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RESEARCH ARTICLE

BIANCHI TYPE-V MAGNETIZED COSMOLOGICAL MODEL WITH WET DARK FLUID IN GENERAL RELATIVITY

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ABSTRACT

This paper deals with the study of Bianchi Type-Vcosmological modelwith wet dark fluid and electromagnetic field in general theory of relativity. For solving the Einstein field equations, weassumed that the magnetic field is in *xy*-plane; therefore the current is flowing along the z -axis. Thus F_{12} is the only non-vanishing component of the electromagnetic field tensor F_{ij} . Also somephysical and kinematical properties of the model are discussed.

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INTRODUCTION

Einstein's (1916) general theory of relativity has provided a sophisticated theory of gravitation which has been very successful in describing gravitational phenomenon and also served as a basis for model of the universe. The homogenous isotropic expanding model based on general relativity appears to provide a grand approximation of the observed large-scale properties of the universe. Bianchi type cosmological models are important in the sense that these are spatially homogeneous and anisotropic, from which the process of isotropization of the universe is studied through the passage of time. Moreover, from the theoretical point of view, anisotropic universe has a greater generality than the isotropic models. The occurrence of magnetic field on galactic scale is well-established fact today and their importance for a variety of astrophysical phenomena is generally acknowledge, as pointed out by Zeldovich *et al*. (1983). Also Harrison (1973) has suggested that magnetic field could have a cosmological origin. As a natural consequence we should include magnetic field in energy-momentum tensor of early universe.Cosmological models with an incident magnetic field for various Bianchi space-times have been investigated by several researcher *viz.* Roy and Banerjee (1997), Nayak and Bhuyan (1987) etc. Tikekar and Patel (1992) have obtained some exact solutions of massive string of Bianchi type III space-time in the presence of magnetic field, Shri Ram and Singh (1993) have investigated Bianchi type II, III and IX cosmological models with matter and electromagnetic fields, Bali and Jain (2007) have studied Bianchi type-III non-static magnetized cosmological model for perfect fluid distribution in general relativity.

Even today, one of the basic problems in cosmology is to known the formation of large scale structure of the universe. Cosmological model play a vital role in the understanding of the universe around us. Inview of its importance in explaining the observational cosmology many authors have consider cosmological model with dark energy. The wet dark fluid (WDF) model was in the spirit of generalization Chaplygin gas (GCG), where a physically motivated equation of state was offered with properties relevant for the dark energy problem. Here motivation stems from an empirical equation of state proposed by Tait (1988) and Hayward *et al*. (1967) to treat water and aqueous solution. The equation of state for WDF is very simple

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$$p_{WDF} = \gamma(\rho_{WDF} - \dot{\rho}) \qquad \text{.........................(1.1)}$$

and is motivated by the fact that it is good approximation for many fluids,including water, in which the internal attraction of the molecules makesnegative pressures possible.

To find the WDF energy density, we use the energy conservation equation

$$\dot{\rho}_{WDF} + 3H(p_{WDF} + \rho_{WDF}) = 0), \qquad \text{..............................(1.2)}$$

$$\rho_{WDF} = \frac{\gamma}{1+\gamma}\dot{\rho} + \frac{D}{V^{(1+\gamma)}}, \qquad \text{(1.3) ....}$$

where D is constant of integration and V is the volume expansion. WDF naturally includes two components, a piece that behaves as a cosmological constant as well as a piece thatred shifts as a standard fluid with an equation of state $p_{WDF} = \gamma\rho_{WDF}$.

We can show that if we take $D > 0$, this fluid will never violate the strong energy condition

$$p_{WDF} + \rho_{WDF} \geq 0$$

Thus, we get

$$(\rho_{WDF} + \rho_{WDF}) = (1+\gamma)\rho_{WDF} - \gamma\dot{\rho},$$

$$= (1+\gamma)\frac{D}{V^{(1+\gamma)}} \geq 0 \quad .(1.4)$$

The wet dark fluid has been used as dark energy in the homogenousisotropic FRW case by Holman and Naidu (2005), Singh and Caubey (2008) studied Bianchi type -I universe with wet dark fluid.Various cosmological models with wet dark fluid have been investigated by Adhav *et al.* (2010, 2011). Motivated by these works, we have studied in this paper, Bianchi type-Vcosmological model in presence of electromagnetic field withWDF.Our paper is organized as follows:

In section 2, we derive the field equations. In section 3, we deal with the solution of the field equations in presence of electromagnetic field with WDF. Section 4 is mainly concerned with the physical and kinematical properties. The last section contains conclusions.

