



**A STUDY ON CLOUD STRING COSMOLOGICAL MODELS USING DIFFERENT DECELERATING PARAMETERS WITH ELECTROMAGNETIC FIELD IN GENERAL THEORY OF RELATIVITY**

**Dr.T.Ramprasad**, Associate Professor, Department of Mathematics, Vasavi College of Engineering(A), Hyderabad, India.

**Abstract**

In this study, we have investigated the Bianchi type-III anisotropic cosmological model in the presence of cloud strings with electro- magnetic field in general theory of relativity. Exact solutions of field equations are obtained using the fact that shear scalar is proportional to scalar expansion and constant decelerating parameter which is derived from variation law of Hubble parameter proposed by Berman[1] and linearly varying decelerating parameter proposed by Akarsu and Dereli [2]. The dynamics and significance of physical parameters of the model are discussed using a graphical representation of these parameters. The dynamics and significance of physical parameters of the models are discussed.

**Keywords:** Bianchitype-III, electro- magnetic field, linearly varying decelerating parameter, constant decelerating parameter.

**Introduction**

Einstein [5] introduced the general theory of relativity in 1916. It was effective in geometrizing the attraction by distinguishing the metric tensor by gravitational possibilities. Around then Einstein felt that our universe is static and he built static models to clarify the advancement of the universe. After Hubble's experiment [9] it is concluded that our universe is non-static. Then all static models are ruled out and non-static models came into picture. Friedmann [6] was the first one to investigate the most general homogeneous isotropic non-static model described by Robertson-Walker metric.

Spatially homogeneous and isotropic FRW models are the best fit models to speak about the huge scope structure of the current day universe. This fact is confirmed by the analysis of cosmic microwave back ground fluctuations. But FRW models fail to explain the correct matter distribution, in beginning phases of development of the universe and furthermore there is proof of anisotropy in beginning phases of universe. Henceforth the models with anisotropic foundation are appropriate to clarify beginning phases of universe. This way the examination of Bianchi models assumes a crucial job in understanding the beginning phases of development of universe. Several authors studied spatially homogeneous anisotropic Bianchi models to get the relativistic picture of early universe. In particular, Singh and Chaubey [19], Saha and Yadav [17], Adhav et al. [1], Akarsu and Kilnic [3], Yadav et al. [23], Pradhan et al. [15], have examined diverse Bianchi models with normal impeccable liquids.

The past two decades saw a raising importance to string cosmological models and have gotten extensive consideration of researchers in view of their significance in structure arrangement during the early universe. During the state change of the early universe, unconstrained balance breaking offers ascend to an arbitrary system of stable line like topological deformities known as cosmic strings. It is notable that massive strings are the principal components for the development of huge structures like the galaxies and galaxy clusters in the universe. Letlier [12], Stachel [20] and Sahoo [18] examined the different significant highlights of string cosmological models either in the casing work of general relativity or in modified theories of gravitation. Pavon et al. [14] and Mohanty and Pradhan [15] are some of the authors who have investigated bulk viscous cosmological models in general relativity.

The magnetized cosmological model plays a vital role in evolution of the universe and in the formation of galaxies and cluster of galaxies and other stellar bodies. The electromagnetic field which was generated during inflation is also one cause for the present period of accelerated expansion of the universe. The statistical breakdown of isotropy is additionally because of magnetic field. The magnetic



fields are hosted by the galaxies and cluster of galaxies. Subramanian [11] on his paper indicated that magnetic fields have significant on arrangement of stellar structures. Also so many authors have studied magnetized cosmological models. Some prominent in this context are Jimenez and Marato [10], Tripathy et al. [21], Parikh [13] and Grasso [7]. So many authors have studied string models with electromagnetic field to understand the evolution of the universe in early phases. Rahman and Hegazy have studied Bianchi type  $VI_0$  cosmological model with electromagnetic variable decelerating parameter in general relativity [8], mainly Tripathi et al. have investigated magnetized string model in Bianchi type  $-III$  universe [22]. Recently Priyokumar Singh et al. have obtained cloud string cosmological model with electromagnetic field in Bianchi type-I universe in general relativity [16]. Till the date no one has obtained magnetized cloud string model with varying decelerating parameter in the frame work Bianchi type  $-III$  universe in general relativity.

