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Research Article

Space Creation Mechanism during the Expansion of Universe

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We propose a novel mechanism related to the expansion of universe. Recently Verlinde's proposal has been applied to the deformed bosons being a candidate for the dark energy constituents, since the negative pressure of the deformed bosons. The expansion of universe is dependent on the dark energy and implies a creation of space; we admit that the space creation mechanism is related to the deformed bosons and so is the dark energy. In order to relate the dark energy and the mechanism for creation of space, we consider Verlinde's proposal including the Holographic principle for emergence of space, which was recently applied to the deformed bosons. To check the validity of our mechanism, we calculate the ratio of the size of universe before and after the expansion and compare the results with the observational data. We find that the results are consistent with each other and infer that the proposed mechanism works correctly.

1. Introduction

Universe is the structure that contains everything in space such as matter, radiation, or unknown forms of matter and energy. All the things in space are parts of the universe. If something is assumed to be outside of the universe, it would again be a part of the universe, too. Astrophysical observations such as, Supernova Ia [1, 2], large-scale structure [3, 4], the baryon acoustic oscillations [5], and the cosmic microwave background radiation (CMBR) [6–9] show that the universe is experiencing an expansion.

What is the universe expanding into? This seems to be a meaningless question since there is nowhere as outside of the universe while the universe is expanding. In order to answer this question, we clarify that the universe has no edges but a boundary within a limited volume. This volume increases during the expansion of universe. Here extra space is created during the expansion of universe. The universe wraps in upon itself during the expansion by creation of extra space [10].

In order to explain the expansion of universe, an unknown form of energy, called dark energy, is proposed. This unknown form of energy has some interesting properties: for example, it is not clustered somewhere in space but spread all over the universe and it has a negative pressure for driving the expansion of universe [11–14].

We propose a mechanism related to the expansion of universe and its driving affect, dark energy, in this paper. Since the dark energy has a negative pressure and an exotic nature, deformed bosons can be considered as a candidate for the dark energy constituent because of their negative pressure and hypothetical existence [15]. We assume that the creation of space during the expansion of universe is driven by dark energy which is related to the deformed bosons in the framework of Verlinde's Holographic scenario for the emergent of space [16]. After giving a brief summary of Verlinde's proposal [17], we calculate the ratio of the size of universe before and after the expansion and compare the results with the observational data to check the validity of our mechanism.

2. Creation of Space during the Expansion of Universe

The universe consists of galaxies and other matter and energy forms. These constituents can be observed from Earth at the present time because the signals of these objects have had time to reach Earth since the beginning of cosmological expansion. We assume that the universe is isotropic; the distance to the boundary of observable universe is the same in all directions. Therefore, the observable universe is a spherical volume centered on the observer.

We are only able to detect the light from as far back as the time of photon decoupling in the recombination epoch that the photons can be emitted from particles and cannot be quickly absorbed again by other particles. Before this epoch, the universe was filled with plasma and opaque to photons. The last scattering surface is the set of points in space at the exact distance that the photons just reach us today from the time of photon decoupling. The photons detected today are the cosmic microwave background radiation (CMBR).

The CMB photons detected today by microwave detectors with a redshift $z = 1090$ were emitted as visible light about 380.000 years after the Big Bang or 13.8 billion years before now [18]. A photon that has been travelling for 13.8 billion years has taken a distance 13.8 billion light years (1.3×10^{26} m). But due to the expansion of universe, observed photon is now considerably further away than its original distance at the time 13.8 billion years before now. The present distance travelled by the photon is called commoving distance, current proper distance from the beginning of the CMBR, which represents the radius of observable universe. It is estimated that the radius of observable universe is about 46.5 billion light years (4.4×10^{26} m) instead of 13.8 billion light years due to the expansion of universe [19, 20].

The commoving distance from Earth to the boundary of observable universe is about 46.5 billion light years in any direction. The observable universe is thus a sphere with a radius of about 46.5 billion light years [21]. The radius quoted here is the distance now in cosmological time, not the distance at the time photon was emitted. Namely, the CMBR that we observe right now was emitted at the time of photon decoupling, estimated to have occurred about 380.000 years after the Big Bang [22, 23] or 13.8 Billion light years before right now. By using the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric which is used to model the expanding universe, the radius of universe at the time of photon decoupling is estimated. If at the present time a photon with a redshift $z = 1090$ is detected, then the scale factor is $a = 1/(1+z) = 1/1091$ at the time the photon was originally emitted [24, 25]. Therefore, the present radius 46.5 billion light years that has been travelled by the originally emitted oldest CMBR photons reduces to 42.6 million light years (4×10^{23} m) [26].

