Article

Cosmological Model of Bianchi Type-V in Perfect Fluid and Lyra Geometry with Self-Creation Theory of Gravitation

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Abstract

Bianchi Type V cosmological model in barotropic perfect fluid with Lyra geometry within the framework of self-creation theory of gravitation is investigated. To get the deterministic solution of the model, we have made assumption that universe is filled with barotropic fluid distribution which leads to $p = \gamma\rho,\ 0 \le \gamma \le 1$, p being the isotropic pressure and ρ be the energy density of the universe. The physical and geometrical properties of the model and singularities in the model are also discussed.

Keywords: Bianchi Type V, barotropic fluid, Lyra geometry, self-creation theory.

Introduction

Weyl (41) made one of the best attempts in this direction. He introduced a generalization of Riemannian geometry in an attempt to unify gravitation and electromagnetism. Later Lyra (14) suggested a modification of Riemannian geometry which has a close resemblance to Weyl's geometry, the connection is metric preserving as in Riemannian geometry and length transfer are integrable. Lyra introduced a gauge function which removed the non-integrability condition of the length of a vector under parallel transport. Thus Riemannian geometry was modified by Lyra and was given new name Lyra's geometry.

Soleng (39) has investigated that constant gauge function α in Lyra's geometry either included a creation field or is equal to Hoyle (9) creation field cosmology or contains a special vacuum field which with the gauge vector term, may be considered as a cosmological term. Beesham (5) investigated FRW cosmological models in Lyra's manifold with time dependent displacement field, the model so obtained, solve the singularity, entropy and horizon problems which exists in the standard models of cosmology based on Riemannian geometry. Singh and Singh (33, 34) have investigated Bianchi Type I, III and Kantowski-Sachs cosmological models with time dependent displacement field and have made a comparative study of R-W models with constant deceleration parameter in Lyra's geometry. Singh and Singh (35, 36) have also investigated Bianchi Types I, V and VI_0 cosmological models in Lyra geometry.

Bhowmik and Rajput (6) have investigated anisotropic Bianchi Type I cosmological models based on Lyra geometry considering deceleration parameter constant and time dependent.

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Pradhan et al. (19-22) and Rahaman et al.(24 -26) in a series of papers have investigated cosmological models based on Lyra geometry with constant and time dependent displacement field in different contexts. Mohanty et al.(16) have investigated a five dimensional model within the framework of Lyra geometry. Recently Bali and Chandnani (1) have investigated Bianchi Type I cosmological models with time dependent gauge function for perfect fluid distribution within the framework of Lyra geometry. Pradhan et al. studied various aspects of cosmological models in light of Lyra geometry (19-22).

Since Mach's principle is not substantiated by general relativity, there has been some interesting attempts to generalize the general theory of gravitation by incorporating Mach's principle and other desired features which were lacking in the original theory and hence Barber (3) modified it by coupling the scalar field with the energy momentum tensor so that the Mach's principle is substantially accommodate by the theory. Pimental (17) and Soleng (37) have presented the Robertson Walker solutions in self-creation theory of gravitation by using power law relation between the expansion factor of the universe and the scalar field.

Reddy and Venkateswarlu (29) have obtained spatially homogeneous and anisotropic Bianchi Type-VI_0 cosmological models in Barber's self-creation theory of gravitation in both vacuum as well as in presence of perfect fluid with pressure equal to energy density. Venkateswarlu and Reddy (40) have also got spatially homogeneous and anisotropic Bianchi Type-I cosmological macro models when the source of gravitational field is a perfect fluid. Bianchi Type-II and III models in self-creation cosmology have been deduced by Shanti and Rao (32). Rao and Sanyasiraju (27) have discussed Bianchi Type VIII and IX in zero mass scalar fields and self-creation cosmology. S. Ram and Singh (31) studied Bianchi Type-I cosmological models with variable G and Λ. Pradhan and Vishwakarma (23) studied LRS Bianchi Type-I cosmological models in self-creation theory of gravitation. Bali and Upadhaya (2) have presented Bianchi Type-I string dust magnetized cosmological models. Pradhan and Pandey (18) have studied bulk viscous cosmological models in Barber's second self-creation theory. Reddy et al. (30) discussed some vacuum models in self-creation theory.

