Cosmic acceleration in an anisotropic background with bulk viscosity in the presence of constant declaration parameter

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Abstract: In this paper, we analyze a cosmological situation proposing a variation law in which a simple linear function of Hubble’s parameter that is the deceleration parameter provides the scale factor $a$ as $a = e^{\frac{2}{\beta\sqrt{2\beta t + k}}}$ (where $\beta$, $k$ are constants). We got the cosmological models in which the Universe begins from a non-solitary state and grows exponentially with infinite time $t$ till late occasions. The deceleration parameter in the model is observed to be time subordinate. The deceleration parameter in the model is found to be time dependent. It is seen that this parameter shows the development from initial decelerating period to the present accelerating period of expansion. The deceleration parameter supplies the biggest value and the fastest rate at which the universe is expanding. The cosmological term $\Lambda$ approaches to zero when $t$ approaches to infinite.

Keywords: Cosmological Model, Constant deceleration parameter, Einstein Field Equations, Linear Equations.

1. Introduction

Cosmology is the analysis of the fundamental systems and movements of our cosmos which concerns with their foundation and growth. It also includes learning about the movements of the heavenly bodies. The universe is not only isotropic but also uniform according to the current condition of growth. The field equations of Einstein are a system of simultaneous nonlinear differential equations. In the field equations, physical solutions have been identified in the context of cosmology and astrophysics. Einstein introduced to a cosmological term $\Lambda$ in physics to explain the general theory of relativity. In cosmology, the problem of cosmological constant is considered to be one of the greatest problem. In the Einstein’s field equations, this cosmological constant problem was primarily specified. This can be done by considering different values for cosmological constant. In the current years, there has been significant and essential evidence about the recognition of Lambda as an Einstein's cosmological constant.

A theory of universe combines dynamic degrees of freedom with matter fields. Therefore through development of cosmos and formation of elements, ($\Lambda$) reduces to its current slight value as the universe is very old so this constant value is very small. There are two fundamental concepts; firstly, vacuum energy density that is directly related to the cosmological term which is also one of the fundamental problems of physics. Secondly, enormous scale conduct of the universe could be understood from the cosmological term that tells us that the noticeable universe is a major one and almost level.

In addition the estimated worth of the cosmological concept and the expected value of the Quantum Field Theory (QFT) of the standard model is one of the outstanding problems in Physics. Cosmic Inflation is described by an era of expedite growth is known as inflation, is some of greatest outstanding experiment to find the solution of the issues related to Big Bang cosmology such as
uniformity, isotropy, and smoothness of the cosmos, in the very initial universe considered by [1]–[4]. The characteristics of the resolutions of the field equations of Einstein which are a system of simultaneous nonlinear differential equations, has been observed for a perfect fluid which have uniform spatial segments orthogonal to the fluid flow in this manuscript. In the field equations, physical solutions have been identified in the context of cosmology and astrophysics. We propose properties of substance or properties of spacios for solving the field equations which require the metric of corresponding space of [5]. [6] assumed the scale factor of principle of divergence generates the solution to field equations. The matter of several investigation for the solution of field equations of Einstein is specified by cosmological scale variable R (t). Cosmological models with cosmological term that are equivalent to scale factor. According to the prior history, they examined lambda as varying (−2)^{th} power of R which is denoted as the scale factor investigated by [6]–[13]. By deriving the value of L = α R^2 + βH^2 considers by [14] in the metric of Robertson – Walker, R is indicated as the scale factor, H is signified as the Hubble parameter and amendable dimensionless parameters are signified as α, β.

