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Two fluid Axially Symmetric Cosmological Models in f(R,T) Theory of Gravitation

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Abstract

In this paper we have investigated two fluid axially symmetric cosmological models in $f(R,T)$ theory of gravitation. To get the deterministic model, we have assumed a supplementary condition $H_3 = kH_1$, where H_1 and H_3 are Hubble parameters and k is constant. Two-fluid model in $f(R,T)$ theory of gravitation, one fluid represents the matter content of the universe and another fluid is chosen to model the cosmic microwave background radiation. Some geometric aspects of the model are also discussed.

Keywords: Two fluid, Axially symmetric, $f(R,T)$ theory.

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1 Introduction

In recent years, several modified gravity theories like f(R) gravity, f(G) gravity, f(T) gravity and so on investigated by many workers. Nojiri and Odintsov [1]-[2] have proposed Noteworthy amongst them are f (R) theory of gravity and a general scheme for the modified f(R) gravity reconstruction from any realistic FRW cosmology . The presence of a late time cosmic acceleration of the universe in f(R) gravity studied by Carroll et al.[3]. FRW models in f(R) gravity evaluated by Paul et al.[4]. A physically viable f(R) gravity model, which showed the unification of early time inflation and late time acceleration, has developed by Shamir [5]. Ali Shojai and Fatimah Shojai [6] have discussed some new exact static spherically symmetric interior solutions of metric f(R) gravitational theories.
f(R,T) modified theory of gravity developed by Harko et al [7] , where T denotes the trace of the energy momentum tensor and R is the curvature scalar. A spatially homogeneous Bianchi type-III cosmological model in the presence of a perfect fluid source in f(R,T) theory with negative constant deceleration parameter investigated by Reddy et al [8]. Rao and Neelima [9]-[10] have presented Bianchi type-VIo universes and perfect fluid Einstein-Rosen in f(R,T) gravity. A new class of Bianchi cosmological models in f(R,T) gravity evaluated by Chaubey and Shukla [11]. Reddy and Kumar [12] have obtained by LRS Bianchi type -II Universe in f(R,T) theory of gravity. FRW viscous fluid cosmological model in f(R,T) gravity derived by Naidu et al.[13]. Shri Ram et al. [14] have examined anisotropic cosmological models in f(R,T) theory of gravitation. Pawar and Solanke [15] have investigated the physical behavior of LRS Bianchi type I cosmological model in f(R,T) theory of gravity. Dark energy cosmological models in f(R,T) theory of gravity studied by Pawar and Agrawal [16].
Cosmological models with two fluids have derived by McIntosh [17]. Bianchi type VI0 model with two fluid source developed by Coley and Dunn [18]. Pant and Oli [19] have discussed two- fluid Bianchi type II cosmological models. Oli [20] has constructed Biachi type-I two fluid cosmological models with a variable G

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and Λ. Verma [21] has examined qualitative analysis of two fluids FRW cosmological models. Bainchi type IX two fluids cosmological models in General Relativity have obtained by Pawar and Dagwal [22]. Two-fluid cosmological model in Bianchi type V space time without variable G and Λ studied by Singh et al.[23]. Two fluid cosmological models in Kaluza-Klein space time examined by Samanta [24]. Venkateswarlu [25] has presented Kaluza-Klein mesonic cosmological model with two-fluid source. Singh et al.[26] have obtained two-fluid cosmological model of Bianchi type-V with negative constant deceleration parameter. Recently, two fluids tilted cosmological model in General Relativity and Axially Bianchi type-I mesonic cosmological models with two fluid sources in Lyra Geometry presented by Pawar and Dagwal [27]-[28].
Axially symmetric cosmological models with string dust cloud source developed by Bhattacharaya and Karade [29]. Reddy and Rao [30] have constructed axially symmetric Bianchi type-I cosmological model. Axially symmetric Bianchi type-I cosmological model with negative constant deceleration parameter presented by Reddy et al.[31]. Axially symmetric perfect fluid cosmological models in Brans-Dicke scalar tensor theory of gravitation derived by Rao et al.[32]. Axially symmetric space-time with strange quark matter attached to string cloud in bimetric theory studied by Sahoo[33].Axially Symmetric Bianchi Type-I Bulk-Viscous Cosmological Models with Time-Dependent Λ and q investigated by Nawsad Ali [34].

