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Holographic Dark Energy in Bianchi Type VI_0 Space Time with Cosmological Constant in Theory of Relativity

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ABSTRACT: In this manuscript we have studied minimally interacting field Dark matter and Holographic Dark energy in Bianchi type VI_0 cosmological model with cosmological constant Λ in theory of relativity. The solution of Einstein's field equations have been obtained by using relation between the special law of variation for Hubble parameter which metric potential and shear velocity is proportional to scalar expansion and gives a constant value of deceleration parameter. Some physical and geometrical aspects of the model are also discussed.

Keywords: Bianchi type VI_0 space time, Hubble parameter, cosmological constant Λ deceleration parameter, Holographic Dark energy.

I. INTRODUCTION

The present study deals with minimally interacting fields Dark matter and Holographic Dark energy in Bianchi type VI_0 cosmological model with decaying cosmological constant Λ .Various observational data of modern cosmology based on measurement indicates that our universe is an accelerated expansion. This was observed by (Reiss et al. [21]), SNe Ia (Perlmutter et al.[19]), WMAP (Bennett[4]), Sdss (Tegmark[36]) and X-ray (Allen[1]). The concept of dark energy refers to a kind of exotic energy with negative pressure whose origin skill remains a mystery. Astronomical observation i.e. Wilkinson, microwave Astrophysics Probe indicates that the dark energy occupies 76% of the energy of our universe. 20% dark matter and baryonic matter and radiations occupies near about 4% of total energy of the universe. There are many proposal to explain the dark energy. The nature of the dark energy and dark matter is unknown and many radically different models have been proposed such as at tiny positive cosmological constant , quintessence (Caldwell;; et al [6]),(Liddle and Scherrer [15]), (Steinhard et al. [24]), DGP brane (Dvali et al.[9]); (Deffayet [10]); the nonlinear E(R) models (Capozziello et al. [7]),(Carroll et al. [8]); (Nojiri and Odintsov [18]) and dark energy in brine worlds.

Among the anisotropic space times, Bianchi type VI_0 space is one of the most convenient for testing different cosmological models. Berman [3] proposed a special law of variation of Hubble parameter in FRW space time,which yields a constant value of deceleration parameter. Such a law of variation of Hubble parameter is not inconsistent with the observations and is also approximately valid for slowly time varying deceleration parameter model.The law provides explicit forms of scale factor governing the FRW universe and facilitates to describe accelerating as well as decelerating modes of evolution of the universe.Models with constant deceleration parameterhave been extensively studied in the literature in different contexts (Kumar and Singh [14]).

Using holographic principal of quantum gravity theory (Susskind [23]) a viable holographic dark energy model was constructed by Li [16]. The holographic dark energy model is successful in explaining the observational data. Holographic dark energy is the nature of DE can also be studied according to some basic quantum gravitational principle. According to this principle [5], the degrees of freedom in a bounded system should be finite and does not scale by it volume but with its boundary era. Here ρ_λ is the vacuum energy density. Using this idea in cosmology we take ρ_λ as DE density. The holographic principle is considered as another alternative to the solution of DE problem. This principle was first considered by G.'t Hooft[12] in the context of black hole physics. In the context of dark energy problem though the holographic principle proposes a relation between the holographic dark energy density ρ_λ and the Hubble parameter (H) as $\rho_\lambda = H^2$,it does not contribute to the present accelerated expansion of the universe. In [11], Granda and Olivers proposed a holographic density of the form $\rho_\lambda \approx \alpha H^2 + \beta H$,whereH is the Hubble parameter and α, β are constants which must satisfy the conditions imposed by the current observational data.

