novikov 2006]) and put pressure, discrete curvature parameter and cosmological constant λ_0 to zero:

$$(2-3\beta)\frac{\ddot{a}}{a} + (1+3\beta-9\gamma)(\frac{\dot{a}}{a})^2 = 0, \qquad 3_a$$

$$-\beta\frac{\ddot{a}}{a} + (1+\beta-3\gamma)(\frac{\dot{a}}{a})^2 = \frac{8\pi}{3}G_*\varepsilon. \qquad 3_b$$

Here points indicate differentiation over τ. Two special cases have been indicated (Novikov 2006): 1) for $\beta = 2/3$ and $\gamma \neq 1/3$ stationary solution exist; 2) for $\beta = 2\gamma$ the global energy is conserved. This last condition may correspond to the assumption that our universe is unique (no external influence of hypothetical multiverse).

It turns out (Chefranov & Novikov 2010a,b) that in the case of energy conservation ($\beta = 2\gamma$), which includes the concept of dark energy, (3)-(4) can be derived from the variational principle by simply replacing the cosmological constant λ_0 (in the Lagrangian) by $\lambda = \lambda_0 - \gamma\sigma^2$. Moreover, the case with $\gamma = 1/3$ (and $\beta = 2/3$), which was noticed in (Novikov 2006), is indeed very special. Only in this case, equation (3_a) is identity and from (3_b) we have exact analytical solution with exponential character (Chefranov & Novikov 2010a,b):

$$a(\tau) = a_0\exp[H_0\tau - 2\pi(\tau/L_*)^2],\ L_* = (G_* w_0)^{-1/2} \qquad 5$$

Here subscript 0 indicate present epoch ($\tau = 0$) and H_0 is the Hubble constant ($H = a^{-1}da/d\tau$). Solution (5) corresponds to continuous and metric-affecting production of dark matter particles out of vacuum, with its density $\rho_0 = w_0c^{-2}$ being retain constant during the expansion of spatially flat Universe. This solution is shown (Chefranov & Novikov 2010a,b) to be stable in the regime of cosmological expansion until $t_{\max}$ about 38 billion years. After that time, the solution becomes unstable and characterizes the inverse process of dark matter particle absorption by the vacuum in the regime of contraction of the universe. This can imply the need for considering the change of regime (5) at $t > t_{\max}$ to a different evolutionary regime, possibly, with a different value of the parameter γ or with the more general model (4) from (Novikov 2006).

Mass m_0 of dark matter particles can be estimated by comparing characteristic scale L_* from (5) with the relativistic uncertainty of particle position (Berestetskii, Lifghitz & Pitaevskii 1982) $\hbar/m_0c$, where $\hbar$ is the Plank constant. We get:

$$m_0 \sim \hbar(G_*\rho_0)^{1/2} \sim 10^{-66}gram. \qquad 6$$

This is also an example of trivialisation, because similar estimate we got before (Chefranov & Novikov 2010a,b) from more complicated consideration, which involves solution of a model equation for a quantum field. According to (6), dark matter particles are ultralight and their uncertainty of position (of the same order as $ct_{\max}$) is more than twice bigger than size of the visible universe. It means that universe has a halo of dark matter particles. This halo potentially can influence the visible part of universe, producing effects similar to influence of hypothetical multiverse. The same effect (large uncertainty of dark matter particle position) can explain halo of a galaxy, which is more easy to observe (see recent paper [Mouhcine, Ibata & Rejkuba 2011] and references therein).

3. Comparison with cosmological observations

For comparison with observational data, it is convenient to use the redshift $z = a_0/a(\tau) - 1$. From (5) we got:

$$h(z) = H(z)/H_0 = [1 + 3\Omega_M \ln(1+z)]^{1/2}, \ \Omega_M = w_0/\varepsilon_c, \ \varepsilon_c = 3H_0^2/8\pi G_*, \qquad 7$$

where ε_c is the critical energy density. The following function (see (2.1) in (Cai et al. 2009) is used to analyze the observations of supernovae SnIa:

$$\mu(z) = m - M = 5\log_{10}(\frac{d_L}{M_{pc}}) + 25, \ d_L = \frac{1+z}{H_0}\int_0^z \frac{dz'}{h(z')}. \qquad 8$$

Here μ is the distance module, m and M are apparent and absolute magnitudes of the source correspondingly and d_L is the luminosity distance. The presented below figure compares the dependence $\mu(z)$ that we derived at $\Omega_M = 0.3$ for $h(z)$ from (7) with the observational data used in (Cai et al. 2009) and with $\mu(z)$ for other theoretical models (Cai et al. 2009). We see from the figure that the exact solution (7) for the presented z range agrees well with the observational data. Note, that the used data are model-independent, i.e., not related to any model-theoretical conclusions.

