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A Simple Model of Cosmic Inflation

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***Abstract*- Inflationary Cosmology serves to solve the problems of Standard Big Bang Cosmology, particularly the horizon problem, the flatness problem and the relic abundance problem. However, the theories haven't effectively been able to relate inflation to dark energy and explain how inflation field can actually be converted to dark energy under low energy conditions. A simple model of cosmic inflation aims to complete such holes in inflationary cosmology. Moreover, it also aims to simplify the concepts of inflation by relating it to classical physics. This model is a beautiful hybrid involving some of the classical concepts of Physics which along with the modern concepts can effectively explain the phenomenon of inflation. The inflation field is due to a centrifugal force that is created due to the circular motion of the vacuum particles during the instant of big bang along with the outward pressure initially created due to a phenomenon described in the article. The theory also explains why the inflation field converted to Dark Energy dilutes slower than ordinary matter over time which leads to dominance of dark energy in the later era of the Universe.**

***Keywords*- Cosmic Inflation, Simple Model of Inflation, Inflation and Dark Energy.**

I. INTRODUCTION

The Big Bang Theory was one of the major achievements of the 20th century in the field of Cosmology. However, it had three major problems: the "Flatness problem", the "Monopole problem" and the "Horizon problem".

Observations reveal that the distant points on the CMB, which are separated by distances larger than light would have travelled at that time, are in thermal equilibrium. This is a problem because nothing faster than light could have done the thermalization. This is called the "Horizon problem". Moreover, the Universe seems to be flat on the largest scales i.e. Ω_0 is 1 ± 0.01 which indicates a nearly flat geometry. For Ω to be so close to 1 today, the mass-energy density of the Universe had to be even closer to the critical density in the early ages of the Universe. Ω had to be equal to 1 within one in hundred trillion, which seems to be a unrealistic "fine-tuning" of the Universe [1]. This is called the "Flatness problem". In addition, the Grand Unified Theories (GUT) predict the production of monopoles and other relic abundances. Their density dilutes slower than that of radiation as they are the matter components of the Universe, so we expect them to dominate the present Universe [2]. However, no magnetic monopole has ever been observed scientifically which is why we call it the "Monopole Problem".

Attempts were made to solve the problems of the Big Bang Theory, the best of which turned out to be the theories of Cosmic Inflation. It was proposed for the first time by Alan Guth, 1981[3]. His model explained the exponential expansion of the Universe caused by cosmological phase transition of the Universe in a super-cooled meta-stable vacuum state. He assumed the energy density of vacuum to remain constant. However, taking high probability of bubble formation made inflation too short to solve any cosmological problem and taking low probability of bubble formation made long inflation which requires a fine-tuned Universe with an extremely low Ω [4].

In this paper, we propose a completely new model of Cosmic Inflation based on simple concepts without requiring many complicated ideas. This inflation is created by a centrifugal force of vacuum particles which are in circular motion during the beginning of the Universe and get scattered away as the Universe evolved in its very early phases. Just after the big bang, the rapid expansion causes massive drop in pressure which causes the Universe to collapse back but it doesn't collapse beyond a certain density. Then, it experiences an outward force which acts along the direction of centrifugal force of vacuum particles, thus adding to the inflation field for an instant causing exponential expansion. Later, this force became dominant over the pressure created due to decrease in temperature and continued its domination until the time when the pressure finally balanced the force. This very force provides the inflation field and how inflation field evolves over time has been discussed in two different models and a hybrid model has also been presented which combines the ideas of both the models to provide a much reasonable theory of inflation. Moreover, the hybrid model can also explain how the inflation field later got transformed into Dark Energy.

