LRS BIANCHI TYPE-II BULK VISCOUS STRING COSMOLOGICAL MODEL IN BARBER'S SECOND SELF-CREATION THEORY

N. K. Ashtankar[1*], M. S. Borkar[2], V. M. Raut[3] and N. P. Gaikwad[4]
[1*]Department of Mathematics, Bajaj Institute of Technology, Wardha (MH), India
[2]P. G. Department of Mathematics, Mahatma JyotibaPhule Educational Campus, Amravati Road, RTM Nagpur University, Nagpur, India
[3]Department of Mathematics, Shri. Shivaji Science College, Amravati (MH), India
[4]Department of Mathematics, Dharampeth M. P. Deo Memorial Science College, Nagpur
dr.nileshashtankar@rediffmail.com, borkar.mukund@rediffmail.com, vinayraut18@gmail.com
np_gaikwad@rediffmail.com

ABSTRACT

The LRS Bianchi type-II metric with stringviscous fluid have been evaluated by solving the barber's field equations of second self-creation theory of gravitation and studied the geometrical and physical aspects. The value of constant n $(n > 0)$ affects the behavior of the model. The barber scalar function ϕ determines the nature of proper density ρ, particle density ρ_p and coefficient of bulk viscosity ξ. It is observed that our results are agreed with the result of Tyagi (2010) in the absence of barber scalar function ϕ.

Keywords: *Gravitational theory, Cosmology, Self-Creation Cosmology*

Introduction

The role of Mach's principle in physics is discussed in relationto the equivalence principle. Brans and Dicke (1961)pointed out that as a consequence of a Mach's principle thevalue of gravitational constant should be determined by thematter in the universe and they have taken this concept asthe reason for generalizing the Einstein's theory of generalrelativity (GR) to the scalar-tensor theory of gravitation. In Bransand Dicke's (1961) scalar-tensor theory of gravitation, the tensor field is identified with the space-time ofRiemannian geometry and scalar field is alien to geometry.This theory does not allow the scalar field to interactwith fundamental principles and photons. However, Barber(1982) has modifiedBransand Dicke's(1961) scalar-tensor theoryto develop a continuous creation of matter in the large scalestructure of the universe and proposed two self-creation theories,out of which the first self-creation theory proposed by modifying Bransand Dicke theory (1961) but Brans (1987) has pointed out that the field equations of Barber's first self-creationtheories are not only in disagreement with experimentbut are actually inconsistence, in general and also this theory violetsthe equivalence principle andhence it discarded. The second self-creation (SSC) theory was proposed by Barber (1982) by modifying Einstein's theory of GR (1915)to a variable G-theory and predicts local effects withinthe observational limits. In modification of Einstein's GR, he attached the scalar function ϕ with the energy-momentum tensor on the right hand side of Einstein field equations in order to substantially accommodate the Mach's principle. So that the field equations in Barber's secondself-creation theory are

$$G_{ij} = \left(R_{ij} - \frac{1}{2} R g_{ij} \right) = -\frac{8\pi T_{ij}}{\phi} \tag{1}$$

and the scalar field ϕ satisfies the equation

$$\Box\phi = \frac{8}{3}\pi\eta T \tag{2}$$

where,$\Box\phi = \phi^{k}_{;k}$is the invariant d'Alembertian, ϕ is the Barber scalar function of $t$which is the inverse of Newtoniangravitational constant$G$ in GR, T is the stress of energy momentum tensorT_{ij}, G_{ij} is an Einstein tensor, η is the coupling constant with $0 \leq |\eta| \leq 10^{-1}$. This SSCtheory is a variable G-theory and predicts local effects, which are within the observational limits. In it, the Newtonian gravitational parameter G is not a constant but a function of time parameter t. Also the scalar field ϕ does not gravitate directly but simply divides the matter tensor acting as a reciprocal gravitational constant, which is not the case in GR. This theory is capable of verification or falsification. It can be done by observing the behavior of both bodies of degenerate matter and photons. An observation of anomalous precessions in the orbits of pulsars about central masses and an accurate determination of the deflection of light and radio waves passing close to the sun would verify or falsify such theory and determines λ. The theory predicts the same precession of the perihelia of the planets as general relativity and in that respect agrees with observation.