The several authors in particular Sarkar and Mahanta [31]studied the evolution of holographic dark energy in Bianchi type I space time with constant deceleration parameter. Recently Sarkar [32] have studied holographic dark energy model in Bianchi type I space time with linearly varying deceleration parameter and established a corresponding with generalized chapligin gas models of the universe. Setare [28] studied holographic dark energy model in Brans-Dicke theory. Sarkar [33,34,35] have investigated Bianchi type II cosmological model with interacting holographic dark energy. Very recently Setare and Vanegas [29] have investigated the cosmological dynamics of interacting holographic dark energy model. Kiran et al. [13] have studied bianchi type V minimally interacting holographic dark energy model in the scalar tensor theory of gravitation proposed by Saez and Ballester. Adav et al. [2] have investigated plane symmetric space time with interacting dark matter and holographic dark energy exponential volumetric expansion. Reddy at al.[22] have discussed Kaluza-Klein minimally interacting holographic dark energy model in scalar tensor theory of gravitation also Mete V.G.[38] studied holographic dark energy cosmological model in Scalar Tensor Theory in General Relativity. .Motivated by the above discussion in this paper we studied minimally interacting fields Dark matter and Holographic Dark energy in Bianchi type VI_0 cosmological model. 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 holographic dark energy and dark matter.. Section 4 is mainly concerned with the physical and kinematical properties. The last section contains conclusions.

II. METRIC AND FIELD EQUATIONS

We consider the Bianchi Type VI_0 metric in the form

$$ds^2 = -dt^2 + A^2(t)dx^2 + B^2(t)\exp(-2qx)dy^2 + C^2(t)\exp(2qx)dz^2 \qquad (1)$$

Where q is nonzero constant and A, B, C are scale functions of t only.

The Einstein's Field equations are

$$R_{ij} - \frac{1}{2}Rg_{ij} + \Lambda g_{ij} = -(T_{ij} + \bar{T}_{ij}) \quad (2)$$

The energy momentum tensor of matter and holographic dark energy are define as

$$T_{ij} = \rho_m u_i u_j \quad (3)$$

$$\bar{T}_{ij} = (\rho_\lambda + p_\lambda)u_i u_j + p_\lambda g_{ij} \quad (4)$$

Where ρ_m, ρ_λ are the energy densities of matter and holographic dark energy and p_λ is the pressure of the holographic dark energy.

The Einstein's field equations (2) for the metric (1) with the help of equations (3)-(4) can be written as

$$\frac{\ddot{B}}{B} + \frac{\ddot{C}}{C} + \frac{\dot{B}\dot{C}}{BC} + \frac{q^2}{A^2} + \Lambda = -p_\lambda \quad (5)$$

$$\frac{\ddot{A}}{A} + \frac{\ddot{C}}{C} + \frac{\dot{A}\dot{C}}{AC} - \frac{q^2}{A^2} + \Lambda = -p_\lambda \quad (6)$$

$$\frac{\ddot{B}}{B} + \frac{\ddot{A}}{A} + \frac{\dot{A}\dot{B}}{AB} - \frac{q^2}{A^2} + \Lambda = -p_\lambda \quad (7)$$

$$\frac{\dot{A}\dot{B}}{AB} + \frac{\dot{A}\dot{C}}{AC} + \frac{\dot{B}\dot{C}}{BC} - \frac{q^2}{A^2} + \Lambda = \rho_m + \rho_\lambda \quad (8)$$

$$\frac{\dot{B}}{B}-\frac{\dot{C}}{C}=0 \quad (9)$$

Where (.) over the symbols A, B, C denotes ordinary differentiation with respect to t. The continuity equation of the matter and dark energy is given by

$\dot{\rho}_m + 3H\rho_m + \dot{\rho}_\lambda + 3H(1+\omega)\rho_\lambda$ (10)We assume that the matter and holographic dark energy interact each other hence both the component conserve separately, so that

The continuity equation of holographic dark energy is

$$\dot{\rho}_\lambda + 3H(1+\omega)\rho_\lambda = 0 \quad (11)$$

and the continuity equation of matter is

$$\dot{\rho}_m + 3H\rho_m = 0 \quad (12)$$

Where $\omega = \frac{p_\lambda}{\rho_\lambda}$ is the barotropic equation of state parameter for holographic dark energy. The holographic dark energy density are given by

$$\rho_\lambda = \frac{2}{\alpha-\beta}\left(\dot{H}+\frac{3\alpha}{2}H^2\right) \quad (13)$$

Therefore from equations (11) and (13) yield the barotropic parameter ω a

$$\omega = -1-\frac{(\ddot{H}+3\alpha H\dot{H})}{3H(\dot{H}+\frac{3\alpha}{2}H^2)} \quad (14)$$

