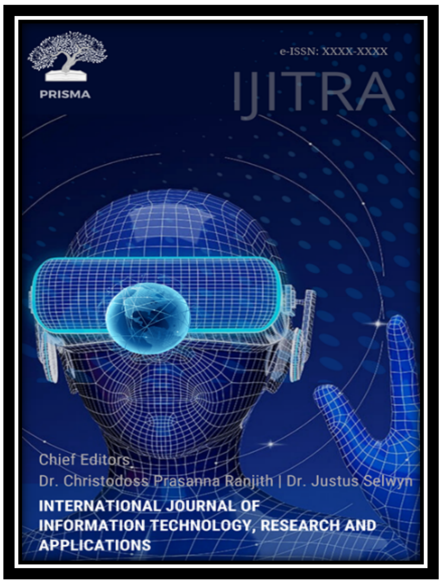

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Anisotropic Magnetized String model with Constant Decelerating Parameter in General Theory of Relativity.

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ABSTRACT

In this article, 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]. The dynamics and significance of physical parameters of the model are discussed using a graphical representation of these parameters. The physical and kinematical properties found in this model exhibit an accelerating expansion of the universe, which are compatible with current cosmological observations.
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I. INTRODUCTION

The discovery of accelerated expansion of the universe led to a number of new ideas in cosmology. Several modifications of Einstein's theory have been proposed from time to time. Einstein's theory of gravitation is generally acclaimed as a satisfactory theory of gravitation. It describes relativity of all kinds of motion that generalizes special theory of relativity and Newtonian theory of gravitation. This is also a beautiful geometric theory of gravitation (Einstein 1916) which gives a unified description of gravity as geometric property of space-time. In particular, the curvature of space-time is directly related to the four momentum and radiation. In this theory the space-time is described by the pseudo Riemannian metric

$$ds^2 = g_{ij}dx^i dx^j \qquad i, j = 1,2,3,4 \qquad (1)$$

and the components of the symmetric tensor g_{ij} act as gravitational potentials., with the general field equations which govern the gravitational field are given by

$$G_{ij} \equiv R_{ij} - \frac{1}{2}Rg_{ij} + \Lambda g_{ij} = -8\pi T_{ij} \qquad (2)$$

where G_{ij} is the Einstain tensor, R_{ij} is the Ricci tensor, R is the scalar curvature, T_{ij} is the energy momentum tensor due to matter and Λ is the cosmological constant. This cosmological constant was introduced by Einstein, while studying static cosmological models. It may be mentioned that, in recent years, the cosmological constant is gaining lime light and attracting many researchers to general relativity but as a variable and not as a constant. Since the Einstein tensor G_{ij} is divergence free, the field equations (2) yield

$$T^{ij}_{;j} \equiv 0 \qquad (3)$$

which can be considered as the energy-momentum conservation equation and which also gives us the equations of motion of matter. Einstein's theory of relativity is in good agreement with the three crucial tests of relativity, namely, gravitational deflection of light, precession of perihelion of planet Mercury and gravitational red shift. This theory has also been successful in describing cosmology and cosmological models of the universe.

Bianchi type cosmological models are important in the sense that these are homogeneous and anisotropic in which a process of isotropization of universe is studied through the passage of time. More over from the theoretical point of view anisotropic universes have a greater generality than isotropic models. Space-times admitting a three-parameter group of automorphisms are important in the discussion of cosmological models. The case where the group is simply transitive over the three-dimensional, constant-time subspace is particularly useful. Bianchi has shown that there are only nine distinct sets of structure constants for groups of this type so that the algebra may be easily used to classify homogeneous space-times. Thus, Bianchi type space-times admit a three-parameter group of motions and hence have only a manageable number of degrees of freedom. During the last three decades there has been considerable work done on anisotropic universes. The simplest of them are the well-known nine types of Bianchi models Taub[18] which are necessarily spatially homogeneous. Out of the nine types of Bianchi models the only types, which tend towards isotropy at arbitrary large times and hence permit the formation of galaxies and the development of intelligent life, are the types-I,V.VII_0 and VII_h Collins and Hawking[3]. A complete list of all exact solutions of Einstein's equations for the Bianchi types I – IX with perfect fluid matter is given by Krammer et al.[8]