With regard to such a vast entropy per baryon, physical phenomenon, as perceived, the noticeable degree of radiation of cosmic background in cosmology, indicates dissipative effect. As it is observed today, for a long time, the process of dissipation continued, and in the early eras of cosmic development, many causes the high degree of isotropy. There are two main elements, the dissipative effect and the coefficient of bulk and shear viscosity that are supposed to be particularly significant in the creation and foundation of the universe. On the account of this assumption, [15] estimates and applies bulk and shear viscosity formulations that determine the role of cosmological entropy production because of the basis of this assumption. The existence of bulk viscosity with reference to general relativity noticed by [16], which causes solutions to be formed such as inflation etc. A basic description of the bulk viscosity which behaves as a real representative in the growing universe that is called the theory of the negative entropy field observed by [17]. Referencing the viscosity dissipation method, the existence of the cosmological solutions for the homogeneous Bianchi type-I system considered by [18]. The Bianchi type I solution with shear viscosity being the power function of entropy density, in the case of stiff matter, explored by [19]. In the structure of general relativity, the proposal of variable gravitational constant G offered by [20], [21], they suggested the variation connecting the variation of G with Λ. By applying this method, number of authors [22]–[31] explored Bianchies models. Bianchi form-I model with changing gravitational constant and lambda, as an isotropic and uniform smooth universe occupied with substance and a cosmological term that is equivalent to Hubble parameter H proved in the latest papers of [32].

The Prime purpose of proposed work is to explore with variable lambda in the model of the perfect fluid which contains matter in the uniform Bianchi form-I, for the stiff matter, the square of the Hubble parameter is proportionate to cosmological term, though we acquired the results of Einstein’s equations. This manuscript expands the categorization which contains all the Local Rotational Symmetry solutions for electromagnetic field as well as perfect fluid by a term which signifies a variable cosmological constant deviating with time, afterwards we will generalize the flat Robertson – Walker metric. In Bianchi metrics, for the mean Hubble parameter, we achieved required results for the equations by supposing a special law of variation that gives a consistent rate of deceleration parameter [33]–[35]. For specific cosmos, the supposition on the mean Hubble parameter describe not only the scale factors exactly but also to observe the other cosmological parameters. The manuscript leads by the series of sections as mentioned: In section 2, the basic definitions of the models are mentioned. In the division 3, their solution are obtained. In section 4, the conclusion drawn from the results.

2. The metric and field equations

Line element

\[ ds^2 = dt^2 - A^2(t) \, dx^2 - B^2(t) \, [dy^2 + dz^2] \]  \tag{1}

defines the spatially uniform and anisotropic Bianchi type-I metric space time,
where the metric potentials $A$ and $B$ are functions of $t$ only. In natural units ($c = 1, 8\pi G = 1$), the field equations, in the case of an imperfect bulk viscous fluid, the energy momentum $(T_{ij}^\mu)$ tensor is specified by

$$T_{ij} = (\rho + p) v_i v_j - p g_{ij}$$

in which $p$ is the pressure of perfect fluid and energy density of the cosmic matter is denoted by $\rho$.

The four velocity vector is denoted by $v_i$, therefore $v_i v^i = 1$.

The equation of state is defined as $p = \omega \rho$, $0 \leq \omega \leq 1$ (3)

With time dependent $G$ and lambda, the field equations of Einstein is specified by [36] as

$$R_{ij} - \frac{1}{2} R g_{ij} = \Lambda(t) g_{ij} - T_{ij} (8\pi G(t))$$

(4)

In co-moving co-ordinate system, by using equation of metric (1) and equation of energy-momentum tensor (2), then (4) the field equation gives as

$$2B^* B^* + \left(\frac{B^*}{B}\right)^2 = -8\pi G p + \Lambda$$

(5)

$$A^* A + 2B^* B = -8\pi G p + \Lambda$$

(6)

$$2A^B + \left(\frac{B}{B}\right)^2 = 8\pi G \rho + \Lambda$$

(7)

"*", denotes ordinary differentiation, with respect to the cosmic time $t$. By taking into consideration, the vanishing divergence of the Einstein tensor is given as

$$8\pi G \left[\rho^* + (\rho + p) \left(\frac{A^*}{A} + \frac{2B^*}{B}\right)\right] + 8\pi G \rho^* + \Lambda^* = 0$$

(8)

The equation of energy conservation gives $(T_{i,j}^\mu = 0)$

$$\rho^* + (\rho + p) \left(\frac{A^*}{A} + \frac{2B^*}{B}\right) = 0$$

(9)

By substituting the value of equation (9) in the equation (8), we get $G$ and $\Lambda$ coupled field specified by

$$8\pi G \rho^* + \Lambda^* = 0$$

(10)

The equation (10) representing as lambda ($\Lambda$) is a constant when $G$ is a constant.