Venkateshwarlu et al. (39) also discussed string cosmological models in self-creation theory. Katore et al. (13) studied plane symmetric cosmological models with negative constant deceleration parameter in self-creation theory. Jain et al. (10) presented Bianchi Type-I cosmological model with a varying Λ term in self-creation theory of gravitation. Rao and Vinutha (28) deduced some results on exact Bianchi Type II,VIII and IX string models and plane symmetric string models in self-creation theory. Barber (4) again reviewed his theory of self-creation. Recently Jain and Yadav (11) studied LRS Bianchi Type I radiation model with a varying Λ term in self-creation theory. Very recently Borkar and Ashtankar (7) studied Bianchi Type-I bulk viscous barotropic cosmological models in self-creation theory. Jaiswal and Tiwari (12) explored some of the features of shear free Bianchi-V string models in self-creation.

In this paper we consider the Bianchi Type-V barotropic perfect fluid cosmological model in Lyra geometry and self-creation theory of gravitation. In first section we have formulated metric and field equations. In next section we try to some solutions of the field equations derived in previous section. In the next section we have calculated some physical parameters of the model obtained in second section. In the subsequent section conclusions are given.

Metric and Field Equations

We consider Bianchi V metric in the form

$$ds^2 = -dt^2 + A^2dx^2 + B^2e^{2x}dy^2 + C^2e^{2x}dz^2 \tag{1}$$

Where A, B, C are functions of 't' alone.

Energy momentum tensor T_i^j for perfect fluid distribution is given by

$$T_i^j = (\rho + p)v_iv^j + pg_i^j \tag{2}$$

where $v_i = (0,0,0,-1)$, $v_iv^j = -1$, $\alpha_i = (0,0,0,\beta(t))$; $v_4 = -1$; $v^4 = 1$

p is isotropic pressure, ρ the matter density, v^i is fluid flow vector and β the gauge function. Einstein's field equations in normal gauge for Lyra's manifold in self-creation theory of gravitation are given by

$$R_i^j - \frac{1}{2}Rg_i^j + \frac{3}{2}\alpha_i\alpha^j - \frac{3}{4}\alpha_k\alpha^k g_i^j = -\frac{8\pi G}{C^4}\varphi^{-1}T_i^j \tag{3}$$

$$\text{and} \quad \phi_{;k}^k = \frac{8\pi}{3}\eta T \tag{4}$$

where $\phi_{;k}^k$ is invariant D'Alembertian and the contracted tensor T is the trace of energy momentum tensor describing all non-gravitational and non-scalar field matter and density. Here η is coupling constant to be determined from experiments, because of homogeneity condition imposed by the metric the scalar field ϕ will be function of 't' only.

For the above line element (1), the Einstein's field equations (3) and (4) are given by

$$\frac{B_{44}}{B} + \frac{C_{44}}{C} + \frac{B_4C_4}{BC} - \frac{1}{A^2} + \frac{3}{4}\beta^2 = -\frac{8\pi p}{\phi} \tag{5}$$

$$\frac{A_{44}}{A} + \frac{C_{44}}{C} + \frac{A_4C_4}{AC} - \frac{1}{A^2} + \frac{3}{4}\beta^2 = -\frac{8\pi p}{\phi} \tag{6}$$

$$\frac{A_{44}}{A} + \frac{B_{44}}{B} + \frac{A_4B_4}{AB} - \frac{1}{A^2} + \frac{3}{4}\beta^2 = -\frac{8\pi p}{\phi} \tag{7}$$

$$\frac{A_4B_4}{AB} + \frac{B_4C_4}{BC} + \frac{A_4C_4}{AC} - \frac{3}{A^2} - \frac{3}{4}\beta^2 = \frac{8\pi\rho}{\phi} \tag{8}$$

$$\frac{2A_4}{A} - \frac{B_4}{B} - \frac{C_4}{C} = 0 \tag{9}$$

and $$\phi_{44}+\phi_4\left(\frac{A_4}{A}+\frac{B_4}{B}+\frac{C_4}{C}\right)=\frac{8\pi}{3}\eta(\rho-3p) \tag{10}$$

Here we have used units in which G = 1 and C = 1.

