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Inflationary Dynamics of Tsallis Holographic Scalar Field Models in Chern-Simons Modified Gravity

Gargee Chakraborty and Surajit Chattopadhyay

Department of Mathematics, Amity University Kolkata, Major Arterial Road, Action Area II, Rajarhat, New Town, Kolkata 700135, India.

E-mail: `gargeeck138@gmail.com`

Abstract. The present study report reconstruction schemes for tachyon scalar field model of Dark Energy through Tsallis holographic dark fluid under the framework of Chern-Simons modified gravity. Emergent scale factor has been assumed. Reproducing the conservation equation for a coupled model with interaction term we have reconstructed the scalar field and the corresponding potential. The reconstructed energy density have been plotted for the case. Evolutionary behaviour of potential for the case have been pictorially presented.

1. Introduction

Late time acceleration of the universe is observationally established by Reiss et al. [1] and Perlmutter et al. [2]. Some exotic matter characterised by negative pressure is thought to be responsible for driving this acceleration. This exotic matter is dubbed as "Dark Energy" (DE) [3]. Equation of state (EoS) parameter of DE is given by $w = \frac{p}{\rho}$, where ρ is the density of DE and p is its pressure and w should be less than $-\frac{1}{3}$ i.e., $w < -\frac{1}{3}$. It may be noted that around 68.3% of the total energy density of this observable universe is contributed by DE. Remaining densities are due to dark matter (DM), ordinary baryonic matter and radiation. However, the contribution due to baryonic matter and radiation can be considered to be negligible with respect to the total density of the universe. The observational datas obtained with Cosmic Microwave Background (CMB), Baryon Accoustic Oscillation (BAO), Large Scale Structures, etc also support the late time accleration of the universe [1, 2, 4, 5, 6, 7, 8, 9, 10]. The late time acceleration of the universe is not only the accelerated phase of the universe but there was another early accelerated phase of the universe is known as inflation. Λ is the simplest candidate of DE having $w = -1$. The limitation of Λ is that it cannot give the time evolution of EoS parameter. To overcome the limitations, the dynamic EoS candidate are considered namely scalar field models, holographic models of DE and Chaplygin gas models [3, 11].Various literatures have been studied [12, 13, 14, 15, 16]. The holographic dark energy (HDE) based on the holographic principle, is considered as a promising approach for solving the complex puzzle of DE. The present study is done by considering general model of Tsallis entropy expression and obeying the holographic hypothesis into account [17]. The Tsallis holographic density is given by [18, 19, 20, 21]:

$$\rho_D = BL^{2\delta-4} \tag{1}$$

where, B is the Tsallis HDE parameter. Chern-Simons (CS) modified gravity is an extension of General Theory of Relativity. It captures the order, gravitational parity violation which couples

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gravity via scalar fields. In CS modified gravity, Friedmann equation gets modified to [22, 23]: $H^2 = \frac{1}{3}(\rho_m + \rho_D) + \frac{1}{6}\dot{\theta}^2$ where, θ is the dynamical term and is given by $\ddot{\theta} + 3H\dot{\theta} = 0$.

2. Considering Tsallis Tachyon Scalar Field in Chern Simons Modified Gravity

Tachyon particles are assumed to violate a number of important physical properties and are purely a hypothetical concept [24, 25]. Higgs field with imaginary mass is believed to exist. The scale factor for emergent universe can be chosen as [25]:

$$a(t) = a_0(\lambda + e^{\mu t})^n \tag{2}$$

where a_0, μ, λ, n are positive constant. For Tachyon scalar field, the density and pressure respectively are:

$$\rho_T = \frac{V(\phi)}{\sqrt{1-\dot{\phi}^2}} \tag{3}$$

and

$$p_T = -V(\phi)\sqrt{1-\dot{\phi}^2} \tag{4}$$

where $V(\phi)$ is the potential of scalar field ϕ.
In Subsection2.1 and Subsection2.2, we will study the evolution of energy density and potential of the case respectively.

