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Existence and Non existence of String Cosmological Models in Bimetric Theory of Gravitation

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Abstract

In this paper, I have investigated some magnetized cosmological modes with and without magnetic field in Rosen's bimetric theory of gravitation .To get determinate solution we have assumed that σ is proportional to θ and ζθ = constant where σ is shear, θ is the expansion in the model and ζ is the coefficient of bulk viscosity. The model exists for $n > 64\pi K e^{2u}/3\beta$, for positive Λ . The model never dusty with zero value of Λ and model describes dusty universe for $n = 1/2\,(128\,\pi K e^{2u}/\beta+1)$ with $\Lambda \neq 0$. In the absence of magnetic field K, the model exist for $n \neq 1/2$ and the model is dusty for $n = 1/2$ and in this case the cosmological constant Λ always positive.
The bulk viscosity β makes a role and affects the physical behavior of the model. In the absence of it, the model does not exist, since $\in$, λ and Λ all are negative. Further in the absence of both magnetic field K and bulk viscosity β , the model represents vacuum universe with zero cosmological constant Λ , but has a constant shear.

Introduction

The Rosen's bimetric theory is the theory of gravitation based on two metrics. One is the fundamental metric tensor g_{ij} describes the gravitational potential and the second metric γ_{ij} refers to the flat space–time and describes the inertial forces associated with the acceleration of the frame of reference. The metric tensor g_{ij} determines the Riemannian geometry of the curved space time which plays the same role as given in Einstein's general relativity and it interacts with matter. The background metric γ_{ij} refers to the geometry of the empty universe (no matter but gravitation is there) and describes the inertial forces. The metric tensor γ_{ij} has no direct physical significance but appears in the field equations. Therefore it interacts with g_{ij} but not directly with matter. One can regard γ_{ij} as giving the geometry that would exists if there were no matter. In the absence of matter one would have $g_{ij} = \gamma_{ij}$. Thus at every point of space–time, there are two metrics

$$ds^2 = g_{ij} dx^i dx^j \qquad (1)$$

$$d\eta^2 = \gamma_{ij} dx^i dx^j \qquad (2)$$

The field equations of Rosen's (1974) bimetric theory of gravitation are

$$N_i^j - \frac{1}{2} N \delta_i^j + \Lambda\, g_i^j = -8\pi k T_i^j$$

(3)

where $N_i^j = \frac{1}{2}\gamma^{pr}\left(g^{sj} g_{si|p}\right)_{|r}$, $N = N_i^i$, $k = \sqrt{\frac{g}{\gamma}}$ together with $g = \det(g_{ij})$ and $\gamma = \det(\gamma_{ij})$. Here the vertical bar $(\,|\,)$ stands for γ–covariant differentiation and T_i^j is the energy–momentum tensor of matter fields.

Several aspects of bimetric theory of gravitation have been studied by Rosen(1974,1977), Karade(1980), Katore et al (2006) , Israelit(1981) , Khadekar et al (2007) . In particular, Reddy et al (1998) have obtained some Bianchi Type cosmological models in bimetric theory of gravitation. The purpose of Rosen's bimetric theory is to get rid of the singularities that occur in general relativity that was appearing in the big–bang in cosmological models and therefore, recently, there has been a lot of interest in cosmological models in related to Rosen's bimetric theory of gravitation. In the context of general relativity cosmic strings do not occur in Bianchi Type models. Some Bianchi Type cosmological models – two in four and one in higher dimensions– are studied by Krori et al (1994). They showed that the cosmic strings do not occur in Bianchi Type V cosmology.

In this paper, I have investigated some magnetized cosmological modes with and without magnetic field in Rosen's bimetric theory of gravitation .To get determinate solution we have assumed that σ is proportional to θ and ζθ = constant where σ is shear, θ is the expansion in the model and ζ is the coefficient of bulk viscosity. The model exists for $n > 64\pi K e^{2u} / 3\beta$, for positive Λ . The model never dusty with zero value of Λ and model describes dusty universe for $n = 1/2\,(128\,\pi K e^{2u} / \beta + 1)$ with $\Lambda \neq 0$. In the absence of magnetic field K, the model exist for $n \neq 1/2$ and the model is dusty for $n = 1/2$ and in this case the cosmological constant Λ always positive. The bulk viscosity β makes a role and affects the physical behavior of the model. In the absence of it, the model does not exist, since $\in$, λ and Λ all are negative. Further in the absence of both magnetic field K and bulk viscosity β , the model represents vacuum universe with zero cosmological constant Λ , but has a constant shear.

