LRS Bianchi Type-V Cosmological Model For Barotropic Fluid Distribution With Varying Λ(t) In Creation Field Theory Of Gravitation

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Abstract— We have studied the Hoyle-Narlikar C-field cosmology for LRS Bianchi type-V space-times with varying cosmological constant $\Lambda(t)$, when the universe is filled with barotropic fluid distribution. To get deterministic solution, we assumed that $\Lambda = \frac{1}{a^2}$ as considered by as in Chen & Wu (*Phys. Rev. D*, 41:695, 1990), where a is a scale factor. The various special cases of the model (33) *viz*. dust filled universe $(p=0)$ and radiation dominated era $(\rho = 3p)$, stiff fluid universe $(\rho = p)$ are also discussed. The physical aspects for these models are also studied.

Keywords — *C*-Field cosmology, Barotropic fluid, varying cosmological constant $\Lambda(t)$.

1 Introduction

THE model of the universe used for the investigations dealing with physical process called as a big-bang model. The big-bang model has various problems like; singularity in the past and may possibly in the future; No remarkable predictions in the big-bang model that explain the origin, evolution and characteristic of structures in the universe; the conservation of the energy is violated; further, the flatness and horizon problem in the big bang model of the universe. To overcome these problems in the big-bang model, alternative theories were proposed from time to time. The most popular theory was put forward by Bondi & Gold [1] called steady state theory. The remarkable approach of this theory is that the universes neither have any singular beginning nor an end on the cosmological background and statistical properties of large scale features of the universe do not change. To maintain the constancy of matter density, they contemplate a very slow but continuous creation of matter in contrast to explosive creation at $t = 0$ of standard model. The theory fails for not giving any physical justification for continuous creation of matter and the principle of conservation of matter was violated in this formalism. To overcome this difficulty, Hoyle & Narlikar [2] adopt a field theoretical approach by introducing a massless and chargeless scalar-field C in the Einstein-Hilbert action to account for matter creation. The theory proposed by Hoyle and Narlikar called as C-field theory which has no big-bang type singularity as in Bondi & Gold steady state theory. It is pointed out by Narlikar [3] that matter creation is accomplished at the expense of negative energy C-field. Narlikar & Padmanabhan [4] have obtained solution of Einstein field equations admitting radiation with negative energy massless scalar field C. Chatterjee & Banerjee [5] have extended the study of Hoyle-Narlikar theory [6, 7, 8] in higher dimensional space times. Singh & Chaubey [9] have investigated Bianchi type I, III, V, VI_0 and Kantowski-Sachs universes in creation-field theory. Adhav *et al*. [10, 11] have studied LRS Bianchi type-I and LRS Bianchi type-V cosmological models in creation field cosmology. Bali & Kumawat [12] have studied FRW cosmological models with variable G in C-field cosmology. Katore [13] has studied plane symmetric universe in C-field cosmology. Recently, Bali & Saraf [14] have investigated C-field cosmological model for dust distribution with varying Λ in FRW space time.

The problem of the cosmological constant is very important problem among the discussions of cosmologists. From the wide range of cosmological observations it is noted that the universe possesses non-zero cosmological constant denoted by 'Λ'. Recently, large numbers of cosmological models have been studied by the inclusion of cosmological constant Λ and studied the role of Λ at very early and later stages of the evolution of the universe. Bergmann [15] has interpreted the cosmological constant Λ in terms of Higgs scalar field. In quantum field theory, the cosmological constant is considered as the vacuum energy density. Dolgov [16, 17] shows that cosmological constant remains constant in the absence of any interaction with matter and radiation. Bertolami [18] considered cosmological models with a variable cosmological constant of the form $\Lambda \sim t^{-2}$. Chen & Wu [19] have also solved the problem by considering $\Lambda \sim R^{-2}$, where R is the scale factor in the Robertson-Walker space time. Krause & Turner [20] have suggested that universe possess a non-zero cosmological constant. Recently, the value of cosmological constant $\Lambda = 1.934 \times 10^{-35} s^{-2}$ was predicted by the cosmological relativistic theory of Carmeli & Kuzmenko [21]. This value of cosmological constant matches with measurements obtained by High-Z Supernovae Team and Supernovae Cosmological Project (Garnavich *et al*. [22], Riess