2.1. Evolution of Energy Density

In this subsection, we will study the behaviour of EoS parameter of Tsallis Tachyon scalar field in CS modified gravity. We consider an interaction between DE and DM. The conservation equation is:

$$\dot{\rho}_D + 3H(\rho_D + p_D) = -Q \tag{5}$$

and

$$\dot{\rho}_m + 3H\rho_m = Q \tag{6}$$

where, ρ_D and ρ_m are the density of DE and pressureless DM respectively, interacting term $Q = 3Hb^2\rho_m$, b is the interacting parameter, H is the Hubble parameter. We know $H = \frac{\dot{a}}{a}$. Using the emergent scale factor from Eq.(2), we get H as:

$$H = \frac{e^{t\mu}n\mu}{e^{t\mu} + \lambda} \tag{7}$$

Solving differential equation (6), we get ρ_m as

$$\rho_m = \left(e^{t\mu} + \lambda\right)^{3\left(-1+b^2\right)n} \rho_{m0} \tag{8}$$

Now, we will find the dynamical term θ of CS modified gravity. Using H from Eq.(7) in the second degree differential equation of θ, we obtain θ. Now, differentiating the Friedmann equation in CS modified gravity with respect to t and using $\rho_D = \rho_T$ in the conservation equation (5), we get

$$6\dot{H} - \frac{\dot{\rho}_m}{H} + 3\dot{\theta}^2 + 3\frac{V(\phi)}{\sqrt{1-\dot{\phi}^2}}\dot{\phi}^2 = -3b^2\rho_m \tag{9}$$

Using H from Eq.(7), ρ_m from Eq.(8), θ that we obtained in the Eq.(9), we get

$$\frac{V(\phi)}{\sqrt{1-\dot{\phi}^2}}\dot{\phi}^2 = \left(e^{t\mu}+\lambda\right)^{-2-6n}\left(-C_1{}^2\left(e^{t\mu}+\lambda\right)^2-\rho_{m0}\left(e^{t\mu}+\lambda\right)^{2+3\left(1+b^2\right)n}-2e^{t\mu}n\lambda\left(e^{t\mu}+\lambda\right)^{6n}\mu^2\right) \tag{10}$$

Now, using H from Eq.(7), ρ_m from Eq.(8), ρ_T from Eq.(3) and $p_D = p_T$ in the Friedmann equation in CS modified gravity, we get

$$\frac{V(\phi)}{\sqrt{1-\dot{\phi}^2}} = \frac{1}{2}\left(e^{t\mu}+\lambda\right)^{-2-6n}\left(-C_1{}^2\left(e^{t\mu}+\lambda\right)^2-2\rho_{m0}\left(e^{t\mu}+\lambda\right)^{2+3\left(1+b^2\right)n}+6e^{2t\mu}n^2\left(e^{t\mu}+\lambda\right)^{6n}\mu^2\right) \tag{11}$$

Hence, the reconstructed IR cut-off can be obtained by taking the correspondence between Tsallis HDE and Tachyonic scalar field. From the density expression ρ_D (Eq.(1)) of Tsallis HDE and using reconstructed IR cutoff we obtained, we get the reconstructed density ρ_{rec} of Tsallis Tachyonic scalar field in CS modified gravity as

$$\rho_{rec} = \frac{\left(e^{t\mu}+\lambda\right)^{-2-6n}\left(-C_1{}^2\left(e^{t\mu}+\lambda\right)^2-2\rho_{m0}\left(e^{t\mu}+\lambda\right)^{2+3\left(1+b^2\right)n}+6e^{2t\mu}n^2\left(e^{t\mu}+\lambda\right)^{6n}\mu^2\right)}{2} \tag{12}$$

We plotted ρ_{rec} (Eq.(12)) versus t in the Fig.1 by considering $C_1 = 0.009$, $\lambda = 1.1$, $\mu = 0.8$, $\rho_{m0} = 0.32$ and $b = 1.0360742761694692$.

