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LRS BIANCHI TYPE II VISCOUS FLUID COSMOLOGICAL MODELS WITH MAGNETIC FIELD IN THE FRAMEWORK OF LYRA GEOMETRY

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Abstract: In this paper, we have studied Bianchi Type-II viscous fluid cosmological models with magnetic field and time dependent gauge function (ϕ_i) in the framework of Layra's geometry. The magnetic field is considered in $YZ-$plane. We have assumed that expansion (θ) in the model bears a constant ratio to shear (σ). The physical and geometrical aspects of the model in presence and absence of magnetic field are also discussed.

1. Introduction

Weyl [24] suggested a non-Riemannian geometrical theory of gravitation and electromagnetism. But due to non-integrability of the length transfer of a vector under parallel transport, this theory was not considered seriously. Later on, Lyra[13] removed this non-integrability condition by introducing a gauge function into modified Riemannian geometry. Halford [8] has pointed out that the vector field ϕ_i in Lyra's geometry plays the role of cosmological constant Λ in the general relativistic treatment. It is shown by Halford [8] that the scalar tensor treatment based on Lyra's geometry predicts the same effects within observational limits as the Einsteins general theory of relativity. Singh and Sharma [19] have studied the Bianchi type II anisotropic cosmological models in the theory based on Lyra's geometry in normal gauge in the pressence and absence of magnetic field. Amirhashchi [1] investigated locally rotationally symmetric Bianchi type II stiff fluid cosmological model with decaying vaccum energy density Λ in general relativity. Maartens [16] concluded that magnetic fields are observed not only in stars, but in galaxies, clusters and even in high redshift Lyman-α systems. In principle, these fields could play an important role in structure formation and also affect the anisotropies in the cosmic microwave background radiation.

He also explained that the study of cosmological magnetic fields not only quantify these effects on large-scale structure and on the CMB, but also answers one of the outstanding puzzles of modern cosmology. When and how do magnetic fields originate? They are either primordial, i.e created before the onset of structure formation, or they are generated during the process of structure formation itself. Chandel and Ram [4] have investigated a one parameter family of totally anisotropic Bianchi type II string cosmological models with bulk viscous fluid in Lyra geometry. Bali and Kumawat [2] have studied a tilted cosmological model for a barotropic fluid distribution with heat conduction in the framework of Bianchi type II spacetime. Sharma [17] have investigated Bianchi type II cosmological model with and without bulk viscosity. Desikan [5] considered a linearly varying deceleration parameter and obtained solutions for a flat FRW cosmological model in Lyra geometry. Dubey et al. [6] examined the behavior of spatially homogeneous and anisotropic Bianchi type II cosmological model with anisotropic dark energy in Lyra geometry. Singh et al. [20] have investigated the effect of bulk viscosity and time varying gravitational parameter G on the evolution of a five dimensional model of the universe within the framework of Lyra geometry. Yadav and Jain [26] have studied a nonzero time dependent cosmological constant Λ model for disordered radiaion in the framework of Barber's second self creation theory of gravitation. Bali et al. [3] also discussed LRS Bianchi type II massive string cosmological models with magnetic field in Lyra's geometry.

Recently, Katore and Kapse [10] have studied the anisotropic and homogeneous Bianchi type -VI_0 universe with dark matter and holographic dark energy components in the framework of general relativity and Lyra's geometry. Ram et al.[15] have investigated a Kantowski-Sachs cosmological model of the universe filled with anisotropic dark enery within the framework of Lyra's geometry. Sahoo et al.[18] have studied spatially homogeneous and anisotropic Bianchi type-II strring cosmological model with bulk viscosity in Lyra's geometry. Yadav and Bhardwaj [25] have studied the existance of Lyra's cosmology in a hybrid universe with minimal interaction between dark energy and normal matter using Bianchi V spacetime. Tsamparlls et al.[23] have studied symmetries of space time embadded within electromagnetic string fluid. Panov et al.[14] have constructed a Bianchi type-II cosnological model with expansion and rotation.

In this paper, we have established the field equation in section 2. In section 3, we have provided the solution of field equations. The physical and geometrical aspects of the model in presence and absence of magnetic field are dicussed in section 4 and 5, respectively. The conclusion is presented in the section 6.

