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Holographic Dark Energy Model with Chaplygin Gas

B. C. Paul

*Physics Department, North Bengal University,
Siliguri, Dist. : Darjeeling, Pin : West Bengal, India
India*

1. Introduction

Recent cosmological observations namely, high redshift surveys of type Ia Supernovae, CMB etc. predict that the present universe is passing through an accelerating phase of expansion [1]. The discovery of anisotropy in the Cosmic Microwave Background (CMB) by the Cosmic Microwave Background Explorer (in short, COBE) satellite marked a major advance in cosmology. CMB anisotropy in general alongwith COBE data now provide some of the most powerful tests of cosmological theories, particularly theories concerning the formation of large-scale structure of the universe. It is now generally believed that the universe has emerged out of an inflationary phase in the past. It has been recently predicted that the present universe is undergoing an accelerating phase of expansion. The above two observational facts in the universe do not find explanation in the framework of Einstein general theory of Relativity (GTR) with normal matter. It is known that early inflation may be realized in a semiclassical theory of gravity where matter is described by quantum fields [2]. Starobinsky obtained inflationary solution considering a curvature squared term in the Einstein-Hilbert action [3] long before the advent of inflation was known. However, the efficacy of inflation is known only after the seminal work of Guth who first employed the phase transition mechanism to accommodate inflation. Thereafter more than a dozen of inflationary model came up. The early inflationary universe can be realized either by (i) a modification of gravitational sector of action introducing higher order terms or [4], (ii) a modification of the matter sector instead of perfect fluid, matter is described by quantum fields. Another way of realizing inflation is to consider imperfect fluid. In the case of matter, the equation of state (in short, EOS) is $p = \omega \rho$ where p represents the pressure and ρ represents the energy density, inflation is permitted if $\omega = -1$. For a homogeneous scalar field the condition for inflation is achieved when the potential energy of the field dominates over the kinetic energy. The inflationary period ends when the scalar field or the inflaton field reaches the minimum of the potential. Thereafter the field oscillates and a small comoving volume grows to accommodate the whole universe. The universe decelerates during matter dominated era but the recent observation is that the universe is accelerating. The present accelerating phase can be realized with EOS parameter $\omega < -1$. The usual fields in the standard model of particle physics are not suitable to obtain such accelerating phase of the present universe. In fact it is a challenge

to theoretical physics to describe the origin of such matter density. Recent astronomical data when interpreted in the context of the big-bang model have provided some interesting information about the composition of the universe. The total energy density is shared among a number of fluids that comprises the universe. While Big-Bang nucleosynthesis data suggest that baryonic matter can account for only about 4 % of the total energy density, the cold dark matter (CDM) is about 23 % and the third part, called dark energy, constitutes the remaining 73 % of the total energy density of the universe. To accommodate such a huge energy density various kinds of exotic matters are taken into account as a possible candidate for the dark energy. Among the different theories put forwarded in the literature in recent times, the single component fluid known as Chaplygin gas with an equation of state (EOS) $p = -\frac{B}{\rho}$ [5], where ρ and p are the energy density and pressure respectively and B is a constant has attracted large interest in cosmology. The above equation of state, however, has been conceived in studies of adiabatic fields. It was used to describe lifting forces on a plane wing in aerodynamics process. In cosmology, although it admits an accelerating universe, fails to address structure formation and cosmological perturbation power spectrum [11]. Subsequently, a modified form of the equation of state $p = -\frac{B}{\rho^\alpha}$ with $0 \leq \alpha \leq 1$ was also considered to construct a viable cosmological model [6, 7], which is known as generalized Chaplygin gas (GCG). It has two free parameters B and α respectively. The fluid behaves initially like dust for small size of the universe, but at a later epoch the fluid may be described by an equation of state $p = \omega\rho$. It has string connection, the above EOS can be obtained from the Nambu-Goto action for a D-brane moving in a (D+2) -dimensional space-time in the light cone parametrization. The EOS for GCG has been further modified to

