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Strange Quark Matter Coupled to String Cloud in Five Dimensional Bianchi Type-III Space Time in General Relativity

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Abstract
In this paper the author has studied higher dimensional Bianchi type-III cosmological models with strange quark matter coupled to the string cloud in general relativity. I have also attained different classes of solutions by taking different functional forms of metric potentials. Here I investigated that models are expanding, shearing and non-rotating. Also, some physical and kinematic nature of the model was analyzed.

Keywords: *Five dimensional Bianchi type-III space time, quark matter, cosmic strings and general relativity*

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INTRODUCTION
Cosmological models play an important role in the understanding of the universe. Nowadays universe appears as an astronomical deliberation, to be of the Friedmann-Robertson-Walker (FRW) type. That is the familiar FRW cosmological model which defines a homogeneous and isotropic diffusion for its matter content, and has been successful in defining the current state of the universe. Currently, higher dimensional space time is a vibrant field of research in the attempts to link gravity with other gauge interaction [1-30]. The idea of extra dimensions is relevant in cosmology, especially at the early universe; theoretically, the current 4D stage of the universe might have been introduced by a multidimensional phase. In reality, there occur solutions of Einstein's equations in which the standard dimensions expand while extra dimension contracts to Planckian dimension which is very difficult to detect with the available experimental equipments [31, 32]. It is promoting to note that both the ideas of higher dimensional space time and string theory presumed mingled importance in the domain of the early universe.

The idea of string theory was introduced to describe events of the early of the evolution of the universe. The general relativistic concept of strings was developed by Stachel and Letelier [33, 34]. The gravitational waves of cosmic strings have been capaciously discussed by Vilenkin [35]; Gott in general relativity [36]. Relativistic string models of Bianchi space time have been developed by Krori *et al.* [37], Banerjee and Bhuj [38], and Tikekar and Patel [39].

In this study, I will couple strange quark matter to string cloud. It is feasible to couple strange quark matter to the string cloud because one of such changes during the phase changes of the universe could be Quark Glucon Plasma (OGP)-Hardon gas (called Quark-Hardon phase changes) when catholic temperature was T≈200 Mev. The attainability of the presence of quark matter dates back to primitive seventies. Bodmer and Witten considered two ways of formation of strange matter [40, 41]. The Quark-Hadrom phase changes in the early universe and transition of neutron stars into strange ones at ultrahigh densities. In the theories of forcible interaction, quark bag models deduce that splitting of physical vacuum occurs inside hadrons. So, vacuum energy densities inside and outside a hadron become necessarily different and the vacuum pressure on the bag wall compensates the pressure of quarks matter, is correct, then some of neutrons stars could absolutely be strange stars, made of strange matter [42, 43].

Generally, strange quark matter is formed with an equation of state based on the bag model of quark matter, in which quark segregation is described by an energy term corresponding to the volume. In this model, quarks are considered as degenerated Fermi gales, which occur only in a region of space enriched with a vacuum energy density B_C known as the bag constant. In this model, the quark matter is possessed of mass-less u, d quarks, massive s quarks and electrons.

In the bag model, quarks are mass-less and non-interacting. So, we have quark pressure:

$$P_q=\frac{\rho_q}{3} \tag{1}$$

Where, ρ_q is the quark energy density.

Now the total energy density is:

$$\rho=\rho_q+B_c \tag{2}$$

But the total pressure is:

$$P=P_q-B_c \tag{3}$$

In this paper, I have worked out Einstein's field equations for Five-dimensional Bianchi type-III, Space-time with strange quark matter coupled to the string cloud.

THE METRIC AND FIELD EQUATIONS

I take up the space time of five-dimensional Bianchi type-III metric in the form:

$$ds^2=dt^2-A^2dx^2-B^2e^{2ax}dy^2-C^2dz^2-D^2d\Psi^2 \tag{4}$$

Here A, B, C, D are the functions of time 't' only.

The energy momentum tensor for string cloud is given by:

$$T_{ij}=\rho u_i u_j-\rho_s x_i x_j \tag{5}$$

Here, ρ is the rest energy density for the cloud of strings with particles coupled to them and ρ_s is the string tension density. They are given by:

$$\rho=\rho_p+\rho_s \tag{6}$$

Where, ρ_p is the particle energy density.