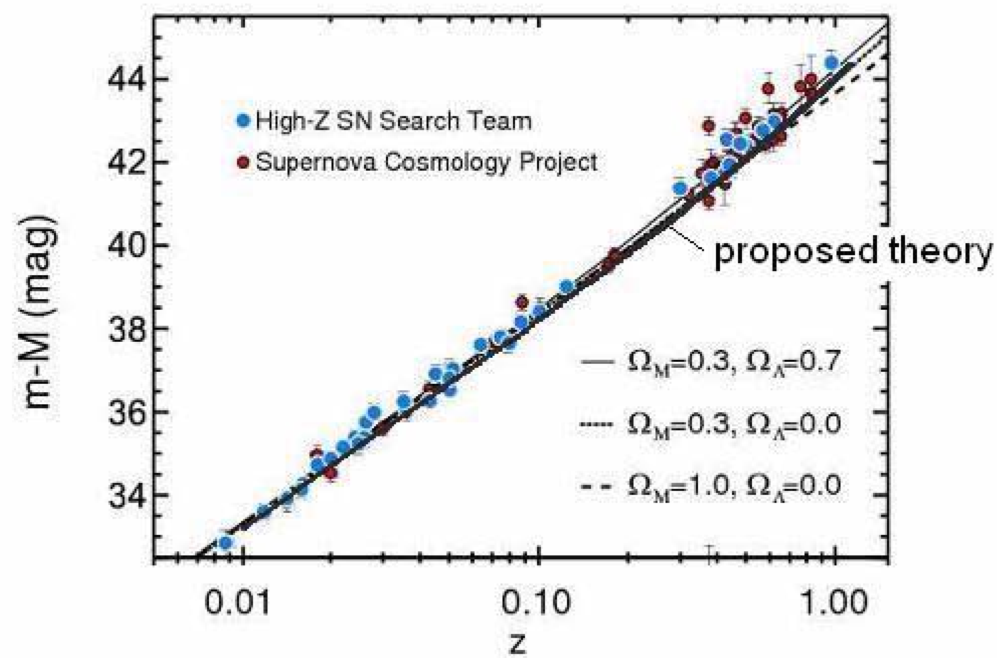

Figure capture: Comparison of the experimental data with the results of theoretical models.

The thick solid line corresponds to exact solution (5) in representation (7,8) obtained here at $\Omega_M = 0.3$ (the ratio of the entire ordinary matter, including the dark one, to the critical density).The thin solid, dotted and dashed lines correspond to the three models with different Ω_M and Ω_Λ (the ratio of the dark energy density to the critical density). The circles indicate the observational data of two teams of researches.

In (Chefranov & Novikov 2010a,b) it is shown that solution (5) also quantitatively agrees with the baryonic acoustic peak measurements (SDSS-BAO data) [Sahni & Starobinsky 1999; Eisenstein et al. 2005] and consistent with recently found reduction of acceleration of the expanding Universe (Shfieloo, Sahni & Starobinsky 2009).

4. Discussion

In retrospect, some early theoretical papers are relevant to our work, particularly, (Gliner 1965, 1970; Sakharov 1967; Starobinskii 1978). These and others relevant papers are discussed in (Chefranov & Novikov 2010a,b). The physical nature of the ultralight dark matter particles is also discussed in (Chefranov & Novikov 2010a,b) and arguments in favor of scalar massive photon pairs are presented there. So, the dark matter, which penetrate our visible universe and beyond (halo), could be light, packed into photon pairs. Irrespective of a particular interpretation, the quantity m_0 defined in (6) can also serve as a basis for subsequent reconsideration of the problem of divergence in quantum field theory (Landau &Pomeranchuk 1955; Novikov 2005a).

The next step in presented theory is description of synthesis of ordinary matter out of indicated above primary dark matter particles (PDMP). Let us stress that the obtained exact analytical solution with exponential character (5) is unique and does not have any fitting parameters. If we start with variational principle (see text above formula (5)), which automatically ensures global energy conservation, than we have only one parameter γ. The special value of this parameter $\gamma = 1/3$ is determined by the unique exponential character of solution (5) and by coincidence of this solution with the solution of corresponding quantum field equation (see details in [Chefranov & Novikov 2010a,b]). According to this solution, our universe was born in infinite past out of small fluctuation. The averaged density of PDMP is very high: $n = \rho_0/m_0 \sim 10^{36} cm^{-3}$. With such density, we can expect multiple collisions with formation of more heavy particles in some sort of "natural selection". During the steady and stable expansion of the universe, the ordinary matter was synthesized in this way, probably, starting with light particles. This process was accompanied by radiation, which is reflected in CMB. The eqilibrium character of CMB and the global condition $R \approx 0$ are naturally explained by the large amount of time available for the evolution. Some peculiarities of CMB can be associated with synthesis of various particles in expanding universe. The type of evolution, which is described by exact solution (5), is more "quiet" than the usually accepted "Big Bang + Inflation" scenario. The development of more detailed theory of the quiet evolution of our universe and corresponding experimental investigation, in our opinion, will greatly benefit humankind. We hope that the scientific community will joint this effort.

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