Inserting equation (3) into equation (9) and then integrating, we get

$$\rho = \frac{k}{R^3 (\omega + 1)}$$

(11)

here $k$ signifies as the constant of integration that is $k > 0$.

Volume of this model is specified by

$$V = R^3 = AB^2$$

(12)

The Average scale factor is denoted as $R$, that is $R = [AB^2]^{1/3}$ of locally rotationally symmetric Bianchi type $- I$ universe.

From the equations (5), (6) and (7)

$$\frac{A^*}{A} - \frac{B^*}{B} = \frac{k_1}{R^3}$$

(13)

The constant of integration is denoted by $k_1$. The Hubble-parameter $H$, and deceleration parameter $q$, shear $\sigma$ and the volume expansion $\theta$ given by

$$\theta = 3H = \frac{3R^*}{R}$$

$$H = \frac{R^*}{R} = \frac{1}{3} \frac{V^*}{V} = \frac{1}{3} \left[\frac{A^*}{A} + \frac{2B^*}{B}\right],$$

$$\sigma = \frac{k}{\sqrt{3} R^3}$$

3
In terms of $H$, $\sigma$ and $q$, the equations (5) to (7) and also equation (9) can be specified by

\[
q = -1 - \frac{H^2}{H^2} = -\frac{-RR^*}{|R|^2}
\]

By Overduin et al. [37] define

\[
\rho_c = \frac{3H^2}{8\pi G}
\]

\[
\rho_v = \frac{\Lambda}{8\pi G}
\]

\[
\Omega = \frac{\rho}{\rho_c} = \frac{8\pi G}{3H^2}
\]

which are, respectively, the critical density, vacuum density and density parameter. By substituting these values in the equation (15), we acquire

\[
\frac{3\sigma^2}{\theta^2} = 1 - \frac{24\pi G \rho}{H^2} - \frac{3\Lambda}{\theta^2}
\]

Signifies that for $\Lambda \geq 0$

\[
0 \leq \sigma^2 \leq \frac{1}{3} \theta^2,
\]

\[
0 \leq \frac{8\pi G \rho}{\theta^2} \leq \frac{1}{3}
\]

Therefore the existence of negative lambda gives more for anisotropy whereas positive lambda lowers the upper limit of anisotropy.

From (14), and (15), we have

\[
\frac{d\theta}{dt} = -12\pi G \rho - 3m \frac{\sigma^2}{\theta^2} + \frac{3}{2} \Lambda - \frac{\theta^2}{2}
\]

That indicates, during the evolution of time, the rate of volume expansion reduces and therefore the existence of positive lambda implies that the universe is slowing down its rate of decay whereas a negative lambda would support it.

\[
\sigma^* = -\frac{3\sigma R^*}{R}
\]

It indicates that in the growing universe, the value of $\sigma$ reduces and for infinitely value of $R$. The value of $\sigma$ is insignificant.

### 3. Solution of the field equations

Five equations in six unknowns ($A, B, \rho, p, G$ and $\Lambda$) are provided by the system of equations (3), (5) – (7) and (10). For completely solving the system, an extra equation is required. Number of authors recognized the decline of lambda. Lambda approaches to $(-2)^{th}$ power of $a$ which is denoted as the scale factor in the metric of Roberston –Walker, examined by [13]. Lambda approaches to $(-3)^{th}$ power of $a$ which is represented as the scale factor, examined by [6]–[12] observed the value of lambda approaches to $(-m)^{th}$ power of $a$ which is indicated as scale factor where value of $m$ is constant.