Consequently, we summarize the size of universe before and after the expansion as follows: the radius of universe 380.000 years after the Big Bang was 42.6 million light years and the radius of universe now (13.8 billion years after the Big Bang) is 46.5 billion light years. This extra created space is led by the expansion of universe which is driven by the dark energy. In fact the large-scale structure of universe takes its first form at the end of about 10^{-32} seconds after the Big Bang by the inflationary scenario which states that the space expands exponentially at the very beginning of the Big Bang, such as between the seconds 10^{-36} and 10^{-32}. This inflationary expansion is more rapid than the late time accelerated expansion of universe driven by dark energy. After the inflationary period, the universe expands in a less accelerated phase. Inflation is very similar to the expansion of dark energy and it can be considered as the reason of very early time expansion of the universe to accelerate. According to Verlinde's proposal the created space during the exponential expansion of inflationary scenario at the beginning of universe can be estimated from the energy density data of the inflation present in between the times 10^{-36} and 10^{-32} seconds after the Big Bang.

Dark energy is an unknown form of energy in astronomy and cosmology and is understood to permeate all of the space to expand the universe [27]. Dark energy is very homogeneous, not very dense, and is not known to interact with any of the fundamental forces except gravity. The explicit constituent of the dark energy has not still been understood and many studies have been performed to find a candidate solution for the dark energy constituent [28–36].

The existence of dark energy has indirect evidences coming from three independent sources. One is the distance measurements and their relation to redshift. Second is the theoretical necessity of a type of additional energy contribution that is not baryonic or dark matter to form a flat universe. Last one is the implications from measures of large scale wave-patterns of mass density in the universe [37].

Since the dark energy must have a strong negative pressure in order to expand the universe, we admit the deformed bosons to dark energy, because the deformed bosons have also negative pressure as the dark energy [15]. Because the pressure also contributes to gravitational attraction, like mass, due to the stress-energy tensor in general relativity, strong negative pressure causes the expansion of universe with the gravitational repulsion. This is in fact a gravitational repulsion. Therefore, the deformed bosons that have a negative pressure can be considered as the dark energy.

Since the dark energy is uniformly distributed all over the universe in a very low density, roughly 10^{-27} kg/m^3, it should dominate the mass-energy ratio of universe. The best current measurements indicate that the dark energy contributes 68.3% of the total energy in the present day universe, while the baryonic matter and the dark matter contribute 4.9% and 26.8% of the total energy, respectively [38–41].

The five-year WMAP data in 2008 put an interesting measurement on the mass-energy ratio of universe. The measurements put constraints on the content of universe at the time that the CMBR was emitted, 380.000 years after the Big Bang. At this time 10% of the universe was made up of neutrinos, 12% of atoms, 15% of photons, and 63% of dark matter and vanishingly small percentage is made up of dark energy [42]. According to the early dark energy (EDE) cosmologies this vanishingly small percentage is tried to be determined [43–45]. The best estimated amount of the early dark energy density EDE2 in [46] is about 1/1000 of the present day dark energy value. Briefly if the present day contribution of dark energy is 68.3% of the total mass-energy of universe, then the contribution at the time CMBR was released is 0.0683%.

By using the above dark energy ratios, we will try to calculate the additional created space while the universe has been expanding between 380.000 years after the Big Bang and the present day (13.8 billion years after the Big Bang). We then compare the obtained results with the radii of universe given above for these times. To calculate the additional created space, we will use Verlinde's proposal that is the Holographic principle for emergence of space, since this proposal can be applied to the deformed bosons as a candidate for the dark energy [16].

Verlinde states that the gravity and space are thought to be emergent with the existence of matter or more generally energy. String theory and its related developments give some clues in this direction. Particularly important clues come from the open/closed string correspondence. It gives evidences for the fact that gravity and space can emerge from a microscopic description. The central notion to derive gravity and space is the information associated with the matter or energy, which is measured in terms of entropy [17].

The assumption is that the information associated with a part of space obeys the Holographic principle [47, 48]. The most powerful supporting evidence for the Holographic principle is given by black hole physics [49, 50] and the Ads/CFT correspondence [51]. This principle indicates that the least part of microscopic degrees of freedom is represented holographically on the boundary of space.

An important point is that only a finite number of degrees of freedom are associated with a given spatial volume in the Holographic principle. The matter or equivalently the energy is distributed evenly over the degrees of freedom, and this leads to a temperature [17].

Space is a storage device for information associated with matter or energy. Given the fact that the maximal information is finite for each part of space, we can assume that the information is stored in points of a discretized space. We assume that the information is stored in discrete bits on the surfaces of space, called screens [17].