The physical and geometrical parameters to be used to solve the field equations for the space time given by Eq. (1) have the following forms

The average scale factor $R=(ABC)^{\frac{1}{3}}$ (15)

The mean Hubble's parameter $H=\frac{\dot{R}}{R}$ (16)

an important observed quantity in cosmology is the deceleration parameter q which is define as

$$q=-\frac{R\ddot{R}}{\dot{R}^2}=-1-\frac{\dot{H}}{H} \quad (17)$$

The average anisotropic parameter Δ is define as

$$\Delta=\frac{1}{3}\sum_{i=1}^{3}\left(\frac{\Delta H_i}{H}\right)^2 \quad (18)$$

where $\Delta H_i = H_i - H$ and $H_i(i=1,2,3)$ represent the directional Hubble parameters

the shear scalar expansion (θ) and the shear scalar (σ) are

$$\theta=\frac{\dot{A}}{A}+\frac{\dot{B}}{B}+\frac{\dot{C}}{C} \quad (19)$$

$$\sigma^2=\frac{1}{2}\left(\frac{\dot{A}^2}{A^2}+\frac{\dot{B}^2}{B^2}+\frac{\dot{C}^2}{C^2}-\frac{\dot{A}\dot{B}}{AB}-\frac{\dot{B}\dot{C}}{BC}-\frac{\dot{A}\dot{C}}{AC}\right) \quad (20)$$

III. SOLUTION OF THE FIELD EQUATIONS

The field equations (5)-(9) are system of five equations with seven unknowns $A, B, C, \rho_m, \rho_\lambda, p_\lambda, \Lambda$. We need two additional conditions to obtained solution of the system.

Equation (9) leads to

$B = kC$ (21)

Where k is integrating constant.

For any physical relevant model the Hubbel parameter H and deceleration parameter q are most important observational quantities in cosmology.The law of variation of parameter that yields a constant deceleration parameter.This type of relation have already been consider by Berman[3] and Berman and Gomidel for FRW model.Later on many authors Singh and Baghel[30], Singh and Kumar [25-27]Maharaj and Naidoo[17],Pradhan et al. [20],Yadav and Yadav[37] have studied flat FRW and Bianchi type models by using the special law of Hubble parameter.

Since the line element (1) is completely characterized by Hubble's parameter H. Therefore according to the law of variation of parameter His related to the average scale factor by the relation

$H = k_1 R^{-n}$ (22)

Where $k_1(>0)$ and $(n \geq 0)$ are constants.

From equations (16) and (22), yields

$\dot{R} = k_1 R^{-n+1}$ (23)

and $\ddot{R} = -k_1^2 (n-1) R^{-2n+1}$ (24)

using (23) and (24) in (17) we get

$q = n - 1$ for $n \neq 0$ (25)

$q = -1$ for $n = 0$ (26)

Observe that the values of deceleration parameter are constant.The sign of q indicates whether the model accelerates or not. The positive sign of q $(n > 1)$ corresponds to decelerating models whereas the negative sign $-1 \leq q < 0$ for $0 \leq n < 1$ indicates acceleration and $q = 0$ for $n = 1$ corresponds to expansion with constant velocity.

Let us we assume that the expansion scalar (θ) and the shear scalar (σ) in the model are proportional this leads to

$A = B^m$ (27)

Using (21) and (27) we obtain the average scale factor R as

$R = (k_1 t + k_2)^{\frac{1}{n}}$ for $n \neq 0$ (28)

$R = k_3 \exp(k_1 t)$ for $n = 0$ (29)

Where k_2 and k_3 are constant of integration.

Model-I

Model for $n \neq 0$

Using equations (16), (21), (27) and (28) we have the scale factor as

$B = c_1 (k_1 t + k_2)^{\frac{1}{l}}$ (30)

$A = c_2 (k_1 t + k_2)^{\frac{m}{l}}$ (31)

$C = c_3 (k_1 t + k_2)^{\frac{1}{l}}$ (32)

Where $l = \dfrac{n(m+2)}{3}$, $c_1 = k^{\frac{1}{m+2}}$, $c_2 = c_1^m$ and $c_3 = k^{\frac{-(m+1)}{(m+2)}}$