At the very early stages of the evolution the universe had undergone a number of phase transitions as it cooled down from its hot initial state. During the phase transitions the symmetry of the universe is broken spontaneously and it can give rise to various forms of topological defects. A defect is a discontinuity in the vacuum and depending on the topology of the vacuum the defects could be cosmic strings, domain walls, monopoles and textures (Kibble[9]; Mermin [12]). Pando et al.[13] have proposed that the topological defects are responsible for structure formation of the universe. Among the above topological defects strings have important astrophysical consequences, namely, double quasar problem and galaxy formation can, well, be explained by strings (Vilenkin and Shellard[21]). Vilenkin [22] has shown that the strings can act as a gravitational lense and hence astronomical observations may detect these objects. String theory is also considered as the promising candidate for unification of all forces. The present-day configurations of the universe are not contradicted by large scale network of the strings in the early universe. They are also considered as one of the sources of density perturbations that are required for formation of large-scale structure in the universe. Stachel[17], Letelier[11], Shiwarz[16] presented a brief chronology of some of the major developments that has taken place in string theory.

The general relativistic treatment of strings was initiated by Stachel[17] and Letelier[10]. According to Letelier[10], the massive strings are nothing but geometric strings (mass less) with particles attached along its extension. So the total energy-momentum tensor for a cloud of massive strings can be written as [for a detailed derivation of energy-momentum tensor for a cloud of strings one can refer Letelier[10,11]; Stachel[17]

$$T_{ij} = \rho u_i u_j \qquad (4)$$

Where ρ is the rest energy density for a cloud of strings with particles attached to them. So we can write

$$\rho = \rho_p + \lambda \qquad (5)$$

ρ_p being the particle energy density andλ being the tension density of the string. The four- velocity u^i for the cloud of particles and the four- vector x^i the direction of string, satisfy

$$u_i u_j = 1 = -x_i x^j \quad and \quad u_i x^i = 0 \qquad (6)$$

In fact, the first category of models with constant deceleration parameter is that of models where the cosmic expansion is driven by the big-bang impulse; all the matter and radiation energy is produced at the big-bang epoch and the universe has a singular origin. In the second category of models with constant q, the cosmic expansion is driven by the creation of matter particles and the universe has a non-singular origin.

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 [7] in his paper indicated that magnetic fields have significance in the arrangement of stellar structures. Also so many authors have studied magnetized cosmological models. Some prominent in this context are Jimenez and Marato[6], Tripathy et al.[19], Parikh [14] and Grasso [4]. So many authors have studied string models with electromagnetic field to understand the evolution of the universe in early phases. Hegazy and Rahman [5] have studied Bianchi type VI_0 cosmological model with electromagnetic variable decelerating parameter in general relativity, mainly Tripathi et al.2017[20] have investigated magnetized string model in Bianchi type –III universe. Recently Priyo kumar Singh et al.[15] have obtained cloud string cosmological model with electromagnetic field in Bianchi type-I universe in general relativity. Till date no one has obtained magnetized cloud string model with constant 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 unchanged 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 constant deceleration parameter. Sect.4 manages the physical conversation of the model and last segment contains a few conclusions of the acquired model.

II. METRIC AND FIELD EQUATIONS:

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

$$ds^2 = -dt^2 + P^2dx^2 + Q^2e^{-2x}dy^2 + R^2dz^2 \tag{7}$$

Where $P = P(t), Q = Q(t), R = R(t)$.

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

$$T_j^i = \rho u^i u_j - \lambda x^i x_j + E_j^i \tag{8}$$

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

Here x_i , u_i satisfies

$$u^i u_i = -x^i x_i = -1 \tag{9}$$

and

$$u^i x_i = 0 \tag{10}$$

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

$$u^i = (0,0,0,1) \tag{11}$$

and

$$x^i = \left(\frac{1}{P}, 0,0,0\right) \tag{12}$$

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

$$E_i^j = -F_{ir}F^{jr} + \frac{1}{4}F_{ab}F^{ab}g_i^j \tag{13}$$

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} inF_{ij}.

i.e. $F_{ij} = 0$ $\quad for i,j = 1,2,3,4$ except F_{14}.

The non-vanishing components of E_i^j derived from equation (13) are

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

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

$$G_j^i = -T_j^i \tag{15}$$

Where G_j^i is Einstein tensor.

