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Article

Identification of Source of Energy for Creation of Universe and Prediction of Minimum Possible Length by New Cosmological Model

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Abstract

Law of conservation of energy is the most well-established law of modern physics. But, inflationary cosmological model which assumes the universe to be created from a point of singularity has not been able to identify the source of energy for creation of this universe. As per uncertainty principle, a quantum vacuum fluctuation can at most create energy of ~10^{-8} kg in a Planck time of ~5.4×10^{-44} s whereas total positive energy due to matter/vacuum existing in the universe is more than ~10^{54} kg. To solve this problem, we have recently published a new cosmological model (Biswaranjan Dikshit, *Canadian Journal of Physics*, 100, 218-225, [2022]) in which we have mathematically proved that the total energy of the universe can be zero right from the beginning of the universe to till date due to negative gravitational potential energy and thus law of conservation of energy can be satisfied during creation of the universe from nothing. In this article, starting from a simple argument, we explain why net energy of the universe can be zero only in our model, not in standard cosmological model. An interesting fact pointed out in this paper is that the factor ~10^{62} by which radius of universe has increased from its starting value of ~10^{-36} m to present value of ~10^{26} m is same as the factor by which positive energy has increased from Planck energy ~10^{-8} kg to present value ~10^{54} kg. This is in agreement with our new model that predicts the positive energy of universe to be proportional to the radius of universe. We also bring out to the notice that zero energy universe is possible only if smallest possible length in nature is, $l_{min}=l_p(\pi/2)^{1/2} \approx 2.0\times10^{-35}$ m. Minimum possible length is important in theory of quantum gravity and string theory.

Keywords: Law of conservation of Energy; Minimum length; Planck length; Dark energy

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1. Introduction

Law of conservation of energy is the most sacred law in the history of science as not a single experiment till date has reported violation of the law. However, as per uncertainty principle, a quantum vacuum fluctuation can at most create energy of ~0.02mg in a Planck time of ~5.4 ×10^{-44} s. Then, a natural question arises, what was the source of energy for creation of all the matter in the universe which is about ~10^{54} kg including the dark matter ?

Often it is stated [1], in an expanding space-time, Einstein's field equation doesn't imply conservation of energy due to matter and radiation. This appears so because Einstein's theory of gravity is a geometric theory and it considers only matter and radiation in its energy-momentum tensor, not the gravitational potential energy. This doesn't mean, gravitational potential energy doesn't exist. It just means, in Einstein's theory of gravity, we deal with curvature of space-time to calculate the dynamics of material bodies. Role of gravitational potential energy is taken over by curvature of space-time. That's why in general theory of relativity, "covariant divergence" of energy-momentum tensor is taken to be zero, not the "ordinary divergence". Covariant divergence includes a term related to curvature. So, we can say that the gravitational potential energy is stored in the form of curvature of space-time. For example, an apple falling from a height gains kinetic energy because the gravitational potential energy becomes more and more negative. From Newtonian perspective, potential energy reduces because of gravitational interaction between apple and earth, whereas from Einstein's perspective, potential energy reduces because of change in curvature of space-time between apple and earth. Thus, concept of gravitational potential energy is perfectly valid in general theory of relativity and law of conservation of energy is supposed to be satisfied in a true cosmological model. This is possible during creation of universe from nothing only if net energy of the universe (including positive matter/vacuum energy and negative gravitational potential energy) is proved to be zero right from the beginning to till date. As pointed out by Kross [2], proof of such a zero-energy universe needs the flatness of space as an assumption i.e. zero-energy universe is a consequence of flatness. Since the space became flat only after inflation, the question about the source of energy before and during inflation remains unanswered.

In our recently published paper [3], by quantizing the zero-point fields existing in the space, we have mathematically proved that the total energy of the universe can be zero right from the beginning of the universe and law of conservation of energy can be satisfied during creation of the universe without using flatness of space as an assumption. In the present paper, using a simple argument, we explain why net energy of the universe could be zero in our model and why it is not possible in standard cosmological model.

We also bring out to the notice of reader that our cosmological model gives the exact value of smallest possible length in nature. Although earlier researchers have speculated that minimum possible length might be of the order of the Planck length, its exact value was not predicted [4-5]. In our model, total energy of the universe can be zero (leading to conservation of energy during creation of the universe) only if the minimum possible length becomes equal to a specific value given in section-3. Finally, we present a discussion on some unique features and verifiability of our model.