$$p = A\rho - \frac{B}{\rho^\alpha} \quad \text{with } 0 \leq \alpha \leq 1. \quad (1)$$

where A is an equation of state parameter and B is a constant, known as modified GCG. The modified GCG has three free parameters. In the early universe when the scale factor of the universe $a(t)$ was small, the modified GCG gas corresponds to a barotropic fluid (if one considers $A = \frac{1}{3}$ it corresponds to radiation and $A = 0$ it corresponds to matter). Thus at one extreme end modified GCG behaves as ordinary fluid and at the other extreme when the universe is sufficiently large it behaves as cosmological constant which can be fitted to a Λ CDM model. In a flat Friedmann model it is shown [6] that the modified generalized Chaplygin gas may be equivalently described in terms of a homogeneous minimally coupled scalar field ϕ . Barrow [10] has outlined a method to fit Chaplygin gas in FRW universe. Gorini *et al.* [11] using the above scheme obtained the corresponding homogeneous scalar field $\phi(t)$ in a potential $V(\phi)$ which can be used to obtain a viable cosmological model with modified Chaplygin gas. Another form of EOS for Chaplygin gas [12] is considered recently which is given by

$$p = A\rho - \frac{B(a)}{\rho^\alpha} \quad \text{with } 0 \leq \alpha \leq 1, \quad (2)$$

with a variable $B = B_0 a^{-3n}$, B_0 is a constant and a is the scale factor of the universe. The fluid described by the above equation is of much importance now-a-days which is known as variable Chaplygin gas. Using the scheme given by Gorini and his coworkers the corresponding homogeneous scalar field $\phi(t)$ and its potential $V(\phi)$ may be obtained. Guo and Zhang [13] obtained cosmological model using the EOS for variable Chaplygin gas. It is

therefore important to track the dark energy component of the energy density in terms of the above EOS. Cosmological observational results will be used to obtain the necessary constraints [14].

Recently holographic principle [15, 16] is incorporated in cosmology [17-20] to track the dark energy content of the universe following the work of Cohen *et al.* [21]. Holographic principle is a speculative conjecture about quantum gravity theories proposed by G't Hooft. The idea is subsequently promoted by Fischler and Susskind [15] claiming that all the information contained in a spatial volume may be represented by a theory that lives on the boundary of that space. For a given finite region of space it may contain matter and energy within it. If this energy be less than a critical value then the region collapses to a black hole. A black hole is known theoretically to have an entropy which is proportional to its surface area of its event horizon. The event horizon of a black hole encloses a volume, thus a more massive black hole have larger event horizon and encloses larger volume. The most massive black hole that can be fitted in a given region is the one whose event horizon corresponds exactly to the boundary of the given region under consideration. The maximal limit of entropy for an ordinary region of space is directly proportional to the surface area of the region and not to its volume. Thus, according to holographic principle, under suitable conditions all the information about a physical system inside a spatial region is encoded in the boundary. The basic idea of a holographic dark energy in cosmology is that the saturation of the entropy bound may be related to an unknown ultra-violet (UV) scale Λ to some known cosmological scale in order to enable it to find a viable formula for the dark energy which may be quantum gravity in origin and it is characterized by Λ . The choice of UV-Infra Red (IR) connection from the covariant entropy bound leads to a universe dominated by blackhole states. According to Cohen *et al.* [21] for any state in the Hilbert space with energy E , the corresponding Schwarzschild radius $R_s \sim E$, may be less than the IR cut off value L (where L is a cosmological scale). It is possible to derive a relation between the UV cutoff $\rho_\Lambda^{1/4}$ and the IR cutoff which eventually leads to a constraint $\left(\frac{8\pi G}{c^2}\right) L^3 \left(\frac{\rho_\Lambda}{3}\right) \leq L$ [22] where ρ_Λ is the energy density corresponding to dark energy characterized by Λ , G is Newton's gravitational constant and c is a parameter in the theory. The holographic dark energy density is