\[
\Lambda = \frac{a}{R^m}, \text{ signifies a decaying vacuum energy density.}
\]

By substituting the equations (11) and (20) in the equation (10), then

\[
G = \frac{a m}{8\pi k} \left[ \frac{R^{2\omega+3-m}}{3\omega+3-m} \right]
\]

By using the equations (13), (18) and (19), we acquire

\[
\frac{R^*}{R} + 2 \left[ \frac{R^*}{R} \right]^2 - \frac{am(1-\omega)}{2(3\omega+3-m)R^m} - \frac{a}{R^m} = 0
\]

### 3.1. When the value $\omega = 0$ then Vacuum solution

Take the value $\omega = 0$, 

\[
q = -1 - \frac{H^2}{H^2} = -\frac{-RR^*}{|R|^2}
\]
The value of the equation (22) turn into
\[ \frac{R^{*}}{R} + 2 \left( \frac{R^{*}}{R} \right)^{2} - \frac{a(m-6)}{2(m-3)} \frac{1}{R^m} = 0 \] (23)

To acquire the time progression of Hubble parameter, integrate the equation (23)
\[ \frac{R^{*}}{R} = H = \sqrt{\frac{a}{3-m}} \left[ \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right]^{-1} \] (24)

Here \( t_0 \) is a constant,

To acquire the value of scale factor, using the equation (24)
\[ R = \left( \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right)^{2/m} \] (25)

By substituting the equation (25) into the equation (13), the equation of metric (1) exist as
\[ ds^2 = dt^2 + \left( \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right)^{4/m} \times \]
\[ -m_1^2 \exp \left( \frac{8k_1}{3} \sqrt{\frac{3-m}{a}} \right) \left( \frac{1}{m-6} \left( \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right)^{m-6} \right) \]
\[ m_2^2 \exp \left( 4k_1 \sqrt{\frac{3-m}{a}} \right) \left( \frac{1}{m-6} \left( \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right)^{m-6} \right) \]
\[ \left( dy^2 + dz^2 \right) \] (26)

Here \( m_1 \) and \( m_2 \) signifies as constants.

From the above model (26), \( \rho \) is denoted as matter density, \( p \) is denoted as pressure and \( G \) signifies as gravitational constant, \( \Lambda \) is denoted as cosmological constant and the spatial volume is denoted as \( V \) are specified as
\[ V = \left( \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right)^{6/m} \] , (27)
\[ \rho = \frac{k}{m} \left( \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right)^{6/m} \] (28)
for \( p = 0 \), (29)
\[ G = \frac{a m}{8\pi k (3-m)} \left[ \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right]^{2/m(3-m)} \] (30)

\( \Lambda = a \left[ \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right]^{-2} \) (31)

\( \theta \) is denoted as expansion scalar, \( \sigma \) signifies by shear
\[ \theta = 3 \frac{a}{\sqrt{3-m}} \left[ \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right]^{-1} \] (32)
\[ \sigma = \frac{k}{\sqrt{3}} \left[ \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right]^{-6/m} \] (33)
\( \Omega = \frac{\rho}{\rho_c} = \frac{m}{3} \) is the density parameter (34)

For acquired model, value of deceleration parameter \( q \) specifies as
\[ q = \frac{m}{2} - 1 \] (35)

\( \rho_v \) is denoted as the vacuum energy, \( \rho_c \) is denoted as density critical density are
\[ \rho_v = \frac{k (3-m)}{m} \left[ \frac{m}{2} \sqrt{\left( \frac{a}{3-m} \right) t + t_0} \right]^{-6/m} \] (36)
\[ \rho_c = \frac{3k}{m} \left[ \frac{m}{2} \sqrt{\frac{a}{3-m}} t + t_0 \right]^{-6/m} \]  

(37)

From the given model (26), it has been noticed that for \( 0 < m < 3 \), if \( t = t' \) then value of the spatial volume \( V = 0 \) and also the value of \( t' = \frac{-t_0}{m} \sqrt{\frac{a}{3-m}} \) and the value of \( \theta \) which is denoted as expansion scalar is infinite, that displays that our space begins to grow at \( t = t' \) with zero volume and an infinite rate of development.