By using equations (15) and (8) for the metric (7), the non-vanishing field equation can be obtained as

$$\frac{\ddot{Q}}{Q} + \frac{\ddot{R}}{R} + \frac{\dot{Q}\dot{R}}{QR} = \lambda - \frac{1}{2P^2}(F_{14})^2 \tag{16}$$

$$\frac{\ddot{P}}{P} + \frac{\ddot{R}}{R} + \frac{\dot{P}\dot{R}}{PR} = \frac{1}{2P^2}(F_{14})^2 \tag{17}$$

$$\frac{\ddot{P}}{P} + \frac{\dot{P}\dot{Q}}{PQ} + \frac{\ddot{Q}}{Q} - \frac{1}{P^2} = \frac{1}{2P^2}(F_{14})^2 \tag{18}$$

$$\frac{\dot{P}\dot{Q}}{PQ} + \frac{\dot{Q}\dot{R}}{QR} + \frac{\dot{P}\dot{R}}{PR} - \frac{1}{P^2} = \rho - \frac{1}{2P^2}(F_{14})^2 \tag{19}$$

$$\frac{\dot{P}}{P} - \frac{\dot{Q}}{Q} = 0 \tag{20}$$

where overhead single, double dots denotes for first and second order derivatives w.r.t t respectively.

For the equation (7), the scale factor $a(t)$, spatial volume V, Hubble parameter H, Scalar expansion θ, shear scalar σ^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

$$a(t) = (PQR)^{\frac{1}{3}} \tag{21}$$

$$V = \left(a(t)\right)^3 = PQR \tag{22}$$

$$H = \frac{1}{3}\left(\frac{\dot{P}}{P} + \frac{\dot{Q}}{Q} + \frac{\dot{R}}{R}\right) \tag{23}$$

$$\theta = u^i_{;i} = 3H = \left(\frac{\dot{P}}{P} + \frac{\dot{Q}}{Q} + \frac{\dot{R}}{R}\right) \tag{24}$$

$$\sigma^2 = \frac{1}{2}\sigma_{ij}\sigma^{ij} = \frac{1}{2}\left(\frac{\dot{P}^2}{P^2} + \frac{\dot{Q}^2}{Q^2} + \frac{\dot{R}^2}{R^2}\right) - \frac{1}{6}(\theta^2) \tag{25}$$

$$A_h = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{H_i - H}{H}\right)^2 \tag{26}$$

III. SOLUTIONS AND MODEL:

From equation (20) it is obtained that

$$P = kQ \tag{27}$$

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

$$P = Q \tag{28}$$

Using eq. (28) the field equations (16)-(19) reduces to

$$\frac{\ddot{Q}}{Q} + \frac{\ddot{R}}{R} + \frac{\dot{Q}\dot{R}}{QR} = \frac{\lambda}{2} \tag{29}$$

$$\left(\frac{\dot{Q}}{Q}\right)^2 + 2\frac{\ddot{Q}}{Q} - \frac{1}{Q^2} = \frac{1}{2Q^2}(F_{14})^2 \tag{30}$$

$$\left(\frac{\dot{Q}}{Q}\right)^2 + 2\frac{\dot{Q}\dot{R}}{QR} - \frac{1}{Q^2} = \rho - \frac{1}{2Q^2}(F_{14})^2 \tag{31}$$

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

(i) The shear scalar σ^2 is proportional to scalar expansion θ so that we can take (Collins et al. [2])

$$Q = R^n \tag{32}$$

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

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

$$q = -\frac{a\ddot{a}}{\dot{a}^2} = m - 1 \tag{33}$$

where m is a constant.

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

$$a(t) = (c_1 mt + c_2)^{\frac{1}{m}} \tag{34}$$

where c_1, c_2 are integration constants.

from equations (34),(32) and (28) we can obtain the metric potentials are obtained as follows

$$R = (c_1 mt + c_2)^{\frac{3}{m(2n+1)}} \tag{35}$$

$$\boldsymbol{Q = (c_1 mt + c_2)^{\frac{3n}{m(2n+1)}} = P} \tag{36}$$

by using equations (35),(36) the metric eq.(7) can be written as

$$ds^2 = -dt^2 + (c_1 mt + c_2)^{\frac{6n}{m(2n+1)}}dx^2 + (c_1 mt + c_2)^{\frac{6n}{m(2n+1)}}e^{-2x}dy^2 + (c_1 mt + c_2)^{\frac{6}{m(2n+1)}}dz^2 \tag{37}$$

Eq. (37) represents the magnetized cloud string cosmological model with constant deceleration parameter in Einstein's theory of general relativity.

