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LRS BIANCHI TYPE-I COSMOLOGICAL MODEL WITH QUARK AND STRANGE QUARK MATTER IN F(R) GRAVITY

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ABSTRACT

In this paper, we studied LRS Bianchi type-I Cosmological Model in the presence of quark and Strange quark matter in f(R) gravity. Energy density and pressure are evaluated for quark and strange quark matter. Some Physical parameters are also studied.

Keywords: - LRS Bianchi type –I, Quark and Strange quark matter, f(R) gravity.

I. INTRODUCTION

Modern cosmological observational data [1-6] confirms that our universe is currently, undergoing an accelerated expansion. These results when combined with observations of cosmic microwave background (CMB) and large scale structure (LSS) observations, strongly suggest that the universe is dominated by an exotic component with large negative pressure called as Dark energy. However accelerated expansion nature of the universe is still changing problem in modern cosmology. To explain such issues of current cosmic acceleration modification of Einstein Hilbert action is one of the alternatives the approach which leads to modified theories of gravitation. A few of modified theories of gravity such are f(T) theory of gravity, f(R,T) theory of gravity and f(R) theory of gravity. f (T) theory of gravity, where T is the scalar Torsion has been proposed to explain current acceleration of the universe without involving dark energy. M.Sharif et. al. [7] considered spatial homogeneous and anisotropic Bianchi type-I universe in f(T) gravity. T.P.Sotiriou[8] had been discussed large scale structure in f(T) gravity. Ratbay M [9] has shown that the accelerating expansion of the universe understood by the f(T) gravity models.

Herkoet. al. [10] proposed the modified theory which is the generalized version of f(R) theory of gravity known as f(R,T) theory of gravity, where the gravitational langrangian involves an arbitrary function of the scalar curvature R and the trace of energy momentum T. Adhav [11] studied the exact solutions of Locally Rotationally symmetric Bianchi type-I space time. D.R.K Reddy et. al. [12] studied Bianchi type-II model in f(R, T) theory. FarasatShamir et. al. [13] obtained exact solutions of Bianchi type-I and V model in f(R, T) gravity with assumption of constant deceleration parameters variation law of Hubble Parameters.

Among these theories f(R) theory of gravity is considered to be the most suitable due to its cosmological importance. f(R) actions first studied by Weyl[14] and Eddington[15]. Nojiri and Odintsov [16] have explored visible dark energy models of f(R)gravity which shown the unification of early inflation and late time acceleration. Lobo and Oliveira [17] constructed warm whole geometries in the context of f(R) theories of gravity. Sharif and Kausar [18] discussed various vacuum Bianchi typemodels in f(R) theory of gravity. Santhiet. al. [19] has studied Bianchi type-III bulk viscous string cosmological models in f(R) theory of gravity. Shamir [20] has investigated dynamics of LRS Bianchi type-I Power law f(R) cosmology. Yilmazet. al. [21] studied quark and strange quark matter inf(R) gravity for Bianchi type-I and V space-times

At an early stage when the temperature of the universe was T = 200Mev, the phase transition of the universe took place from quark glucon plasma to hadron gas, which is referred as 'quark hadron phase' There are two ways of formation of quark matter. One is the 'quark hadron phase' transition in the early universe and second is the conversion of neutron stars into strange ones at ultrahigh densities. In the bag model, it is assumed that quarks are mass less and non interacting with quark pressure $p_q = \frac{\rho_q}{3}$ where ρ_q is the quark energy. Quarks are considered as degenerate Fermi gas, which exist only in a region of space providing with a vacuum energy density B_c called as the bag constant.

The total energy density is

$$\rho = \rho_q + B_C$$

Total energy pressure

$$p = p_q - B_C$$

The equation of state for strange quark matter

$$p = \frac{(\rho - 4B_c)}{3}$$

In the Brookhaven National Laboratory quark gluon plasma as created as perfect fluid with equation of state

$$p = (\gamma - 1)\rho, \quad 1 \le \gamma \le 2$$

In order to view recent developments in the observational physics many polytropic quark star models are suggested in theoretical physics (Lai and Xu, [22]). Ozelet. al., [23] have analyzed Kaluza-Klain strange quark matter cosmological models in general theory of relativity. Mahantaet. al., [24] have investigated Bianchi type-III string cloud attached to quark matter in the context of self creation theory. Rao and Neelima[25] have obtained exact solutions for Bianchi type-VI0 strange quark matter with string cloud in Barbers self creation theory of gravitation. Sahoo and Mishra [26] have studied higher dimensional Bianchi type-IIIcosmological models with strange quark matter and string cloud in general theory of relativity. Sen and Aygun[27] have discussed higher dimensional flat Friedmann-Robertson-Walker cosmological models for string cloud with perfect fluid attached to strange quark matter in self creation theory. Chirde and Kadam[28] have investigated Bianchi type-III strange quark matter cosmological models attached to string cloud in general theory of relativity and Brans-Dick theory of gravitation.