Many researchers have been studied the theory, developed the models of the universe and investigated geometrical and physical aspects of the universe in this SCC theory.Pimental (1985) and Soleng (1987)have presented the Robertson Walker solutions in SSC theory of gravitation by using power law relation between the expansion factor of the universe and the scalar field. Reddy and Venkateswarlu (1989) have obtained spatially homogeneous and anisotropic Bianchi type-VI_0 cosmological models in Barber's self-creation theory of gravitation both in vacuum and in presence of perfect fluid with pressure equal to energy density. Venkateswarlu and Reddy(1990) have also got spatially homogeneous and anisotropic Bianchi type-I cosmological macro models when the source of gravitational field is a perfect fluid. Bianchi type-II and III models in self-creation cosmology have been deduced by Shanti and Rao (1991). V.U.M. Rao and SanyasiRaju (1992) have discussed Bianchi type VIII and IX in zero mass scalar fields and self-creation cosmology. Shri Ram and C.P. Sigh (1997)have obtained spatially homogeneous and isotropic R-W model of the universe in the presence of perfect fluid by using 'gamma law' equation of state. There are also many other researchers[11-21] who have been deduced the models like plane and axially symmetric cosmological models, FRW cosmological model and also Bianchi type-I, II, VIII and IX string cosmological models in self-creation theory of gravitation. Recently Borkar and Ashtankar (2012, 2013, 2016) have been developed the plane symmetric viscous fluid cosmological model with varying Λ-term, Bianchi type- I bulk viscous barotropic fluid cosmological model with varying Λ and functional relation on Hubble parameter and LRS Bianchi type-II cosmological model with string bulk viscous fluid and magnetic field in self-creation theory of gravitation and they studied the geometrical and physical aspects of the models.

In this paper, an attempt has been made to take-up the study of LRS Bianchi type-II model with bulk string viscous fluid since it play an important role in current modern cosmology for simplification and description of the large scale behavior of the universe and it is realized that such model do not exist for $n = 1, 2$ and exist otherwise with effective role of Barber scalar function ϕ that it dominate the nature of proper density ρ, particle density ρ_p and coefficient of bulk viscosity ξ.

The Metric and Field Equations:

We consider the Bianchi type-II space-time in the form

$$ds^2 = -dt^2 + A^2(dx^2 + dz^2) + B^2(dy - xdz)^2 \quad (3)$$

where A and B are functions of t alone.

The energy-momentum tensor T_i^j for a cloud of strings with bulk viscous fluid is given by

$$T_i^j = \rho\, v_i v^j - \lambda\, x_i x^j - \xi\, v^l_{|l}\left(g_i^j + v_i v^j\right) \quad (4)$$

in which the four velocity vector v^i and the displacement vector x^i are to be assumed as

$$v^i = (0,0,0,1)\,,\ x^i = \left(\frac{1}{A}, 0,0,0\right) \quad (5)$$

and they satisfy the conditions

$$v_i v^i = -1 = -\, x_i x^i \quad (6)$$

The quantityξ is the coefficient of bulk viscosity, ρ is the proper density of a cloud strings, $\lambda$is the string tension density. The particle density ρ_p of the configuration is defined as $\rho = (\rho_p + \lambda)$.Here and hereafter, the vertical stroke (|) stands for covariant derivatives.

The scalar expansion θ is defined as $v^l_{|l}$ and it has value

$$\theta = \left(\frac{2\,A_4}{A} + \frac{B_4}{B}\right) \quad (7)$$

From equation (4), we write the components of energy momentum tensor T_i^j as

$$T_1^1 = -(\lambda + \xi\theta), \quad T_2^2 = -\xi\theta\,, \quad T_3^3 = -\xi\theta\,, \quad T_4^4 = -\rho, \quad T_i^j = 0\,, \quad i \neq j \quad (8)$$