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et al. [23], Schmidt *et al.* [24], Perlmutter *et al.* [25]). Number of cosmological models in which Λ decays with time have been investigated by number of authors *viz*. Singh & Singh [26], Lui & Wesson [27], Pradhan & Pande [28], Adhav *et al.*[29], Singh & Kumar [30], Ram & Verma [31]. Tyagi & Singh [32] have studied magnetized anti-stiff fluid cosmological models in LRS Bianchi type-V universe with time dependent Λ and variable magnetic permeability. Baghel & Singh [33] have investigated Bianchi type-V universe with bulk viscous matter and time varying gravitational and cosmological constants. Bali & Saraf [34] have investigated C-field cosmological model for Barotropic fluid distribution with varying Λ in FRW space-time. Recently, Ghate *et al.* [35, 36] have studied Kaluza-Klein and LRS Bianchi type-V dust filled universes with varying $\Lambda(t)$ in creation field theory of gravitation.

In this paper, we have investigated LRS Bianchi type-V space-times for barotropic fluid distribution with varying cosmological constant $\Lambda(t)$ in the creation field theory of gravitation. The solution of the field equations are obtained by assuming a relation $\Lambda = \frac{1}{a^2}$ (Chen & Wu [19]), where a is a scale factor. This work is organized as follows. In Section 2, the model and field equations have been presented. The solution of field equations with special cases (i) dust filled universe $(p=0)$, (ii) radiation dominated universe $(\rho = 3p)$ & (iii) stiff fluid universe $(\rho = p)$ has been discussed in Section 3. Then in Section 4, the physical aspects of the model have been discussed. In the last Section 5 concluding remarks have been expressed.

2. METRIC AND FIELD EQUATIONS :

LRS Bianchi type-V metric is considered in the form

$$ds^2 = dt^2 - a^2 dx^2 - b^2 e^{-2mx}(dy^2 + dz^2), \tag{1}$$

where a, b are scale factors which are functions of cosmic time t and m is a constant.

The Einstein's field equations by introduction of C-field is modified by Hoyle and Narlikar [6, 7, 8] with varying Λ is given by

$$R_i^j - \frac{1}{2} R g_i^j = -8\pi G\left[\underset{(m)}{T_i^j} + \underset{(c)}{T_i^j}\right] - \Lambda(t) g_i^j . \tag{2}$$

The energy momentum tensor $\underset{(m)}{T_i^j}$ for perfect fluid and creation field $\underset{(c)}{T_i^j}$ are given by

$$\underset{(m)}{T_i^j} = (\rho + p)\upsilon_i \upsilon^j - p g_i^j \tag{3}$$

and

$$\underset{(c)}{T_i^j} = -f\left(C_i C^j - \frac{1}{2} g_i^j C^\alpha C_\alpha\right), \tag{4}$$

Here ρ is the energy density of massive particles and p is the pressure. v_i are co-moving four velocities which obeys the relation $v_i v^j = 1$. $v_\alpha = 0$, $\alpha = 1, 2, 3$. The coupling constant between matter and creation field is greater than zero. It is assumed that creation field C is a function of time only i.e. $C(x,t) = C(t)$.

The Hoyle-Narlikar field equations (2) for the metric (1) with the help of equations (3) and (4) given by

$$\frac{\dot b^2}{b^2} + 2\frac{\dot a \dot b}{a b} - \frac{3m^2}{a^2} = 8\pi G\left(\rho - \frac{1}{2} f \dot C^2\right) + \Lambda , \tag{5}$$

$$2\frac{\ddot b}{b} + \frac{\dot b^2}{b^2} - \frac{m^2}{a^2} = 8\pi G\left(-p + \frac{1}{2} f \dot C^2\right) + \Lambda , \tag{6}$$

$$\frac{\ddot a}{a} + \frac{\ddot b}{b} + \frac{\dot a \dot b}{a b} - \frac{m^2}{a^2} = 8\pi G\left(-p + \frac{1}{2} f \dot C^2\right) + \Lambda , \tag{7}$$

$$\frac{\dot a}{a} = \frac{\dot b}{b} . \tag{8}$$

where overhead dot $(\dot{})$ denotes differentiation with respect to time t.

From equation (8), we get

$$b = Ka , \tag{9}$$

where K is constant of integration.