II. BRIEF HISTORY OF INFLATIONARY COSMOLOGY

A scalar field's energy density changes during the cosmological phase transition and plays the role of the cosmological constant [5]. Some cases include discontinuous changes due to first order phase transition from false vacuum state. Gennady Chibisov and Linde (1978) tried to build a model of exponentially expanding Universe involving false vacuum only to realize how inhomogeneous the so-described Universe would be after the collision of bubble walls. As a result, they decided to stop pursuing this idea [4]. A semi-realistic model was introduced by Alexei Starobinsky in 1979-1980 [6-7] which was somewhat complicated and not in alignment with the objectives of inflationary cosmology. The model didn't explain the horizon problem but considered the Universe to be homogeneous and isotropic from the very beginning which definitely was far from the objective of inflationary cosmology. However, this model was free from the "graceful exit problem" and it predicted gravitational waves with a flat spectrum [8]. This model provided a context upon which a mechanism for producing adiabatic perturbation of the metric with flat spectrum was developed by Mukhanov and Chibisov (1981). In 1981, Alan Guth proposed a simple inflationary model involving super cooling during the cosmological phase transitions [3]. According to him, the Universe (during inflation) expands exponentially in a super-cooled false vacuum state which is metastable, has no fields or particles and has large energy density. Since empty space remains empty during expansion, the energy density remains constant and that causes exponential expansion of the Universe. The Universe becomes huge in a small period of time and its shape gets flattened due to the rapid expansion just like a fully blown balloon looks flat to an ant on it. Ultimately, false vacuum decays, new phase bubbles undergo collision and the temperature of the Universe increases. This model, which played a significant role in the development of inflationary cosmology by solving the major problems of Standard Cosmology, is currently known as "old inflation". However, the "old inflation" is problematic because if we consider the probability of bubble formation to be high, bubbles of new phase form near each other which makes inflation short and unable to solve the problems of Standard Cosmology. Moreover, the resulting Universe would be inhomogeneous and anisotropic. In contrast, considerations of less probability of bubble formation means they form far from each other in which the inflation is long and each bubble represents a Universe with an extremely small Ω. So, this model faces the graceful exit problem as it doesn't work and cannot be improved [4]. New inflationary theory in 1981-1982 solved the above problem as inflation was described to begin in one of two conditions: in false vacuum, or in unstable state at the maximum of effective potential. The field of inflation gradually rolls down in effective potential which is responsible for a homogeneous Universe [4]. This model became very popular, but it has certain drawbacks. The effective potential of the inflation field φ should have a flat plateau when $\varphi=0$ which looks like a fine-tuning. Moreover, many versions of this scenario describe inflation field which doesn't attain thermal equilibrium with other fields and in such condition, it is inappropriate to use the theory of cosmological phase transition.

The problem with the old and new inflation was that they both required a Universe that was relatively homogeneous, in thermal equilibrium from the very beginning and big enough to last until the start of inflation. Clearly, assumptions favored inflation to be a mere intermediate stage of the Universe's evolution. However, a radical change was brought in 1983 by the introduction of the chaotic inflation scenario which solved the problems of the old and new inflation theory. Chaotic inflation can occur in theories with flat enough region in potential that allows slow-roll regime to exist [7].

III. A SIMPLE MODEL OF INFLATION

This is a new model of inflation that is based upon the basic concepts of Classical Physics and includes some complex modern concepts. The main purpose of this model is to simplify the way we understand Cosmic Inflation and also to link Cosmic Inflation with Dark Energy in the simplest possible way. It also aims to open up new ideas regarding how inflation can be described even in terms of simple model without the need of many complicated concepts.