2. Requirement for Zero-energy universe and applicability of new cosmological model

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Just like in a 3-D space, surface of a balloon (2-sphere) is two dimensional and isotropic, in a 4-D space, surface of a 3-sphere is three dimensional and isotropic. Following the Einstein's idea, we consider our universe to lie on the surface of such a 3-sphere existing in a four-dimensional (4-D) space. If we put dots on the surface of a balloon and expand it, the dots will move away from each other. Similarly, galaxies in our universe lying on the surface of expanding 3-sphere, recede away from each other. Even if our universe is closed, its spatial curvature cannot be detected by us as our space freely expands under gravitation just as an observer freely falling in a gravitational field cannot detect the curvature of space-time. Mathematically, as per our recent paper [3], observed flatness of space is due to the fact that total energy density (due to vacuum, matter and radiation) comes out to be exactly equal to the critical density, $u = \frac{3c^2H^2}{8\pi G}$ required for observed flatness. For such a spherical universe, gravitational potential energy must be (using Newtonian expression, not the general relativistic expression [6-7] as average intergalactic separation of galaxies is much more than Schwarzschild radius) ,

$$U_{grav} \ \alpha \ \frac{M^2}{R}$$

Or

$$U_{grav} = -k \ \frac{M^2}{R} \tag{1}$$

Where M is mass equivalent of total energy due to vacuum, matter and radiation, R is radius of universe, k is the proportionality constant depending upon universal gravitational constant G and the minus sign indicates that gravitational potential energy is negative.

To get a net zero-energy universe by cancellation, magnitude of (negative) gravitational potential energy must be same as the mass equivalent of other forms of (positive) energy viz. vacuum, matter and radiation. So,

$$|U_{grav}| = M$$

Or

$$k\frac{M^2}{R} = M$$

$$\Rightarrow \quad M \ \alpha \ R \tag{2}$$

Thus, zero-energy universe is possible only in a continuous creation model where total energy due to vacuum, matter and radiation is directly proportional to the radius of the universe. Since, volume 'V' of space increases as,

$$V \ \alpha \ R^3 \tag{3}$$

Dividing Eq. (2) and (3), the requirement for zero-energy universe can be stated in terms of Energy density of space $\rho = M/V$ as,

$$\rho \ \alpha \ \frac{1}{R^2} \tag{4}$$

Surprisingly, total positive energy U due to vacuum, matter and radiation in our recently published new cosmological model [3] naturally (by quantization) comes out to be directly proportional to the radius of the universe matching with the condition given by Eq. (2) ($U = \frac{3\pi^2 c^4 R}{2\beta^2 G}$ where β is a constant of the order of unity and if R is much greater than Planck length) and total energy density u in our model is inversely proportional to square of radius of universe ($u = \frac{3c^4}{4\beta^2 G R^2}$) agreeing with the condition given by Eq. (4). That's why the net energy of the universe including gravitational potential energy could be zero in our model and law of conservation of energy could be satisfied starting from beginning of the universe.

In contrast, in standard ΛCDM (Dark energy Cold Dark Matter) model of cosmology, dark/vacuum energy density is assumed to be *constant* (which implies total energy due to vacuum is directly proportional to R^3) and matter energy density is assumed to vary as $1/R^3$ (which implies total matter energy is constant). These contradict Eq. (2) and (4). So, standard model cannot lead to a zero-energy universe and hence law of conservation of energy cannot be satisfied during creation of universe from nothing.

Of course, in our model, just at the time of creation, universe was an empty bubble of space of radius $R_i = \frac{l_p}{\sqrt{8\pi}} \approx 3.22 \times 10^{-36}\ m$ (where l_p is Planck length) containing only vacuum energy due to zero-point field having energy allowed by uncertainty principle. As the space gradually expanded due to negative pressure of vacuum as per Einstein's field equations, gravitational potential energy became more and more negative and to conserve net energy, positive energy in the form of other quantized modes of zero-point fields, matter and radiation appeared. Today, we see a huge amount of (positive) energy of ~10^{54} kg due to vacuum, matter and radiation as compared to the initial Planck energy of ~10^{-8} kg because radius of universe has also increased from initial value of ~10^{-36} m to present value of ~10^{26} m (Note that both mass and radius have undergone change by *same factor i.e. 10^{62}* and this is in agreement with our new model that predicts the positive energy of universe to be proportional to the radius of universe).