Inspired by the above discussion and investigations, in this paper we have considered the magnetized cloud string cosmological model with straightly changing deceleration parameter in Bianchi type-III space time in General hypothesis of relativity proposed by Einstein. This paper is sorted out as follows: in sect.2 field equations are determined in Bianchi type-III universe. In sect.3 the solutions of field conditions are determined with the assistance of directly fluctuating deceleration parameter. Sect.4 manages the physical conversation of the model and last segment contains a few finishes of the acquired model.

### Metric and Field Equations:

The spatially homogeneous anisotropic Bianchi type-III metric is of the form

$$ds^2 = -dt^2 + X^2 dx^2 + Y^2 e^{-2x} dy^2 + Z^2 dz^2 \quad (1)$$

Where  $X = X(t), Y = Y(t), Z = Z(t)$ .

The mixed tensor form of energy momentum tensor for strings with electromagnetic field is

$$T_j^i = \rho u^i u_j - \lambda x^i x_j + E_j^i \quad (2)$$

where  $\rho$  denotes the density of strings which is equal to  $\rho = \rho_p + \lambda$ , here  $\rho_p, \lambda$  denote the particle density and tension density of the string respectively.

Here  $x_i, u_i$  satisfies

$$u^i u_i = -x^i x_i = -1 \quad (3)$$

and

$$u^i x_i = 0 \quad (4)$$

Also  $u^i$  and  $x^i$  in the direction of parallel to x-axis are given by

$$u^i = (0, 0, 0, 1) \quad (5)$$

and

$$x^i = \left(\frac{1}{L}, 0, 0, 0\right) \quad (6)$$

The electromagnetic field  $E_{ij}$  in mixed tensor form considered as

$$E_i^j = -F_{ir} F^{jr} + \frac{1}{4} F_{ab} F^{ab} g_i^j \quad (7)$$

where  $F_{ij}$  is electromagnetic field tensor.

By quantizing the magnetic field along x-axis, we will get only one non- vanishing component  $F_{14}$  in  $F_{ij}$ . i.e.  $F_{ij} = 0$  for  $i, j = 1, 2, 3, 4$  except  $F_{14}$ .

The non-vanishing components of  $E_i^j$  derived from equation (7) are

$$E_1^1 = -E_2^2 = -E_3^3 = E_4^4 = \frac{1}{2A^2} (F_{14})^2 \quad (8)$$

The field equations in general theory of relativity (with  $\frac{8\pi G}{c^4} = 1$ ) is given by

$$G_j^i = -T_j^i \quad (9)$$

Where  $G_j^i$  is Einstein tensor.



By using equations (9) and (2) for the metric (1), the non-vanishing field equation can be obtained as

$$\frac{\ddot{Y}}{Y} + \frac{\ddot{Z}}{Z} + \frac{\dot{Y}\dot{Z}}{YZ} = \lambda - \frac{1}{2X^2}(F_{14})^2 \tag{10}$$

$$\frac{\ddot{Y}}{Y} + \frac{\ddot{Z}}{Z} + \frac{\dot{Y}\dot{Z}}{YZ} = \frac{1}{2X^2}(F_{14})^2 \tag{11}$$

$$\frac{\ddot{X}}{X} + \frac{\dot{X}\dot{Y}}{XY} + \frac{\dot{Y}}{Y} - \frac{1}{X^2} = \frac{1}{2X^2}(F_{14})^2 \tag{12}$$

$$\frac{\ddot{X}}{X} + \frac{\dot{X}\dot{Y}}{XY} + \frac{\dot{Y}}{Y} - \frac{1}{X^2} = \rho - \frac{1}{2X^2}(F_{14})^2 \tag{13}$$

$$\frac{\ddot{X}}{X} - \frac{\dot{Y}}{Y} = 0 \tag{14}$$

where overhead single, double dots denotes for first and second order derivatives w.r.t  $t$  respectively. For the equation (1), the scale factor  $a(t)$ , spatial volume  $V$ , Hubble parameter  $H$ , Scalar expansion  $\theta$ , shear scalar  $\sigma^2$  and average anisotropy parameter  $A_h$  are the physical and kinematical parameters which can be used to solve the above field equations. They are defined as follows