$$\rho_\Lambda = 3c^2 M_P^2 L^{-2}, \quad (3)$$

where $M_P^{-2} = 8\pi G$. It is known that the present acceleration may be described if $\omega_\Lambda = \frac{p_\Lambda}{\rho_\Lambda} < -\frac{1}{3}$. If one considers $L \sim \frac{1}{H}$ it gives $\omega_\Lambda = 0$. A holographic cosmological constant model based on Hubble scale as IR cut off does not permit accelerating universe. It is also examined [17] that the holographic dark energy model based on the particle horizon as the IR cutoff is not suitable for an accelerating universe. However, an alternative model of dark energy using particle horizon in closed model is also proposed [23]. Li [18] has obtained an accelerating universe considering event horizon as the cosmological scale. The model is consistent with the cosmological observations. Thus to have a model consistent with observed universe one should adopt the covariant entropy bound and choose L to be event horizon [24]. Considering a correspondence of holographic dark energy and Chaplygin gas the field potential is reconstructed [25, 26]. In this chapter we consider variable Chaplygin gas whose EOS is given by eq. (2) and set up a correspondence with holographic dark energy to reconstruct scalar field potential. The holographic description of the variable Chaplygin

gas as a dark energy in FRW universe is considered to explain the dark energy needed for an accelerating universe at late epoch.

The chapter is organized as follows : in sec. 2, the relevant field equation with modified variable Chaplygin gas in FRW universe is presented. Considering correspondence of holographic dark energy fields with modified variable chaplygin gas, we determine the field and the corresponding potential is reconstructed. in sec. 3, squared speed of sound for holographic dark energy is evaluated for stability analysis. Finally in sec. 4, a brief discussion is given.

2. Field equation and modified variable chaplygin gas

The Einstein's field equation is given by

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = 8\pi G T_{\mu\nu} \quad (4)$$

where $T_{\mu\nu}$ is the energy momentum tensor.

We consider a Robertson-Walker (RW) metric given by

$$ds^2 = -dt^2 + a^2(t) \left[\frac{dr^2}{1 - kr^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2) \right] \quad (5)$$

where $a(t)$ is the scale factor of the universe. The energy momentum tensor is $T^\mu_\nu = (\rho, -p, -p, -p)$ where ρ and p are energy density and pressure respectively.

Using RW metric given by (5) and the energy momentum tensor, the Einstein's field equation (4) yields

$$H^2 + \frac{k}{a^2} = \frac{1}{3M_P^2}\rho \quad (6)$$

where we use $8\pi G = M_P^2$, $H = \frac{\dot{a}}{a}$ is the Hubble parameter. The conservation equation for matter is given by

$$\frac{d\rho}{dt} + 3H(\rho + p) = 0 \quad (7)$$

where $\rho = \rho_{matter} + \rho_\Lambda$, where ρ_Λ is the energy density corresponding to Λ . For modified variable chaplygin gas (henceforth, VCG), we use EOS given by eq. (2) in eq. (6), which yields

$$\rho_\Lambda = \left(\frac{(1+\alpha)B_0}{(1+\alpha)(1+A)-n} \frac{1}{a^{3n}} + \frac{C_0}{a^m} \right)^{\frac{1}{1+\alpha}} \quad (8)$$

where C_0 is an integration constant and we denote $m = 3(1+A)(1+\alpha)$. However, for modified Chaplygin gas (i.e., for $n = 0$) it reduces to

$$\rho_\Lambda = \left(\frac{B_0}{1+A} + \frac{C_0}{a^m} \right)^{\frac{1}{1+\alpha}}.$$

We now define the following

$$\Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{cr}}, \quad \Omega_m = \frac{\rho_m}{\rho_{cr}}, \quad \Omega_k = \frac{k}{a^2 H^2} \quad (9)$$

where $\rho_{cr} = 3M_p^2 H^2$, Ω_Λ , Ω_m and Ω_k represent density parameter corresponding to Λ , matter and curvature respectively.