The energy conservation equation $T^{j}_{i;j}=0$ leads to

$$\rho_4+(\rho+p)\left(\frac{A_4}{A}+\frac{B_4}{B}+\frac{C_4}{C}\right)=0 \tag{11}$$

and the conservation of LHS of equation (3) leads to

$$\frac{3}{2}\beta\beta_4+\frac{3}{2}\beta^2\left(\frac{A_4}{A}+\frac{B_4}{B}+\frac{C_4}{C}\right)=0 \tag{12}$$

Solution of Field Equations

From equations (5) and (6) we have

$$\frac{B_{44}}{B}+\frac{B_4C_4}{BC}=\frac{A_{44}}{A}+\frac{A_4C_4}{AC} \tag{13}$$

From equations (6) and (7) we have

$$\frac{C_{44}}{C}+\frac{A_4C_4}{AC}=\frac{B_{44}}{B}+\frac{A_4B_4}{AB} \tag{14}$$

Equation (9) leads to

$$A=l(BC)^{1/2} \tag{15}$$

where l is the constant of integration.

Multiplying equation (8) by γ and adding to equation (7), we get

$$\frac{A_{44}}{A}+\frac{B_{44}}{B}+(1+\gamma)\frac{A_4B_4}{AB}-(1+3\gamma)\frac{1}{A^2}+\frac{3(1-\gamma)}{4}\beta^2+\gamma\frac{B_4C_4}{BC}+\gamma\frac{A_4C_4}{AC}=\gamma\rho-p \tag{16}$$

Applying barotropic condition $p=\gamma\rho$, equation (16) leads to

$$\frac{A_{44}}{A}+\frac{B_{44}}{B}+(1+\gamma)\frac{A_4B_4}{AB}-(3\gamma+1)\frac{1}{A^2}+\frac{3(1-\gamma)}{4}\beta^2+\gamma\frac{B_4C_4}{BC}+\gamma\frac{A_4C_4}{AC}=0 \tag{17}$$

With the help of equations (12) and (15) we get

$$\beta=0 \tag{18}$$

or

$$\beta = \frac{k_1}{(BC)^{3/2}} \tag{19}$$

where k_1 is constant of integration.

Using equations (15) and (19) in equation (17) we get

$$\frac{3}{2}\frac{B_{44}}{B} + \frac{1}{2}\frac{C_{44}}{C} + \frac{B_4 C_4}{BC}\left[\frac{1}{2} + \frac{(1+\gamma)}{2} + \frac{3\gamma}{2}\right] + \frac{B_4^2}{B^2}\left[\frac{1}{4} + \frac{\gamma}{2}\right] + \frac{C_4^2}{C^2}\left[-\frac{1}{4} + \frac{\gamma}{2}\right] - \frac{(3\gamma+1)}{l^2 BC} + \frac{3(1-\gamma)}{4}\frac{W^2}{(BC)^3} = 0 \tag{20}$$

Let

$$BC = \mu \quad , \qquad \frac{B}{C} = \upsilon \tag{21}$$

Then

$$B^2 = \mu\upsilon \text{ and } C^2 = \frac{\mu}{\upsilon} \tag{22}$$

Using equations (21) and (22) in (20) we get

$$\frac{\mu_{44}}{\mu} + \frac{1}{2}\frac{\upsilon_{44}}{\upsilon} + \frac{(3\gamma-1)}{4}\frac{\mu_4^2}{\mu^2} + \frac{3}{4}\frac{\mu_4\upsilon_4}{\mu\upsilon} - \left(\frac{\gamma+1}{4}\right)\frac{\gamma_4^2}{\upsilon^2} - \frac{(3\gamma+1)}{l^2}\frac{1}{\mu} - \frac{3}{4}\frac{(\gamma-1)}{\mu^3}k_1^{\,2} = 0 \tag{23}$$

Combining equations (9) and (14) and using equations (21) and (22) we get

$$\frac{\upsilon_4}{\upsilon} = \frac{k_2}{\mu^{3/2}} \tag{24}$$

where k_2 is constant of integration.