The metric andfield equations

We consider the Bianchi type-V line elementin the form

$$ds^2 = dt^2 - A^2dx^2 - e^{-2\alpha x}(B^2dy^2 + C^2dz^2), \qquad \text{...................................(2.1)}$$

where A, B and C are functions of cosmic time t.

The Einstein's field equations for cosmological term with $G = C = 1$ can be written as

$$G_{ij} = -T_i^j + E_i^j, \qquad \text{(2.2) ....}$$

where G_{ij} is an Einstein tensor, R isthe scalar curvature, E_i^j is the electromagnetic field given by

$$E_i^j = \frac{1}{4\pi}\left[-F_{il}F^{il} + \frac{1}{4}g_i^jF_{lm}F^{lm}\right]. \qquad \text{.......................................(2.3)}$$

We assume that the magnetic field is in xy-plane; therefore the current is flowing along the z-axis. Thus F_{12} is the only non-vanishing component of the electromagnetic field tensor F_{ij}.

In a co-moving co-ordinate system, we have

$$v^i = (0,0,0,1), \quad x^i = (0,0,\frac{1}{c},0), \qquad \text{(2.4) ....}$$

The First set ofMaxwell's Equation is

$$F_{ij:l} + F_{jk,i} + F_{ki;j} = 0, \quad \lfloor F^{ik}\sqrt{-g}\rfloor k = 0 \qquad \text{......................................(2.5)}$$

Thisleads to

$$F_{12} = ke^{-ax} , \quad \text{..............................(2.6)}$$

where k is the constant so that magnetic field depends upon space co-ordinate x only.

In equations (2.3),(2.4) and (2.6), it follows that

$$F_{12} = 0 \cdot$$

Now, the nonvanishing components of E_i^j corresponding to the line element (2.1) are given by

$$E_1^1 = \frac{H^2}{8\pi A^2} = E_4^4 , E_2^2 = -\frac{H^2}{8\pi A^2} = E_3^3 , \quad \text{..............................(2.7)}$$

Also, we have energy conservation equation

$$T^{ij}_{;j} = 0 , \quad \text{..............................(2.8)}$$

The energy-momentum tensor for cloud of string given by

$$T_{ij} = (\rho + p)u_i u_j - pg_{ij} , \quad \text{..............................(2.9)}$$

where ρ is the density of the perfect fluid and p is its pressure. Here the four velocity vector u_i and x_i satisfy the standard relations.

$$u_i u^j = -x_i x^j = 1, \text{ and } u^i x_j = 0 , \quad \text{..............................(2.10)}$$

In the comoving co-ordinate system, from equations (2.9) and (2.10), weobtain

$$T_1^1 = T_2^2 = T_3^3 = -p \quad , \quad T_0^0 = \rho \quad \text{..............................(2.11)}$$

The field equation (2.2) for the metric (2.1) with help of equations (2.8) to (2.10) can be written as

$$\frac{\ddot{B}}{B} + \frac{\ddot{C}}{C} + \frac{\dot{B}\dot{C}}{BC} - \frac{\alpha^2}{A^2} = p + \frac{H^2}{8\pi A^2} , \quad \text{..............................(2.12)}$$

$$\frac{\ddot{A}}{A} + \frac{\ddot{C}}{C} + \frac{\dot{A}\dot{C}}{AC} - \frac{\alpha^2}{A^2} = p - \frac{H^2}{8\pi A^2} , \quad \text{..............................(2.13)}$$

$$\frac{\ddot{A}}{A} + \frac{\ddot{B}}{B} + \frac{\dot{A}\dot{B}}{AB} - \frac{\alpha^2}{A^2} = p - \frac{H^2}{8\pi A^2} , \quad \text{..............................(2.14)}$$

$$\frac{\dot{A}\dot{B}}{AB} + \frac{\dot{A}\dot{C}}{AC} + \frac{\dot{B}\dot{C}}{BC} - \frac{3\alpha^2}{A^2} = -\rho + \frac{H^2}{8\pi A^2} , \quad \text{..............................(2.15)}$$

$$2\alpha\frac{\dot{A}}{A} + \alpha\frac{\dot{B}}{B} + \alpha\frac{\dot{C}}{C} = 0 , \quad \text{..............................(2.16)}$$

where over dot (.) denotes differentiation with respective to *t*.