Katore [29] acquired FRW cosmological model with quark and strange quark matter attached to the string cloud in general relativity. Agrawal and Pawar [30] studied plane symmetric cosmological model in the presence of quark and strange quark matter in f(R,T) gravity. Chirde and Shekh [31] studied transition between general relativity and quantum gravity using dark and strange quark matter with some Kinematical test. Considering above in this paper we tried to find the LRS Bianchi type-I solutions using quark and strange quark matter in f(R) theory of gravity. Energy and pressure are evaluated for quark and strange quark matter. The physical behavior of the model is also studied. The chapter is organized as follows. In section 2,f(R) gravity formalism is given. Metric and field equations are discussed in section 3. In section 4, solution of the field equation are discussed. In section 5 and 6, LRS Bianchi type-I solutions for quark and strange quark matter are found respectively and in section 7, some physical parameter of the model are calculated and in last section conclusion is given.

II. f(R) GRAVITY FORMALISM

The $f(R)$ theory of gravity is the generalization of general relativity. The action for this theory is given by

$$S = \frac{1}{16\pi}\int f(R)\sqrt{-g}\, d^4x + \int L_m \sqrt{-g}\, d^4x \qquad (2.1)$$

Here $f(R)$ is a general function of the Ricci scalar, $k^2 = 8\pi G = 1$, g is the determinant of the metric g_{ij} and L_m is metric Lagrangian.

It is noted that this action is obtained just by replacing R by $f(R)$ in standard Einstein-Hilbert action.

The corresponding field equation are found by varying the action with respect to the metric g_{ij}

$$F(R)R_{ij} - \frac{1}{2} f(R)g_{ij} - \nabla_i \nabla_j F(R) + g_{ij} \Box F(R) = T_{ij}^M \tag{2.2}$$

Where $F(R) \equiv \frac{df(R)}{dR}$, $\Box \equiv \nabla^i \nabla_i$ (2.3)

∇_i is the covariant derivative and T_{ij} is the standard matter energy-momentum tensor derived from the Lagrangian L_m.

III. METRIC AND FIELD EQUATIONS

The line element of LRS Bianchi type-I space time is described by

$$ds^2 = dt^2 - A^2 dx^2 - B^2(dy^2 + dz^2) \tag{3.1}$$

Where A, B are called cosmic scale factors which are functions of time t

The corresponding Ricci scalar curvature for Bianchi type-I model is given by

$$R = -2\left[\frac{\ddot{A}}{A} + 2\frac{\ddot{B}}{B} + 2\frac{\dot{A}\dot{B}}{AB} + \frac{\dot{B}^2}{B^2}\right] \tag{3.2}$$

Where dot (.) represents derivative with respect to t.

We define the average scale factors as follows

$$a = \sqrt[3]{AB^2} \tag{3.3}$$

The spatial volume of the universe is defines as

$$V = a^3 = AB^2 \tag{3.4}$$

We define the generalized mean Hubble parameter H in the form

$$H = \frac{1}{3}\frac{\dot{V}}{V} = \frac{\dot{a}}{a} = \frac{1}{3}[H_1 + H_2 + H_3] \quad Where \quad H_1 = \frac{\dot{A}}{A}, H_2 = H_3 = \frac{\dot{B}}{B}$$

are the directional Hubble parameter in the direction of x, y *and* z *axis* *respectively*

$$H = \frac{1}{3}\left(\frac{\dot{A}}{A} + 2\frac{\dot{B}}{B}\right) \tag{3.5}$$

The expansion scalar and shear scalar are defines as follows

$$\theta = 3H = \frac{\dot{A}}{A} + 2\frac{\dot{B}}{B} \tag{3.6}$$

$$\sigma^2 = \frac{1}{3}\left(\frac{\dot{A}}{A} - \frac{\dot{B}}{B}\right)^2 \tag{3.7}$$

Where $\sigma^2 = \frac{1}{2}\sigma_{ij}\sigma^{ij}$ and $\sigma_{ij} = \frac{1}{2}\left(\nabla_j \mu_i + \nabla_i \mu_j\right) - \frac{1}{n-1} g_{ij}\theta^2$

We define an anisotropic parameter of the expansion as

$$A_m = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{H_i - H}{H}\right)^2 = \frac{2}{3}\frac{\sigma^2}{H^2} \tag{3.8}$$

Where H_i (i=1, 2, 3) are the directional Hubble parameter in the directions of x, y *and* z *axis* respectively.

