RESEARCH ARTICLE

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Study of Strange Quark Matter and Variable Λ in Bianchi VI Universe

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Abstract

The present paper deals with strange quark matter i.e. $p = \frac{1}{3}(\rho - 4B_c)$ in the presence of variable cosmological term in Bianchi VI universe. Here we adopt the physical conditions (i)The shear scalar is proportional to expansion scalar and (ii) The time dependent cosmological term of the type $\Lambda = \alpha_0 \frac{\dot{R}^2}{R^2}$, for the simplification of field equations. We observed some cosmological parameters such as deceleration parameter, quark density, quark pressure etc. Lastly we conclude with the discussion of cosmological perturbations of resultant universe. Also graphs are plotted for the detail study of the resultant model.

Keywords: Bianchi VI metric,Strange quark matter, variablecosmological term.

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Introduction

General Relativity is a welldefined theory of gravitation which includes singularities (Black holes, Big-Bang etc.) and observed inconsistency by observational data [1]. The present scenario states that the universe must be accelerating and expanding. Due to dark energy there causes acceleration in the expansion regarding universe which is undefined and not havingany kind of proof of their presence. Therefore this fact motivates the upcoming scientists towardsmodified gravity. Nowadays they are taking interest in the new theory i. e. quark matter. The standard models havingnparticle physics, it is seen that Big-Bang occurs at high temperature which expands first and then cool down.

Lateron the universe becomes in the stage of phase transition while the temperature decreases to some particular point and then within short time (few second) during Big-Bang, quark gluons phase arises in which quark, gluousas well as antiquarks get together for making hadrons. Such hadrons are important to form the present Baryonic matter. The quark matter contains up quark (u) and down quark (d) contains strange quarks (S*) strange matter may be fundamental for baryon matter for high level densities studied by Witten [2]. It is seen that the energy undergoes β decay into strange quark matter. In the Literature [3], it is observed that the strange matter reaches to stable state having neutral charge. In [4] it is investigated that strange quark matter depends on Bag constant for stability. In GR, various cosmologists proposed strange quark matter to study the nature of universe. Torres and Menezes [5] have obtained the model of strange quark matter to observe the stability. Yilmaz et.al. [6] studied space-time geometry of quark and strange quark.

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The quark made from massless u, d quark, electrons and massive s quarks in this model. For the detail study refer [7-11].Considering non- interacting massless quarks in modified bag model, the expression of pressure for quark is

$$p_q = \frac{\rho_q}{3} \quad (1)$$

here ρ_q is the density for quark.

The total energy density [12] is $\rho = \rho_q + B_c$ (2)

We consider the EoS for strange quark matter [13,14] as follows:

$$p = \frac{1}{3}(\rho - 4B_c) \quad (3)$$

Where B_c is bag constant.

The parameter B_c stands for linear parameter of the equation of state for MIT bag model. Which is incorrect in that model, whereas the quark masses are density-dependent (QMDD model).

Some researchers [15-17] observed bag model.In [18], The Chandrasekhar limit for strange stars described by a linear equation of state (describing quark matter with density-dependent quark masses) is evaluated. The new equation of state for strange matter based on a model of interquark potential is obtained by Dey et.al. [19]. After that Gonadek[20] have been studied approximated EoS expressed by $p = \in (\rho - \rho_0)$ (4)

where $\in$ is a constant and ρ_0 is the energy density when pressure is zero.

Katoreet. al. [21] have found Bianchi models to study quark matter in the presence of domain wall. Pawar and Shahare [22] observed that Dynamics of tilted Bianchi type- III cosmological model in f(R,T) gravity. Hatwaret.al. [23] studied the nature of Quark and Strange quark in f(G) theory of gravitation . Recently Maurya et.al. [24] investigated domain walls with quark matter in Bianchi type V universe. LRS Bianchi type I metric with strange quark matter and $\Lambda(t)$ in f(R, T) gravity is obtained by Vijay Singh and Aroonkumar Beesham [25].Some important results are discussed by [26-28].

On the large scale, the universe may be isotropic and homogeneous stated by results from Astronomy. Initially the universe did not having common property regarding isotropy. Bianchi I to IX cosmological models are taken as homogeneous space-time. Several authors studied the cosmological scenarios in which cosmological term Λ is a function of time t. By taking various kinds of decay laws, a lot of models were investigated to study the nature of variations of cosmological term by [29-33]. Khadekar et. al. [34] proposed Bianchi type VI cosmological model with varying Λ in GR. Some observations [35] obtained similar types of conclusions in this regards. In different contexts, various aspects of quark gluon have examined by [36,37].