IV. PHYSICAL DISCUSSION OF THE MODEL:

The physical and kinematical parameters V, H, θ, σ^2 and A_h which are very important in physical discussion of the model are as follows

$$V = \left(c_1 mt + c_2\right)^{\frac{3}{m}} \tag{38}$$

$$H = \frac{c_1}{c_1 mt + c_2} \tag{39}$$

$$\theta = \frac{3c_1}{c_1 mt + c_2} \tag{40}$$

$$\sigma^2 = \frac{3\left(n-1\right)^2 c_1^2}{\left(2n+1\right)^2 \left(c_1 mt + c_2\right)^2} \tag{41}$$

$$A_h = \frac{2\left(n-1\right)^2}{\left(2n+1\right)^2} \tag{42}$$

From (34) and (35), we have

$$\lim_{t\to\infty} \frac{\sigma^2}{\theta^2} = \frac{\left(n-1\right)^2}{3\left(2n+1\right)^2} = \text{constant} \quad \left(\neq 0\, from\, n \neq 1\right) \tag{43}$$

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

$$\lambda = \frac{6c_1^{\,2}\left[3\left(n^2+n+1\right) - m\left(2n^2+3n+1\right)\right]}{\left(2n+1\right)^2 \left(c_1 mt + c_2\right)^2} \tag{44}$$

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

$$\rho = \frac{6nc_1^{\,2}\left(3-m\right)}{\left(2n+1\right)\left(c_1 mt + c_2\right)^2} - 2\left(c_1 mt + c_2\right)^{\frac{-6n}{m(2n+1)}} \tag{45}$$

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

$$F_{14}^{\,2} = \frac{nc_1^{\,2}\left(54n - 24mn - 12m\right)}{\left(2n+1\right)^2}\left(c_1 mt + c_2\right)^{\frac{6n-4mn-2m}{m(2n+1)}} - 2 \tag{46}$$

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

$$\rho_p = \frac{6c_1^{\,2}\left[m\left(2n+1\right) + 3\left(n^2-1\right)\right]}{\left(2n+1\right)^2 \left(c_1 mt + c_2\right)^2} - 2\left(c_1 mt + c_2\right)^{\frac{-6n}{m(2n+1)}} \tag{47}$$

For the physical discussion of the parameters we choose $m = 0.5, c_1 = 1, c_2 = 1\, and\ n = 0.5$, the discussion about parameters and the graphs of parameters versus time t (Gyr) are as follows