Using equation (9), Field equations (5)-(7) reduce to

$$3\frac{\dot a^2}{a^2} - 3\frac{m^2}{a^2} = 8\pi G\left(\rho - \frac{1}{2} f \dot C^2\right) + \Lambda , \tag{10}$$

$$2\frac{\ddot a}{a} + \frac{\dot a^2}{a^2} - \frac{m^2}{a^2} = 8\pi G\left(-p + \frac{1}{2} f \dot C^2\right) + \Lambda . \tag{11}$$

The conservation equation

$$\left(8\pi G T_i^j + \Lambda g_i^j\right)_{;j} = 0 , \tag{12}$$

leads to

$$8\pi \dot G\left[\rho - \frac{1}{2} f \dot C^2\right] + 8\pi G\left[\dot\rho - f \dot C \ddot C + 3\rho\frac{\dot a}{a} - 3 f \dot C^2 \frac{\dot a}{a} + 3p\frac{\dot a}{a}\right] + \dot\Lambda = 0 . \tag{13}$$

Using G = constant, equation (13) leads to

$$8\pi G\left[\dot\rho - f \dot C \ddot C + 3\rho\frac{\dot a}{a} - 3 f \dot C^2 \frac{\dot a}{a} + 3p\frac{\dot a}{a}\right] + \dot\Lambda = 0 . \tag{14}$$

Now using $p = \gamma\rho$, equation (14) reduce to

$$8\pi G\left[\dot\rho - f \dot C \ddot C + 3\rho\frac{\dot a}{a} - 3 f \dot C^2 \frac{\dot a}{a} + 3\gamma\rho\frac{\dot a}{a}\right] + \dot\Lambda = 0 . \tag{15}$$

3. SOLUTION OF THE FIELD EQUATIONS :

Following Hoyle and Narlikar, the source equation of C-field: $C^i_{;i} = n/f$ leads to $C = t$, for large values of r. Thus $\dot C = 1$.

Now using $\dot C = 1$ and barotropic condition $p = \gamma\rho$ in equation (11), we get

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$$-8\pi G\gamma\rho = 2\frac{\ddot{a}}{a} + \frac{\dot{a}^2}{a^2} - \frac{m^2}{a^2} - 4\pi Gf - \Lambda, \quad (16)$$

where $0 \le \gamma \le 1$.

Using $\dot{C} = 1$ in equation (10) therein, we obtained

$$8\pi G\rho = 3\frac{\dot{a}^2}{a^2} - 3\frac{m^2}{a^2} + 4\pi Gf - \Lambda. \quad (17)$$

Solving equations (16) and (17), we get

$$2\frac{\ddot{a}}{a} + (1+3\gamma)\frac{\dot{a}^2}{a^2} = (1-\gamma)4\pi Gf + (1+3\gamma)\frac{m^2}{a^2} + (\gamma+1)\Lambda. \quad (18)$$

To get deterministic solution in terms of cosmic time t, we assume that $\Lambda = \frac{1}{a^2}$, where a is scale factor. {Chen & Wu (*Phys. Rev. D* 41:695,1990)}.

Using $\Lambda = \frac{1}{a^2}$ in equation (18), we get

$$2\ddot{a} + (1+3\gamma)\frac{\dot{a}^2}{a} = (1-\gamma)4\pi Gfa + \frac{1}{a}\left[(\gamma+1) + (1+3\gamma)m^2\right]. \quad (19)$$

To get the solution of equation (19), Let $\dot{a} = F(a)$.

which implies that $\ddot{a} = FF'$, where $F' = \frac{dF}{da}$.

Substituting in equation (19), it leads to

$$\frac{dF^2}{da} + \frac{(1+3\gamma)}{a}F^2 = (1-\gamma)4\pi Gfa + \frac{1}{a}\left[(\gamma+1) + (1+3\gamma)m^2\right], \quad (20)$$

which simplifies to

$$F^2 = \frac{4\pi Gf(1-\gamma)}{3(1+\gamma)}a^2 + \left[\frac{1+\gamma}{1+3\gamma} + m^2\right]. \quad (21)$$

For simplicity, the integration constant taken to be zero.

Equation (21) simplifies to

$$\frac{da}{\sqrt{\alpha a^2 + \beta}} = dt, \quad (22)$$

where $\alpha = \frac{4\pi Gf(1-\gamma)}{3(1+\gamma)}$, $\beta = \frac{1+\gamma}{1+3\gamma} + m^2$. (23)

Equation (22) on integration gives

$$a = \sqrt{\frac{\beta}{\alpha}}\sinh\sqrt{\alpha}t. \quad (24)$$

Thus, we have

$$\Lambda = \frac{1}{a^2} = \frac{\alpha}{\beta}\operatorname{cosech}^2\sqrt{\alpha}t. \quad (25)$$

