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Dynamics of bulk viscous pressure effected inflation in braneworld scenario

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ABSTRACT

The main goal of the present work is to examine the possible realization of warm chaotic inflation and logamediate inflation within the framework of a modified Chaplygin gas brane-world model. In this respect, the slow-roll parameters, number of e-folds, scalar-tensor power spectra, spectral indices, tensor–scalar ratio and running of scalar spectral index is being evaluated. These parameters are being analyzed for variable as well as constant dissipation and bulk viscous coefficients. Further, the trajectories among the inflationary parameters such as $n_s-\phi$, n_s-r, $\alpha_s-\phi$ and $n_s-\alpha_s$ are also developed to examine their behavior as well as physical cosmology. Some of results of inflationary parameters in all cases are: $r<0.11$, $n_s=0.96\pm0.025$ and $\alpha_s=-0.019\pm0.025$. It is interesting to mention here that the results of inflationary parameters are consistent with BICEP2, WMAP $(7+9)$ and Planck data.

1. Introduction

Inflation is a very successful substitutional class of advanced cosmology. It formulates the source of anisotropy of the cosmic microwave background as well as of the large-scale structure (LSS) of the universe [1,2]. In warm inflationary models, the radiation production arises during inflationary period and reheating is avoided [3]. The thermal fluctuations could be obtain in these models which may play a crucial role to produce initial fluctuations which are crucial for LSS formation. Warm inflationary period ends when the universe stops inflating and after that, the universe enters in radiation phase smoothly [3]. In the end, remaining inflatons or dominant radiation fields produced the matter components of the universe.

For the sake of simplicity, the particles (which are produced due to inflaton decay) are assumed as massless particles (or radiation) in warm inflation models. The existence of massive particles has been considered in [4] and corresponding perturbation parameters of this model have been presented in [5]. In this scenario the existence of massive particles may be altered the dynamics of the inflationary universe by modification the fluid pressure. Decay of the massive particles within the fluid is an entropy-producing scalar phenomenon, in other hand “bulk viscous pressure” has entropy-producing property. Therefore the decay of particles may be considered by a bulk viscous pressure $\Pi=-3\xi H$ [6], where H is Hubble parameter and ξ is phenomenological coefficient of bulk viscosity. This coefficient is positive-definite by the second law of thermodynamics and depends on the energy density of the fluid.

During inflationary phase, the forms of energy density like radiation or matter were dominated by the vacuum energy while the scale factor increased exponentially over time [7]. The acceleration of the early universe in the inflationary models is usually governed by a scalar field (inflaton) with an effective potential which shows the evolution of this field. The inflationary epoch can be divided into epochs such as slow-roll and reheating [8,9]. During the slow-roll approximation, the universe inflates as the interactions between inflatons and other fields become negligibly small and the potential energy dominates the kinetic energy. After this period, the universe enters the last stage of inflation, i.e., the reheating era, in which the kinetic and potential energies are comparable. Here the inflation starts to oscillate around the minimum of its potential while losing its energy to massless particles [10–16]. The bulk and shear viscosities have significant role in dissipative effects which are substantial in growth of the universe. That is, a dissipative term accommodated the transfer of energy to the radiation fluctuation with the help of scalar field during warm inflation.

The original inflation which is known as old inflation, considered the inflaton which was stopped in a metastatic false vacuum. That inflation had to exit to the true vacuum via first-order conversion but the exit could not take place completely. Later on, Albrecht and Steinhardt [17] have advised the crammed edition of inflation which is known as new inflation. Although, these

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assumptions endure from theoretical problems like initial conditions and the duration of inflation. Later on, Linde [18] looked for the case that the initial conditions for scalar field driving inflation may be chaotic called chaotic inflation. This model of inflation can solve the persisting problems when potential was selected as quadratic form.

A plethora of works have been done with this chaotic inflation in different theories of gravity. For example, Herrera [19] studied the conditions of inflation for warm inflationary universe model in loop quantum cosmology. They used the chaotic potential to develop the model for bulk and dissipative coefficient as constant. They satisfied the results of the model with observation data WMAP5. Herrera and Olivares [10] investigated the warm inflationary universe models in the context of logamediate inflation. All required parameters had been discussed in weak and strong regimes and satisfied with WMAP7. Setare and Kamali [8] investigated warm-viscous inflation on the brane by taking chaotic potential and found that the values of all involved parameters are consistent with WMAP9, Planck and BICEP2 observational data. Barrow and Liddle [20] worked on intermediate inflation for calculating the spectral index and showed that the perturbation spectral index n_s can be greater than unity on astrophysical scales.

Setare and Kamali [21] worked on warm-tachyon inflationary universe model in the context of loop quantum cosmology. They also developed the inflationary scenario by considering the exponential potential and discussed the different features in detail. All necessary parameters are compatible with recent observational data such as Planck, WMAP9 and BICEP2. Herrera and Campo [22] examined the slow-roll parameters, inflaton, energy density, entropy density, etc., on the brane intermediate inflationary model in high dissipative regime and found consistency with WMAP5. Zarrouki and Bennai [23] took a CG model with an exponential potential in framework of braneworld model. They adopted the slow-roll approximation in the high-energy limit to derive all inflationary spectrum perturbation parameters which had been satisfied by recent observational data from WMAP7.