We assume here that the origin of dark energy is a scalar field. Making use of Barrow's scheme [10], we get the following

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) = \rho = \left(\frac{B_1}{a^{3n}} + \frac{C_o}{a^m} \right)^{\frac{1}{\alpha+1}}, \quad (10)$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) = p = \frac{\frac{(n-1-\alpha)B_1}{(1+\alpha)a^{3n}} + \frac{AC_o}{a^m}}{\left(\frac{B_1}{a^{3n}} + \frac{C_o}{a^m} \right)^{\frac{\alpha}{1+\alpha}}}, \quad (11)$$

where $B_1 = \frac{(1+\alpha)B_o}{(1+\alpha)(1+A)-n}$. Now the corresponding scalar field potential and its kinetic energy term is obtained from above which are given by

$$V(\phi) = \frac{\frac{C_o(1-A)}{2a^m} + \frac{1+\alpha-n}{1+\alpha} \frac{B_1}{a^{3n}}}{\left(\frac{B_1}{a^{3n}} + \frac{C_o}{a^m} \right)^{\frac{\alpha}{1+\alpha}}}, \quad (12)$$

$$\dot{\phi}^2 = \frac{\frac{nB_1}{(1+\alpha)a^{3n}} + \frac{C_o(1+A)}{a^m}}{\left(\frac{B_1}{a^{3n}} + \frac{C_o(1+A)}{a^m} \right)^{\frac{\alpha}{1+\alpha}}} \quad (13)$$

For MCG in a flat universe ($k = 0$), eq. (13) can be integrated which yields

$$\phi = \pm \frac{2}{\sqrt{m}} \sinh^{-1} \left[\sqrt{\frac{C_o}{B_1}} a^{-\frac{m}{2}} \right] \quad (14)$$

when $n = 0$ [27] and the corresponding potential is given by

$$V(\phi) = \frac{\frac{B_o}{1+A} + \frac{B_o(1-A)}{2(1+A)} \sinh^2 \left(\sqrt{\frac{3(1+A)(1+\alpha)}{2}} \phi \right)}{\left(\frac{B_o}{1+A} \right)^{\frac{\alpha}{1+\alpha}} \cosh^{\frac{2\alpha}{1+\alpha}} \left(\sqrt{\frac{3(1+A)(1+\alpha)}{2}} \phi \right)} \quad (15)$$

The above equation further reduces to that obtained in Ref. [26] for $\alpha = 1$, $A = 0$ and $n = 0$. Now we consider that the scalar field model of dark energy described by modified variable Chaplygin gas which corresponds to holographic dark energy of the universe. In this section we reconstruct the corresponding potential. Let us now consider a non-flat universe with $k \neq 0$ and use the holographic dark energy density given in (3) as

$$\rho_\Lambda = 3c^2 M_p^2 L^{-2}, \quad (16)$$

where L is the cosmological length scale for tracking the field corresponding to holographic dark energy in the universe. The parameter L is defined as

$$L = ar(t). \quad (17)$$

where $a(t)$ is the scale factor of the universe and $r(t)$ is relevant to the future event horizon of the universe. Using Robertson-Walker metric one gets [19]

$$\begin{aligned} L &= \frac{a(t)}{\sqrt{|k|}} \sin \left[\sqrt{|k|} R_h(t) / a(t) \right] \text{ for } k = +1, \\ &= R_h \text{ for } k = 0, \\ &= \frac{a(t)}{\sqrt{|k|}} \sinh \left[\sqrt{|k|} R_h(t) / a(t) \right] \text{ for } k = -1. \end{aligned} \quad (18)$$

where R_h represents the event horizon which is given by

$$R_h = a(t) \int_t^\infty \frac{dt'}{a(t')} = a(t) \int_0^{r_1} \frac{dr}{\sqrt{1 - kr^2}}. \quad (19)$$