Therefore the model (1) with the help of equations (30),(31) and (32) can be written as

$$ds^2 = -dt^2 + c_2^2 (k_1 t + k_2)^{\frac{2m}{l}} dx^2 + c_1^2 (k_1 t + k_2)^{\frac{2}{l}} \exp(-2qx) dy^2 + c_3^2 (k_1 t + k_2)^{\frac{2}{l}} \exp(2qx) dz^2$$
(33)

Here we consider two cases i) The cosmological constant $\Lambda = 0$ ii) $\Lambda \neq 0$

Case I:- $\Lambda = 0$

In this case the energy density of the matter (ρ_m) and density of holographic dark energy (ρ_λ) and the pressure (p_λ) of the holographic dark energy are given by

$$\rho_m = \frac{c}{(k_1 t + k_2)^{\frac{3}{n}}} \quad (34)$$

where c is an integrating constant.

$$\rho_\lambda = \frac{k_1^2 (3\alpha - 2n)}{(\alpha - \beta)[n(k_1 t + k_2)]^2} \quad (35)$$

$$p_\lambda = \frac{(2l-3)k_1^2}{l^2 (k_1 t + k_2)^2} + \frac{q^2}{c_2^2 (k_1 t + k_2)^{\frac{2m}{l}}} \quad (36)$$

Case-II For $\Lambda \neq 0$

In this case the energy density of the matter (ρ_m) and density of holographic dark energy (ρ_λ) pressure (p_λ) of the holographic dark energy and cosmological constant (Λ) are given by

$$\rho_m = \frac{c}{(k_1 t + k_2)^{\frac{3}{n}}} \quad (35)$$

where c is an integrating constant.

$$\rho_\lambda = \frac{k_1^2 (3\alpha - 2n)}{(\alpha - \beta)[n(k_1 t + k_2)]^2} \quad (36)$$

$$\Lambda = \frac{P}{(k_1 t + k_2)^2} + \frac{c_1}{(k_1 t + k_2)^{\frac{3}{n}}} + \frac{q^2}{c_2^2 (k_1 t + k_2)^{\frac{2m}{l}}} \quad (37)$$

$$p_\lambda = \frac{Q}{(k_1 t + k_2)^2} - \frac{c_1}{(k_1 t + k_2)^{\frac{3}{n}}} \quad (38)$$

where $P = \frac{k_1^2 (3\alpha - 2n)}{(\alpha - \beta) n^2} - \frac{(2m+1)k_1}{l}$ and $Q = \left[\frac{(2m+1)k_1}{l} - \frac{k_1^2 (m+1)(1-l) + m^2}{l^2} - \frac{k_1^2 (3\alpha - 2n)}{(\alpha - \beta) n^2} \right]$

Model-II

Model for $n = 0$ $i.e. q = -1$

Using equations (16), (21), (27) and (28) we have the scale factor as

$$B = C_1 \exp(l_0 t) \quad (39)$$

$$A = C_2 \exp(m l_0 t) \quad (40)$$

$$C = C_3 \exp(l_0 t) \quad (41)$$

Where $l_0 = \frac{3k_1}{(m+2)}, C_1 = k_3^{\frac{3}{m+2}} k^{\frac{1}{m+2}}, C_2 = C_1^m$ and $C_3 = \frac{C_1}{k}$

Therefore the model (1) with the help of equations (39),(40) and (41) can be written as

$$ds^2 = -dt^2 + C_2^2 \exp(2ml_0t)dx^2 + C_1^2 \exp 2(l_0t - qx)dy^2 + C_3^2 \exp 2(l_0t + qx)dz^2 \quad (42)$$

Consider two cases i) the cosmological constant $\Lambda = 0$ ii) $\Lambda \neq 0$

Case I:- $\Lambda = 0$

In this case the energy density of the matter (ρ_m) and density of holographic dark energy (ρ_λ) and the pressure (p_λ) of the holographic dark energy are given by

$$\rho_m = c\left[k_3 e^{k_1 t}\right]^{-3} \quad (43)$$

where c is an integrating constant.