A. How Simple Inflation Takes Place

After the big-bang, the temperature decreases rapidly even within couple of fractions of seconds. That causes volumetric contraction as

$$\Delta V = V\Upsilon\Delta\theta \quad (1)$$

Where ΔV (Change in volume) is negative since $\Delta\theta$ (Change in temperature) is negative. Υ is the cubical expansivity of the space-time fabric. This causes rapid contraction of the Universe, but at a point when the density again reaches above a maximum density ρ_{max}, enormous outward pressure is created. When ΔV is massive, contraction begins which leads to further heating that ultimately leads to positive $\Delta\theta$ and causes outward push. This enormous push along with outward centrifugal force cause massive and exponential expansion of the Universe- this phenomenon is called Cosmic Inflation. Afterwards, the decrease in temperature is much less which is why the Universe cannot contract back again but continues to be dominated by the centrifugal force.

$$F_{inflation} = P_{out}A + \frac{mv^2}{r} \quad (2)$$

Where v= circular speed of the vacuum particles of the spacetime fabric which constitute the framework of the Universe, m = mass equivalent of the Energy, P_{out}= outward pressure and A=Area of the spacetime fabric.

So, inflation field equals $\frac{P_{out}}{m}A + \frac{v^2}{r}$. However, the expansion causes decrease of temperature and this lead to inwards Pressure which is much less compared to the enormous pressure exerted by the centrifugal force.

$$\text{Inflation Field } (\varphi) = \frac{v^2}{r} - \frac{P_{in}}{m}A \quad (3)$$

Where P_{in} = inward pressure created due to decrease in temperature during inflation.

Inflation continues until the $\frac{v^2}{r}$ term decreases significantly enough in one of the models and the term with P_{in} increases by an enormous amount due to decrease in temperature so that

$$\frac{v^2}{r} = \frac{P_{in}}{m}A + \frac{P_{exerted\ by\ mass}}{M}A \quad (4)$$

Where, m is the mass equivalent of the energy of vacuum particles and M is the mass of baryons.

As M = ρ_{mass}V, the above equation becomes $\frac{v^2}{r} = \frac{P_{in}}{m}A + \frac{P_{exerted\ by\ mass}}{\rho_{mass}V}A$ and since equation of state (ω) = 0 for mass, so the mass of baryons doesn't affect the inflation field. So, we get:

$$\frac{v^2}{r} = \frac{P_{in}}{m}A \quad (5)$$

B. Explanation of v and r

The total energy in vacuum is the sum of energy of particles within the space-time fabric which are in motion. Though they are dark in the sense that they don't reveal themselves to us in any other way except by the virtue of their anti-gravity effects created by their motion around circular-path (the centre being a comparatively heavy particle within the space-time fabric itself) , they have significant impact on the evolution of the Universe. Their motion is constant over time and they are net zero energy particles as they and their anti-particles can simultaneously get formed but they rarely interact (or don't interact at all) , which is why they don't get annihilated.

C. Explanation of the term $\frac{v^2}{r}$

The term $\frac{mv^2}{r}$is the centrifugal force experienced by the space-time fabric. Thus, $\frac{v^2}{r}$is the centrifugal force experienced by unit mass-energy equivalent of the space-time fabric. This can also be defined as the force per unit equivalent mass of vacuum energy. Thus, vacuum energy can be defined as:

$$E = \frac{Fc^2 r}{v^2} = \frac{Fc^2}{(\phi + \frac{P_{in}}{m}A)} \quad (6)$$

[Since $\phi = \frac{v^2}{r} - \frac{P_{in}}{m}A$]

For $P_{in}=0$,

$$E = \frac{Fc^2}{\phi} \quad (7)$$

Equation (7) shows that with increase in inflation field, the energy of vacuum decreases, This is because of conversion of energy of vacuum to inflation field energy. In other words, the inflation field exists at the cost of the energy of vacuum particles. And inflation force (F) is given as

$$F_{inflation} = \frac{Ev^2}{rc^2} \quad (8)$$

The Work done during inflation is calculated as:

$$W = P_{inflation}\,\Delta V \quad (9)$$

Since $F_{inflation} = P_{inflation}$ X A ,where A is the average area of the space time fabric and using Equation (1)

$$W = \frac{Ev^2}{rc^2 A} VY\Delta\theta \quad (10)$$

The scale factor of the Universe increased by a factor of about 10^{26}, during inflation [9]. Therefore, the volume increased by a factor of about 10^{78}. So, Eq. (9) yields:

$$W = P_{inflation}(10^{78} - 1)V = P_{inflation}(10^{78}V) \quad (11)$$

D. Evolution of $\frac{v^2}{r}$ *over time*

D1. Model with decreasing r:

Let us consider that the term r decreases over time. As a result, the inflation field increases over time and the end of inflation becomes hard to explain. Even though we can introduce the P_{in} term to be very large during the end of inflation due to enormous decrease in temperature over a small amount of time, the inflation would stop for a while and then continue again. For inflation to be stopped, certain events need to take place during the time when inflation temporarily stops. The field has to decay simultaneously to Dark Energy particles. Decaying of the field means that the anti-particles which are in motion suddenly stops (or decreases) exerting the centrifugal force essential to produce the outward pull. Since the energy of anti-particles decreases significantly at that time, they finally become stable and behave as Dark Energy particles. However, their energy isn't high enough to start another inflation. The space continues to expand under the influence of matter as well as dark energy. The matter dominates the early era whereas after significant decrease in density, the Dark Energy dominates the expansion of the Universe-causing accelerated expansion.

D2. Model with increasing r:

Let us consider for a while that the term r increases with time. This would lead to decrease in inflation field over time and thus, explain the end of inflation much easily without the need of significantly high inward pressure. If the same field that drove inflation is currently driving accelerating expansion, the reason could be the dilution in density of matter which dropped significantly below so that the gravitational pressure could no longer resist the field of inflation.

$$r \;\alpha\; a(t) \quad (12)$$

Where a=scale factor of the Universe.

Therefore, considering that v is constant, we get

$$\frac{v^2}{r} \alpha \frac{1}{a(t)} \tag{13}$$

In this way, both the models serve well to explain the end of inflation as well as the beginning of era dominated by Dark Energy.

D3. A Hybrid Model of the Two:

In this model, the radius r increases over time, and the energy of the vacuum particles gets significantly low in the fraction of seconds when inflation is balanced by inward pressure. So, the inflation field decreases over time. This has advantages over the above models because unlike the model with decreasing r, it doesn't have to deal with assumptions that P_{in} had to be extraordinarily high to balance the increased inflation field. Moreover, it also gives a reasonable explanation of how inflation ends by the decay of inflation field particles to Dark Energy particles. It has the advantages of both the models and lacks the drawbacks of both the models.

E. Conversion of Inflation field to Dark Energy

If E be the amount of energy released from the anti-particles of space-time fabric, the new velocity of the vacuum particles v_{new} is given by:

$$\frac{v^2}{r} - \frac{E}{mr} = \frac{{v_{new}}^2}{r} \tag{14}$$

$$v^2 - c^2 = {v_{new}}^2 \tag{15}$$

which is valid because the particles of space-time fabric can travel faster than the speed of light. Since the velocity decreases by a huge amount, the new energy of the anti-particles is too low to start another inflation field. This means the change in acceleration decreases over time. If the change in acceleration stops about billions of years from now, the acceleration then would still be enough to end the Universe in Ice and Cold.

F. Explanation of the reason of centrifugal force

When the Universe just began to expand, the antiparticles in vacuum were in circular motion. As the Universe expanded, they got scattered and their apparent centrifugal force caused the accelerated expansion of the Universe. However, consideration of evolution of r over time is important because not all the antiparticles suddenly stopped their circular motion as the Universe began its expansion. Some of them continued their motion and thus, their r mattered in the evolution of inflation field.

After the end of inflation, however, the circular motion gets almost completely ceased. Some of the released energy gets converted into conventional matter.

G. Explanation of the evolution of the term "A" over time

Since the term "A" increases over time in equation (2), the term P_{in} becomes significantly high enough for dominating the inflation field and causes the end of inflation. However, the significance of "A" in a low-energy Dark Energy Physics hasn't yet been discussed. It will be discussed in upcoming publications.