Here R_h is measured in r direction and L represents the radius of the event horizon measured on the sphere of the horizon. Using the definition of $\Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{cr}}$ and $\rho_{cr} = 3M_p^2 H^2$, one can derive [20]

$$HL = \frac{c}{\sqrt{\Omega_\Lambda}}. \quad (20)$$

Using eqs. (19)- (20), we determine the rate of change of L with respect to t which is

$$\begin{aligned} \dot{L} &= \frac{c}{\sqrt{\Omega_\Lambda}} - \frac{1}{\sqrt{|k|}} \cos \left(\frac{\sqrt{|k|} R_h}{a(t)} \right) \text{ for } k = +1, \\ &= \frac{c}{\sqrt{\Omega_\Lambda}} - 1 \text{ for } k = 0, \\ &= \frac{c}{\sqrt{\Omega_\Lambda}} - \frac{1}{\sqrt{|k|}} \cosh \left(\frac{\sqrt{|k|} R_h}{a(t)} \right) \text{ for } k = -1. \end{aligned} \quad (21)$$

Using eqs. (16) -(21), we obtain the holographic energy density ρ_Λ , which is given by

$$\frac{d\rho_\Lambda}{dt} = -2H \left[1 - \frac{\sqrt{\Omega_\Lambda}}{c} \frac{1}{\sqrt{|k|}} f(X) \right] \rho_\Lambda, \quad (22)$$

here we use the notation, henceforth,

$$f(X) = \cos(X) \text{ } [1, \cosh(X)] \text{ for } k = 1 \text{ } [0, -1], \quad (23)$$

with $X = \frac{R_h}{a(t)}$. The energy conservation equation is

$$\frac{d\rho_\Lambda}{dt} + 3H(1 + \omega_\Lambda)\rho_\Lambda = 0 \quad (24)$$

which is used to determine the equation of state parameter

$$\omega_\Lambda = - \left(\frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c} f(X) \right). \quad (25)$$

Now we assume holographic dark energy density which is equivalent to the modified variable Chaplygin gas energy density. The corresponding energy density may be obtained using eq. (8). The EOS parameter follows from eq. (2)

$$\omega = \frac{p}{\rho} = A - \frac{B(a)}{\rho^{\alpha+1}}. \quad (26)$$

We now consider correspondence between the holographic dark energy and modified Chaplygin gas energy density. Using eqs. (8), (16) and (22), one obtains

$$B_o = (3c^2 M_P^2 L^{-2})^{\alpha+1} a^{3n} \left[A + \frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3c} f(X) \right], \quad (27)$$

$$C_o = (3c^2 M_P^2 L^{-2})^{\alpha+1} a^m \left[1 - \frac{(1+\alpha)(A + \frac{1}{3} + 2\frac{\sqrt{\Omega_\Lambda}}{3c} f(X))}{(1+\alpha)(A+1) - n} \right]. \quad (28)$$

Consequently one determines the scalar field potential which is given by

$$V(\phi) = \frac{3c^2 M_P^2 L^{-2}}{2} \left[1 - A + \frac{(1+\alpha)(1+A) - 2n}{(1+\alpha)(1+A) - n} \left(A + \frac{1}{3} + \frac{2\sqrt{\Omega_\Lambda}}{3} f(X) \right) \right], \quad (29)$$

and the corresponding kinetic energy of the field is

$$\dot{\phi}^2 = 2c^2 M_P^2 L^{-2} \left[1 - \frac{\sqrt{\Omega_\Lambda}}{c} f(X) \right]. \quad (30)$$