$$\rho_\lambda = \frac{2k_1^2(3\alpha+1)}{(\alpha-\beta)} \quad (44)$$

$$p_\lambda = -\left[3l_0^2 + \frac{q^2}{C_2^2 \exp(2ml_0t)}\right] \quad (45)$$

Case-II For $\Lambda \neq 0$

In this case the energy density of the matter (ρ_m) and density of holographic dark energy (ρ_λ), pressure (p_λ) of the holographic dark energy and cosmological constant (Λ) are given by

$$\rho_m = c\left[k_3 e^{k_1 t}\right]^{-3} \quad (46)$$

where c is an integrating constant.

$$\rho_\lambda = \frac{2k_1^2(3\alpha+1)}{(\alpha-\beta)} \quad (47)$$

$$\Lambda = c\left[k_3 e^{k_1 t}\right]^{-3} + \frac{2k_1^2(3\alpha+1)}{\alpha-\beta} - (2m+1)l_0^2 + \frac{q^2}{C_2^2 \exp(2ml_0t)} \quad (48)$$

$$p_\lambda = m(1-m)l_0^2 - ck_3 \exp(-3k_1t) - \frac{2k_1^2(3\alpha+1)}{\alpha-\beta} \quad (49)$$

Observe that for $n = 0$ the holographic dark energy density remains constant.

IV. SOME PHYSICAL AND KINEMATICAL PROPERTIES OF THE MODEL

Some physical and geometrical parameters of cosmological model have following expression
the spatial volume

$$V = ABC \quad (50)$$

The scalar expansion $$\theta = \frac{3k}{(k_1t + k_2)} \quad (51)$$

The shear scalar is $$\sigma^2 = \frac{1}{3}\frac{(m-1)^2 k_1^2}{l^2(k_1t+k_2)^2} \quad (52)$$

The Hubble parameter is $$H = \frac{k}{k_1t + k_2} \quad (53)$$

The anisotropic parameter $$\bar{A} = \frac{1}{3}\left[\frac{(m+2)k_1}{kl} - 1\right]^2 \quad (54)$$

The equation of state parameter of holographic dark energy is

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$$\omega = \frac{kk_1^2}{(k_1 t + k_2)^3}(2 - 3\alpha k) \quad (55)$$

The coincident parameter is

$$r = \frac{\rho_\lambda}{\rho_m} = \frac{k_1^2(3\alpha - 2n)}{c_1(\alpha - \beta)n^2 (k_1 t + k_2)^{\frac{2n-3}{n}}} \quad (56)$$

For $n = 0$ the coincident parameter becomes

$$r = \frac{2c_1(3\alpha + 1)}{(\alpha - \beta)k_3 \exp(-3c_1 t)} \quad (57)$$

The matter density parameter Ω_m and holographic dark energy density parameter Ω_λ are given by

$$\Omega_m = \frac{\rho_m}{3H^2} \text{ and } \Omega_\lambda = \frac{\rho_\lambda}{3H^2} \quad (58)$$

Using equations (35),(36),(53) and (58) we obtain density parameter as

$$\Omega = \Omega_m + \Omega_\lambda = \frac{c_1(k_1 t + k_2)^{\frac{2n-3}{n}}}{3k^2} + \frac{k_1^2(3\alpha - 2n)}{(\alpha - \beta)3k^2 n^2} \quad \text{for } n \neq 0 \quad (59)$$

Here we observe that the overall density parameter i.e. the sum of energy density parameter approaches to constant at late time so at late time the universe becomes flat.The volume V increases with time increases which shows the expansion of the universe. The Hubble parameter and the shear scalar are decreases and tends to zero as time increases. from equation (55) shows that the equation of parameter is a function of time.

V. CONCLUSION

In this paper the law of variation of Hubble parameter for Bianchi type VI_0 cosmological model filled with dark matter and holographic dark energy gives two types of models for $n = 0$ and for $n \neq 0$ in general theory of relativity.For $n \neq 0$ the deceleration parameter is positive that indicates power law of expansion of the universe and for $n = 0$ the deceleration parameter is negative that indicates exponential expansion of the universe. In both the models we also discuss the two cases $\Lambda = 0$ and $\Lambda \neq 0$. The cosmological constant Λ is a decreasing function of time. We observed that the holographic dark energy density decreases with the evolution of the universe and the average density parameter approaches to constant at late time, so the universe becomes flat which is supported to recent observations.

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