Solutions of Rosen's Field Equations

We consider Bianchi Type I metric in the form

$$ds^2 = -dt^2 + A^2 dx^2 + B^2 dy^2 + C^2 dz^2$$

where A, B and C are functions of t – alone. Here $B \neq C$ otherwise, we get LRS Bianchi Type I model.

The flat metric corresponding to metric (4) is

$$d\eta^2 = -dt^2 + dx^2 + dy^2 + dz^2$$

The energy momentum tensor T_i^j for string dust is given by

$$T_i^j = \in \upsilon_i \upsilon^j - \lambda x_i x^j - \zeta \upsilon^{\ell}_{;\ell}\,(g_i^j + \upsilon_i \upsilon^j) + E_i^j$$

(6)

with

$$\upsilon_i \upsilon^i = -x_i x^i = -1 \qquad (7)$$

and

$$\upsilon^i x_i = 0 \qquad (8)$$

In this model $\in$ is the rest energy density for a cloud of strings and is given by $\in = \in_p + \lambda$ where $\in_p$ and λ denote the particle density and the string tension density of the system of strings respectively, x^i is the direction of strings and ζ is the coefficient of bulk viscosity.

The electromagnetic field E_{ij} is (given by Lichnerowicz (1967)

$$E_{ij} = \bar{\mu}\left[\,|h|^2\left(\upsilon_i \upsilon_j + \frac{1}{2} g_{ij}\right) - h_i h_j\right] \qquad (9)$$

where four velocity vector υ_i is given by

$$g_{ij} \upsilon^i \upsilon^j = -1 \qquad (10)$$

and $\bar{\mu}$ is the magnetic permeability and the magnetic flux vector h_i defined by

$$h_i = \frac{\sqrt{-g}}{2\bar{\mu}} \in_{ijkl} F^{kl} \upsilon^j \qquad (11)$$

where F_{kl} is the electromagnetic field tensor and $\in_{ijkl}$ is the Levi-Civita tensor density

Assume the commoving coordinates system, so that $\upsilon^1 = \upsilon^2 = \upsilon^3 = 0,\ \upsilon^4 = 1.$

Further we assume that the incident magnetic field is taken along x-axis so that

$$h_1 \neq o \text{ and } h_2 = h_3 = h_4 = 0$$

The first set of Maxwell's equation

$$F_{[ij,k]} = 0 \tag{12}$$

Yield

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

Due to the assumption of infinite electrical conductivity, we have $F_{14} = F_{24} = F_{34} = 0$.

The only non-vanishing competent of F_{ij} is F_{23}. So that

$$h_1 = \frac{AH}{\bar{\mu}BC} \tag{13}$$

and

$$|h|^2 = \frac{H^2}{\bar{\mu}^2 B^2C^2}$$

From equation (9) we obtain

$$-E_1^1 = E_2^2 = E_3^3 = -E_4^4 = \frac{H^2}{2\bar{\mu}B^2C^2}$$

From equation (6), we obtain

$$T_1^1 = \left(-\lambda - \frac{H^2}{2\bar{\mu}B^2C^2} - \zeta\upsilon^\ell_{;\ell}\right),\ T_2^2 = T_3^3 = \left(\frac{H^2}{2\bar{\mu}B^2C^2} - \zeta\upsilon^\ell_{;\ell}\right),\ T_4^4 = -\left(\in + \frac{H^2}{2\bar{\mu}B^2C^2}\right) \tag{16}$$