We assume that the boundary is a closed surface of a sphere with already emerged space inside the sphere. It is assumed that the boundary is a storage device for the information. By using the Holographic principle, it is obtained that the maximal storage space or the total number of bits is proportional to the surface area A of the sphere. Here each fundamental bit occupies one unit cell on the boundary surface. Then the total number of bits N is written as [17] $N = Ac^3/G\hbar$, where G is Newton's constant, c is speed of light, and $\hbar$ is the reduced Planck's constant. Only assumption made here is the proportionality of total number of bits and area of boundary surface.

Suppose the space in the sphere emerges due to a mass M with energy $E = Mc^2$. This energy is divided evenly over the bits N. Then the temperature T is determined by the equipartition rule $E = Nk_BT/2$, as the average energy per bit [17]. Here k_B is Boltzmann's constant. By using $A = 4\pi R^2$, we can find the radius of emergent spherical space due to mass M and the volume of emergent space.

We now apply Verlinde's proposal of Holographic principle for emergence of space in the expansion of universe. Since the dark energy is responsible from the expansion of universe, we hold dark energy responsible for the mechanism of creation of space during the expansion of universe in the framework of Holographic principle. In order to check the validity of our proposal, we evaluate the sizes of created space before and during the expansion of universe by using total number of bits and average energy. Then we compare the results with the observational data given above.

We will calculate the ratio of radius of universe at the time 380.000 years after the Big Bang and the radius at the present time. Since we will use the equations for bit number and energy, we need the temperatures of universe at those times. As it is mentioned above, the epoch when the universe reached the age of 380.000 years is called recombination and decoupling. At this age the temperature of universe fall down to 3000 K and the photons no longer interact with the matter, and consequently the photons retained the blackbody radiation. Those photons, which started their journey at a temperature of 3000 K, are observed today as the CMBR at a temperature of 2.75 K due to the expansion of universe which stretched the wavelengths of background radiation [52, 53]. Now we can calculate the ratio of radii by using these temperatures and above mass-energy percentages of the dark energy.

Let the radius and the temperature of universe at the age of 380.000 years be initial radius and temperature, R_0 and T_0, respectively. Then let the present radius and the temperature be final radius and temperature, R_f and T_f, respectively. Also the initial and final mass-energy concentration of dark energy can be labeled as E_0 and E_f, respectively. According to bit number and energy equations, we can write $E_0/E_f = R_0^2\ T_0/R_f^2\ T_f$, where we used $A = 4\pi R^2$ in the total number of bits N. By inserting the temperatures 3000 K and 2.75 K instead of T_0 and T_f, respectively, with the mass-energy concentrations in [46] for dark energy 68.3% and 0.0683% instead of E_0 and E_f, respectively, we obtain the ratio of radii, such as $R_f/R_0 = 1044.5$. This is the ratio of radius of universe at the age of 380.000 years old when CMBR starts to radiate and the radius of present universe, obtained by Verlinde's Holographic principle implying that the creation of space during the expansion is due to the dark energy concentration difference.

The ratio of observable radii for the radius of universe at the time 380.000 years after the Big Bang which is 42.6 million light years and the radius of present universe which is 46.5 billion light years is $R_f/R_0 = 46.5 \times 10^9$ ly$/42.6 \times 10^6$ ly $= 1091.5$. When we compare the theoretical ratio 1044.5 with the observational ratio 1091.5, we obtain a very big accuracy in comparison to very big cosmological distances.

3. Conclusions

The mechanism proposed here is mainly based on Verlinde's Holographic principle for the emergence of space due to a matter-energy source; here the source is deformed bosons as the dark energy. Since it is clear that there occurs a creation of space during the expansion of universe between the ages 380.000 years old and the present age, we dedicate the creation of space here to the dark energy being responsible from the expansion of universe. To relate the dark energy and creation of space, we consider Verlinde's proposal by using the dark energy density instead of the mass term. We check the validity of proposed mechanism by calculating the ratio of radii of universe before and after the expansion. The present radius of universe after the expansion carries information about the created space during the expansion. The ratio of radii that is theoretically obtained from the proposed mechanism is consistent with the ratio of observational radii values belonging to 380.000 years old and present universe.

The consistency on the ratios of radii implies that the proposed mechanism works right. The core of our proposition is that the expansion of universe is equivalent to the creation of space controlled by the dark energy in the framework of Verlinde's Holographic principle for the emergent of space due to a mass-energy source.

Competing Interests

The authors declare that they have no competing interests.

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