In our paper and we investigate the model by introducing strange quark matter with variable cosmological term in Bianchi VI metric. The structure of the paper is as :The brief introduction is present in section 1. In section 2, we describe the bianchi VI metric and its field equations.The solution of the model having strange quark matter is found in section 3. Section 4 present the geometrical and physical aspect of the resultant model. Finally, paper is summarized with observations and interpretations with the help of graphs.

Bianchi VI Metric and Field Equations

Here we take bianchi VI metricas

$$ds^2 = -dt^2 + Z_1^{\,2} dx^2 + Z_2^{\,2} e^{-2x} dy^2 + Z_3^2 e^{2x} dz^2 \quad (5)$$

where Z_1, Z_2 and Z_3 are the scale factors depends on cosmic time *t*.

The universe is assumed to filled in the form

$$T_{ij} = (\rho + p) u_i u^j + p g_{ij} \quad (6)$$

Here ρ , p and θ are the density, pressure and expansion scalar respectively and u^i is the velocity four vector with

$$u_i u^j = -1 \quad (7)$$

The Einstein field equations for metric (5) are as follows

$$R_{ij} - \frac{1}{2} R g_{ij} = -8\pi G T_{ij} + \Lambda(t) \quad (8)$$

here T_{ij} represents the energy momentum tensor, R and R_{ij} are the Ricci scalar and Ricci tensor respectively, and Λ is the variable cosmological term.

With the help of (6) for the line element (5), we can obtain the field equations (8) as follows:

$$\frac{\ddot{Z}_1}{Z_1}+\frac{\ddot{Z}_2}{Z_2}+\frac{\dot{Z}_1\dot{Z}_3}{Z_1Z_3}-\frac{1}{Z_1^2}=-8\pi Gp+\Lambda \quad (9)$$

$$\frac{\ddot{Z}_1}{Z_1}+\frac{\ddot{Z}_3}{Z_3}+\frac{\dot{Z}_1\dot{Z}_2}{Z_1Z_3}-\frac{1}{Z_1^2}=-8\pi Gp+\Lambda \quad (10)$$

$$\frac{\ddot{Z}_2}{Z_2}+\frac{\ddot{Z}_3}{Z_3}+\frac{\dot{Z}_2\dot{Z}_3}{Z_2Z_3}+\frac{1}{Z_1^2}=-8\pi Gp+\Lambda \quad (11)$$

$$\frac{\dot{Z}_1\dot{Z}_2}{Z_1Z_2}+\frac{\dot{Z}_2\dot{Z}_3}{Z_2Z_3}+\frac{\dot{Z}_1\dot{Z}_3}{Z_1Z_3}-\frac{1}{Z_1^2}=8\pi G\rho+\Lambda \quad (12)$$

$$\frac{\dot{Z}_2}{Z_2}-\frac{\dot{Z}_3}{Z_3}=0 \quad (13)$$

(dot is the notation of derivative)

SOLUTION OF THE METRIC

From eq (13), we can obtain

$$Z_2 = k_0 Z_3 \quad (14)$$

Where k_0 is the integrating constant. Therefore with the help of eq (14), we can arrange thefield equations ($8\pi G=1$) as follows:

$$\frac{2\dot{Z}_1\dot{Z}_2}{Z_1Z_2}+\frac{\dot{Z}_2^2}{Z_2^2}-\frac{1}{Z_1^2}=\rho+\Lambda \quad (15)$$

$$\frac{2\ddot{Z}_2}{Z_2}+\frac{\dot{Z}_2^2}{Z_2^2}+\frac{1}{Z_1^2}=-p+\Lambda \quad (16)$$

$$\frac{\ddot{Z}_1}{Z_1}+\frac{\ddot{Z}_2}{Z_2}+\frac{\dot{Z}_1\dot{Z}_2}{Z_1Z_3}-\frac{1}{Z_1^2}=-p+\Lambda \quad (17)$$

For the line element (5), we define the dynamical parameters as follows:

Average scale factor and the spatial volume

$$R^3 = V = Z_1 Z_2^2 \quad (18)$$

The Hubble parameter

$$H=\frac{1}{3}\left(\frac{\dot{Z}_1}{Z_1}+\frac{2\dot{Z}_2}{Z_2}\right) \quad (19)$$