The various vibrational modes of the string represent the various types of particles because these modes are seen as various masses or spins. Therefore, I will consider quarks as substitute particles in the string cloud. Hence I take strange quark matter energy density in the string cloud. So Eq. (6) becomes:

$$\rho=\rho_q+\rho_s+B_c \tag{7}$$

The velocity u^i explains the cloud velocity and x^i corresponds to the direction of anisotropy. Here we have considered the first coordinate is space like:

$$\text{Where, } u^i=(1, 0, 0, 0, 0) \tag{8}$$

Without loss of generality, we select:

$$X^i=(0, 0, 0, 1, 0) \tag{9}$$

I have u^i and x^i with gratifying conditions:

$$U_iU^i=-x_ix^i=1 \text{ and } U^iX_i=0 \tag{10}$$

The Einstein's field equation is given by:

$$R_{ij}-\frac{1}{2}Rg_{ij}=-T_{ij} \tag{11}$$

Using the Eqs. (5)–(10), the field Eq. (11) for matric (4) can be written as:

$$\frac{A'B'}{AB}+\frac{A'C'}{AC}+\frac{A'D'}{AD}+\frac{B'C'}{BC}+\frac{B'D'}{BD}+\frac{C'D'}{CD}-\frac{a^2}{A^2}=\rho \tag{12}$$

$$\frac{B''}{B}+\frac{C''}{C}+\frac{D''}{D}+\frac{B'C'}{BC}+\frac{B'D'}{BD}+\frac{C'D'}{CD}=0 \tag{13}$$

$$\frac{A''}{A}+\frac{C''}{C}+\frac{D''}{D}+\frac{A'C'}{AC}+\frac{A'D'}{AD}+\frac{C'D'}{CD}=0 \tag{14}$$

$$\frac{A''}{A}+\frac{B''}{B}+\frac{D''}{D}+\frac{A'B'}{AB}+\frac{A'D'}{AD}+\frac{B'D'}{BD}-\frac{a^2}{A^2}=\rho_s \tag{15}$$

$$\frac{A''}{A}+\frac{B''}{B}+\frac{C''}{C}+\frac{A'B'}{AB}+\frac{A'C'}{AC}+\frac{B'C'}{BC}-\frac{a^2}{A^2}=0 \tag{16}$$

$$\frac{A'}{A}=\frac{B'}{B} \tag{17}$$

SOLUTIONS OF FIELD EQUATIONS

From Eq. (17) it can be shown that A=μB, where μ is an arbitrary constant. So I have five equations in six unknowns. For deterministic solutions I need one statement I shall explore physically significant solutions of the field Eqs. (12)–(17) by taking a simplifying statement to the field variables A, B, C, D.

For cleanness, I take μ=1 and get:

$$A=B \tag{18}$$

Using Eq. (18), (12)-(16) reduce to:

$$\left(\frac{A'}{A}\right)^2+2\frac{A'C'}{AC}+2\frac{A'D'}{AD}+\frac{C'D'}{CD}-\frac{a^2}{A^2}=\rho \tag{19}$$

$$\frac{A''}{A}+\frac{C''}{C}+\frac{D''}{D}+\frac{A'C'}{AC}+\frac{A'D'}{AD}+\frac{C'D'}{CD}=0 \tag{20}$$

$$2\frac{A''}{A}+\frac{D''}{D}+\left(\frac{A'}{A}\right)^2+2\frac{A'D'}{AD}-\frac{a^2}{A^2}=\rho_s \tag{21}$$

$$2\frac{A''}{A}+\frac{C''}{C}+\left(\frac{A'}{A}\right)^2+2\frac{A'C'}{AC}-\frac{a^2}{A^2}=0 \tag{22}$$

Now to obtain a certain solution, one extra condition is desired. So we suppose a relation between metric coefficient given by:

$$C=A^n \tag{23}$$

Where, n is a constant. With help of Eq. (23) and solving Eq. (22),

We get:

$$A=K_3(K_1t+K_2)^{\frac{1}{N+1}} \tag{24}$$

Where, $K_3=(N+1)^{\frac{1}{N+1}}$

And $N=\frac{n^2+n+1}{n+2}$

From Eqs. (25) and (24), we obtain:

$$C=K_4\left(K_1 t + K_2\right)^{\frac{n}{N+1}} \tag{25}$$

Where, $K_4=(K_3)^n$

With help of Eqs. (24) and (23), Eq. (20) becomes:

$$\begin{aligned}&\left(K_1t + K_2\right)^2 D'' + \left(\frac{K_1}{N+1}\right)(n+1)) \left(K_1 t + K_2\right)D' \\ &+ \frac{K_1^2}{(N+1)^2}\left(n^2 - nN - N\right) D = 0\end{aligned} \tag{26}$$

Which on integration yields:

$$D = C_1 \left(K_1t + K_2\right)^{\frac{(N-n) + \sqrt{(N+n)^2 + 4\left(N-n^2\right)}}{2(N+1)}} \tag{27}$$

Or $$D = C_2 \left(K_1t + K_2\right)^{\frac{(N-n) - \sqrt{(n+N)^2 + 4\left(N-n^2\right)}}{2(N+1)}} \tag{28}$$

Now the above solutions give two different set of models.