Barber's field equations (1) and (2)for the line-element (3)with the components of energy momentum tensor fromequations (8), takes the form

$$\frac{A_{44}}{A}+\frac{B_{44}}{B}+\frac{A_4B_4}{AB}+\frac{B^2}{4A^4}=(\lambda+\xi\theta)\,8\pi\phi^{-1} \quad (9)$$

$$2\frac{A_{44}}{A}+\frac{{A_4}^2}{A^2}-\frac{3B^2}{4A^4}=\xi\theta\,8\pi\phi^{-1} \quad (10)$$

$$\frac{A_{44}}{A}+\frac{B_{44}}{B}+\frac{A_4B_4}{AB}+\frac{B^2}{4A^4}=\xi\theta\,8\pi\phi^{-1} \quad (11)$$

$$\frac{{A_4}^2}{A^2}+2\frac{A_4B_4}{AB}-\frac{B^2}{4A^4}=\rho\,8\pi\phi^{-1} \quad (12)$$

$$\phi_{44}+\phi_4\left[2\frac{A_4}{A}+\frac{B_4}{B}\right]=d_1(\lambda+3\xi\theta+\rho) \quad (13)$$

where,

$d_1=\frac{8\pi\eta}{3}$is a constant and

$A_4=\frac{dA}{dt},\ B_4=\frac{dB}{dt}, A_{44}=\frac{d^2A}{dt^2}$etc.

Solution of the Field Equations

Our aim is to solve the above differential equations (9-13) and find the values of A, B and physical parameters ρ, λ, ξ and ϕ and interpret them in related with the nature of barber scalar function ϕ. There are five differential equations (9-13) in six unknowns and hence in order to have a solution, we must assume one extra condition which we can takeshear σ is proportional to the scalarexpansion θ, (Collins et al.(1980), Bali(1986)). This condition leads the relation between the metric potential A and B as

$$B=lA^n \quad (14)$$

where$l$ and $n(>0)$ are constants.

The equations (10) and (11), leads the differential equation

$$A_{44}+(1+n)\frac{{A_4}^2}{A}=\frac{l^2}{(1-n)}A^{2n-3} \quad (15)$$

To simplify this differential equation, we assume$A_4=u$,$A_{44}=A_4\frac{du}{dA}$, then this equation (15) is reduced to

$$u\frac{du}{dA}+(1+n)\frac{u^2}{A}=\frac{l^2}{(1-n)}A^{2n-3}$$

which is a Bernoulli equation and it has solution

$$u^2=\left(\frac{dA}{dt}\right)^2=\frac{l^2}{2n(1-n)}A^{2n-2}+\frac{c_1}{A^{2n+2}}$$

where,c_1 is the constant of integration. To find the value of A, for simplicity, we assume $c_1=0$. So that

$$\frac{dA}{dt}=\frac{l}{\sqrt{2n(1-n)}}A^{n-1}$$

which on integrating, we get

$$\frac{A^{2-n}}{2-n}=\frac{l}{\sqrt{2n(1-n)}}t+c_2$$

where, c_2 is the constant of integration. In particular for $c_2=0$, we have

$$A^2=\left(\frac{l^2(2-n)^2}{2n(1-n)}t^2\right)^{\frac{1}{2-n}},\ n\neq 1,2 \quad (16)$$

Using equation (16) in equation (14), we write

$$B^2=l^2\left(\frac{l^2(2-n)^2}{2n(1-n)}t^2\right)^{\frac{n}{2-n}},\ n\neq 1,2 \quad (17)$$

Thus the solution of Barber's field equations for LRS Bianchi type-II metricis given by equations (16) and (17) and the required model is

$$ds^2=-dt^2+\left(\frac{l(2-n)}{\sqrt{2n(1-n)}}\right)^{\frac{2}{2-n}}t^{\frac{2}{2-n}}(dx^2+dz^2)+l^2\left(\frac{l(2-n)}{\sqrt{2n(1-n)}}\right)^{\frac{2n}{2-n}}t^{\frac{2n}{2-n}}(dy-xdz)^2,$$
$$n\neq 1,2 \quad (18)$$

Geometrical and Physical Significance

Using the values of A and B from equations (16) and (17), we have calculated the value of $\xi\theta$from equation (10) and the value of ρ from equation (12) respectively as

$$\xi\theta=\frac{(3n-2)(n+1)}{16\pi(2-n)^2t^2}\phi$$

and

$$\rho=\frac{(n+1)(n+2)}{16\pi(2-n)^2t^2}\phi$$

From equations (9) and (11), we have calculated the string tension density$\lambda$and it is $\lambda=0$