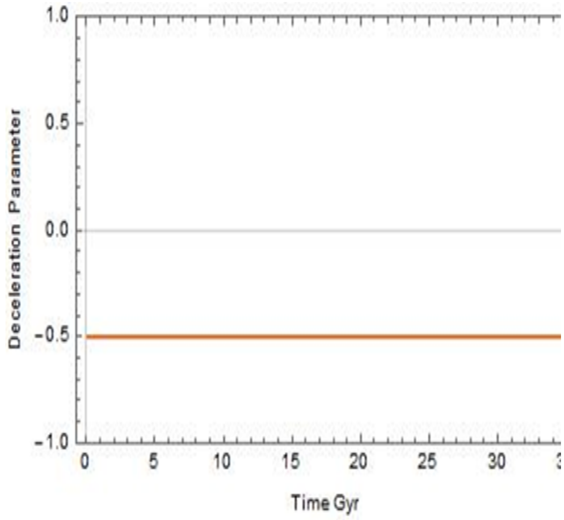

Figure 1: q versus t

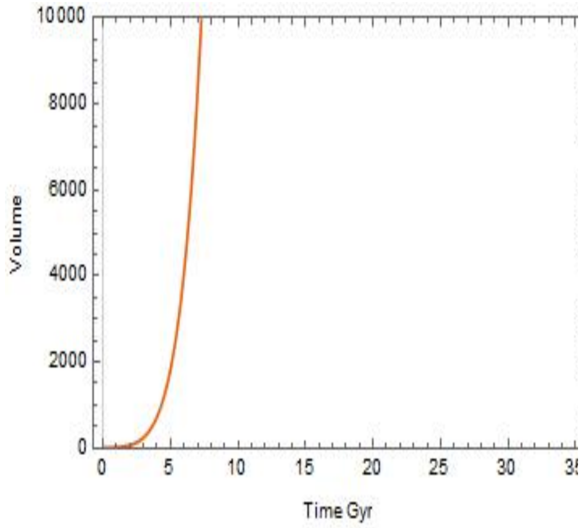

Figure2: V versus time t

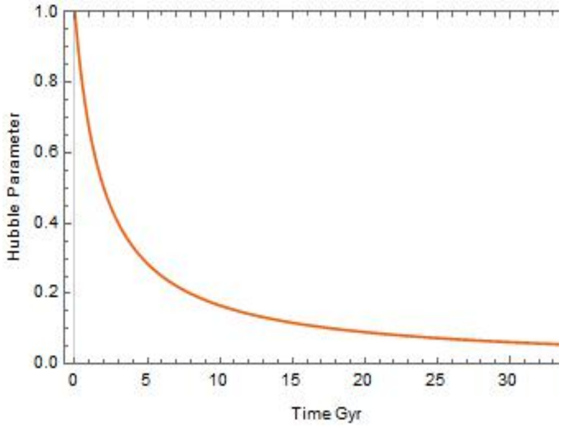

Figure3: H versus time t

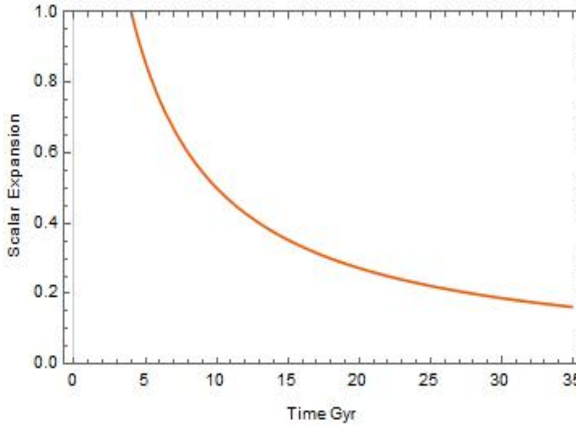

Figure 4: θ versuss time t

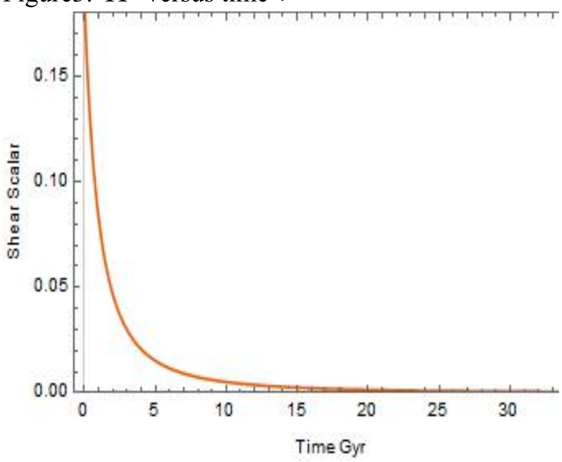

Figure 5: σ^2 versus time t.