Setare and Kamali [24] worked on brane with warm-viscous inflationary universe model in tachyon field theory. They calculated the parameters of this inflationary model (e.g., slow-roll parameters, inflaton, energy density, entropy density, etc.) which has been compatible with WMAP7. Herrera et al. [25] studied the general form of dissipative coefficient in the context of warm intermediate and logamediate inflationary universe models for weak and strong dissipative epochs. The parameters of the model are restricted by recent observational data from WMAP9 and Planck data. Sharif and Saleem [26] investigated the consequences of bulk viscous pressure on inflationary model by using modified Chaplygin gas (MCG) during intermediate era for two different choices of coefficients. The parameters of the model has been restricted by recent observational data from WMAP7 and Planck data. Bamba and Odintsov [27] have also considered inflationary cosmology in a viscous fluid model.

We arrange this paper as follows: In the proceeding section, we will provide the detailed discussion for the braneworld model in the context of MCG. Section 3 contains the information about disordered parameters for chaotic potential in the strong dissipative regime. Further this section divided into two subsections, i.e., (i) bulk and dissipative coefficients as variable. (ii) Bulk and dissipative coefficients as constant. In Section 4, we develop our model by considering logamediate inflation. Finally, the summarized form of our results has been discussed in Section 5.

2. Inflationary scenario for brane

In this section, we examine the different features of inflationary MCG model by considering the FRW universe which is compressed the matter radiation and scalar field. We check the braneworld model by taking scalar potential as chaotic. A lot of work has been done on the possibility that we resides in a three-dimensional space embedded in an extra-dimensional world. In this scenario, five-dimensional models in which universe would be a hypersurface has attained a great attention. The four-dimensional Einstein's equations projected onto the brane have been explored by Shiromizu et al. [28]. The approaches which made on the basis of brane-world in the early-time cosmology favor a particular model of cosmic evolution featured by quadratic relations between the energy density and the Hubble parameter, dubbed quadratic cosmology [29]. Thus, a quadratic term of the energy density in brane cosmology appears as extra term in Friedmann equation. Such a term usually makes easier to get inflationary scenario in the early Universe [30]. The spatially flat FRW space comprised by line element, identified as:

$$ds^2 = -dt^2 + a^2(t)(dx^2 + dy^2 + dz^2),$$

where $a(t)$ is the scale factor. Einstein's field equations in the braneworld theory with cosmological constant as a matter and source fields bounded to 3-brane may be designed on to the brane as a following equation [24]

$$G_{\mu\nu} = -\Lambda_4 g_{\mu\nu} + \left(\frac{8\pi}{M_4^2}\right)T_{\mu\nu} + \left(\frac{8\pi}{M_5^2}\right)^2 \pi_{\mu\nu} - E_{\mu\nu},$$

where $E_{\mu\nu}$ is a projection of 5d Weyl tensor, M_4 and M_5 are Planck scales in four and five dimensions respectively, $T_{\mu\nu}$ is energy-momentum tensor on the brane and $\pi_{\mu\nu}$ is a tensor quadratic in $T_{\mu\nu}$. Effectual cosmological constant Λ_4 on the brane in terms of 3-brane tension (λ) and 5d cosmological constant (Λ) is given by

$$\Lambda_4 = \frac{4\pi}{M_5^3}\left(\Lambda + \frac{4\pi}{3M_5^3}\lambda^2\right),$$

and 4d Planck scale is determined by 5d Planck scale as

$$M_4 = \left(\frac{3}{4\pi}\right)^{\frac{1}{2}}\left(\frac{M_5^2}{\sqrt{\lambda}}\right)M_5 .$$

In spatially flat FRW model, Friedmann equation from Einstein's field equation turns out to be [31]

$$H^2 = \frac{\Lambda_4}{3} + \left(\frac{8\pi}{3M_4^2}\right)\rho_\tau + \left(\frac{4\pi}{3M_5^2}\right)\rho_\tau^2 + \frac{\varepsilon}{a^4},$$

where ρ_τ is total energy density on the brane. In the above equation, last term denotes the shape of the bulk gravitons on the brane, where a^4 is an integration constant which comes up from Weyl tensor $E_{\mu\nu}$. The projected Weyl tensor term in the effectual Einstein equation may be neglected because this term may be speedily stretched when the inflation starts. It is also assumed that the Λ_4 is negligible in the early universe. The Friedmann equation is reduced to

$$H^2 = \frac{8\pi}{3M_4^2}\rho_\tau\left(1 + \frac{\rho_\tau}{2\lambda}\right) = \frac{8\pi}{6\lambda M_4^2}\left(2\lambda\rho_\tau + \rho_\tau^2\right). \quad (1)$$

The high energy epoch has been taken then we will consider $\lambda \ll \rho_\tau$ [22], which results Eq. (1) as

$$H^2 = \frac{8\pi}{6\lambda M_4^2}\rho_\tau^2 . \quad (2)$$

Some cosmological observations like Supernovae 1a (SNe 1a), cosmological microwave background (CMB) and Wilkinson Microwave Anisotropy Probe (WMAP) etc., specify the accelerated growth of the universe [32]. In general, a negative pressure is guaranteed to this accelerated growth which is named as dark energy. The different types of dark energy models are quintessence, k-essence, tachyon, cosmological constant, phantom, CG, holographic, quintom and extra dimensional models. An attractive idea to unify