$$a(t) = (XYZ)^{\frac{1}{3}} \tag{15}$$

$$V = (Z(t))^3 = XYZ \tag{16}$$

$$H = \frac{1}{3}\left(\frac{\dot{X}}{X} + \frac{\dot{Y}}{Y} + \frac{\dot{Z}}{Z}\right) \tag{17}$$

$$\theta = u^i_{;i} = 3H = \left(\frac{\dot{X}}{X} + \frac{\dot{Y}}{Y} + \frac{\dot{Z}}{Z}\right) \tag{18}$$

$$\sigma^2 = \frac{1}{2}\sigma_{ij}\sigma^{ij} = \frac{1}{2}\left(\frac{\dot{X}^2}{X^2} + \frac{\dot{Y}^2}{Y^2} + \frac{\dot{Z}^2}{Z^2}\right) - \frac{1}{6}(\theta^2) \tag{19}$$

$$A_h = \frac{1}{3}\sum_{i=1}^3\left(\frac{H_i-H}{H}\right)^2 \tag{20}$$

**Solutions and Model:**

From equation (14) it is obtained that

$$X = kY \tag{21}$$

where  $k$  is constant of integration. Without loss of generality we can choose  $k = 1$ , so

$$X = Y \tag{22}$$

Using eq. (22) the field equations (10)-(13) reduces to

$$\frac{\ddot{Y}}{Y} + \frac{\ddot{Z}}{Z} + \frac{\dot{Y}\dot{Z}}{YZ} = \lambda \tag{23}$$

$$\left(\frac{\dot{Y}}{Y}\right)^2 + 2\frac{\dot{Y}}{Y} - \frac{1}{Y^2} = \frac{1}{2Y^2}(F_{14})^2 \tag{24}$$

$$\left(\frac{\dot{Y}}{Y}\right)^2 + 2\frac{\dot{X}\dot{Y}}{XY} - \frac{1}{Y^2} = \rho - \frac{1}{2Y^2}(F_{14})^2 \tag{25}$$

Clearly this is a system of three differential equations in five unknowns  $B, C, \lambda, \rho$  and  $F_{14}$ . To get the solution of these highly non-linear differential equations we use the following conditions which are physically important.

**3.1. Case(1): Model with varying decelerating parameter**

The shear scalar  $\sigma^2$  is proportional to scalar expansion  $\theta$  so that we can take (Collins et al. [4])

$$Y = Z^n \tag{26}$$

where  $n \neq 1$  is a constant and preserves the anisotropic nature of the model.

A generalized linearly varying deceleration parameter (Akarsu and Dereli [2])

$$q = -\frac{a\ddot{a}}{\dot{a}^2} = -kt + m - 1 \tag{27}$$



where  $k > 0$  and  $m > 0$ .

from equation (27) we can obtain  $R(t)$  as follows

$$R(t) = c_2 e^{\frac{2}{m} \tanh^{-1}\left(\frac{k}{m}t-1\right)} = c_2 \left(\frac{\frac{k}{m}t}{2-\frac{k}{m}t}\right)^{\frac{1}{m}} \tag{28}$$

where  $c_2$  is integration constant which can be choose as unity.

from equations (28),(26) and (22) we can obtain the metric potentials are obtained as follows

$$Z = \left(\frac{\frac{k}{m}t}{2-\frac{k}{m}t}\right)^{\frac{3}{m(2n+1)}} \tag{29}$$

$$Y = \left(\frac{\frac{k}{m}t}{2-\frac{k}{m}t}\right)^{\frac{3n}{m(2n+1)}} = X \tag{30}$$

by using equations (29),(30) the metric eq.(1) can be written as

$$ds^2 = -dt^2 + \left(\frac{\frac{k}{m}t}{2-\frac{k}{m}t}\right)^{\frac{6n}{m(2n+1)}} dx^2 + \left(\frac{\frac{k}{m}t}{2-\frac{k}{m}t}\right)^{\frac{6n}{m(2n+1)}} e^{-2x} dy^2 + \left(\frac{\frac{k}{m}t}{2-\frac{k}{m}t}\right)^{\frac{6}{m(2n+1)}} dz^2 \tag{31}$$

Eq. (31) represents the magnetized cloud string cosmological model with linearly changing deceleration parameter in Einstein's theory of general relativity.