2.2. Evolution of Potential

In this subsection, we will study the behaviour of potential of the Tsallis HDE of Tachyon scalar field model in CS modified gravity. For deducing potential V, we need $\dot{\phi}$. Dividing Eq.(10) by Eq.(11), we get $\dot{\phi}^2$ as

$$\dot{\phi}^2 = \frac{2\left(C_1{}^2\left(e^{t\mu}+\lambda\right)^2+\rho_{m0}\left(e^{t\mu}+\lambda\right)^{2+3\left(1+b^2\right)n}+2e^{t\mu}n\lambda\left(e^{t\mu}+\lambda\right)^{6n}\mu^2\right)}{C_1{}^2\left(e^{t\mu}+\lambda\right)^2+2\rho_{m0}\left(e^{t\mu}+\lambda\right)^{2+3(1+b^2)n}-6e^{2t\mu}n^2\left(e^{t\mu}+\lambda\right)^{6n}\mu^2} \tag{13}$$

Using $\dot{\phi}^2$ from the Eq.(13) in Friedmann equation in CS modified gravity and by taking the correspondence between Tsallis HDE and Tachyon scalar field i.e., $\rho_D = \rho_T$, we get potential V as

$$V = \frac{\left(e^{t\mu}+\lambda\right)^{-2-6n}\left(C_1{}^2\left(e^{t\mu}+\lambda\right)^2+2e^{t\mu}n\left(e^{t\mu}+\lambda\right)^{6n}\left(3e^{t\mu}n+2\lambda\right)\mu^2\right)}{2\sqrt{-\frac{C_1{}^2(e^{t\mu}+\lambda)^2+2e^{t\mu}n(e^{t\mu}+\lambda)^{6n}(3e^{t\mu}n+2\lambda)\mu^2}{C_1{}^2(e^{t\mu}+\lambda)^2+2\rho_{m0}(e^{t\mu}+\lambda)^{2+3\left(1+b^2\right)n}-6e^{2t\mu}n^2(e^{t\mu}+\lambda)^{6n}\mu^2}}} \tag{14}$$

We have plotted the evolution of potential V (Eq.(14)) of the Tsallis HDE of Tachyon scalar field model in CS modified gravity against the cosmic time t and b in the Fig.2.

3. conclusion

Firstly, we have plotted reconstructed density ρ_{rec} (12) of Tsallis Tachyonic scalar field in CS modified gravity against the cosmic time t in the Fig.1 and found out to be positive and increasing with respect to the cosmic time t. Hence, it indicates that the contribution of the Tsallis HDE in Tachyon scalar field in CS modified gravity is increasing with the evolution of the universe. Furthermore, in the Fig.2, we have plotted potential V (Eq.(14)) for the same case against the cosmic time t and b and it is found out to be positive, which is consistent with the expansion of the universe.

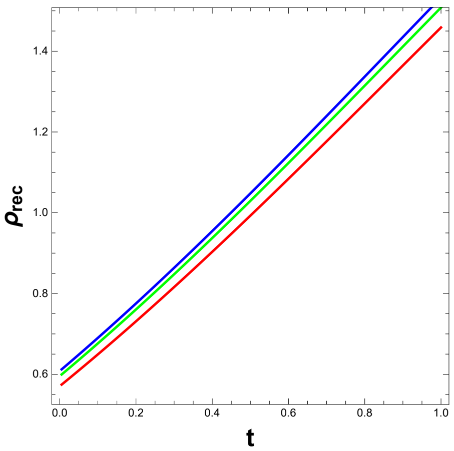

Figure 1. Evolution of reconstructed density ρ_{rec} (Eq.(12)) of Tsallis Tachyonic scalar field in CS modified gravity against the cosmic time t. The red, green and blue line corresponds to $n =$ 1.5, 1.52 *and* 1.54 respectively.

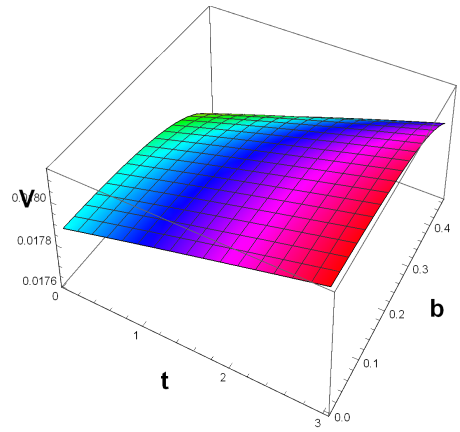

Figure 2. Evolution of potential V (Eq.(14)) of Tsallis Tachyonic scalar field in CS modified gravity against the cosmic time t and b. We consider $C_1 = 0.006$, $n = 10$, $\rho_{m0} = 0.32$, $\lambda = 0.3$, $\mu = 0.01$.

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