It is interesting to note that for $n = 0$ the potential reduces to the form that obtained by Paul *et al.* [27] and for $n = 0$ and $A = 0$, it reduces to that form obtained by Setare [25] (where B_o is to be replaced by A). We now substitute $x (= \ln a(t))$, to transform the time derivative to the derivative with logarithm of the scale factor, which is the most useful function in this case. Consequently from eq. (30) one obtains

$$\phi' = M_P \sqrt{2\Omega_\Lambda \left(1 - \frac{\sqrt{\Omega_\Lambda}}{c} f(X) \right)} \quad (31)$$

where $()'$ prime represents derivative with respect to x . Thus, the evolution of the scalar field is given by

$$\phi(a) - \phi(a_o) = \sqrt{2} M_P \int_{\ln a_o}^{\ln a} \sqrt{\Omega_\Lambda \left(1 - \frac{\sqrt{\Omega_\Lambda}}{c} f(X) \right)} dx. \quad (32)$$

3. Squared speed for Holographic Dark Energy (HDE) or stability of HDE :

We consider a closed universe model ($k = 1$) in this case. The dark energy equation of state parameter given by eq. (32) reduces to

$$\omega_\Lambda = -\frac{1}{3} \left(1 + \frac{2}{c} \sqrt{\Omega_\Lambda} \cos y \right) \quad (33)$$

where $y = \frac{R_H}{a(t)}$. The minimum value it can take is $\omega_{min} = -\frac{1}{3} (1 + 2\sqrt{\Omega_\Lambda})$ and one obtains a lower bound $\omega_{min} = -0.9154$ for $\Omega_\Lambda = 0.76$ with $c = 1$. Taking variation of the state parameter with respect to $x = \ln a$, we get [17]

$$\frac{\Omega'_\Lambda}{\Omega_\Lambda^2} = (1 - \Omega_\Lambda) \left(\frac{2}{c} \frac{1}{\Omega_\Lambda} \cos y + \frac{1}{1 - a\gamma} \frac{1}{\Omega_\Lambda} \right) \quad (34)$$

and the variation of equation of state parameter becomes

$$\omega'_\Lambda = -\frac{\sqrt{\Omega_\Lambda}}{3c} \left[\frac{1 - \Omega_\Lambda}{1 - \gamma a} + \frac{2\sqrt{\Omega_\Lambda}}{c} (1 - \Omega_\Lambda \cos^2 y) \right], \quad (35)$$

where $\gamma = \frac{\Omega_k^o}{\Omega_m^o}$. We now introduce the squared speed of holographic dark energy fluid as

$$v_\Lambda^2 = \frac{dp_\Lambda}{d\rho_\Lambda} = \frac{\dot{p}_\Lambda}{\dot{\rho}_\Lambda} = \frac{p'_\Lambda}{\rho'_\Lambda}, \quad (36)$$

where variation of eq. (30) w.r.t. x is given by

$$p'_\Lambda = \omega'_\Lambda \rho_\Lambda + \omega_\Lambda \rho'_\Lambda. \quad (37)$$

Using the eqs. (36) and (37) we get

$$v_\Lambda^2 = \omega'_\Lambda \frac{\rho_\Lambda}{\rho'_\Lambda} + \omega_\Lambda$$

which now becomes

$$v_\Lambda^2 = -\frac{1}{3} - \frac{2}{3c} \sqrt{\Omega_\Lambda} \cos y + \frac{1}{6c} \sqrt{\Omega_\Lambda} \left[\frac{\frac{1-\Omega_\Lambda}{1-\gamma a} + \frac{2}{c} \sqrt{\Omega_\Lambda} (1 - \Omega_\Lambda \cos^2 y)}{1 - \frac{\Omega_\Lambda}{c} \cos y} \right]. \quad (38)$$