### 3.2. Physical discussion of the model:

The physical and kinematical parameters  $V, H, \theta, \sigma^2$  and  $A_h$  which are very important in physical discussion of the model are as follows

$$V = \left(\frac{\frac{kt}{m}}{2-\frac{kt}{m}}\right)^{\frac{3}{m}} \tag{32}$$

$$H = \frac{2}{t(2m-kt)} \tag{33}$$

$$\theta = \frac{6}{t(2m-kt)} \tag{34}$$

$$\sigma^2 = \frac{12(n-1)^2}{t^2(2n+1)^2(2m-kt)^2} \tag{35}$$

$$A_h = \frac{2(n-1)^2}{(2n+1)^2} \tag{36}$$

From (34) and (35), we have

$$\lim_{t \rightarrow \infty} \frac{\sigma^2}{\theta^2} = \frac{(n-1)^2}{3(2n+1)^2} = \text{constant } (\neq 0 \text{ from } n \neq 1) \tag{37}$$

The string density is obtained from eqns. (23),(29) and (30) as follows

$$\lambda = \frac{72(n^2+n+1)+12(n+1)(2m-2kt)(2n+1)}{t^2(2n+1)^2(2m-kt)^2} \tag{38}$$

From eqns. (24),(25),(29) and (30) the energy density is obtained as

$$\rho = \frac{72n+24mn-24nkt}{t^2(2n+1)(2m-kt)^2} - 2 \left(\frac{2m-kt}{kt}\right)^{\frac{6n}{m(2n+1)}} \tag{39}$$

From eqns. (24),(29) and (30) we obtain  $F_{14}^2$  is obtained as

$$F_{14}^2 = 2 \left(\frac{kt}{2m-kt}\right)^{\frac{6n}{m(2n+1)}} \left(\frac{108n^2+24n(2n+1)(m-kt)}{t^2(2n+1)^2(2m-kt)^2}\right) - 2 \tag{40}$$

The particle density is obtained from  $\rho_p = \rho - \lambda$  as follows



$$\rho_p = \frac{72n^2 - 48mn - 24m - 72 + 24k(2n+1)t}{t^2(2n+1)^2(2m-kt)^2} - 2 \left( \frac{2m-kt}{kt} \right)^{\frac{6n}{m(2n+1)}} \quad (41)$$

### 3.3. Case(2): Model with constant decelerating parameter

Variation of the Hubble's parameter proposed by Berman[1] which yields constant deceleration parameter models defined by

$$q = -\frac{a\ddot{a}}{\dot{a}^2} = m - 1 \quad (42)$$

where  $m$  is a constant.

from equation (33) we can obtain  $a(t)$  as follows

$$a(t) = (c_1mt + c_2)^{\frac{1}{m}} \quad (43)$$

where  $c_1, c_2$  are integration constants.

from equations (26),(43) and (28) we can obtain the metric potentials are obtained as follows

$$Z = (c_1mt + c_2)^{\frac{3}{m(2n+1)}} \quad (44)$$

$$Y = (c_1mt + c_2)^{\frac{3n}{m(2n+1)}} = X \quad (45)$$

by using equations (44),(45) the metric eq.(1) can be written as

$$ds^2 = -dt^2 + (c_1mt + c_2)^{\frac{6n}{m(2n+1)}} dx^2 + (c_1mt + c_2)^{\frac{6n}{m(2n+1)}} e^{-2x} dy^2 + (c_1mt + c_2)^{\frac{6}{m(2n+1)}} dz^2 \quad (46)$$

Eq. (46) represents the magnetized cloud string cosmological model with constant deceleration parameter in Einstein's theory of general relativity.

### 3.4. Physical discussion of the model:

The physical and kinematical parameters  $V, H, \theta, \sigma^2$  and  $A_h$  which are very important in physical discussion of the model are as follows

$$V = (c_1mt + c_2)^{\frac{3}{m}} \quad (47)$$

$$H = \frac{c_1}{c_1mt + c_2} \quad (48)$$

$$\theta = \frac{3c_1}{c_1mt + c_2} \quad (49)$$

$$\sigma^2 = \frac{3(n-1)^2 c_1^2}{(2n+1)^2 (c_1mt + c_2)^2} \quad (50)$$

$$A_h = \frac{2(n-1)^2}{(2n+1)^2} \quad (51)$$

From (43) and (44), we have

$$\lim_{t \rightarrow \infty} \frac{\sigma^2}{\theta^2} = \frac{(n-1)^2}{3(2n+1)^2} = \text{constant } (\neq 0 \text{ from } n \neq 1) \quad (52)$$