H. How Mass influences the field of Dark Energy

Explanations of equation (4) indicate that the field of inflation is not affected by the pressure of mass. However, we know that Dark Energy causes accelerated expansion of the Universe and the presence of matter actually acts as a resistance to expansion. This is because Dark Energy has anti-gravity effects whereas matter has gravitational effects. So, presence of high density of matter can cause deceleration of the Universe by dominating the anti-gravity effects of Dark Energy. This is exactly what had happened until few billion years ago when the matter density got diluted significantly. Thus, under the low-energy Physics conditions after the stabilization of inflation-causing anti-particles into Dark Energy particles, the expansion is affected by the presence of mass. However, the field of inflation in itself is absolutely independent of the presence of mass as indicated in equation (4).

I. Equation of State of the mass of vacuum particles

From Equation (3), we get the following condition at the end of Inflation epoch:

$$\frac{v^2}{r} = -\frac{P_{in}}{m}A \quad (16)$$

which can be further written as:

$$\frac{v^2}{r} = -\frac{P_{in}}{V_v \rho_v}A \quad (17)$$

where V_v= volume of the particle of vacuum and ρ_v = density of the particle of vacuum. As a result, the equation of state (ω) can be written as:

$$\omega = -\frac{v^2}{Ar}V_v \quad (18)$$

From this equation, we can clearly see that $\omega<0$ which is why it is different from ordinary matter with $\omega=0$. In the above equations, negative sign indicates that the pressure and the centrifugal force are opposite in direction. Now, the evolution of its density is given by the relation:

$$\rho \propto a^{-3(1+\omega)} \quad (19)$$

Clearly, the density ρ_v decreases slower than that of ordinary matter (since for normal matter$\rho \propto a^{-3}$). This is why it dominates the latter phases of the Universe in the form of Dark Energy.

IV. CONCLUSION

In models of inflation like Chaotic Inflation, Eternal Inflation and Hybrid Inflation, [10-11] much complicated concepts are involved with complex mathematics and thus, the kind of simplicity that is required for the understanding of the fundamental laws of nature is not available. In chaotic inflation model, we consider that the inflation can start from any chaotic kind of condition, which is a major advantage over the over new inflation which requires preciously thermalized initial conditions for inflation to begin. It also follows the Copernican Principle much better compared to new inflation as it doesn't demand such finely-tuned-initially-thermalized conditions for inflation to begin [7]. Moreover, eternal inflation goes a step beyond that and explains the inflationary model in terms of multiverse, making all the seeming "fine tuning" situations just a mere possibility out of trillions of other possibilities in the sea of Multiverse [11]. Thus, it makes sense to appreciate chaotic inflation and eternal inflation. Moreover, the hybrid models are designed with more than one field, influencing each other- one rolling faster than the other one and one dominating the inflation than the other one [10]. Even though the theory of hybrid inflation can combine the advantages of multiple theories by constructing a hybrid of various models, it still is complicated and the fact that "simplicity" is a major priority in Physics should be considered. Moreover, the fields involved in these theories are related to quantum mechanics and require understanding of the modern concepts in Physics for one to completely grasp these concepts. However, we have constructed a simple model of inflation using classical concepts of physics as the fundamental concepts even though some help has been taken from the modern concepts. Moreover, we have added few concepts of our own. As a result, this theory is simple and yet does the job done by the existing complicated models. In addition, it also explains how Dark Energy evolved after the end of Cosmic Inflation. This aims to solve the fundamental problems in Cosmology (of Dark Energy and Cosmic Inflation) with a simplified approach- a quality that a good theory should have. Even though the concepts may seem too simple, they do open up new ideas and new ways on how cosmic inflation can be thought of without going much deeper into the potential-well concepts and without introducing multiple fields which require complex understanding. Moreover, this theory can also serve as an inspiration regarding how simplicity can be prioritized on solving other existing problems of Physics and Cosmology.

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