The variation of v_Λ^2 with Ω_Λ is shown in fig. 1 for different y values. It is found that for a given value of c , a , γ , the model admits a positive squared speed for $\Omega_\Lambda > 0$. However, Ω_Λ is bounded below otherwise instability develops. We note also that for $\frac{(2n+1)\pi}{2} < y < \frac{(2n+3)\pi}{2}$, (where n is an integer) no instability develops. We plot the case for $n = 0$ in fig. 2, it is evident that for $y \leq \frac{\pi}{2}$ and $y \geq \frac{3\pi}{2}$, the squared speed for holographic dark energy becomes negative which led to instability. But for the region $\frac{\pi}{2} < y < \frac{3\pi}{2}$ with $n = 0$ no such instability develops. It is also found that for $y = 0$ i.e., in flat case the holographic dark energy model is always unstable [28].

4. Discussions

Holographic dark energy model is explored here in a FRW universe with a scalar field which describes the modified variable Chaplygin gas. We consider correspondence of holographic dark energy and the modified variable Chaplygin gas to reconstruct the potential. Since a complete theory of quantum gravity is yet to emerge, we adopt the above approach to understand the nature of dark energy. We determine the evolution of the field and reconstruct the potential of the Holographic dark energy in the case of flat, closed and open models of

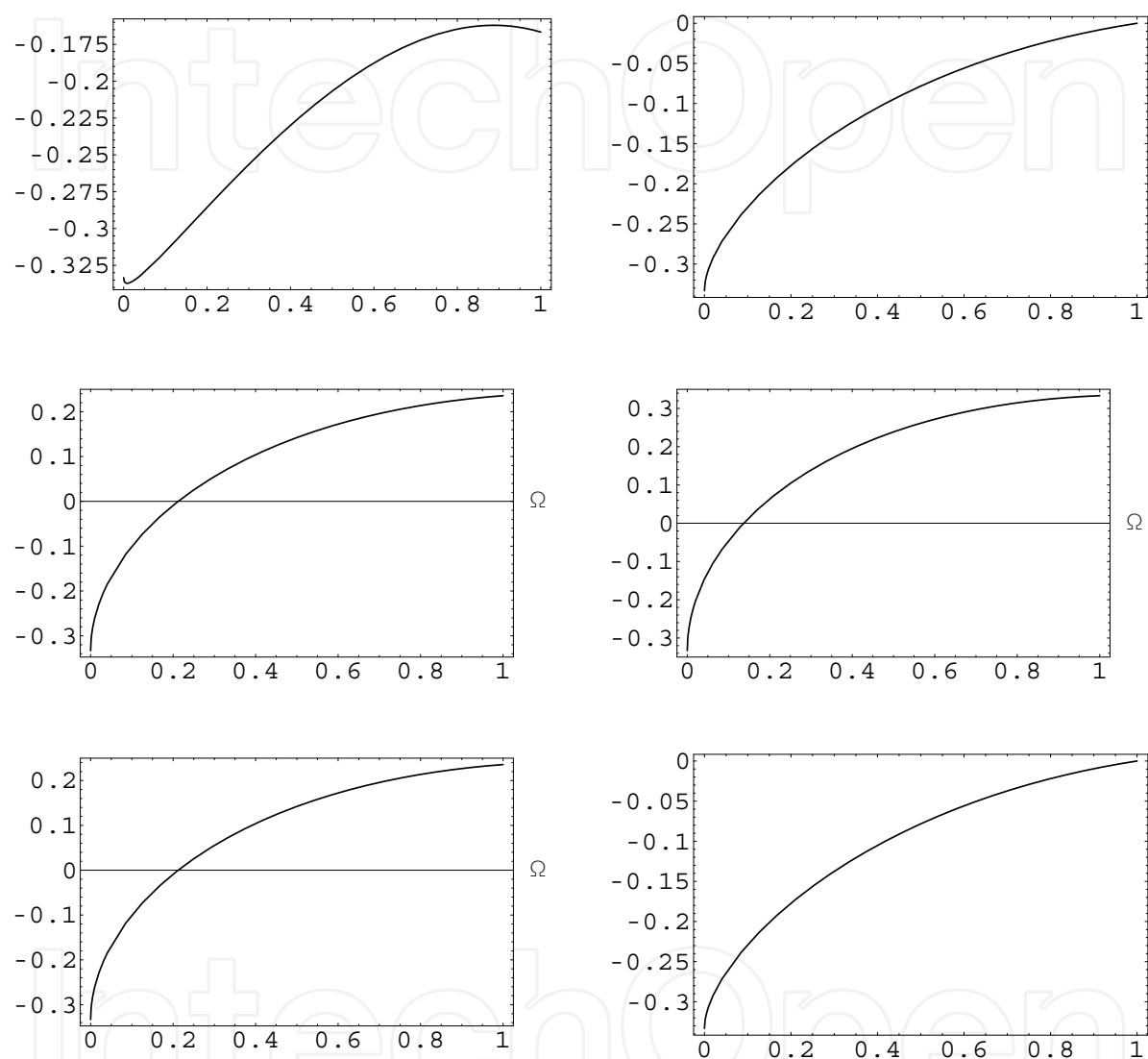


Fig. 1. shows the plot of v_Λ^2 versus Ω_Λ for different values of γ with $c = 1$, $\gamma = 1/3$ and $a = 1$, in the first array the figures are for $\gamma = \frac{\pi}{3}$ and $\gamma = \frac{\pi}{2}$, in the second array for $\gamma = \frac{1.5\pi}{2}$, $\gamma = \pi$ and in the third array for $\gamma = \frac{2.5\pi}{2}$, $\gamma = \frac{3\pi}{2}$.