Using equation (16), Rosen's field equation (3) gives

$$\frac{-A_{44}}{A} + \frac{B_{44}}{B} + \frac{C_{44}}{C} + \frac{{A_4}^2}{A^2} - \frac{{B_4}^2}{B^2} - \frac{{C_4}^2}{C^2} = 16\pi\, ABC\left(\lambda + \frac{H^2}{2\bar{\mu}B^2C^2} + \zeta\upsilon^\ell_{;\ell}\right) - 2\Lambda \tag{17}$$

$$\frac{A_{44}}{A} - \frac{B_{44}}{B} + \frac{C_{44}}{C} - \frac{{A_4}^2}{A^2} + \frac{{B_4}^2}{B^2} - \frac{{C_4}^2}{C^2} = 16\pi\, ABC\left(-\frac{H^2}{2\bar{\mu}B^2C^2} + \zeta\upsilon^\ell_{;\ell}\right) - 2\Lambda \tag{18}$$

$$\frac{A_{44}}{A} + \frac{B_{44}}{B} - \frac{C_{44}}{C} - \frac{{A_4}^2}{A^2} - \frac{{B_4}^2}{B^2} + \frac{{C_4}^2}{C^2} = 16\pi\, ABC\left(-\frac{H^2}{2\bar{\mu}B^2C^2} + \zeta\upsilon^\ell_{;\ell}\right) - 2\Lambda \tag{19}$$

$$\frac{A_{44}}{A} + \frac{B_{44}}{B} + \frac{C_{44}}{C} - \frac{{A_4}^2}{A^2} - \frac{{B_4}^2}{B^2} - \frac{{C_4}^2}{C^2} = 16\pi\, ABC\left(\in + \frac{H^2}{2\bar{\mu}B^2C^2}\right) - 2\Lambda \tag{20}$$

where $A_4 = \frac{dA}{dt}, B_4 = \frac{dB}{dt}, C_4 = \frac{dC}{dt}$ etc.

Equations (17) to (20) are four equations in six unknowns $A, B, C, \lambda, \in$ and Λ therefore to deduce a determinate solution, we assume two extra conditions. First is that the shear tensor σ_i^j is proportional to the expansion (θ) which leads to

$$A = (BC)^n, \quad \text{where } n > 0 \tag{21}$$

and second is string dust Zel'dovich condition (1980)

$$\in = \lambda \tag{22}$$

i.e., the rest energy density is equal to the string tension density.

From equations (19) and (20), we obtain

$$2\frac{C_4^2}{C^2} - 2\frac{C_{44}}{C} = 16\pi\, ABC\left(\zeta\upsilon^\ell_{;\ell} - \in - \frac{H^2}{\bar{\mu}B^2C^2}\right) \tag{23}$$

Adding equation (17) and (23) together and using the condition ε =λ , we get

$$\frac{B_{44}}{B} - \frac{A_{44}}{A} - \frac{C_{44}}{C} + \frac{{A_4}^2}{A^2} - \frac{{B_4}^2}{B^2} + \frac{{C_4}^2}{C^2} = 16\pi\, ABC\left(2\zeta\,\upsilon^\ell_{;\ell} - \frac{H^2}{2\bar{\mu}B^2C^2}\right) - 2\Lambda \tag{24}$$

From equations (21) and (24), we write

$$(n-1)\frac{{B_4}^2}{B^2} + (n+1)\frac{{C_4}^2}{C^2} + (1-n)\frac{B_{44}}{B} - (n+1)\frac{C_{44}}{C} = -16\pi\, K(BC)^{n-1} + 32\pi(BC)^{n+1}\zeta\upsilon^\ell_{;\ell} - 2\Lambda \tag{25}$$

where

$$K = \frac{H^2}{2\bar{\mu}}$$

From equations (18) and (19), we obtain

$$\frac{C_{44}}{C}-\frac{B_{44}}{B}=\frac{C_4{}^2}{C^2}-\frac{B_4{}^2}{B^2} \tag{26}$$

On simplifying above equation, we get

$$\frac{(CB_4-BC_4)_4}{(CB_4-BC_4)}=\frac{(BC)_4}{BC} \tag{27}$$

which on integrating yield

$$C^2\left(\frac{B}{C}\right)_4=LBC \tag{28}$$

where L is the constant of integration.