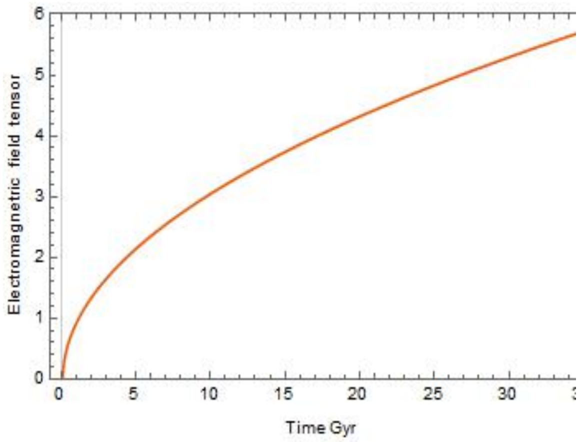

Figure 6: F_{14} versus time t

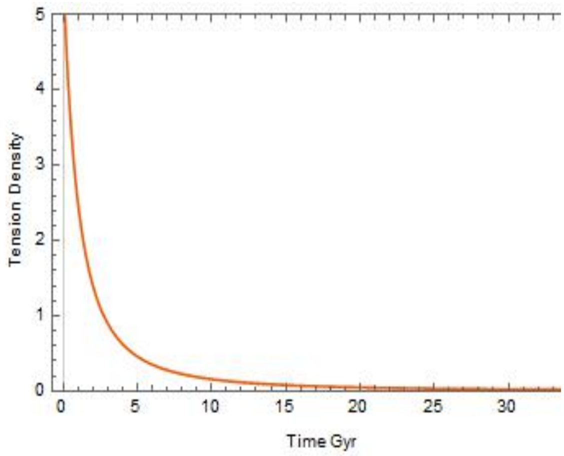

Figure 7: λ versus time t

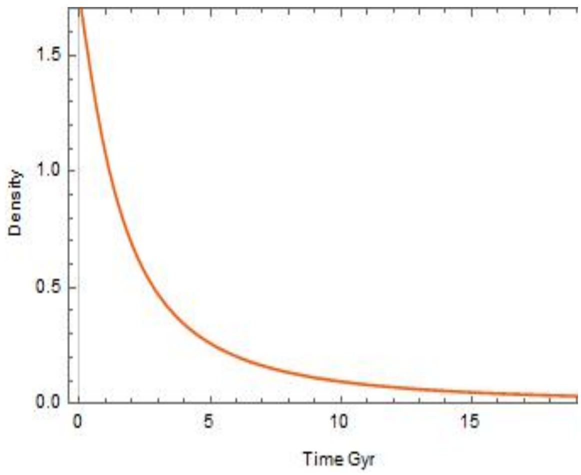

Figure 8: ρ versus time t

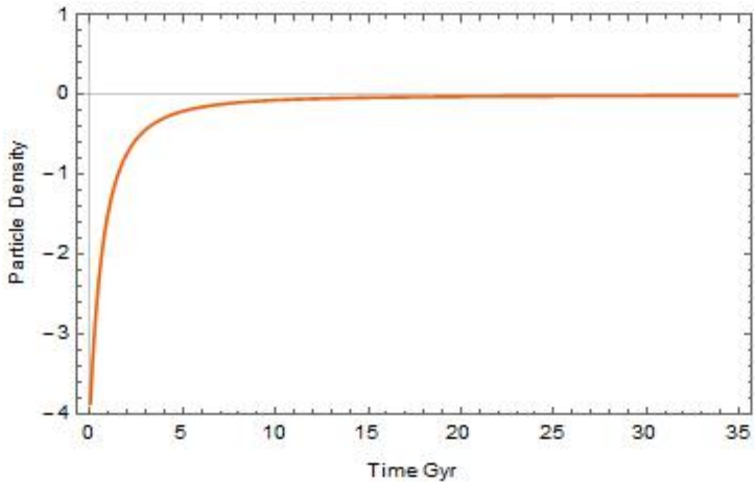

Figure 9: ρ_p versus time t

From the above results, the physical discussion of the obtained model is done in section 5. To get a clear picture about the parameters which are involved in physical discussion of the model, we have drawn the graphs of parameters versus time t by choosing the unknowns as $m = 0.5, c_1 = 1, c_2 = 1 \, and \;\; n = 0.5$. We conclude our results in next section as follows.

V. CONCLUSION

We have obtained a Bianchi type-III string cosmological model in the presence of electro-magnetic field in Einstein's theory of general relativity. We have used the constant deceleration parameter which is derived from variation law of Hubble's parameter proposed by Berman [1] to get the determinate solution of the model. We have obtained various cosmological parameters to get a clear picture of evolution and accelerated expansion of the model. It is observed from figure (2), that the spatial volume increases with respect to time *t*, which shows the spatial expansion of the universe. From figures (3, 4, 5, 8), it is seen that the parameters H, θ, σ^2 and ρ diverge at initial epoch i.e. $t = 0$ and decreases to tend a finite value as $t \to \infty$. It can be seen From Figs. 3 and 1 that $H > 0$ and *q* is constant $q < 0$ throughout the evolution of the universe. So, the obtained model universe is expanding with constant acceleration. It is seen that

$\lim_{t\to\infty} \frac{\sigma^2}{\theta^2} = \frac{(n-1)^2}{3(2n+1)^2} = \text{constant} \;\; (\neq 0 \;\; from \;\; n \neq 1)$, so, the obtained model is anisotropic and it does not tend to isotropic nature for $t \to \infty$. From Fig. 7, it is seen that λ is diverges at the time of Big

Bang i.e. ($t = 0$) and tends to zero as $t \to \infty$. From this it is observed that the early universe is dominated by strings and for $t \to \infty$ they disappear by losing their energy by radiation. So the obtained model is matter dominated. From Fig. 9, ρ_p has a large negative value at $t = 0$ and it approaches a constant positive finite value as $t \to \infty$. So, the universe will be dominated by particles for late time. The non-vanishing component of magnetic field F_{14} is obtained as a increasing function of time *t* as depicted in Fig. 6. The strings and magnetic field are co-existing in this model. So, we hope that the obtained model has a good agreement with the present-day scenario of the universe.

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