Let us consider the matter contents energy momentum tensor T_{ij} for quark matter which of the form

$$T_{ij}^{quark} = (p+\rho)\mu_i\mu_j - pg_{ij} = diag(\rho,\ -p,\ -p, -p) \tag{3.9}$$

where $\rho = \rho_q + B_C$ is the quark matter total energy density and $p = p_q - B_C$ is the quark matter total energy pressure of the fluid and u_i is the four-velocity such that $u_i u^i = 1$.

The EOS parameter for quark matter is define as

$$p_q = \omega\rho_q \quad ,0 \le \omega \le 1 \tag{3.10}$$

For strange quark matter, linear equation of state is given by

$$p = \omega(\rho - \rho_0) \tag{3.11}$$

Where ω is a constant and $\rho_0 = 4B_c$

The above linear equation of state is reduced to the following EoS for strange quark matter in the bag model.

$$p = \frac{(\rho - 4Bc)}{3} \quad \textit{where} \quad Bc \text{ is a bag constant} \tag{3.12}$$

In The co-moving co-ordinate system, field equation (2.2) for metric (3.1) with the help of equation (3.9) can be written as

$$\left(\frac{\ddot{A}}{A}+2\frac{\dot{A}\dot{B}}{AB}\right)F+\frac{1}{2}f(R)-2\frac{\dot{B}}{B}\dot{F}-\ddot{F}=\left(p_q-Bc\right) \quad , \quad \text{for i, j=1} \tag{3.13}$$

$$\left(\frac{\ddot{B}}{B}+\frac{\dot{B}^2}{B^2}+\frac{\dot{A}\dot{B}}{AB}\right)F+\frac{1}{2}f(R)-\frac{\dot{A}}{A}\dot{F}-\frac{\dot{B}}{B}\dot{F}-\ddot{F}=\left(p_q-Bc\right) \text{ , for i, j= 2, 3} \tag{3.14}$$

$$\left(\frac{\ddot{A}}{A}+2\frac{\ddot{B}}{B}\right)F+\frac{1}{2}f(R)-\frac{\dot{A}}{A}\dot{F}-2\frac{\dot{B}}{B}\dot{F}=-(\rho_q+Bc) \quad , \quad \text{for i, j=4} \tag{3.15}$$

Subtracting equation (3.15) from (3.13), we get

$$\left(2\frac{\dot{A}\dot{B}}{AB}-2\frac{\ddot{B}}{B}\right)F+\frac{\dot{A}}{A}\dot{F}-\ddot{F}=(p_q+\rho_q) \tag{3.16}$$

Subtracting equation (3.15) from (3.14), we get

$$\left(-\frac{\ddot{A}}{A}-\frac{\ddot{B}}{B}+\frac{\dot{B}^2}{B^2}+\frac{\dot{A}\dot{B}}{AB}\right)F+\frac{\dot{B}}{B}\dot{F}-\ddot{F}=(p_q+\rho_q) \tag{3.17}$$

IV. SOLUTION OF THE FIELD EQUATION

Using power law relation between scale factor $'a'$ *and scale field* $'F'$

$$F=la^m \tag{4.1}$$

Where l is constant of proportionality and m is integer
We assume that shear scalar is proportional to the expansion scale, this
Assumption gives an anisotropic relation between the scale factors A & B as follows

$$A=B^n \tag{4.2}$$

Here n is arbitrary constant, $n\neq 1$

Subtracting equation (3.17) from (3.16), we get

$$\frac{\ddot{A}}{A}-\frac{\ddot{B}}{B}+\frac{\dot{A}\dot{B}}{AB}-\frac{\dot{B}^2}{B^2}+\frac{\dot{A}\dot{F}}{AF}-\frac{\dot{B}\dot{F}}{BF}=0 \tag{4.3}$$