Spatial volume and the scale factor for the metric (2.1) are defined respectively by

$$V = R^3 = ABC , \quad \text{..............................(2.17)}$$

$$R = (ABC)^{\frac{1}{3}} , \quad \text{..............................(2.18)}$$

The physical quantities of observational interest in cosmology are the expansion scalar (θ) , shear scalar σ^2 and the mean anisotropic parameter (A_m) defined as

$$\theta = 3H = \left(\frac{\dot{A}}{A} + \frac{\dot{B}}{B} + \frac{\dot{C}}{C}\right), \quad \text{.......................................(2.19)}$$

$$2\sigma^2 = \sum_{i=1}^{3}\left(H_i^2 - \frac{\theta^2}{3}\right), \quad \text{..(2.20)}$$

$$A_m = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{H_i - H}{H}\right)^2, \quad \text{..(2.21)}$$

Solutionsof the field equations

From equations (2.13) and (2.14) we get.

$$\frac{\ddot{B}}{B} + \frac{\dot{A}\dot{B}}{AB} - \frac{\ddot{C}}{C} - \frac{\dot{A}\dot{C}}{AC} = 0 \cdot \quad \text{..(3.1)}$$

Integrating equation (2.16) we obtain

$$A^2 = k(BC), \quad \text{.......................................(3.2)}$$

where k is constant of integration. The constant k , without loss of generality, can be chosen as unity so that we have from equation (3.2),

$$A^2 = (BC)\cdot \quad \text{...(3.3)}$$

In order to get a deterministic solution, we take the following plausible physical conditions:

i) The shear scalar σ is proportional to scalar expansion θ, which leads to the linear relationship between the metric potentials B and C , that is

$$B = C^n, \quad \text{..(3.4)}$$

where $n \neq 0$ is a constant

ii) With the help of special law of variation of Hubble's parameter proposed by Berman (1983) yield constant declaration parameter model of the universe,

$$q = \frac{-R\ddot{R}}{\dot{R}^2}, \quad \text{...(3.5)}$$

this admits the solution

$$R = (at + b)^{\frac{1}{1+q}}, \quad \text{..(3.6)}$$

where $a \neq 0$ and b are constants of integration.

This implies that the condition for acceleratedexpansion of universe is $1 + q > 0$.

Now from equations (2.18), (3.3), (3.4) and (3.6), we obtain

$$A = (at + b)^{\frac{1}{1+q}}, \quad \text{...(3.7)}$$

$$B = (at + b)^{\frac{2n}{(1+q)(1+n)}}, \quad \text{...(3.8)}$$

$$C = (at + b)^{\frac{2}{(1+q)(1+n)}}, \quad \text{..(3.9)}$$

Using equation (3.4) in equation (3.1), we obtain

$n = 1$

Using this value of n in equations (3.7), (3.8) and (3.9) and by a suitable choice of co-ordinates and constants.

The metric (2.1) can be written as

$$ds^2 = dt^2 - t^{\frac{2}{1+q}}\left[dx^2 + e^{-2\alpha x}(dy^2 + dz^2)\right] \quad , \qquad \text{……………………………………...(3.10)}$$

The geometrical and physical significance of model

In this section we discuss some physical and kinematical properties of WDF model. The pressure density p_{WDF} and energy density ρ_{WDF} of the model (3.10) are given by

$$p_{WDF} = \frac{H^2}{8\pi t^{\frac{2}{(1+q)}}} - \frac{1}{(1+q)^2 t^2} - \frac{\alpha^2}{t^{\frac{2}{(1+q)}}} \quad , \qquad \text{…………………………………...(4.11)}$$

$$\rho_{WDF} = \frac{3\alpha^2}{t^{\frac{2}{(1+q)}}} + \frac{H^2}{8\pi t^{\frac{2}{(1+q)}}} - \frac{3}{(1+q)t^2} \, . \qquad \text{…………………………………(4.12)}$$

Further we find the volume, mean Hubble parameter, expansion scalar θ, shear scalar σ and mean anisotropic parameter A_m as

$$V = \frac{3}{t^{(1+q)}} \quad , \qquad \text{………………………………….(4.13)}$$

$$H = \frac{1}{(1+q)t} \, , \qquad \text{………………………………….(4.14)}$$

$$\theta = 3H = \frac{3}{(1+q)t} \, , \qquad \text{………………………………….(4.15)}$$

$$\sigma^2 = 0 \, , \qquad \text{………………………………….(4.16)}$$

$$A_m = 0 . \qquad \text{……………………………………(4.17)}$$

Conclusion

In this paper, we have presented two categories of Bianchi type-V cosmological solutions of wet dark fluid and electromagnetic field in general theory of relativity. In this work, we have presented an exact solution of Einstein's field equations for a spatially homogeneousand anisotropic Bianchi type-V space-time in the presence of electromagnetic field withWet Dark Fluid. In general, the model is expanding, shearing and non-rotating. The models presented in this paper could give an appropriate description of the evolution of the Universe. Also, all the physical and kinematical parameters are decreasing function of time and ultimately tend to zero for large time. Thus, the present model may be a useful tool for describing the early stages of the evolution of physical universe.

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