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PERFECT FLUID AND SCALAR FIELD IN HIGHER DIMENSION

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Abstract

In this study, we examine perfect fluid and scalar field in higher dimensional FRW model. Also, we obtain dynamic solutions, H Hubble parameter, q deceleration parameter and w the state of equation parameter of perfect fluid and scalar field. Finally, the thermodynamics of perfect fluid and scalar field have been studied.

Keywords: Perfect Fluid, Scalar Field, Higher Dimension, Hubble Parameter.

INTRODUCTION

Recent astrophysical observation and scientific researches demostrate that the expansion of the universe is accelerating [1], [2]. Scalar fields have been considered one of the methods of explaining Dark Energy [3]. Researches indicate that dark energy causes the accelaration of the our universe [4], [5], [6]. Dark energy has been exotic component [3]. If $w = -1$ the candidate of dark energy is cosmological constant Λ [7, references there in]. If $w \succ -1$ the candidate of dark energy is scalar field (quintessence) [7], [8, references there in]. If $w \prec -1$ the candidate of dark energy is phantom energy [8], [9, references there in].

In this study, we investigate perfect fluid and scalar field in higher dimensional FRW model. The paper is organizeted as follows. In sec.2 the solutions of Einstein field equations for perfect fluid and scalar field are obtained. In sec.3 concluding remarks are deliver.

EINSTEIN'S FIELD EQUATIONS

Einstein's field equations

$$G_{ab} \equiv R_{ab} - \frac{1}{2} g_{ab} R = \chi T_{ab} \tag{1}$$

where G_{ab} is Einstein's tensor which defines geometry of space-time. R_{ab} is Ricci tensor, g_{ab} is metric tensor, R is Ricci scalar, χ is constant and T_{ab} is energy- momentum tensor defining the matter content of the universe [9].

We will consider the following FRW metric $(n+2)$ dimension

$$dS^2 = dt^2 - a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2 (dX_n)^2\right] \tag{2}$$

where $a(t)$ is scale factor, $k = 0, \mp 1$ is curvature parameter and

$$dX_n^2 = d\theta_1^2 + \sin^2\theta_1 d\theta_2^2 + \ldots + \sin^2\theta_1 \sin^2\theta_2 \ldots \sin^2\theta_{n-1} d\theta_n^2$$

[9]. We will choose the following energy- momentum tensor which are perfect fluid and scalar field [10].

$$T_t = T_m + T_\phi$$

$$T_m = (\rho_m + p_m)U_a U_b - p_m g_{ab} \tag{3}$$

$$T_\varphi = \varepsilon \partial_\mu \emptyset \partial_\nu \emptyset - g_{\mu\nu}\left[\frac{1}{2}\varepsilon g^{\mu\nu}\partial_\mu \emptyset \partial_\nu \emptyset - V(\emptyset)\right]$$

Where T_m is the perfect fluid's energy- momentum tensor, $T_\emptyset$ is the scalar field's energy- momentum tensor, U_a, U_b are the components of the velocity.

Einstein's field equations for eqs. (2) and (3) is

$$\frac{n(n+1)}{2}\left[\frac{\dot{a}^2+k}{a^2}\right] = \frac{8\pi G}{c^4}(\rho_m + \rho_\emptyset) \tag{4}$$

$$-n\frac{\ddot{a}}{a} - \frac{n(n-1)}{2}\left[\frac{\dot{a}^2+k}{a^2}\right] = \frac{8\pi G}{c^4}(p_m + p_\emptyset) \tag{5}$$

where $8\pi G = c^4 = 1, k = 0$ [11]. ρ_m is the perfect fluid's energy density, $\rho_\emptyset$ is the scalar field's energy density, p_m is the perfect fluid's pressure and $p_\emptyset$ is the scalar field's pressure.

The condition of [3], [12]

$$a(t) = e^{\mu(\ln(t))^\alpha}, \ \mu\lambda \succ 0 \quad \text{and} \quad \alpha > 1 \tag{6}$$

From eqs. (4), (5) and (6) we have

$$\rho_t = \rho_m + \rho_\emptyset = \frac{n(n+1)\mu^2\alpha^2(\ln(t))^{2\alpha-2}}{2t^2} \tag{7}$$

and

$$p_t = p_m + p_\emptyset = -\frac{n(n+1)\mu^2\alpha^2}{2t^2}(\ln(t))^{2\alpha-2} + \frac{n\mu\alpha}{t^2}\left[\frac{(\alpha-1)(\ln(t))^{\alpha-2}}{t^2} + \ln(t)\right]^{\alpha-1} \tag{8}$$

Hubble parameter is as follows

$$H = \frac{\dot{a}}{a} = \frac{\mu\alpha(\ln(t))^{\alpha-1}}{t} \tag{9}$$

Deceleration parameter is as follows [3]

$$q = -\frac{a\ddot{a}}{\dot{a}^2} = 1 - \frac{[(\alpha-1)(\ln(t))^{\alpha-2} + \ln(t)]^{\alpha-1}}{\mu\alpha(\ln(t))^{2\alpha-2}} \tag{10}$$

[13], [14] has implied first and second laws of thermodynamics for V volume such as

$$TdS = dE + pdV \tag{11}$$

$$T \equiv \frac{(\rho_t + p_t)}{S}V \tag{12}$$

where E is energy, p is pressure, V is volume, S is entropy and T is temperature [15], [16]. Volume is as follows

$$V = a^{n+1} \tag{13}$$

Using eqs. (7), (8), (12) and (13), we obtain

$$T \equiv \frac{\frac{n\mu\alpha}{t^2}\left[\frac{(\alpha-1)(\ln(t))^{\alpha-2}}{t^2} + \ln(t)\right]^{\alpha-1}}{S}\left[e^{\mu(\ln(t))^\alpha}\right]^{n+1} \tag{14}$$

We get the following w the state of equation parameter

$$w_t = \frac{p_t}{\rho_t} = \frac{p_m + p_\emptyset}{\rho_m + \rho_\emptyset} = -1 + \frac{2\left[\frac{(\alpha-1)(\ln(t))^{\alpha-2}}{t^2} + \ln(t)\right]^{\alpha-1}}{(n+1)\mu\alpha(\ln(t))^{2\alpha-2}} \quad (15)$$

where $w_t > -1$. So, the total matter higher dimension $(n+2)$ universe behaves quintessence-like.

CONCLUSIONS

In this study, perfect fluid and scalar field have been studied in higher dimensional FRW model. We obtain the dynamical components, H Hubble parameter, q deceleration parameter and w the state of equation parameter of the model have been obtained for the case of $a(t) = e^{\mu(\ln(t))^{\alpha}}$, $\mu\lambda > 0$ and $\alpha > 1$ [3], [12] the scale factors. Also, the thermodynamics of perfect fluid and scalar field have been studied. From equation of (15), it is obtained that total substrate of universe behaves as the quintessence-like in the higher dimension. The resulting solutions also include 4- dimensional solutions that were previously made solutions [3], [12].

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