2 Model and Field Equations

We consider metric in the form

$$ds^2 = dt^2 - A^2[d\chi^2 + \alpha^2(\chi)d\phi^2] - B^2dz^2, \tag{2.1}$$

where A and B are functions of t alone and α is function of χ.
The Einsteins field equation in $f(R,T)$ theory of gravity for the function given by

$$f(R,T) = R + 2f(T) \tag{2.2}$$

as

$$R_{ij} - \frac{1}{2}Rg_{ij} = T_{ij} + 2f'T_{ij} + [2pf'(T) + f(T)]g_{ij}, \tag{2.3}$$

The energy momentum tensor for perfect fluids given by

$$T_{ij} = T_{ij}^{(m)} + T_{ij}^{(r)}, \tag{2.4}$$

where $T_{ij}^{(m)}$ is energy-momentum tensor for the matter field with density ρ_m ,pressure p_m and four-velocity $u_1^{(m)} = (0,0,0,1)$ with $g^{ij}u_i^{(m)}u_j^{(m)} = 1$. $T_{ij}^{(r)}$ is energy-momentum tensor for the radiation field with density ρ_r , pressure $p_r = \frac{1}{3}\rho_r$ and four-velocity $u_1^{(r)} = (0,0,0,1)$ with $g^{ij}u_i^{(r)}u_j^{(r)} = 1$
Thus,

$$T_{ij}^{(m)} = (\rho_m + p_m)u_i^{(m)}u_j^{(m)} - p_m g_{ij}, \tag{2.5}$$

$$T_{ij}^{(r)} = \frac{4}{3}\rho_r u_i^{(r)}u_j^{(r)} - \frac{1}{3}\rho_r g_{ij}, \tag{2.6}$$

and the prime denotes differentiation with respect to the argument.
We choose the function $f(T)$ as the trace of the stress energy tensor of the matter so that

$$f(T) = \lambda T, \tag{2.7}$$

where λ is an arbitrary constant.
The field equation (3) for metric (1) reduce to

$$\frac{A_{44}}{A} + \frac{B_{44}}{B} + \frac{A_4B_4}{AB} = (1+3\lambda)p_m + (\frac{\rho_r}{3} - \lambda\rho_m), \tag{2.8}$$

$$2\frac{A_{44}}{A} + (\frac{A_4}{A})^2 - \frac{\alpha_{11}}{A^2\alpha} = (1+3\lambda)p_m + (\frac{\rho_r}{3} - \lambda\rho_m), \tag{2.9}$$

$$(\frac{A_4}{A})^2 + 2\frac{A_4B_4}{AB} - \frac{\alpha_{11}}{A^2\alpha} = -(1+3\lambda)\rho_m - (1+\frac{8\lambda}{3})\rho_r + \rho_m\lambda, \tag{2.10}$$

equation of state

$$p_m = (\gamma - 1)\rho_m \qquad 1 \leq \gamma \leq 2 \tag{2.11}$$

Here the index 4 after a field variable denotes the differentiation with respect to time t.
The function dependence of the metric together with Equation (9) and (10) imply,

$$\frac{\alpha_{11}}{\alpha} = m^2, \tag{2.12}$$

m is constant
If $m = 0$, then $\alpha(\chi) = c_1\chi + c_2, \chi > 0$, where c_1 and c_2 are integration constant. Without loss of generality, by taking $c_1 = 1$ and $c_2 = 0$ we get $\alpha(\chi) = \chi$.
With the help of equation (12), the set of equation (8)-(11) reduces to

$$\frac{A_{44}}{A} + \frac{B_{44}}{B} + \frac{A_4 B_4}{AB} = (1 + 3\lambda)p_m + (\frac{\rho_r}{3} - \lambda\rho_m), \tag{2.13}$$

$$2\frac{A_{44}}{A} + (\frac{A_4}{A})^2 = (1 + 3\lambda)p_m + (\frac{\rho_r}{3} - \lambda\rho_m), \tag{2.14}$$

$$(\frac{A_4}{A})^2 + 2\frac{A_4 B_4}{AB} = -(1 + 3\lambda)\rho_m - (1 + \frac{8\lambda}{3})\rho_r + \rho_m\lambda, \tag{2.15}$$

equation of state

$$p_m = (\gamma - 1)\rho_m \qquad 1 \leq \gamma \leq 2 \tag{2.16}$$

Solving equation (13) and (14) we get

$$\frac{A_{44}}{A} + (\frac{A_4}{A})^2 - \frac{B_{44}}{B} - \frac{A_4 B_4}{AB} = 0. \tag{2.17}$$