Scalar expansion

$$\theta = 3H \quad (20)$$

Shear scalar

$$\sigma^2=\frac{1}{2}\left(\frac{\dot{Z}_1^2}{Z_1^2}+\frac{2\dot{Z}_2^2}{Z_2^2}\right)-\frac{\theta^2}{6} \quad (21)$$

$$\text{Relative Anisotropy}=\frac{\sigma^2}{\rho} \quad (22)$$

Average anisotropy parameter

$$\Delta = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{H_i - H}{H}\right)^2 \quad (23)$$

The deceleration parameter

$$q=-1-\frac{\dot{H}}{H^2} \quad (24)$$

Therefore, we have three field equations and five unknowns so we can assume the following two conditions:

$$\Lambda = \alpha_0 \frac{\dot{R}^2}{R^2} \quad (25)$$

And $Z_1 = Z_2^{\gamma}, \quad \gamma > 0$ (26)

To find the solution, here we use eq (3), (25)and (26) in the field equations and then obtain the following differential equation

$$\frac{\ddot{Z}_2}{Z_2}+\frac{M_0}{3}\frac{\dot{Z}_2^2}{Z_2^2}=\frac{2B_c}{3}Z_2-\frac{1}{Z_2^{2\gamma-1}} \quad (27)$$

Where

$$M_0=\left[(\gamma+2)-\frac{2\alpha(\gamma+2)^2}{9}\right]$$

The solution of eq (27) is given by

$$Z_2=\left\{A_0\sinh(k_1 t+k_2)\right\}^{\frac{1}{\gamma}} \quad (28)$$

Where k_1 and k_2 are integrating

constants $A_0 = \left(\dfrac{k_0 + 3}{2(3\gamma - 3 - k_0) B_c} \right)^{\frac{1}{2}}$

Hence the resultant metric becomes

$$ds^2 = -dt^2 + \{A_0 \sinh(k_1 t + k_2)\}^2 dx^2 + \{A_0 \sinh(k_1 t + k_2)\}^{\frac{2}{\gamma}} e^{-2x} dy^2 + \{A_0 \sinh(k_1 t + k_2)\}^{\frac{2}{\gamma}} e^{2x} dz^2 \quad (29)$$

Physical and Geometrical Aspects

For the resultant model (29) we can obtain the expressions for scale factor, the spatial volume, the Hubble parameter, scalar expansion and shear scalar are given by

$$R^3 = A_0^{\frac{3(\gamma+2)}{\gamma}} \{\sinh(k_1 t + k_2)\}^{\frac{3(\gamma+2)}{\gamma}} \quad (30)$$

$$V = A_0^{\frac{(\gamma+2)}{\gamma}} \{\sinh(k_1 t + k_2)\}^{\frac{(\gamma+2)}{\gamma}} \quad (31)$$

$$H = \frac{(\gamma+2)k_1}{3\gamma} \{\coth(k_1 t + k_2)\} \quad (32)$$

$$\theta = \frac{(\gamma+2)k_1}{\gamma} \{\coth(k_1 t + k_2)\} \quad (33)$$

$$\sigma^2 = \frac{(n-1)^2 k_1^2}{3\gamma^2} \{\coth^2(k_1 t + k_2)\} \quad (34)$$

The expression for density is given by

$$\rho = \left((2\gamma+1) - \frac{\alpha(\gamma+2)^2}{9} \right) \frac{k_1^2}{\gamma^2} . \{\coth^2(k_1 t + k_2)\} - \frac{1}{A_0^2} \cos ech^2(k_1 t + k_2) \quad (35)$$

The expression for pressure is given by

$$p = \frac{1}{3} \left[\frac{M_0 k_1^2}{\gamma^2} \coth^2(k_1 t + k_2) - \frac{1}{A_0^2} \cos ech^2(k_1 t + k_2) - 4B_c \right] \quad (36)$$

Hence the expressions for strangequark density and strange quark pressure are given by

$$\rho_q = \left((2\gamma+1) - \frac{\alpha(\gamma+2)^2}{9} \right) \frac{k_1^2}{\gamma^2} . \{\coth^2(k_1 t + k_2)\} - \frac{1}{A_0^2} \cos ech^2(k_1 t + k_2) - B_c \quad (37)$$

$$p_q = \frac{1}{3} \left\{ B_0 \{\coth^2(k_1 t + k_2)\} - \frac{1}{A_0^2} \cos ech^2(k_1 t + k_2) - B_c \right\} \quad (38)$$

where

$$B_0 = \left((2\gamma+1) - \frac{\alpha(\gamma+2)^2}{9} \right) \frac{k_1^2}{\gamma^2}$$