Using assumptions $BC=\mu$ and $\frac{B}{C}=\nu$, the above equation (28) leads to

$$\frac{\nu_4}{\nu}=L \tag{29}$$

Now using equation (21) and the condition $BC=\mu$ and $\frac{B}{C}=\nu$, the equation (25) gives

$$-n\left(\frac{\mu_{44}}{\mu}\right)+n\frac{\mu_4^2}{\mu^2}=-16\pi K\mu^{(n-1)}+32\pi\mu^{(n+1)}\zeta\upsilon^{\ell}_{;\ell}-2\Lambda \tag{30}$$

Applying the condition $\xi\theta$ = constant to the above equation, we get

$$\mu_{44}-\frac{\mu_4^2}{\mu}+\beta\mu^{n+2}=\frac{16\pi K}{n}\mu^n+\frac{2\Lambda\mu}{n} \tag{31}$$

where

$$\beta=\frac{32\pi}{n}\zeta\upsilon^{\ell}_{;\ell}$$

which reduces to

$$\frac{d}{d\mu}\left[f^2\right]+(-\frac{2}{\mu})f^2=2\left[\frac{16\pi K}{n}-\beta\mu^2\right]\mu^n+\frac{4\Lambda\mu}{n} \tag{32}$$

where $\mu_4=f(\mu)$.

The differential equation (32) has solution

$$f^2=P\mu^2+\frac{32\pi K}{n(n-1)}\mu^{n+1}-\frac{2\beta}{n+1}\mu^{n+3}+\frac{4\Lambda}{n}\mu^2\log\mu \tag{33}$$

where *P* is the constant of integration.

From equation (29) we write

$$\log\nu=\int\frac{L\,d\mu}{\sqrt{P\mu^2+\frac{32\pi K}{n(n-1)}\mu^{n+1}-\frac{2\beta}{(n+1)}\mu^{n+3}+\frac{4\Lambda}{n}\mu^2\log\mu}}+\log b \tag{34}$$

Using $\mu_4=f(\mu)$ and expression (33), the metric (4) will be

$$ds^2=-\frac{d\mu^2}{\left[P\mu^2+\frac{32\pi K}{n(n-1)}\mu^{(n+1)}-\frac{2\beta}{(n+1)}\mu^{(n+3)}+\frac{4\Lambda}{n}\mu^2\log\mu\right]}+\mu^{2n}dx^2+\mu\nu\,dy^2+\frac{\mu}{\nu}dz^2 \tag{35}$$

where ν is determined by equation (34).

After suitable transformation of coordinates i.e., putting $\mu=T,\ x=X,\ y=Y,\ z=Z$ the above metric (35) takes the form

$$ds^2=-\frac{dT^2}{\left[PT^2+\frac{32\pi K}{n(n-1)}T^{(n+1)}-\frac{2\beta}{(n+1)}T^{(n+3)}+\frac{4\Lambda}{n}T^2\log T\right]}+T^{2n}dX^2+T\nu dY^2+\frac{T}{\nu}dZ^2 \tag{36}$$

Now choosing the cosmic time $u=\pm\log T$. For convenience, we can select $u=-\log T$, then the model (36) goes over to

$$ds^2 = -\frac{du^2}{\left[P + \frac{32\pi K}{n(n-1)} e^{-u(n-1)} - \frac{2\beta}{(n+1)} e^{-u(n+1)} - \frac{4\Lambda}{n} u\right]} + e^{-u} \left(e^{-u(2n-1)} dX^2 + v\, dY^2 + \frac{1}{v} dZ^2\right) \tag{37}$$

This is the Bianchi Type-I bulk viscous fluid string dust magnetized cosmological model with Λ-term in bimetric theory of gravitation.

Physical Quantities of the Model

The energy density $\in$, the string tension density λ and cosmological term Λ for the model (37), (in terms of cosmic time u) is given by

$$\in (= \lambda) = \left(-2Ke^{2u} + \frac{(2n-1)\beta}{64\pi}\right) \tag{38}$$

$$\Lambda = \left(-8\pi K e^{-u(n-1)} + \frac{3}{8} n\beta\, e^{-u(n+1)}\right) \tag{39}$$

It is noticed that the energy density $\in$, the string tension density λ and cosmological term Λ all are positive if $n > (64\pi K e^{2u})/3\beta$, which suggested the existence of the model for $n > (64\pi K e^{2u})/3\beta$ with positive cosmological constant Λ. Further $\in (= \lambda) = \Lambda = 0$, for $n = -1/4$ which is not possible, since $n > 0$ and hence we never get the dust model with zero value of cosmological constant Λ. The model is dusty for $n = 1/2\,(128\pi K e^{2u}/\beta + 1)$. It is seen that $\in (= \lambda) > 0$, and $\Lambda < 0$, for $n = -1/4$, (not permissible) and thus the model does not exist with negative values of cosmological constant Λ.