The expansion θ is given by equation (7) and it has value

$$\theta=\frac{(2+n)}{(2-n)t}$$

With this value of θ, we write the value of coefficient of bulk viscosity ξ as

$$\xi = \frac{(3n-2)(n+1)}{16\pi(4-n^2)t}\phi$$

Lastly we have calculated the value of Barber's scalar function ϕ from equation (13) and with the values of A, B, ξ, θ, ρ and λ given earlier, we write the value of ϕas

$$\phi = D_1 t^{m_1} + D_2 t^{m_2} \tag{19}$$

in which D_1, D_2, $m_1$and $m_2$are constants and the values of m_1 and m_2 are

$$m_1 = \frac{1}{n-2}\left(n + \sqrt{n^2 - \frac{\eta}{3}(5n-2)(n+1)}\right) \text{and} m_2 = \frac{1}{n-2}\left(n - \sqrt{n^2 - \frac{\eta}{3}(5n-2)(n+1)}\right) \tag{20}$$

We bifurcate the value of ϕas

$$\phi = \phi_1 + \phi_2 \tag{21}$$

where,

$$\phi_1 = D_1 t^{m_1} \tag{22}$$

and

$$\phi_2 = D_2 t^{m_2} \tag{23}$$

When coupling constant $\eta \to 0$, thenthe scalar function ϕ_2 approaches constant value whereas the scalar function ϕ_1 is a variable of time t. In order to match with Einstein general relativity, the scalar function ϕ should be constant, when $\eta \to 0$. Hence we are neglecting the time variable function$\phi_1$of t in our further discussion. Therefore equation (21) leads

$$\phi = \phi_2 = t^{\frac{1}{n-2}\left(n-\sqrt{n^2-\frac{\eta}{3}(5n-2)(n+1)}\right)} \tag{24}$$

with suitable constant $D_2 = 1$.

Thus the physical parameters like, proper density ρ of cloud string, particle density ρ_p, string tension density λ, expansion θ,coefficient of bulk viscosity $\xi$and shear $\sigma$for the model (18) are given by

$$\rho = \rho_p = \frac{(n+1)(n+2)}{16\pi(2-n)^2} t^{\frac{1}{n-2}\left(4-n-\sqrt{n^2-\frac{\eta}{3}(5n-2)(n+1)}\right)} \tag{25}$$

$$\lambda = 0 \tag{26}$$

$$\theta = \frac{(2+n)}{(2-n)t} \tag{27}$$

$$\xi = \frac{(3n-2)(n+1)}{16\pi(4-n^2)} t^{\frac{1}{n-2}\left(2-\sqrt{n^2-\frac{\eta}{3}(5n-2)(n+1)}\right)} \tag{28}$$

$$\sigma = \frac{n-1}{\sqrt{3}(n-2)t} \tag{29}$$

In terms of barber scalar function ϕ, we can express the value of physical parameters ρ, ρ_p and ξ as follows

$$\rho = \rho_p = \frac{(n+1)(n+2)}{16\pi(2-n)^2 t^2}\phi \tag{30}$$

$$\xi = \frac{(3n-2)(n+1)}{16\pi(4-n^2)t}\phi \tag{31}$$

It is observed that, the scale factors A and B do not exists for $n = 1, 2$ consequently our model (18) do not exist for$n = 1, 2$, even though all physical parameters ρ, ρ_p, λ, θ, ξ, σ and even barber scalar function ϕ existfor$n = 1$. Therefore the model is meaningless in particular for $n = 1, 2$. For $n \neq 1$and $n \neq 2$, the model exist with all its physical parameters and model has geometrical and physical significance.

The value of constant n $(n > 0)$ playing the important role to discuss the behavior of the model. For $0 < n < 2, (n \neq 1)$, the model starts with zero scale factors and model is time-like and these scale factors are continuously increases with increase in time t and they diverges to infinity at final stage of time t. For $n > 2$, the scale factors are infinite initially and approaches to zero at final stage of time t. This shows that, the model having scale factors which are diverges to infinity in the beginning and model yield time-like interval at final stage of time t, for $n > 2$.

We are evaluating the model geometrically and physically in view of the nature of barber scalar function ϕ and trying to compare our model with the model (without scalar function ϕ) of Tyagi (2010). In the evaluation, we are taking two cases for the value of n, case (i) $0 < n < 2, n \neq 1$ and case(ii) $n > 2$.