Set-I

With help of Eqs. (24), (25) and (27), the Bianchi type-III cosmological model for strange quark matter coupled to string cloud in general relativity can be written as:

$$\begin{aligned}ds^2 = dt^2 - K_3^2 (K_1t + K_2)^{\frac{2}{N+1}} (dx^2 + e^{2ax}dy^2) - K_4^2 (K_1t + K_2)^{\frac{2n}{N+1}} dz^2 \\ - C_1^2 (K_1t + K_2)^{\frac{(N-n) + \sqrt{(n+N)^2 + 4(N-n)^2}}{(N+1)}} dy^2\end{aligned} \tag{29}$$

Through a suitable choice of coordinates and constants of integration, the above Eq. (29) reduces to:

$$\begin{aligned}ds^2 = \frac{dT^2}{K_1^2} - K_3^2 (T)^{\frac{2}{N+1}} \left(dx^2 + e^{2ax} dy^2\right) - K_4^2 (T)^{\frac{2n}{N+1}} dz^2 \\ - C_1^2 (T)^{\frac{(N-n) + \sqrt{(n+N)^2 + 4(N-n^2)}}{(N+1)}} d\psi^2\end{aligned} \tag{30}$$

Using Eqs. (24), (25) and (27) in Eqs. (19) and (21), we obtain:

- Strong Tension Density:

$$\rho_s = \frac{(1+q-2N+2p)\,K_1^{\,2}}{(N+1)^2\;T^2} - \frac{a^2}{K_3^{\,2}\;(T)^{\frac{2}{N+1}}} \tag{31}$$

- and String Energy Density:

$$\rho = \frac{(1-2n+2p+np)\,K_1^{\,2}}{(N+1)^2\;T^2} - \frac{a^2}{K_3^{\,2}\;(T)^{\frac{2}{N+1}}} \tag{32}$$

Where, $P = \dfrac{(N+1)+\sqrt{(n+N)^2+4\,(N-n^2)}}{2}$

And $\quad q = P\left[\dfrac{-\,(N+n+2)+\sqrt{(n+N)^2+4\,(N-n^2)}}{2}\right]$

- Now Particle Density:

$$\rho_p = \rho - \rho_s = \frac{(\,2n+np-q+2N)\,K_1^{\,2}}{(N+1)^2\;T^2} \tag{33}$$

- Quark Energy Density:

$$\rho_q = \frac{(\,2n+np-q+2N)\,K_1^{\,2}}{(N+1)^2\;T^2} - B_c \tag{34}$$

- Quark Pressure:

$$p_q = \frac{(\,2n+np-q+2N)\,K_1^{\,2}}{3(N+1)^2\;T^2} - \frac{B_c}{3} \tag{35}$$

- Special Volume:

$$V^3 = K_3^{\,2}\;K_4\;C_1\;(T)^{\frac{(4+n+N)+\sqrt{(n+N)^2+4(N-n^2)}}{2(N+1)}}\;e^{ax} \tag{36}$$

- Scalar Expansion:

$$\theta = \frac{(2+n+p)\,k_1}{(N+1)T} \tag{37}$$

- Shear Scalar:

$$\sigma^2 = \frac{1}{2}\left[2\left\{\frac{K_1}{(K+1)}-\frac{1}{3}\right\}^2 + \left\{\frac{nk_1}{(N+1)T}-\frac{1}{3}\right\}^2 + \left\{\frac{PK_1}{(N+1)T}-\frac{1}{3}\right\}^2\right] \tag{38}$$

The string tension density, string energy, scalar expansion and shear scalar turn into infinite for T=0 which represents that the universe starts at T=0. So they acquire initial singularity. However, as T increases, these singularities disappear but the model (30) has no singularities. At preliminary momentum (T=0), quark pressure and density are infinite, then both decrease as T increases. The special volume 'V' is zero when T=0 and becomes infinite when $T\rightarrow\infty$. The expansion scalar θ and shear scalar σ^2 leans to infinity as T=0. Whereas when $T\rightarrow\infty$, expansion scalar θ and shear scalar σ^2 leans to zero. Since $\lim\left(\sigma^2/\theta^2\right)\neq 0$, the model does not come close to isotropy for large value of T. The model is expanding, shearing, no-rotating and has no preliminary singularities.