The directional Hubble parameters in the direction of χ, ϕ and z

$$H_1 = H_2 = \frac{A_4}{A}, \quad and \quad H_3 = \frac{B_4}{B}. \tag{2.18}$$

From equation (17) and (18)

$$(H_1)_4 + 2(H_1)^2 - (H_3)_4 - (H_3)^2 - H_1 H_3 = 0. \tag{2.19}$$

The shear scalar is proportional to the expansion scalar which envisages a linear relationship between Hubble parameter H_1 and H_3 .

$$H_3 = kH_1, \tag{2.20}$$

where k is constant.
Using equation (19) and (20) we get

$$(H_1)_4 + \frac{k^2 + k - 2}{k - 1}(H_1)^2 = 0. \tag{2.21}$$

Integrate equation (21) we get

$$H_1 = \frac{1}{T} \quad and \quad H_3 = \frac{k}{T}, \tag{2.22}$$

where $T = (Mt - a)$, $M = \frac{k^2+k-2}{k-1}$ and a is integration constant.
From equation (22)

$$A = b_1 T^{(\frac{1}{M})}, \quad B = b_2 T^{(\frac{k}{M})} \tag{2.23}$$

where b_1 and b_2 are integration constant.
Equation (23) can be rewritten as

$$A = T^{(\frac{1}{M})}, \quad B = T^{(\frac{k}{M})} \tag{2.24}$$

where $b_1 = b_2 = 1$ without loss of generality.
Hence the line element (1) reduced to

$$ds^2 = \frac{dT^2}{M^2} - T^{\frac{2}{M}}[d\chi^2 + \alpha^2(\chi)d\phi^2] - T^{\frac{2k}{M}}dz^2, \tag{2.25}$$

3 Some Physical and Geometrical Property

Conservation law separated for radiation and matter

$$(\gamma - 2 - 3\gamma)\rho_{m4} + [2H_1 + H_3](2\gamma - 3 - \lambda + 3\lambda\gamma)\rho_m = 0, \tag{3.26}$$

$$(1 + \frac{8\lambda}{3})\rho_{r4} + 4[2H_1 + H_3](\frac{1+2\lambda}{3})\rho_r = 0. \tag{3.27}$$

From equation (22), (26) and (27) we get

$$\rho_m = NT^{\frac{-[2+k](2\gamma-3-\lambda+3\lambda\gamma)}{\gamma-2-3\lambda}}, \tag{3.28}$$

$$\rho_r = N_1 T^{\frac{-[2+k](1+2\lambda)}{3+8\lambda}}. \tag{3.29}$$

where N and N_1 are integration constant.
The density parameter as

$$\Omega_m = \frac{N}{3(2+k)^2}T^{\frac{-[2+k](2\gamma-3-\lambda+3\lambda\gamma)}{\gamma-2-3\lambda}+2}, \tag{3.30}$$

$$,\Omega_r = \frac{N_1}{3(2+k)^2}T^{\frac{-[2+k](1+2\lambda)}{3+8\lambda}+2}. \tag{3.31}$$

Total density parameter as

$$\Omega = \frac{1}{3(2+k)^2}[NT^{\frac{-[2+k](2\gamma-3-\lambda+3\lambda\gamma)}{\gamma-2-3\lambda}+2}+, N_1 T^{\frac{-[2+k](1+2\lambda)}{3+8\lambda}+2}]. \tag{3.32}$$

The scalar expansion and shear scalar are

$$\theta = \frac{2+k}{T}, \tag{3.33}$$

$$\sigma^2 = \frac{2(1-k)^2}{3T^2}. \tag{3.34}$$

The deceleration parameter as

$$q = \frac{m(6+k) - 4(1+k)}{2(1+k)^2}. \tag{3.35}$$

The spatial volume and the rate of expansion H_i in the direction of x, y, z-axis are