Using equations (24), (25), in equation (17) we get

$$8\pi G\rho = (\operatorname{cosech}^2\sqrt{\alpha}t)\left[3\alpha - (3m^2+1)\frac{\alpha}{\beta}\right] + \frac{8\pi Gf}{1+\gamma}. \quad (26)$$

Using equation (24) in metric (1), we obtained

$$ds^2 = dt^2 - \left(\frac{\beta}{\alpha}\sinh^2\sqrt{\alpha}t\right)\left[dx^2 + e^{-2mx}(dy^2 + dz^2)\right] \quad (27)$$

Substituting equations (24), (25) and (26) into equation (15), we get

$$\frac{d\dot{C}^2}{dt} + 6\sqrt{\alpha}\coth\sqrt{\alpha}t\dot{C}^2 =$$
$$6\sqrt{\alpha}\coth\sqrt{\alpha}t\frac{(1+\gamma)}{8\pi Gf}\left[\left(\operatorname{cosech}^2\sqrt{\alpha}t\right)\left(3\alpha - \frac{(3m^2+1)\alpha}{\beta}\right) + 4\pi Gf + 3\alpha\right]$$
$$+\frac{2}{8\pi Gf}\left[\left(3\alpha - \frac{(3m^2+1)}{\beta}\right)\left(-2\sqrt{\alpha}\coth\sqrt{\alpha}t\operatorname{cosech}^2\sqrt{\alpha}t\right)\right]$$
$$-\frac{2\alpha\sqrt{\alpha}}{4\pi Gf\beta}\coth\sqrt{\alpha}t\operatorname{cosech}^2\sqrt{\alpha}t \quad (28)$$

To get deterministic value of $\dot{C}$, we assume $\alpha = 1$.

Thus equation (28) leads to

$$\frac{d\dot{C}^2}{dt} + (6\coth t)\dot{C}^2 = 6\coth t. \quad (29)$$

From equation (29), we get

$$\dot{C}^2(\sinh t)^6 = 6\int\coth t(\sinh t)^6\,dt. \quad (30)$$

On simplification equation (30) reduces to

$$\dot{C} = 1, \quad (31)$$

which again leads to

$$C = t. \quad (32)$$

We find $\dot{C} = 1$, which agrees with the value used in source equation. Thus creation field C is proportional to time t and the metric (1) for constraints mentioned above, leads to

$$ds^2 = dt^2 - \left(\beta\sinh^2 t\right)\left[dx^2 + e^{-2mx}(dy^2 + dz^2)\right] \quad (33)$$

3.1 Special Cases:

We have assumed

$$\alpha = \frac{4\pi Gf(1-\gamma)}{3(1+\gamma)} \text{ and } \beta = \frac{(1+\gamma)}{(1+3\gamma)} + m^2$$

Case I: Dust Filled Universe $(\gamma = 0)$:

(i) For $m = 0$:

$$\alpha = \frac{4\pi Gf}{3} \text{ and } \beta = 1.$$

Equation (22) leads to

$$\frac{da}{\sqrt{a^2 + \frac{1}{u^2}}} = u\,dt, \quad \text{where } \frac{4\pi Gf}{3} = u^2,$$

which again leads to

$$a = \frac{1}{u}\sinh[u(t+t_0)], \quad (34)$$

$$\Lambda = \frac{1}{a^2} = \frac{u^2}{\sinh^2[u(t+t_0)]}, \quad (35)$$

$$q = -\tanh^2[u(t+t_0)]. \quad (36)$$

(ii) For $m = \pm 1$:

$$\alpha = u^2 \text{ and } \beta = 2 .$$

Equation (22) leads to

$$\frac{da}{\sqrt{a^2 + \frac{2}{u^2}}} = udt ,$$

which again leads to

$$a = \frac{2}{u}\sinh[u(t+t_0)], \tag{37}$$

$$\Lambda = \frac{u^2}{4\sinh^2[u(t+t_0)]}, \tag{38}$$

$$q = -\tanh^2[u(t+t_0)]. \tag{39}$$

Case II: Stiff Fluid Universe ($\gamma = 1$):

(i) For $m = 0$:

$$\alpha = 0 \text{ and } \beta = \frac{1}{2}.$$

Equation (22) leads to

$$da = \sqrt{\frac{1}{2}}dt ,$$

which again leads to

$$a = \frac{1}{\sqrt{2}}(t+t_0), \tag{40}$$

$$\Lambda = \frac{2}{(t+t_0)^2}, \tag{41}$$

$$q = 0 . \tag{42}$$

(ii) For $m = \pm 1$:

$$\alpha = 0 \text{ and } \beta = \frac{3}{2}.$$

Equation (22) leads to

$$da = \sqrt{\frac{3}{2}}dt ,$$

which again leads to

$$a = \sqrt{\frac{3}{2}}(t+t_0), \tag{43}$$

$$\Lambda = \frac{2}{3(t+t_0)^2}, \tag{44}$$

$$q = 0 . \tag{45}$$

Case III: Radiation Dominated Universe $\left(\gamma = \frac{1}{3}\right)$:

(i) For $m = 0$:

$$\alpha = \frac{u^2}{2} \text{ and } \beta = \frac{2}{3}.$$

Equation (22) leads to

$$\frac{da}{\sqrt{a^2 + \frac{4}{3u^2}}} = \frac{u}{\sqrt{2}}dt ,$$

which again leads to

$$a = \frac{2}{\sqrt{3u}}\sinh\left[\frac{u}{\sqrt{2}}(t+t_0)\right], \tag{46}$$

$$\Lambda = \frac{3u^2}{4\sinh^2\left[\frac{u}{\sqrt{2}}(t+t_0)\right]} , \tag{47}$$

$$q = -\tanh^2\left[\frac{u}{\sqrt{2}}(t+t_0)\right]. \tag{48}$$

(ii) For $m = \pm 1$:

$$\alpha = \frac{u^2}{2} \text{ and } \beta = \frac{5}{3}.$$

Equation (22) leads to

$$\frac{da}{\sqrt{a^2 + \frac{10}{3u^2}}} = \frac{u}{\sqrt{2}}dt ,$$

which again leads to

$$a = \frac{\sqrt{10}}{\sqrt{3u}}\sinh\left[\frac{u}{\sqrt{2}}(t+t_0)\right], \tag{49}$$

$$\Lambda = \frac{3u^2}{10\sinh^2\left[\frac{u}{\sqrt{2}}(t+t_0)\right]}, \tag{50}$$

$$q = -\tanh^2\left[\frac{u}{\sqrt{2}}(t+t_0)\right]. \tag{51}$$

4. PHYSICAL ASPECTS OF THE MODEL :

The homogeneous mass density (ρ), the cosmological constant (Λ), the scale factor (a) and deceleration parameter (q) for the model (33) given by:

$$8\pi G\rho = \left(3 - \frac{3m^2+1}{\beta}\right)\cos ech^2 t + 4\pi Gf + 3 , \tag{52}$$

$$\Lambda = \frac{1}{\beta}\cos ech^2 t , \tag{53}$$

$$a = \sqrt{\beta}\sinh t , \tag{54}$$

$$q = -\tanh^2 t , \tag{55}$$

where $\beta = \frac{1+\gamma}{1+3\gamma} + m^2$; $m = 0, 1, -1$.

The reality condition $\rho > 0$ leads to

$$(3\beta - 3m^2 - 1) + \beta(4\pi Gf + 3)\sinh^2 t > 0 .$$

We find $\Lambda \sim \frac{1}{t^2}$, C increases with time, the scale factor (a) increases with time representing inflationary phase. Since $q < 0$, hence the model (33) represents accelerating universe which matches with the result as obtained by Riess *et al.* [23] and Perlmutter *et al.* [25].

5. CONCLUSION :

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1. For dust universe $(\gamma = 0, m = 0 \; and \; \gamma = 0, m = \pm 1)$, the scale factor increases with time representing inflationary universe. The cosmological constant decreases as time increases. The deceleration parameter $q < 0$, which indicates that the universe is accelerating. Hence the model (33) represents accelerating universe which matches with the result as obtained by Riess *et al.* [23] and Perlmutter *et al.* [25].
2. For stiff fluid $(\gamma = 1, m = 0 \; and \; \gamma = 1, m = \pm 1)$, the scale factors and cosmological constant Λ have same behavior i.e. the scale factor increases with time and Λ decreases as time increases. The deceleration parameter $q = 0$ indicating the universe is in uniform motion.
3. For radiation dominated universe $\left(\gamma = \frac{1}{3}, m = 0 \; and \; \gamma = \frac{1}{3}, m = \pm 1\right)$, the model behaves exactly same as for dust and stiff fluid case. The deceleration parameter $q < 0$ which indicates that universe is accelerating. Hence the model (33) represents accelerating universe which matches with the results as obtained by Riess *et al.* [23] and Perlmutter *et al.* [25].

These models match with recent observations. These models resemble exactly same with FRW cosmological model obtained by Bali and Saraf [34].

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