The expression for average anisotropy parameter is given by

$$\Delta = constant \quad (39)$$

The expression for relative anisotropy is given by

$$\text{Relative Anisotropy} = \frac{\dfrac{(\gamma-1)^2 k_1^2}{3\gamma^2} \coth^2(k_1 t + k_2)}{\left((2\gamma+1) - \dfrac{\alpha(\gamma+2)^2}{9} \right) \dfrac{k_1^2}{\gamma^2} \coth^2(k_1 t + k_2) - \dfrac{1}{A_0^2} \cos ech^2(k_1 t + k_2)} \quad (40)$$

The expression deceleration parameter is given by

$$q = \frac{3\gamma}{(\gamma+2)} \sec h^2(k_1 t + k_2) - 1 \quad (41)$$

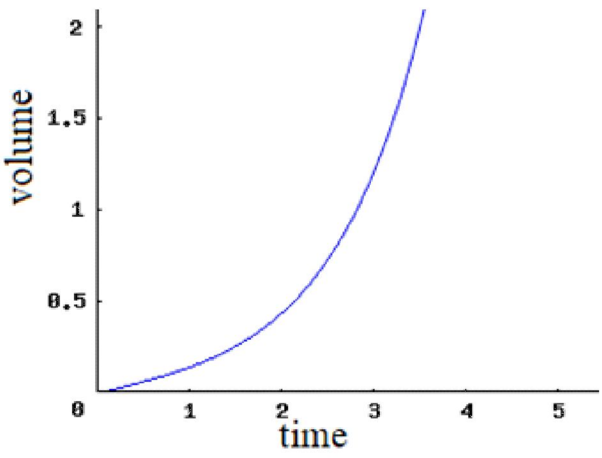

Figure 1 : Time vs volume

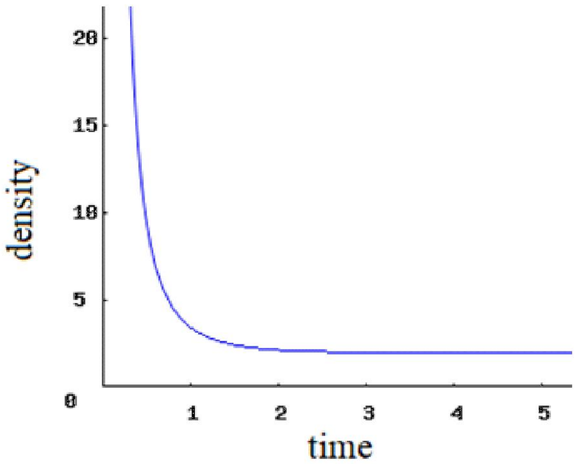

Figure 2 : Time vs density

Interpretation of the results

- It is observed that as t increases, scalar factors Z_1, Z_2 and Z_3 are also increases.
- From the expression (31) it is noticed that volume increases as t increases and becomes zero as t tends to zero and $k_2 = 0$ (Figure 1).
- It is found that the density decreases as time t increases (Figure 2).
- We get deceleration parameter $q < 0$ for suitable values of the constants i.e. $k_1, k_2 \, and \, \gamma$.
- For the resultant model, we find $\frac{\sigma}{\theta} \neq 0$ i.e. the model shows anisotropic in nature.

Conclusion

In the present article, we have considered Bianchi type VI metric with strange quark matter and variable cosmologicalterm Λ.

During early and late time evolution, there are some observational cosmological parameters like hubble parameter, deceleration parameter etc. Such parameters represents dynamics of the universe.From the expression of energy density , we can say that densitydecreases with respect to time t. As time t increases, the density, Hubble parameter, expansion scalar and shear scalar decreases. Therefore it is observed that the resultant universe is anisotropic and expanding in nature. The energy condition is satisfied i.e. $\rho \geq 0$ for the suitable values of constant. It is well-known that the model is accelerating for q < 0which is compatible to recent Supernovae Ia observations. Recent scenario, results, observations and conclusions favours that the universe is accelerating.The results obtained in this article are matches to recent observations.

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