$$V = T^{\frac{2+k}{M}},$$

$$H_1 = H_2 = \frac{1}{T}, \quad H_3 = \frac{k}{T}. \tag{3.36}$$

Initially the density parameter for matter Ω_m , the density parameter for radiation Ω_r and total density parameter Ω are infinite. For large value of T the density parameter for matter Ω_m , the density parameter for radiation Ω_r and total the density parameter for Ω are vanish. When $T = 0$, the scalar expansion and shear scalar are infinity but at $T = \infty$, the scalar expansion and shear scalar are zero. The deceleration parameter is constant and Spatial Volume is constant at $M = \infty$ .The shear scalar are zero at $k = 1$. The rate of expansion H_i in the direction of x, y, z-axis is vanishing at $T = \infty$ but initially the rate of expansion H_i in the direction of x, y, z-axis is infinite. At $\lambda = -\frac{3}{8}$, the density parameter for radiation Ω_r is zero. since $\lim_{T\to\infty}(\frac{\sigma}{\theta}) \neq 0$ the models not approach isotropy for large value of T. In dust Universe $(\gamma = 1)$, the density parameter for matter Ω_m is infinite at $\lambda = -\frac{1}{3}$ .For zeldovich Universe $(\gamma = 2)$, when $\lambda \to 0$, the density parameter for matter Ω_m is infinite. The density parameter for matter Ω_m is infinite at $\lambda \to -\frac{2}{9}$ in radiation Universe$(\gamma = \frac{4}{3})$.

3.1 Case-I $k = 2$

The line element (1) reduced to

$$ds^2 = \frac{dT^2}{4} - T^{\frac{1}{2}}[d\chi^2 + \alpha^2(\chi)d\phi^2] - Tdz^2, \tag{3.37}$$

where $T = (4t - a_1)$, a_1 is integration constant.
The energy density of matter ρ_m and energy density of radiation ρ_r

$$\rho_m = N_3 T^{\frac{-4(2\gamma-3-\lambda+3\lambda\gamma)}{\gamma-2-3\lambda}}, \tag{3.38}$$

$$\rho_r = N_4 T^{\frac{-4(1+2\lambda)}{3+8\lambda}}. \tag{3.39}$$

where N_3 and N_4 are integration constant.
The density parameter as

$$\Omega_m = \frac{N_3}{48} T^{\frac{6\gamma-8+2\lambda+12\lambda\gamma}{2+3\lambda-\gamma}}, \tag{3.40}$$

$$,\Omega_r = \frac{N_4}{48} T^{\frac{2(1+4\lambda)}{3+8\lambda}}. \tag{3.41}$$

Total density parameter as

$$\Omega = \frac{1}{48}[N_3 T^{\frac{6\gamma-8+2\lambda+12\lambda\gamma}{2+3\lambda-\gamma}} + N_4 T^{\frac{2(1+4\lambda)}{3+8\lambda}}]. \tag{3.42}$$

The scalar expansion and shear scalar are

$$\theta = \frac{4}{T}, \tag{3.43}$$

$$\sigma^2 = \frac{2}{3T^2}. \tag{3.44}$$

The deceleration parameter as

$$q = \frac{10}{9}. \tag{3.45}$$

The spatial volume and the rate of expansion H_i in the direction of x, y, z-axis are

$$V = T,$$

$$H_1 = H_2 = \frac{1}{T}, \quad H_3 = \frac{2}{T}. \tag{3.46}$$

When $T = 0$, the density parameter for matter $\Omega_m = 0$, the density parameter for radiation $\Omega_r = 0$ and total the density parameter $\Omega = 0$ but $T = \infty$, the density parameter for matter $\Omega_m = \infty$, the density parameter for radiation $\Omega_r = \infty$ and total the density parameter $\Omega = \infty$. The scalar expansion and shear scalar are infinity at $T = 0$ .For large value of T the scalar expansion and shear scalar are zero. The deceleration parameter is constant. The rate of expansion H_i in the direction of x, y, z-axis is vanishing at $T = \infty$ but initially the rate of expansion H_i in the direction of x, y, z-axis is infinite. since $\lim_{T\to\infty}(\frac{\sigma}{\theta}) \neq 0$ the models not approach isotropy for large value of T . At $\lambda = -\frac{3}{8}$, the density parameter for radiation Ω_r is infinite but at $\lambda = -\frac{1}{4}$ the density parameter for radiation Ω_r is constant. In dust Universe $(\gamma = 1)$, the density parameter for matter Ω_m is infinite at $\lambda = -\frac{1}{3}$ but at $\lambda = \frac{2}{14}$, the density parameter for matter is constant. For zeldovich Universe $(\gamma = 2)$, when $\lambda \to 0$, the density parameter for matter Ω_m is infinite and $\lambda \to -\frac{4}{26}$, the density parameter for matter Ω_m is constant. The density parameter for matter Ω_m is infinite at $\lambda \to -\frac{2}{9}$ and the density parameter for matter Ω_m is constant at $\lambda \to 0$ in radiation Universe $(\gamma = \frac{4}{3})$.