Case (i) $0 < n < 2, n \neq 1$

When $t \to 0$, the quantities ρ, ρ_p, θ, ξ, $\sigma \to \infty$.$\phi \to 0$,for$0 < n \leq 0.4$and$\phi \to \infty$, for $n > 0.4$. At final stage when $t \to \infty$, then ρ, ρ_p, θ, ξ, $\sigma \to 0$and $\phi \to \infty$, for$0 < n \leq 0.4$and$\phi \to 0$, for $n > 0.4$. This suggested that, the model admits very very high range of proper density ρ, particle density ρ_p, scalar expansion θ, coefficient of bulk viscosity ξ and also shear σ in the initial stage and all these parameters decreasing continuously when time t increasing and they are vanishing finally and the model is time-like vaccume. The nature of barber scalar function ϕ is interesting. It is zero for $0 < n \leq 0.4$ and it is infinite for $n > 0.4$ in the beginning stage whereas it plays reversible role i.e.,ϕ is infinity for $0 < n \leq 0.4$and ϕ is zero for $n > 0.4$at final stage.One can say that the role of physical parameters like ρ, ρ_p and $\xi$are governed by scalar function ϕin the beginning as well as in the ending stage of the model.

Case (ii) $n > 2$

It is observed that when $t \to 0$then $\xi, \theta \to -\infty$,ρ, $\rho_p, \sigma \to \infty$ and $\phi \to 0$.When $t \to \infty$, then all the physical parameters ρ, ρ_p, θ ξ and σ tends to zero and $\phi \to \infty$. Thus it is seen that, the model does not exist in the beginning stage, since the scale factors are infinite and also the coefficient of bulk viscosity ξ and scalar expansion θ are minus infinity. At later stage, all physical parameters ρ, ρ_p, θ ξ and σ are zero i.e., they disappeared and the model become vacuume. The nature of barber scalar function ϕ alter the nature of physical parametersρ, ρ_p and ξ in the evolution of the model.At final stage of the model, the barber scalar function ϕ admits infinite value and it cause zero values of the physical parameters ρ, ρ_p and ξ in the model.

It is interesting to point out that, in regard with the geometrical and physical parameters of the model our result are very much agreed the result of Tyagi (2010) in the absence of barber scalar function ϕ.

Summary

1. The LRS Bianchi type II metric have been deduced in Barber's second self-creation theory of gravitation and its geometrical and physical aspects have been analyzed with barber's scalar function ϕ.
2. The value of constant $n(n > 0)$ plays the important role in the evaluation of the model and it is seen that, the model do not exist for $n = 1, 2$.
3. For $0 < n < 2, n \neq 1$, the model admits very very high range of proper density ρ, particledensity ρ_p, scalar expansion θ, coefficient of bulk viscosity ξ and also shear σ in the initialstage and they are vanishing at final stage and the model become time-like vacuum.
4. For $0 < n < 2, n \neq 1$, the nature of barber scalar function ϕ is interesting. It is zero for$0 < n \leq 0.4$ and it is infinite for $n > 0.4$ in the initial stage whereas it plays reversible rolei.e., ϕ is infinite for $0 < n \leq 0.4$ and it is zero for $n > 0.4$ at final stage. It is seen that,the physical parameters like ρ, ρ_p and ξ governed by barber scalar function ϕ.
5. For $n > 2$, the model does not exist in the beginning stage since the scale factors areinfinite and at later stage, the model become vacuum.
6. For $n > 2$, the nature of barber scalar function ϕ alter the nature of physical parametersρ, ρ_p and ξ in the evaluation of model.
7. For $n > 2$, at final stage of the model, the barber scalar function ϕ admit infinite value and it cause zero values of the physical parameters ρ, ρ_p and ξ.
8. It is seen that the string tension density λ admit zero value in the evaluation of the model which shows that string phases are switched off.
9. Since the ration $\frac{\sigma}{\theta} \neq 0$when $t \to \infty$, the model does not isotropize.
10. It is observed that, our result are very much agreed with the result of Tyagi (2010) inthe absence of barber scalar function ϕ.

Conclusion

We have investigated LRS Bianchi type II metric with string viscous fluid by solving the Barber's field equations of second self-creation theory of gravitation and it is seen that the value of constant $n\,(n > 0)$ controlled the geometrical and physical behavior of model. For $= 1, 2$, the model do not exist otherwise it is exist. The barber scalar function ϕ play important role in the behavior of the model and it dominated the nature of proper density ρ, particle density $\rho_p$and coefficient of bulk viscosity ξ.

It is pointed out that our result are very much agreement with the result of Tyagi (2010) in the absence of barber scalar function ϕ.

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