Using equation (24) in equation (23) we get

$$2\mu_{44} + \left(\frac{3\gamma-1}{2}\right)\frac{\mu_4^2}{\mu} = \frac{(\gamma-1)}{2}\left(3k_1^{\,2} + k_2^{\,2}\right)\frac{1}{\mu^2} + \frac{2}{l^2}(3\gamma+1) \tag{25}$$

We put

$$\mu_4 = f(\mu) \tag{26}$$

Then equation (25) reduces to

$$\frac{d}{d\mu}\left(f^2\right)+\frac{\alpha}{\mu}f^2=\frac{b}{\mu^2}+k_3 \tag{27}$$

where $\alpha=\frac{(3\gamma-1)}{2},\ \ b=\frac{\gamma-1}{2}(3k_1^2+k_2^2)\ \ and\ \ k_3=\frac{2}{l^2}(3\gamma+1)$

Which on integration leads to

$$f=\left[\left(\frac{3k_1^2+k_2^2}{3}\right)\frac{1}{\mu}+\frac{4\mu}{l^2}+\frac{S}{\mu^\alpha}\right]^{1/2} \tag{28}$$

where S is constant of integration.

Integrating equation (24) we have

$$\ln\upsilon=\int\frac{L}{\mu^{3/2}}\frac{1}{\sqrt{\left(\frac{3k_1^2+k_2^2}{3}\right)\frac{1}{\mu}+\frac{4}{l^2}\mu+\frac{S}{\mu^\alpha}}}d\mu \tag{29}$$

Hence the metric (1) reduces to

$$ds^2=-\frac{1}{\left[\left(\frac{3k_1^2+k_2^2}{3}\right)\frac{1}{\mu}+\frac{4}{l^2}\mu+\frac{S}{\mu^\alpha}\right]}d\mu^2+l^2\mu dx^2+\mu\upsilon e^{2x}dy^2+\frac{\mu}{\upsilon}e^{2x}dz^2 \tag{30}$$

After using suitable transformations the metric (1) reduces to

$$dS^2=-\frac{1}{\left[\left(\frac{3k_1^2+k_2^2}{3}\right)\frac{1}{T}+\frac{4}{l^2}T+\frac{S}{T^\alpha}\right]}dT^2+TdX^2+T\upsilon e^{2x}dY^2+\frac{T}{\upsilon}e^{2x}dZ^2 \tag{31}$$

Where $lx=X, y=Y, z=Z, \mu=T,\ s=S$ and υ is given by equation (29).

The cosmic time t is given by

$$t=\int\frac{dT}{\sqrt{\left(\frac{3k_1^2+k_2^2}{3}\right)\frac{L}{T}+\frac{4T}{l^2}+\frac{S}{T^\alpha}}} \tag{32}$$

Some Physical and Geometrical Features of the Model

The gauge function (β) is given as

$$\beta=\frac{k_1}{T^{3/2}} \tag{33}$$

For the model (31) expansion (θ) is calculated as

$$\theta = \frac{3}{2T^{1+\frac{\alpha}{2}}}\left[\left(\frac{3k_1^{\,2}+k_2^{\,2}}{3}\right)T^{\alpha-1}+\frac{4}{l^2}T^{\alpha+1}+S\right]^{1/2} \tag{34}$$