2. The Metric and Field Equations

We consider Locally Rotationally Symmetric (LRS) Bianchi type II metric as

$$ds^2 = \eta_{ab}\theta^a\theta^b \tag{1}$$

Where $\eta_{11} = \eta_{22} = \eta_{33} = 1,\ \eta_{44} = -1$

$$\theta^1 = Rdx,\ \theta^2 = S(dy - xdz),\ \theta^3 = Rdz,\ \theta^4 = dt. \tag{2}$$

Thus the metric (1) leads to

$$ds^2 = -dt^2 + R^2dx^2 + S^2(dy - xdz)^2 + R^2dz^2 \tag{3}$$

Where R and S are function of $'t'$ alone.

The energy momentum tensor T_i^j corresponding to the viscous fluid (Landau and Lifshitz, 1963 [11]) and E_i^j the electromagnetic field (Lichnerowicz 1967 [12])

$$T_i^j = (\varepsilon + p)v_i v^j + pg_i^j - \eta(v_i;^j + v^j;i + v^j v^l v_{i;l}$$
$$+ v^j v^l v_{i;l} + v_i v^l v^j;_l) - \left(\varsigma - \frac{2}{3}\eta\right)v^l;_l(g_i^j + v_i v^j) + E_i^j \tag{4}$$

and

$$E_i^j = \mu[|h|^2 (v_i v^j + \frac{1}{2}g_i^j) - h_i h^j] \tag{5}$$

In the above equations ε is the density p is the isotropic pressure $v^l;_l = \theta,$ $v_i = (0,0,0,-1),\ v^i v_i = -1,\ v_4 = -1,\ v^4 = 1.$

η and ς are the two coefficients of viscosity and v^i the flow vector satisfying the equation

$$g_{ij}v^i v^j = -1, \tag{6}$$

With μ being the magnetic permeability and h_i the magnetic flux vector defined by

$$h_i = \frac{\sqrt{-g}}{2\mu}\varepsilon_{ijkl}F^{kl}v^j. \tag{7}$$

Where F^{kl} is the electromagnetic field tensor defined by Synge [22] and ε_{ijkl} the Levi-Civita tensor density. we assume that the current is flowing along the $X-$axis. So magnetic field is in $YZ-$ Plane.

Thus $h_1 \neq 0, h_2 = 0 = h_3 = h_4.$ and F_{23} is the only nonvanishing component of F_{ij}. This leads to $F_{12} = 0 = F_{13}$ by virtue of (7). We also find $F_{14} = 0 = F_{24} = F_{34}$ due to the assumption of infinite electrical conductivity of the fluid.

A cosmological model which contains a global magnetic field is necessarily anisotropic since the magnetic vector specifies a preferred spatial direction. The Maxwell's equation

$$F_{ij;k} + F_{jk;l} + F_{kl;j} = 0 \tag{8}$$

leads to

$$\frac{\partial F_{23}}{\partial t} = 0 \tag{9}$$

(Since F_{23} is the only nonvanishing component and $F_{ij} = -F_{ji}$) which leads to

$$F_{23} = \text{constant} = H \text{ (say)} \tag{10}$$

For $i = 1$ (7) leads to $h_1 = \dfrac{H}{\mu S}$ (11)

Now the components of E_i^j is the line element (3) are as follows:

$$E_1^1 = \frac{H^2}{2\mu R^2 S^2} = -E_2^2 = -E_3^3 = E_4^4 \tag{12}$$

Einstein's modified field equation in normal gauge for Lyra's manifold obtained by Sen [21] is given by

$$R_i^j - \frac{1}{2}Rg_i^j + \frac{3}{2}\phi_i\phi^j - \frac{3}{4}\phi_k\phi^k g_i^j = T_i^j \tag{13}$$

(In geometrized units, where $8\pi G = 1, c = 1$), $\phi_i = (0,0,0,\beta(t))$. β the gauge function.