At primary era, point type singularity is displayed by the space time. When there was initial singularity, at energy density the shear scalar deviates. When \( t \) rises the value of scale factors and spatial volume rises, whereas expansion scalar declines. With increasing time, rate of growth slows down. And \( \rho, \sigma, \rho_v, \rho_c, \Lambda \) reduces when \( t \) rises. Moreover the value of \( \rho, \sigma, \rho_v, \rho_c, \Lambda \) tend to zero, as \( t \to \infty \) then value of scale factors and volume become infinite. Since huge time \( t \), the model would basically provide a void universe. When \( t \) rises, the value of \( G(t) \) also rises and at \( t = t' \) value of the gravitational constant \( G(t) \) is zero. The sectional list of cosmological models wherever the gravitational constant is growing examined by [22], [26], [38]–[40]

The proportion \( \frac{a}{\rho} \) approaches to zero as \( t \) approaches to \( \infty \) offered \( m < 3 \).

Above model tends to isotropy for the hefty value of \( t \), thus it signifies shearing, non-rotating and growing model for the cosmos with a big bang start approaching to isotropy at late times.

This has examined while \( q < 0, \text{ for } 0 < m < 2, \quad q = 0, \text{ for } m = 2, \quad q > 0, \text{ for } 2 < m < 3 \)

so the universe begins with decelerating expansion changes and the expansion changes from a decelerating phase to an accelerating one. This cosmological scenario is in agreement with SNe Ia astronomical observations [41]–[46] strongly suggest this acceleration and it offers a integrated depiction for the development of the universe.

3.2. When the value \( \omega = 1 \) then Zel’dovich Fluid solution

It relates to the equation of state \( \rho = p \). In general relativity, this equation of state has been extensively useful to get cosmological models for dense matter using in [47],

The value of the equation (22) turn into

\[ \frac{R^{*+}}{R} + 2 \left( \frac{R^*}{R} \right)^2 - \frac{a}{R^m} = 0 \]  

(38)

To acquire the time progression of Hubble parameter, integrate the equation (23)

\[ H = \frac{2a}{\sqrt{6-m}} \left( \frac{2a}{6-m} t + t_0 \right)^{-1} \]  

(39)

here \( t_0 \) is a constant,

To acquire the value of scale factor, using the equation (24)

\[ R = \left( \frac{m}{2} \sqrt{\frac{2a}{6-m}} \right)^{2/m} \]  

(40)

By substituting the equation (40) into the equation (13), the equation of metric (1) exist as
\[ ds^2 = dt^2 + \left( \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right)^4 \times \]
\[ \left[ -m_1^2 \exp 2 \left( \frac{8k_1}{3} \left[ \frac{6-m}{2a} \right] \frac{1}{m-6} \left( \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right)^{\frac{m-6}{m}} \right) \right] \, dx^2 - \]
\[ m_2^2 \exp 2 \left( \frac{4k_1}{3} \left[ \frac{6-m}{2a} \right] \frac{1}{m-6} \left( \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right)^{\frac{m-6}{m}} \right) \left( dy^2 + dz^2 \right) \]

(41)

Here \( m_1 \) and \( m_2 \) signifies as constants.

From the above model (41), \( \rho \) is denoted as matter density, \( p \) \( \text{is denoted as pressure and } G \text{ signifies as gravitational constant, } \Lambda \text{ is denoted as cosmological constant and the spatial volume is denoted as } V \text{ are specified as} \)
\[ V = \left( \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right)^{6/m} \times \]
\[ \rho = p = \frac{k}{m \left[ \frac{2a}{6-m} \right] t + t_0} \times \]
\[ G = \frac{am}{8\pi k \left( 6-m \right)} \left[ \frac{m}{2} \left( \frac{2a}{6-m} \right) t + t_0 \right]^{\frac{2}{m} \left( 6-m \right)} \times \]
\[ \Lambda = \left[ \frac{m}{2} \sqrt{\frac{a}{6-m}} t + t_0 \right]^{-2} \times \]