Using equation,(4.1) and (4.2) in (4.3), we get

$$\frac{\ddot{B}}{B}+\left(n+1+\frac{[n+2]m}{3}\right)\frac{\dot{B}^2}{B^2}=0 \tag{4.4}$$

$$\frac{\ddot{B}}{B}+\alpha\frac{\dot{B}^2}{B^2}=0 \tag{4.5}$$

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Where $\alpha = n+1+\frac{[n+2]m}{3}$

Equation (4.5) which on integrating yields

$$B = \beta(k_1 t + k_2)^{\frac{1}{\alpha+1}} \tag{4.6}$$

Where $\beta = (\alpha+1)^{\frac{1}{\alpha+1}}$ *and* k_1, k_2 are the constant of integration.

From equation (4.2), we have

$$A = B^n = \beta^n \ (k_1 t + k_2)^{\frac{n}{\alpha+1}} \tag{4.7}$$

On solving equation (3.3), we get

$$a = \left(AB^2\right)^{\frac{1}{3}} = B^{\frac{n+2}{3}} = \beta^{\frac{n+2}{3}} (k_1 t + k_2)^{\frac{n+2}{3(\alpha+1)}} \tag{4.8}$$

The important quantity is defined as

$$q = \frac{d}{dt}\left(\frac{1}{H}\right) - 1 \ , \tag{4.9}$$

The sign of q indicates whether the model inflates or not. A positive sign of q

Corresponds to the standard deceleration model whereas the negative sign of q Indicates inflation.The recent observation of SNIa. Reveal that the present universe is accelerating and the values of decelerating parameter in the range $-1 < q < 0$.

Using equation (3.5) and (4.8) in equation (4.9) we get

$$q = -1 + \frac{3(\alpha+1)}{n+2} \quad \Rightarrow \quad \alpha + 1 = \frac{(n+2)(1+q)}{3} \tag{4.10}$$

From using this equation, in equation (4.6), (4.7) and (4.8) can be rewrite again

$$B = \beta(k_1 t + k_2)^{\frac{3}{(n+2)(1+q)}} \tag{4.11}$$

$$A = \beta^n \ (k_1 t + k_2)^{\frac{3n}{(n+2)(1+q)}} \tag{4.12}$$

$$a = \beta^{\frac{n+2}{3}} \ (k_1 t + k_2)^{\frac{1}{(q+1)}} \tag{4.13}$$

The metric equation (3.1) with help of the equation (4.11) and (4.12)

$$ds^2 = dt^2 - \beta^{2\alpha} \ (k_1 t + k_2)^{\frac{6n}{(n+2)(1+q)}} - \beta^2 (k_1 t + k_2)^{\frac{6}{(n+2)(1+q)}} \left[dy^2 + dz^2\right] \tag{4.14}$$

V. QUARK MATTER FOR LRS-BIANCHI TYPE-I

From equation (3.16) with the help of linear EoS (3.11) for $\omega=\frac{1}{3}$ gives

$$\left(2\frac{\dot{A}\dot{B}}{AB}-2\frac{\ddot{B}}{B}\right)+\frac{\dot{A}\dot{F}}{AF}-\frac{\ddot{F}}{F}=\frac{4p_q}{F} \tag{5.1}$$

Using equation (4.1),(4.11) & (4.12) in equation (5.1) ,we get the pressure and energy density for quark matter as follows

$$p_q=\frac{\lambda l\beta^{\frac{m(n+2)}{3}}(k_1t+k_2)^{\frac{m}{(q+1)}}}{4(k_1t+k_2)^2}\left\{\begin{matrix}[3n+(n+2)(1+q)]\ [6+m(n+2)]\\ -[18+m^2(n+2)^2]\end{matrix}\right\} \tag{5.2}$$

$$where\ \ \lambda=\frac{k_1^2}{(n+2)^2(1+q)^2}$$

On solving equation (4.10) gives

$$1+q=3+m \qquad \Rightarrow \qquad m=q-2 \tag{5.3}$$

$$p_q=\frac{\lambda l\beta^{\frac{(q-2)(n+2)}{3}}}{4(k_1t+k_2)^{\frac{q+4}{(q+1)}}}\left\{\begin{matrix}[4n+nq+2+2q]\ [2+qn+2q-2n]\\ -[18+(q-2)^2(n+2)^2]\end{matrix}\right\} \tag{5.4}$$