Set-II

With help of Eqs. (24) (25) and (28), the Bianchi type-III cosmological model for strange quark matter coupled to string cloud in general relatively can be written as:

$$ds^2 = dt^2 - K_3^{\,2}\,(K_1 t + K_2)^{\frac{2}{N+1}}\,(dx^2 + e^{2ax}dy^2) - K_4^{\,2}\,(K_1 t + K_2)^{\frac{2n}{N+1}}\,dz^2 - C_2^{\,2}\,(K_1 t + K_2)^{\frac{(N-n)-\sqrt{(n+N)^2+4(N-n)^2}}{(N+1)}}\,dy^2 \tag{39}$$

Through a suitable choice of coordinates and constants of integration, the above Eq. (39) reduces to:

$$ds^2 = \frac{dT^2}{K_1^{\,2}} - K_3^{\,2}\,(T)^{\frac{2}{N+1}}\left(dx^2 + e^{2ax}\,dy^2\right) - K_4^{\,2}\,(T)^{\frac{2n}{N+1}}\,dz^2 - C_2^{\,2}\,(T)^{\frac{(N-n)-\sqrt{(n+N)^2+4(N-n^2)}}{(N+1)}}\,d\psi^2 \tag{40}$$

Using Eqs. (24), (25) and (28) in Eqs. (19) and (21), we obtain.,

- Strong Tension Density:

$$\rho_s = \frac{(1+s-2N+2r)K_1^{\,2}}{(N+1)^2\,T^2} - \frac{a^2}{K_3^{\,2}\,(T)^{\frac{2}{N+1}}} \tag{41}$$

- and String Energy Density:

$$\rho = \frac{(1+2n+2r+nr)K_1^{\,2}}{(N+1)^2\,T^2} - \frac{a^2}{K_3^{\,2}\,(T)^{\frac{2}{N+1}}} \tag{42}$$

Where, $r = \dfrac{(N-n) - \sqrt{(n+N)^2 + 4\,(N-n^2)}}{2}$

And $s = r\left[\dfrac{-(N+n+2) - \sqrt{(n+N)^2 + 4\,(N-n^2)}}{2}\right]$

- Now Particle Density:

$$\rho_p = \rho - \rho_s = \frac{(2n + nr - s + 2N)K_1^{\,2}}{(N+1)^2\,T^2} \tag{43}$$

- Quark Energy Density:

$$\rho_q = \frac{(2n + nr - s + 2N)K_1^{\,2}}{(N+1)^2\,T^2} - B_c \tag{44}$$

- Quark Pressure:

$$p_q = \frac{(2n + nr - s + 2N)K_1^{\,2}}{3(N+1)^2\,T^2} - \frac{B_c}{3} \tag{45}$$

- Special Volume:

$$V^3 = K_3^{\,2}\,K_4\,C_2\,(T)^{\frac{(4+n+N)-\sqrt{(n+N)^2+4(N-n^2)}}{2(N+1)}}\,e^{ax} \tag{46}$$

- Scalar Expansion:

$$\theta = \frac{(2+n+r)k_1}{(N+1)T} \tag{47}$$

- Shear Scalar:

$$\sigma^2 = \frac{1}{2}\left[2\left\{\frac{K_1}{(K+1)} - \frac{1}{3}\right\}^2 + \left\{\frac{nk_1}{(N+1)T} - \frac{1}{3}\right\}^2 + \left\{\frac{rK_1}{(N+1)T} - \frac{1}{3}\right\}^2\right] \tag{48}$$

The string tension density, string energy, scalar expansion and shear scalar turn into infinite for T=0 which represents that the universe starts at T=0. So they possess preliminary singularity. However, as T increases these singularities disappear but the model (40) has no singularities. At preliminary momentum (T=0), quark pressure and density are infinite, then both decreases as T increases. The special volume 'V' is zero when T=0 and turns into infinite when $T \rightarrow \infty$. The expansion scalar θ and shear scalar σ^2 leans to infinity as T=0. Whereas, when $T \rightarrow \infty$, expansion scalar θ and shear scalar σ^2 leans to zero. Since $\lim_{T \rightarrow \infty} \left(\sigma^2 / \theta^2 \right) \neq 0$, the model does not come close to isotropy for large value of T. The model is expanding, shearing, no-rotating and has no preliminary singularities.

CONCLUSION

This paper projects the cosmological solutions of Einstein field equations which have expansion, rotation and shear rotation. The ratio $\frac{\sigma}{\theta}$ for our suggested model is considerably greater than its present value (10^{-3}). The experimental results indicate and justify that the primitive stages of evolution of the universe, which is analogous to result attained by Yilmaz [44]. It is eye-opening to note that as T gradually increases, the scalar expansion θ and shear scalar σ^2 decreases and finally vanishes when $T \rightarrow \infty$.

My result concludes certain consequences, in principle for the astrophysical effects of cosmic evolution, allowing possible relic clue on the priority of extra space at the early universe. However, it may be too immature to come to any particular results in this regard. Hence I am concise on this point.

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