3. Smallest possible distance predicted by new cosmological model

In our cosmological model [3], since the space is closed and spherical, circumference becomes integer multiple of wavelength of zero-point wave leading to quantization of the zero-point fields. Counting all possible modes of zero-point field, we found the vacuum energy density (or dark energy density) to be, $u_{vac} = \frac{c^4}{2\beta^2 G R^2}$ where β is a constant which defines the smallest possible distance or "cut off wavelength" by relation, $l_{min} = \lambda_{min} = \beta l_p$ (l_p is Planck length). Using the expression for u_{vac} in work done during expansion of the

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universe, sum of matter and radiation energy density came out to be, $u_{matter+rad} = \frac{c^4}{4\beta^2 G R^2}$. In the later part of the paper, it was shown, to make the magnitude of (negative) gravitational potential energy equal to the sum total of (positive) vacuum, matter and radiation energy, another parameter γ needed to be equal to 2. This γ was related to β by relation, $\gamma = \sqrt{2\pi}/\beta$. So, putting $\gamma = 2$, value of β comes out to be, $\beta = \sqrt{\frac{\pi}{2}}$. Thus, exact value of minimum possible length in nature, as per our theory, is,

$$l_{min} = l_p \sqrt{\frac{\pi}{2}} \tag{5}$$

Numerical value of the above comes out to be, $l_{min} \approx 1.25 \times l_p \approx 2.0 \times 10^{-35} m$.

So, first (massless) particle of the universe which appeared by excitation of the zero-point field with wavelength equal to the minimum possible length l_{min} must have the energy of

$E = \frac{hc}{l_{min}} = \sqrt{8\pi} \times m_p c^2 \approx 6.11 \times 10^{19}\ GeV$. This is also the maximum possible energy of any particle in nature.

4. Some unique features of the model

In our paper [3], using the R dependent expressions for energy density of vacuum and density of matter-plus-radiation in Friedman equations, we found that the vacuum energy density and matter-plus-radiation energy density can be expressed in terms of Hubble's constant by relations $u_{vac} = \frac{c^2 H^2}{4\pi G}$ and $u_{matter+radiation} = \frac{c^2 H^2}{8\pi G}$ respectively whose numerical values agreed well with the observational data. In our model, the universe in the form of 3-sphere was found to be expanding at double the speed of light ($\frac{dR}{dt} = \gamma c = 2c$). This does not violate the special theory of relativity as it is the speed of 3D space in infinite 4D space whereas special relativity limits the velocity of particles in 3D space to the speed of light. So, radius of universe at any time 't' is given by, $R = 2ct$ and putting it in Eq. (4), we get $\rho\ \alpha\ \frac{1}{t^2}$. This inverse square dependence of energy density with time can be verified in future by collecting cosmic data at different ages of the universe (we can look far to know the past state of universe).

In our model, as the radius of universe increases at constant rate of 2c, the Hubble constant is given by,

$$H = \frac{dR/dt}{R} = \frac{2c}{2ct} = \frac{1}{t} \tag{6}$$

Thus, in our model, Hubble's constant is ***exactly*** equal to the reciprocal of age of the universe. Taking the age of universe to be nearly same as the age of oldest star (Methuselah or HD 140283) i.e. 13.7 billion years [8] and putting it in Eq. (6), the present value of Hubble's constant in our model comes out to be ~71.3 km-s⁻

^{1}/MPc which agrees well with the value directly measured from Cepheid/Supernovae Ia (~73.2 km-s^{-1}/MPc [9]).

Another interesting feature of our model is that total energy density due to vacuum, matter and radiation comes out to be, $u = \frac{3c^2H^2}{8\pi G}$ which is equal to the critical density required to explain the observed flatness of space. Thus, in contrast to conventional cosmological theory, our model doesn't need fine tuning or inflaton field having a specific potential energy distribution to prove flatness.

5. Conclusion:

In this article, we have derived the required condition for creation and evolution of a zero-energy universe from empty space and thereby obeying the law of conservation of energy. This condition dictates that the total positive energy must be directly proportional to the radius of universe or in other words energy density must be inversely proportional to the square of radius ($1/R^2$ dependence) so that total positive energy due to vacuum, matter and radiation is exactly cancelled by the negative gravitational potential energy. Thus, positive energy of the universe is created at the cost of making gravitational potential energy more and more negative. Our new cosmological model [3] satisfies this criterion of zero energy universe whereas standard model doesn't. In our model, although the universe was created from an empty bubble with energy of the order of Planck energy ~10^{-8} kg, presently we see a huge amount of (positive) energy of ~10^{54} kg due to vacuum, matter and radiation because radius of universe has also increased by same factor of ~10^{62} from initial value of ~10^{-36} m to present value of ~10^{26} m and our new model predicts the positive energy of universe to be proportional to the radius of universe.

We have also brought out to the fore that zero energy universe is possible only if smallest possible length in nature is $l_{min} = l_p\sqrt{\frac{\pi}{2}}$ $\approx 2.0 \times 10^{-35}$ m which is of course of the order of the Planck length. Taking this minimum distance as wavelength, maximum energy of a (massless) particle comes out to be $\approx 6.11 \times 10^{19}\ GeV$ which might have appeared at the time of creation of the universe.

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