Similarly using equation (3.10) again, we get

$$\rho_q=\frac{3\lambda l\beta^{\frac{(q-2)(n+2)}{3}}}{4(k_1t+k_2)^{\frac{q+4}{(q+1)}}}\left\{\begin{matrix}[4n+nq+2+2q]\ [2+qn+2q-2n]\\ -[18+(q-2)^2(n+2)^2]\end{matrix}\right\} \tag{5.5}$$

using equation (4.11) and (4.12) in equation (3.2) we get the Ricci scalar as

$$R=\frac{6\lambda}{(k_1t+k_2)^2}\left[n^2(q-2)+4nq-2n-5+4q\right] \tag{5.6}$$

From equation (3.15)by using equation(4.1), (4.11) and (4.12) we get $f(R)$ is given as

$$f(R)=\frac{6l\lambda Q^{\frac{(q-2)(n+2)}{3}}}{(k_1t+k_2)^{\frac{q+4}{(q+1)}}}\left[\frac{1}{2}qn^2+2qn+2q-n^2-n+3n+\frac{19}{2}\right]-2B_C \quad (5.7)$$

VI. STRANGE QUARK MATTER FOR LRS BIANCHI TYPE-I

Using equation (3.16) with the help of EoS parameter (3.10) which is given in

$\rho=\rho_q+B_C$ and $p=p_q-B_C$ we get the pressure and energy density of the strange-quark matter as follows

$$p=\frac{\lambda l\beta^{\frac{(q-2)(n+2)}{3}}}{4(k_1t+k_2)^{\frac{q+4}{(q+1)}}}\times\begin{Bmatrix}[4n+nq+2+2q][2+qn+2q-2n]\\-\left[18+(q-2)^2(n+2)^2\right]\end{Bmatrix}-Bc \quad (6.1)$$

$$\rho=\frac{3\lambda l\beta^{\frac{(q-2)(\alpha+2)}{3}}}{4(k_1t+k_2)^{\frac{q+4}{(q+1)}}}\times\begin{Bmatrix}[4n+nq+2+2q][2+qn+2q-2n]\\-\left[18+(q-2)^2(n+2)^2\right]\end{Bmatrix}+Bc \quad (6.2)$$

VII. SOME PHYSICAL PARAMETER

From equation (3.4) and (4.13), the spatial volume V of the universe is given as:

$$V=\beta^{(n+2)}(k_1t+k_2)^{\frac{3}{(q+1)}} \quad (7.1)$$

Using equation (4.11) and (4.12) in equation (3.5) the directional Hubble's parameter Of the model are given by

$$H_x=\frac{3nk_1}{(n+2)(1+q)}\frac{1}{(k_1t+k_2)},\quad H_y=H_z=\frac{3k_1}{(n+2)(1+q)}\frac{1}{(k_1t+k_2)} \quad (7.2)$$

This gives the mean generalized Hubble's parameter H is given as

$$H=\frac{k_1}{(1+q)}\times\frac{1}{(k_1t+k_2)} \quad (7.3)$$

The expansion scalar θ of the model is found to be

$$\theta=\frac{3k_1}{(1+q)}\times\frac{1}{(k_1t+k_2)} \quad (7.4)$$

The shear scalar σ of the model is

$$\sigma^2=\frac{3(n-1)^2\lambda}{(k_1t+k_2)^2} \quad (7.5)$$

The mean anisotropic parameter A_m of the model is given as

$$A_m=\frac{2}{3}\frac{(3n^2-6n+3)}{(n^2+4n+4)}\quad A_m=\frac{2(n-1)^2}{(n+2)^2} \quad (7.6)$$

VIII. DISCUSSION AND CONCLUSION

It is observed that as cosmic time tends to infinity, all the parameter of the model tends to zero but at time $t = \frac{-k_2}{k_1}$,these parameter tend to ∞ excepts spatial volume. Spatial volume of this model is zero at $t = \frac{-k_2}{k_1}$

For $q < -1$,the modal is expanding. For density and pressure become zero as $t \to \infty$.

For $q > -1$, density and pressure are finite at $t = 0$ and as $t \to \infty$, both are zero

From equation 7.6, it is observed that mean anisotropy parameter A_m is zero for $n = 1$ and the model becomes isotropic and A_m is non-zero for $n \neq 1$. Also it is observed that A_m is not a function of cosmic time therefore it is constant throughout the evolution.

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