The scalar has value

$$\theta = (n+1)\ \left(P + \frac{32\pi K\ \{1+(n-1)u\}}{n(n-1)} e^{-u(n-1)} - \frac{\{3(n+1)u+4\}}{2(n+1)} \beta\, e^{-u(n+1)}\right)^{\frac{1}{2}} \tag{40}$$

The components of shear tensor σ_i^j are given by

$$\sigma_1^1 = \frac{(2n-1)}{3} \left(P + \frac{32\pi K\ \{1+(n-1)u\}}{n(n-1)} e^{-u(n-1)} - \frac{\{3(n+1)u+4\}}{2(n+1)} \beta\, e^{-u(n+1)}\right)^{\frac{1}{2}} \tag{41}$$

$$\sigma_2^2 = -\frac{1}{2}\sigma_1^1 + \frac{L}{2} \tag{42}$$

$$\sigma_3^3 = -\frac{1}{2}\sigma_1^1 - \frac{L}{2} \tag{43}$$

$$\sigma_4^4 = 0 \tag{44}$$

and its magnitude is

$$\sigma^2 = \frac{(2n-1)^2}{12} \left(P + \frac{32\pi K\ \{1+(n-1)u\}}{n(n-1)} e^{-u(n-1)} - \frac{\{3(n+1)u+4\}}{2(n+1)} \beta e^{-u(n+1)}\right) + \frac{L^2}{4} \tag{45}$$

The scalar expansion θ and the components of shear tensor σ_i^j are the decreasing functions of cosmic time u. initially they attain constant values and finally they becomes zero. Thus in the beginning the model has a uniform expansion and there is no expansion at letter stage of cosmic time u.

The spatial volume R is given by

$$R^3 = e^{-u(n+1)} / \left(Pe^{-2u} + \frac{32\pi K}{n} e^{-nu} \left\{\frac{e^u}{(n-1)} + e^{-u} u\right\} - \frac{(3u+4)}{2} \beta \left(e^{-u(n+3)}\right)\right)^{\frac{1}{2}} \tag{46}$$

The spatial volume R of the model is an increasing function of cosmic time u, in the presence of magnetic field K and bulk viscosity β. It is seen that in the beginning of the model, its volume attains the constant value $R = \left(P + \frac{32\pi K}{n(n-1)} - 2\beta\right)$, for $n \neq 1$ and it is an infinite at later stage. This suggested that the model starts with constant volume, (for $n \neq 1$) and it is increasing continuously and diverges to infinity, at final stage of the cosmic time u.

Some Special Cases

A. In the absence of magnetic field K

In the absence of magnetic field K, we write

$$\in (=\lambda) = (2n-1)\beta / 64\,\pi \quad (47)$$

$$\Lambda = \left(\frac{3}{8}\, n\beta\, e^{-u\,(n+1)}\right) \quad (48)$$

$$\theta = (n+1)\,(P - \frac{\{3(n+1)u+4\}}{2(n+1)}\,\beta e^{-u\,(n+1)})^{\frac{1}{2}} \quad (49)$$

$$\sigma_1^1 = \frac{(2n-1)}{3}\left(P - \frac{\{3(n+1)u+4\}}{2(n+1)}\,\beta\, e^{-u\,(n+1)}\right)^{\frac{1}{2}} \quad (50)$$

$$\sigma_2^2 = -\frac{1}{2}\,\sigma_1^1 + \frac{L}{2} \quad (51)$$

$$\sigma_3^3 = -\frac{1}{2}\,\sigma_1^1 - \frac{L}{2} \quad (52)$$

$$\sigma_4^4 = 0 \quad (53)$$

And

$$\sigma^2 = \frac{(2n-1)^2}{12}\left(P - \frac{(3(n+1)u+4)}{2(n+1)}\,\beta\, e^{-u\,(n+1)}\right) + \frac{L^2}{4} \quad (54)$$

$$R^3 = e^{-u(n+1)} / \left(P e^{-2u} - \frac{(3u+4)}{2}\,\beta\, e^{-(n+3)\,u}\right)^{\frac{1}{2}} \quad (55)$$

It is observed that $\in, \lambda, \Lambda > 0$, for $n \neq 1/2$ and $\in (=\lambda) = 0$, for $n = 1/2$. This suggested that the model exist with positive values of cosmological constant Λ for $n \neq 1/2$ and for $n = 1/2$, the model exist but it is dusty universe with positive values of Λ. Thus the model always exist and cosmological constant Λ always positive, in the absence of magnetic field K. The scalar expansion θ, the components of shear tensor and spatial volume are behave in a similar manner as that of behavior appeared in the presence of magnetic field K and they do not yield any new contribution in the absence of magnetic field K.