(42)

(43)

(44)

(45)

\( \theta \) is denoted as expansion scalar, \( \sigma \) signifies by shear
\[ \theta = 3 \left[ \frac{2a}{3-m} \left[ \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right]^{\frac{1}{2}} \right] \times \]
\[ \sigma = \frac{k}{\sqrt{3}} \left[ \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right]^{-6/m} \times \]
\[ \Omega = \frac{\rho}{\rho_c} = \frac{m}{6} \text{ is the density parameter} \times \]

(46)

(47)

(48)

For acquired model, value of deceleration parameter \( q \) specifies as
\[ q = \frac{m}{6} - 1 \times \]

(49)

\( \rho_v \) is denoted as the vacuum energy, \( \rho_c \) is denoted as density critical density are
\[ \rho_v = \frac{k}{m} \left[ \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right]^{-12/m} \times \]
\[ \rho_c = \frac{6k}{m} \left[ \frac{m}{2} \sqrt{\frac{2a}{6-m}} t + t_0 \right]^{-12/m} \times \]

(50)

(51)

From the given model, it has been noticed that for \( m < 6 \), If \( t = t'' \) then value of the spatial volume \( V = 0 \) and also the value of \( t' = \frac{-t_0}{m} \sqrt{\frac{2a}{6-m}} \) and the value of \( \theta \) which is denoted as expansion scalar is infinite, that displays that our space begins to grow at \( t = t'' \) with zero volume and an infinite rate of development. As \( t \) increases, the spatial volume increases but the expansion scalar decreases. Thus, the expansion rate decreases as time increases. When \( t \) approaches to infinity, then the spatial volume become extremely huge. With increasing time then all the parameters \( p, \rho, \omega, \rho_v, \rho_c, \Lambda \) reduces and tend to zero asymptotically. Therefore, the model essentially gives an empty universe for large \( t \). The
proportion $\sigma$ approaches to zero as $t$ approaches to $\infty$ that displays that the model approaches isotropy for large values of $t$. At $t = t'$ the value of $G(t)$, the gravitational constant is zero and In the past era, it becomes extremely huge as $t$ rises, $G$ rises.

In addition to this, It has been noticed that $A \propto \frac{1}{t^2}$ which pursue from the model of [23], [25], [48]–[56]. As these interpretations propose that lambda is very small in the current cosmos so this form of lambda is actually realistic.

4. Conclusion

1. In this manuscript we have studied the cosmological models that shows that the universe starts evolving with zero volume and infinite rate of expansion.
2. We have acquired the cosmological models that shows the homogeneous and isotropic Bianchi form-I Local Rotational Symmetry with variables $G$ and lambda. Required solutions of the field equations of Einstein are achieved by supposing that $A$ is proportionate to $(-m)^{th}$ power of $R$, that is by using a law of variation of scale factor with a variable cosmological term. Two exact Bianchi type-I models have been obtained in detail. The corporal properties of corresponding cosmological models and the behavior of the anisotropic model has been conferred.
3. In the both cases, the model tends to isotropy for the hefty value of $t$. thus it signifies shearing, non-rotating and growing model for the cosmos with a big bang start approaching to isotropy at late times and concludes dynamically anisotropic expansion to the universe which allows for symmetrical Bianchi metrics.
4. The value of the gravitational constant $G(t)$ is zero at the initial singularity and it is increasing with the increase of time.
5. The observations from the different models proposed that the cosmological constant lambda, $A \propto \frac{1}{t^2}$ is very small in the current universe.
6. It presents a unified description of the evolution of the universe which starts with decelerating expansion and expands with acceleration at late times.
7. In the conclusion, in Bianchi type-I space-time Local Rotational Symmetry with variables $G$ and lambda, the results obtained in this manuscript are new and beneficial for a better consideration of the evolution of the universe.

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