The components of shear tensor $\left(\sigma_i^j\right)$ are given by

$$\sigma_1^1 = \frac{1}{3}\left(\frac{2A_4}{A}-\frac{B_4}{B}-\frac{C_4}{C}\right)=0 \quad , \tag{35}$$

$$\sigma_2^2 = \frac{1}{3}\left(\frac{2B_4}{B}-\frac{A_4}{A}-\frac{C_4}{C}\right)=\frac{k_2}{2T^{3/2}}, \tag{36}$$

$$\sigma_3^3 = \frac{1}{3}\left(\frac{2C_4}{C}-\frac{A_4}{A}-\frac{B_4}{B}\right)=-\frac{k_2}{2T^{3/2}} \ , \tag{37}$$

$$\sigma_4^4 = 0 \quad , \tag{38}$$

Hence the shear (σ) is given by

$$\sigma = \frac{k_2}{2T^{3/2}} \quad . \tag{39}$$

The energy density (ρ) is calculated as

$$\rho = \frac{k_4}{T^{3/2(1+\gamma)}} \tag{40}$$

Isotropic pressure (p) is evaluated as

$$p = \frac{\gamma k_4}{T^{3/2(1+\gamma)}} \tag{41}$$

The energy conditions given by Hawking and Ellis (1973)

$$\text{(i)}\ \rho + p > 0 \quad \text{(ii)}\ \ \rho + 3p > 0 \tag{42}$$

are satisfied if $k_4 > 0$.

Also

$$\frac{\sigma}{\theta} = \frac{k_2 T^{1-\alpha/2}}{6}\left[\left(\frac{3k_1^2+k_2^2}{3}\right)T^{\alpha-1}+\frac{4}{l^2}T^{\alpha+1}+S\right]^{-1/2} \tag{43}$$

Hubble parameter (H) is calculated as

$$H = \frac{1}{2T^{1+\frac{\alpha}{2}}}\left[\left(\frac{3k_1^{\,2}+k_2^{\,2}}{3}\right)T^{\alpha-1}+\frac{4}{l^2}T^{\alpha+1}+S\right]^{1/2} \tag{44}$$

The scale factor (R) is given as

$$R^3 = lT^{3/2}e^{2x} \tag{45}$$

The deceleration parameter (q) is calculated as

$$q = \frac{\frac{2}{3T}\left(3k_1^{\,2}+k_2^{\,2}\right)+\left(\frac{3\gamma+1}{2}\right)\frac{S}{T^{\alpha}}}{\left(\frac{3k_1^{\,2}+k_2^{\,2}}{3}\right)\frac{1}{T}+\frac{4T}{l^2}+\frac{S}{T^{\alpha}}} \tag{46}$$

From equation (10) the scalar field (ϕ) is calculated as

$$\phi = \int \frac{k_3}{\left[\left(1-\frac{3}{2}\gamma\right)\mu^{\frac{1+3\gamma}{2}}+\frac{c}{\mu^{3/2}}\right]\left[\left(\frac{3k_1^{\,2}+k_2^{\,2}}{3}\right)\frac{1}{\mu}+\frac{4\mu}{l^2}+\frac{S}{\mu^{\alpha}}\right]^{1/2}}\,d\mu \tag{47}$$

Conclusion

In this paper we have presented Bianchi Type-V barotropic perfect fluid cosmological model in Lyra geometry in the framework of self –creation theory of gravitation. The model (31) starts with a big bang at T=0 and the expansion in the model decreases as the time increases for $\alpha > -2$. The energy conditions given by Hawking and Ellis (1973) $\rho + p > 0$, $\rho + 3p > 0$ are satisfied if $k_4 > 0$. The matter density $\rho \to \infty$ when $T \to 0$ and $\rho \to 0$ when $T \to \infty$ provided $\gamma > -1$. The spatial volume (R^3) increases as time (T) increases. The deceleration parameter $q < 0$ if $T > \left[\frac{-3S(3\gamma+1)}{4(3k_1^2+k_2^2)}\right]^{\frac{1}{\alpha-1}}$, hence the model (31) is in decelerating phase and $q > 0$ if $T < \left[\frac{-3S(3\gamma+1)}{4(3k_1^2+k_2^2)}\right]^{\frac{1}{\alpha-1}}$ then the model (31) is in accelerating phase. Since $\frac{\sigma}{\theta} \neq 0$ hence anisotropy is maintained throughout. The model (31) has POINT TYPE singularity (MacCallum (1971)) at $T = 0$. Shear tensor (σ) increases as time (T) decreases and σ decreases as T increases.

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