3.2 Case-I $k = -2$

The line element (1) reduced to

$$ds^2 = dt^2 - e^{2(l_1 - \frac{t}{a_2})}[d\chi^2 + \alpha^2(\chi)d\phi^2] - e^{2(l_2 + \frac{2t}{a_2})}dz^2, \tag{3.47}$$

where a_2 is integration constant.
The energy density of matter ρ_m and energy density of radiation ρ_r

$$\begin{aligned} \rho_m &= N_5 \\ \rho_r &= N_6. \end{aligned} \tag{3.48}$$

where N_5 and N_6 are integration constant.
The density parameter as

$$\begin{aligned} \Omega_m &= \infty, \\ ,\Omega_r &= \infty. \end{aligned} \tag{3.49}$$

Total density parameter as

$$\Omega = \infty. \tag{3.50}$$

The rate of expansion H_i in the direction of x, y, z-axis, the scalar expansion and shear scalar are

$$\begin{aligned} H_1 = H_2 = -\frac{1}{a}, \quad H_3 &= \frac{2}{a} \\ \theta &= 0, \\ \sigma^2 &= \frac{6}{T^2}. \end{aligned} \tag{3.51}$$

The deceleration parameter as

$$q = 2. \tag{3.52}$$

The spatial volume as

$$V = 1. \tag{3.53}$$

The models are non expanding and shearing universe .The energy density of matter ρ_m and energy density of radiation ρ_r, deceleration parameter, Spatial Volume, The rate of expansion H_i in the direction of x, y, z-axis are constant therefore no effect of T. The shear scalar are infinity at $T = 0$. When $T = \infty$ shear scalar are zero. Since, $\lim_{T\to\infty}(\frac{\sigma}{\theta}) = 0$ the models approach isotropy for large value of T.

4 conclusion:

The models are expanding and shearing universe but in case-II the models is non expanding. Initially the density parameter for matter Ω_m , the density parameter for radiation Ω_r and total the density parameter Ω are infinite. For large value of T the density parameter for matter Ω_m , the density parameter for radiation Ω_r and total the density parameter Ω are vanish. In dust Universe $(\gamma = 1)$, the density parameter for matter Ω_m is infinite at $\lambda = -\frac{1}{3}$. For zeldovich Universe $(\gamma = 2)$, when $\lambda \to 0$, the density parameter for matter Ω_m is infinite. The density parameter for matter Ω_m is infinite at $\lambda = -\frac{2}{9}$ in radiation Universe $(\gamma = \frac{4}{3})$. At$\lambda = -\frac{3}{8}$, the density parameter for radiation Ω_r is zero.
For case-I When $T = 0$, the density parameter for matter $\Omega_m = 0$, the density parameter for radiation $\Omega_r = 0$ and total the density parameter $\Omega = 0$ but $T = \infty$, the density parameter for matter $\Omega_m = \infty$, the density parameter for radiation $\Omega_r = \infty$ and total the density parameter $\Omega = \infty$. At $\lambda = -\frac{3}{8}$, the density parameter for radiation Ω_r is infinite but at $\lambda = -\frac{1}{4}$ the density parameter for radiation Ω_r is constant. In dust Universe

$(\gamma = 1)$, the density parameter for matter Ω_m is infinite at $\lambda = -\frac{1}{3}$ but at $\lambda = \frac{2}{14}$, the density parameter for matter is constant. For zeldovich Universe $(\gamma = 2)$, when $\lambda \to 0$, the density parameter for matter Ω_m is infinite and $\lambda \to -\frac{4}{26}$, the density parameter for matter Ω_m is constant. The density parameter for matter Ω_m is infinite at $\lambda \to -\frac{2}{9}$ and the density parameter for matter Ω_m is constant at $\lambda \to 0$ in radiation Universe $(\gamma = \frac{4}{3})$.All density parameter are infinite in case-II. The scalar expansion and shear scalar are infinity at $T = 0$ .For large value of T the scalar expansion and shear scalar are zero. The rate of expansion H_i in the direction of x, y, z-axis is vanishing at $T = \infty$ but initially the rate of H_i expansion in the direction of x, y, z-axis is infinite. In case-II the rate of expansion H_i in the direction of x, y, z-axis is constant. The deceleration parameter is constant for all case. Since $\lim_{T\to\infty}(\frac{\sigma}{\theta}) \neq 0$ the models not approach isotropy for large value of T. But in case-II,$\lim_{T\to\infty}(\frac{\sigma}{\theta}) = 0$ the models approach isotropy for large value of T.

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