Now the modified Einsteins field equation (13) for the metric (3) leads to

$$\frac{S^2}{4R^4} + \frac{R_4S_4}{RS} + \frac{R_{44}}{R} + \frac{S_{44}}{S} + \frac{3}{4}\beta^2 = -p + 2\eta\frac{R_4}{R} + \left(\varsigma - \frac{2}{3}\eta\right)\theta + \frac{K}{R^2S^2} \tag{14}$$

$$-\frac{3S^2}{4R^4} + \frac{R_4^2}{R^2} + \frac{2R_{44}}{R} + \frac{3}{4}\beta^2 = -p + 2\eta\frac{S_4}{S} + \left(\varsigma - \frac{2}{3}\eta\right)\theta - \frac{K}{R^2S^2} \tag{15}$$

$$-\frac{S^2}{4R^4} + \frac{2R_4S_4}{RS} + \frac{R_4^2}{R^2} - \frac{3}{4}\beta^2 = \varepsilon + \frac{K}{R^2S^2} \tag{16}$$

$$\frac{R_{44}}{R} - \frac{S_{44}}{S} - \frac{S^2}{R^4} - \frac{S_4R_4}{SR} + \frac{R_4^2}{R^2} = -2\eta\left(\frac{S_4}{S} - \frac{R_4}{R}\right) \tag{17}$$

The energy conservation equation $T_{i;j}^j = 0$

$$\varepsilon_4 + \left(2\frac{R_4}{R} + \frac{S_4}{S}\right)\left(\varepsilon + P - \left(\varsigma - \frac{2}{3}\eta\right)\theta\right) - 2\eta\left(2\frac{S_4}{S} - \frac{R_4}{R}\right) = 0 \tag{18}$$

and conservation of left hand side of (13) leads to

$$\left(R_i^j - \frac{1}{2} R g_i^j\right)_{;j} + \frac{3}{2}\left(\phi_i \phi^j\right)_{;j} - \frac{3}{4}\left(\phi_k \phi^k g_i^j\right)_{;j} = 0 \tag{19}$$

which leads to

$$\frac{3}{2}\phi_i\left[\frac{\partial \phi^j}{\partial x^j} + \phi^l \Gamma_{lj}^j\right] + \frac{3}{2}\phi^j\left[\frac{\partial \phi_i}{\partial x^j} - \phi_l \Gamma_{ij}^l\right] - \frac{3}{4} g_i^j \phi^k\left[\frac{\partial \phi_k}{\partial x^j} - \phi_l \Gamma_{lj}^l\right] - \frac{3}{4} g_i^j \phi_k\left[\frac{\partial \phi_i}{\partial x^j} - \phi_l \Gamma_{ij}^l\right] = 0 \tag{20}$$

Which again leads to

$$\frac{3}{2}\beta\beta_4 + \frac{3}{2}\beta^2\left(\frac{2R_4}{R} + \frac{S_4}{S}\right) = 0 \tag{21}$$

Where $\phi_i = (0,0,0,\beta(t))$. (22)

3. Solution of Field Equations

For the determination of the model of the universe, we assume that the shear tensor (σ) is the expansion (θ) which leads to

$$R = S^n \tag{23}$$

From (21), we have

$$\beta = \frac{\alpha}{R^2 S} \tag{24}$$

With α being constant of integration. From equation (15) - (14) we get

$$\frac{R_{44}}{R} - \frac{S_{44}}{S} - \frac{S_4 R_4}{SR} + \frac{S^2}{R^4} = -2\eta\left(\frac{S_4}{S} - \frac{R_4}{R}\right) - \frac{2K}{R^2 S^2} \tag{25}$$

Using (23) and (24) in (25)

$$S_{44} + \gamma \frac{S_4^2}{S} = \frac{1}{n-1} S^{3-4n} - \frac{2K}{n-1} S^{-2n-1} \tag{26}$$

where $\gamma = \dfrac{(n^2 - 2n) + 2l(2n+1)(n-1)}{n-1}$

Now we assume that

$$S_4 = f(S) \tag{27}$$

$$S_{44} = ff^{'} \tag{28}$$

$$f^{'} = \frac{df}{ds} \tag{29}$$

Therefore (26) leads to

$$\frac{df^2}{ds} + \frac{\gamma}{S} f^2 = \frac{1}{n-1} S^{3-4n} - \frac{2K}{n-1} S^{-2n-1} \tag{30}$$

which leads to

$$f^2 = \frac{1}{(n-1)(4+\gamma-4n)} S^{4-4n} - \frac{2K}{(n-1)(\gamma-2n)} S^{-2n} \tag{31}$$