the universe. Although the cosmological observations predict a flat model of the universe, a closed universe with small positive curvature ($\Omega_k = 0.01$) is compatible with observations. So, in this paper we considered non-flat case also. We give here a generalized expression for the potential and the kinetic energy term considering a modified variable Chaplygin gas [12, 13]. The holographic dark energy field and the corresponding potential depend on three parameters namely, A , α and n . The potential and the kinetic energy given by eqs. (11) and (12) reduce to that form obtained by Setare [26] for $A = 0$, $n = 0$ and $\alpha = 1$. However, the result obtained by Paul *et al.* [27] recovered for $n = 0$. The stability of the holographic dark energy is studied in sec. 3 and found that the stability depends on the parameter Ω_Λ . The evolution of the holographic dark energy field follows same pattern in the modified Chaplygin gas, generalized Chaplygin gas and in the variable Chaplygin gas. However, the field potential is found to differ which, however, depends on the EOS parameters $A = 0$, $n = 0$ and $\alpha = 1$. It is found that holographic field potential $V(\phi)$ picks up a constant value for $n = \frac{(1+\alpha)(1+A)}{2}$. It is noted that the model permits a free holographic field when one chooses $A = 1$ and $n = 1 + \alpha$.

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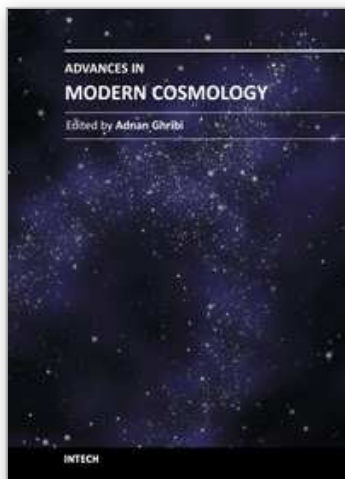
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The twentieth century elevated our understanding of the Universe from its early stages to what it is today and what is to become of it. Cosmology is the weapon that utilizes all the scientific tools that we have created to feel less lost in the immensity of our Universe. The standard model is the theory that explains the best what we observe. Even with all the successes that this theory had, two main questions are still to be answered: What is the nature of dark matter and dark energy? This book attempts to understand these questions while giving some of the most promising advances in modern cosmology.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
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