The string density,energy density are obtained as

$$\lambda = \frac{6c_1^2 [3(n^2+n+1) - m(2n^2+3n+1)]}{(2n+1)^2 (c_1mt + c_2)^2} \quad (53)$$

$$\rho = \frac{6nc_1^2(3-m)}{(2n+1)(c_1mt + c_2)^2} - 2(c_1mt + c_2)^{\frac{-6n}{m(2n+1)}} \quad (54)$$

Also we obtain  $F_{14}^2$  as

$$F_{14}^2 = \frac{nc_1^2(54n-24mn-12m)}{(2n+1)^2} (c_1mt + c_2)^{\frac{6n-4mn-2m}{m(2n+1)}} - 2 \quad (55)$$

The particle density is obtained from  $\rho_p = \rho - \lambda$  as follows

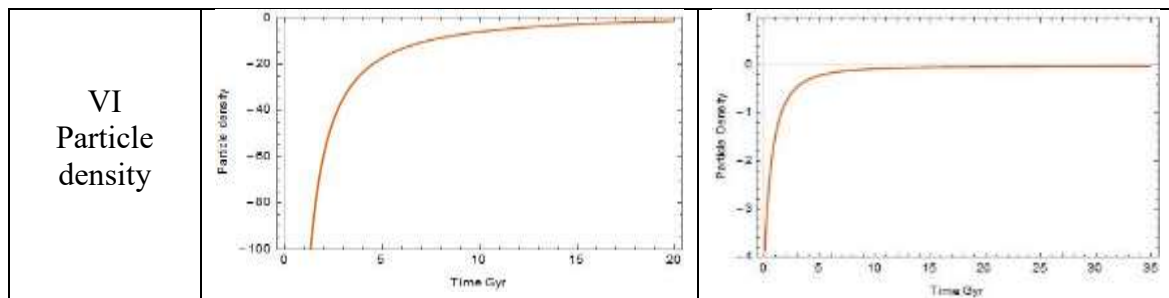
$$\rho_p = \frac{6c_1^2 [m(2n+1) + 3(n^2-1)]}{(2n+1)^2 (c_1mt + c_2)^2} - 2(c_1mt + c_2)^{\frac{-6n}{m(2n+1)}} \quad (56)$$

For the physical discussion of the parameters the discussion about parameters and the graphs of parameters versus time  $t$  (Gyr) are as follows



Parameter	Case(1) With Linearly Varying deceleration ( $k = 0.113, m = 2$ and $n = 2$ )	Case(2) With Constant deceleration ( $m = 0.5, c_1 = 1, c_2 = 1$ and $n = 0.5$ )
I Spatial Volume		
II Deceleration Parameter		
III Tension density		
IV Scalar Expansion		
V Hubble Parameter		





### Conclusions:

We have obtained the magnetized cloud string cosmological model in Bianchi type-III anisotropic universe in Einstein's theory of general relativity. To get the solutions of the field equations we have taken the help of both linearly varying decelerating parameter proposed by Akarsu and Dereli [2] and constant decelerating parameter by Berman[1] in both the cases. It is observed that the spatial volume increases w.r.t. time  $t$  and the parameters  $H, \theta, \sigma^2$  and  $\rho$  decreases as  $t \rightarrow \infty$ . In this model  $H > 0$  throughout the evolution of the universe and  $q < 0$  at present  $t \approx 13.7168$ . This shows that the present day universe which is in accelerated expansion. It is seen that

$\lim_{t \rightarrow \infty} \frac{\sigma^2}{\theta^2} = \frac{(n-1)^2}{3(2n+1)^2} = \text{constant} (\neq 0 \text{ from } n \neq 1)$ , so both the obtained models in the two cases doesnot tend to isotropic nature for  $t \rightarrow \infty$ . It is seen that  $\rho_p$  has a large negative value at  $t = 0$  and it approaches a constant positive finite value as  $t \rightarrow \infty$ . So the universe will be dominated by particles for late time. We have observed the string tension density tends to zero as  $t \rightarrow \infty$ , so the obtained models represents the present day matter dominated universe. So we hope that this models has a good agreement with the present day scenario of the universe.

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