Equation (31) leads to

$$f = \left(\frac{ds}{dt}\right) = \sqrt{L\tau^{4-4n} + M\tau^{-2n}} \tag{32}$$

Where , $L = \frac{1}{(n-1)(4+\gamma-4n)}, M = \frac{-2K}{(n-1)(\gamma-2n)}$

and $S = \tau$ a new coordinate is used.

by(23). We have

$$R = S^n \tag{33}$$

which leads to

$$R = \tau^n \tag{34}$$

Where $S = \tau$

using (32) and (34) in metric (3)

$$ds^2 = -\left(\frac{dt}{ds}\right)^2 ds + R^2 dx^2 + S^2 (dy - xdz)^2 + R^2 dz^2 \tag{35}$$

which again leads to

$$ds^2 = \frac{-d\tau^2}{L\tau^{4-4n} + M\tau^{-2n}} + \tau^{2n}(dx^2 + dz^2) + \tau^2 (dy - xdz)^2 \tag{36}$$

4. Some Physical and Geometrical Features

Using (23), (24), (32) and (34) in (16)

$$\varepsilon = A\tau^{(2-4n)} + B\tau^{-(2n+2)} + C\tau^{-(4n+2)} \tag{37}$$

Where $A = \left((2n+n^2)L - \frac{1}{4}\right)$, $B = \left((2n+n^2)M - K\right)$, $C = -\frac{3}{4}\alpha^2$

Similarly from (14)

$$p = a\tau^{(2-4n)} + b\tau^{-(2n-2)} + c\tau^{-(4n+2)} \tag{38}$$

$$\rho_p = \varepsilon - p = (A-a)\tau^{(2-4n)} + (B-b)\tau^{-(2n+2)} + (C-c)\tau^{-(4n+2)} \tag{39}$$

where $a = \left[L\left\{(2n+1)\left(\frac{2l(n+1)}{3} - 3n^2 - 2\right) - \frac{1}{4}\right\}\right]$

$b = \left[M(n^2+n+1) + K\right]$, and $c = -\frac{3}{4}\alpha^2$,

Equation (24) gives

$$\beta = \frac{\alpha}{\tau^{2n+1}} \tag{40}$$

The expainsion (θ) is given as

$$\theta = \left(\frac{2R_4}{R} + \frac{S_4}{S}\right) \tag{41}$$

which leads to

$$\theta = (2n+1)\sqrt{L\tau^{2-4n} + M\tau^{-(2+2n)}} \tag{42}$$

sincen $\eta \propto \theta$ then $\eta = l\theta$ then

$$\eta = l(2n+1)\sqrt{L\tau^{2-4n} + M\tau^{-(2+2n)}} \tag{43}$$

Shear (σ) is given by

$$\sigma = \frac{1}{\sqrt{3}}\left(\frac{R_4}{R} - \frac{S_4}{S}\right) \tag{44}$$

Which leads to

$$\sigma = \frac{(n-1)}{\sqrt{3}}\sqrt{L\tau^{2-4n} + M\tau^{-(2+2n)}} \tag{45}$$

The deceleration parameter q is given by

$$q = -\frac{R_{44}/R}{R_4^2/R^2}$$

which leads to

$$q = -1 + \frac{1}{n} - \frac{L(2-2n)\tau^{2-4n} + Mn\tau^{-(2+2n)}}{L\tau^{2-2n} + M\tau^{-(2+2n)}} \tag{47}$$

5. Model in Absence of Magnetic Field

The absence of the magnetic field, we put $K = 0$ in (31) then $M = 0$

$$f^2 = LS^{4-4n}$$

where

$$L = \frac{1}{(n-1)(4+\gamma-4n)} \tag{49}$$

Equation (30) leads to

$$\frac{ds}{dt} = S_4 = \sqrt{L\tau^{4-4n}} \tag{50}$$

Where $S = \tau$ then $R = \tau^n$

Then metric (3)

$$ds^2 = -\left(\frac{dt}{ds}\right)^2 ds^2 + R^2dx^2 + S^2(dy - xdz)^2 + R^2dz^2 \tag{51}$$