B. In the absence of bulk viscosity β

In the absence of bulk viscosity β, we have

$$\in (=\lambda) = -2K e^{2u} \quad (56)$$

$$\Lambda = -8\pi K\; e^{-u\,(n-1)} \quad (57)$$

$$\theta = (n+1)(P + \frac{32\pi\, K\{1+(n-1)u\}}{n(n-1)}\, e^{-u(n-1)})^{\frac{1}{2}} \quad (58)$$

$$\sigma_1^1 = \frac{(2n-1)}{3}\left(P + \frac{32\,\pi\, K\,\{1+(n-1)u\}}{n(n-1)}\, e^{-u\,(n-1)}\right)^{\frac{1}{2}} \quad (59)$$

$$\sigma_2^2 = -\frac{1}{2}\,\sigma_1^1 + \frac{L}{2} \quad (60)$$

$$\sigma_3^3 = -\frac{1}{2}\,\sigma_1^1 - \frac{L}{2} \quad (61)$$

$$\sigma_4^4 = 0 \quad (62)$$

$$\sigma^2 = \frac{(2n-1)^2}{12}\left(P + \frac{32\pi K\,\{1+(n-1)u\}}{n(n-1)}\, e^{-u(n-1)}\right) + \frac{L^2}{4} \quad (63)$$

$$R^3 = e^{-u(n+1)} / \left(P e^{-2u} + \frac{32\pi K}{n} e^{-nu} \frac{e^u}{(n-1)} + e^{-u} u\right)^{\frac{1}{2}} \quad (64)$$

In the case of absence of bulk viscosity β, it is seen that $\in$, λ, Λ all are negative shows the nonexistence of the model. The nonexistence of the model is also supported by the values of scalar expansion θ , the components of shear tensor σ_j^i and spatial volume R, as they diverges to infinity, for $n = 1$.

C. In the absence of magnetic field K and bulk viscosity β

For $K = \beta = 0$, the physical quantities have been calculated quantities as

$\in = \lambda = \Lambda = 0$

(65)

$\theta = 0$

(66)

$\sigma_1^1 = \sigma_4^4 = 0\,,\ -\sigma_2^2 = \sigma_3^3 = \frac{L}{2}\,,\ \sigma^2 = \frac{L^2}{4},\ R^3 = 0$ (67)

All the physical quantities $\in$, λ, Λ, θ, σ_1^1, σ_4^4 and R attain zero values shows vacuum model without expansion with zero volume but with constant shear, in the absence of both magnetic field and bulk viscosity.

Conclusions

The cosmological constant Λ playing the important role and affected the behavior of the model in presence as well as in absence of the magnetic field K and the bulk viscosity β in the model. The model exists for $n > 64\pi K e^{2u} / 3\beta$, for positive Λ . The model never dusty with zero value of Λ and model describes dusty universe for $n = 1/2\ (128\ \pi K\ e^{2u} / \beta + 1)$ with $\Lambda \neq 0$. Also if Λ is negative then the model exist in presence of both magnetic field and bulk viscosity. The model has uniform expansion and uniform shear. The model has shear. The model start with nonzero spatial volume and the volume diverges to infinity at final stage.

In the absence of magnetic field K, the model exist for $n \neq 1/2$ and the model is dusty for $n = 1/2$ and in this case the cosmological constant Λ always positive, The nature of scalar expansion, shear and spatial volume is same as that of the nature appeared in the presence of magnetic field. Thus the magnetic field does not affect the physical behavior of the model.

The bulk viscosity β makes a role and affects the physical behavior of the model. In the absence of it, the model does not exist, since $\in$, λ and Λ all are negative. Further in the absence of both magnetic field K and bulk viscosity β , the model represents vacuum universe with zero cosmological constant Λ , but has a constant shear.

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