Which again leads to

$$ds^2 = \frac{-d\tau^2}{L\tau^{4-4n}} + \tau^{2n}(dx^2 + dz^2) + \tau^2(dy - xdz)^2 \tag{52}$$

Since $\beta = \frac{\alpha}{R^2S}$ which leads to $\beta = \frac{\alpha}{\tau^{2n+1}}$ where $S = \tau$ then $R = \tau^n$

The expainsion (θ) is given as

$$\theta = \left(\frac{2R_4}{R} + \frac{S_4}{S} \right) \tag{53}$$

Which leads to

$$\theta = (2n+1)\sqrt{L\tau^{2-4n}} \tag{54}$$

and

$$\eta = l(2n+1)\sqrt{L\tau^{2-4n}} \tag{55}$$

Shear (σ) is given by

$$\sigma = \frac{1}{\sqrt{3}}\left(\frac{R_4}{R} - \frac{S_4}{S} \right) \tag{56}$$

Which leads to

$$\sigma = \frac{(n-1)}{\sqrt{3}}\sqrt{L\tau^{2-4n}} \tag{57}$$

The deceleration parameter q is given by

$$q = -\frac{R_{44}/R}{R_4^2/R^2} \tag{58}$$

$$q = -\frac{(1-n)}{n} \tag{59}$$

The energy condition given by Ellis [7] are (i) $(\varepsilon + p) > 0$ and (ii) $(\varepsilon + 3p) > 0$ (iii) $(\varepsilon - p) > 0$ condition (i) leads to

$$\varepsilon + p = \left[\frac{n^4(4l-3) - 2n^3(l-3) + 2n(5n+5l-2)}{n^2(4l-3) - 2n(l+1) + 2l} \right]$$

$$\frac{1}{\tau^{4n-2}} + \left[\frac{-2k(n^2+3n+1)}{n^2(4l-2) + 2l(n-1)} \right] \frac{1}{\tau^{2n+2}} + \left[\frac{-3\alpha^2}{2} \right] \frac{1}{\tau^{4n+2}} > 0 \tag{60}$$

Condition (ii) leads to

$$\varepsilon + 3p = \left[\frac{3n^4(4l-3) - 6n^3(l-1) + 2n^2(-5l+11) + 16n(2l+1) - 12l}{n^2(4l-3) - 2n(l+1) + 2l} \right]$$

$$\frac{1}{\tau^{4n-2}}+\left[\frac{2k\{n^2(4l-2)-2l(n-1)\}-(8kn^2+8kn+6k)}{n^2(4l-2)-2l(n-1)}\right]\frac{1}{\tau^{2n+2}}+\left[\frac{-3\alpha^2}{2}\right]\frac{1}{\tau^{4n+2}}>0$$
(61)

Condition (iii) leads to

$$\varepsilon-p=$$

$$\left[\frac{4n^4(4l-3)-8n^2(l+1)-(3l-1)-2n(2l^2+l-6)}{n^2(4l-3)-2l(n-1)-2n}\right]\left[\frac{1}{\tau^{4n-2}}\right]$$
$$+\left[\frac{(2l-1)(-4n^2k+2kn-2k)}{n^2(4l-2)-2l(n-l)}\right]\left[\frac{1}{\tau^{2n+2}}\right]>0 \quad (62)$$

6. Conclusion

We have investigated locally rotationally symmetric Bianchi type II viscous fluid cosmological models with magnetic field in Lyra's geometry. Model (36) in the presence of magnetic field starts with a big bang at $\tau=0$ and the expansion in the model decreases as τ increases. The model has point type singularity at $\tau=0$ when $n>0$. Since $\sigma/\theta\neq 0,$ hence anisotropy is maintained throughout. However, if $n=1,$ then model isotropizes. The displacement vector β is initially large but decreases due to lapse of time where $2n+1>0;$ however, β increases continuously when $2n+1<0.$ The matter density $\rho>0$ when $0<n<2.$ The expansion in the model (52) increases as time increases where n = -½. The displacement vector (β) is initially large but decreases due to lapse of time. The model (52) has a point type singularity at $\tau=0,$ where $n>0.$ The reality conditions in the model (52) are satisfied. It represents accelerating universe for n < 1 and decelerating universe for n > 1.

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