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ORIGINAL ARTICLE

Interacting Ricci dark energy with logarithmic correction

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Abstract Motivated by the holographic principle, it has been suggested that the dark energy density may be inversely proportional to the area A of the event horizon of the universe. However, such a model would have a causality problem. In this work, we consider the entropy-corrected version of the holographic dark energy model in the non-flat FRW universe and we propose to replace the future event horizon area with the inverse of the Ricci scalar curvature. We obtain the equation of state (EoS) parameter ω_Λ, the deceleration parameter q and Ω'_D in the presence of interaction between Dark Energy (DE) and Dark Matter (DM). Moreover, we reconstruct the potential and the dynamics of the tachyon, K-essence, dilaton and quintessence scalar field models according to the evolutionary behavior of the interacting entropy-corrected holographic dark energy model.

Keywords Dark energy · Logarithmic entropy correction · Ricci scalar · Scalar field model

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1 Introduction

It is popularly believed among astrophysicists and cosmologists that our universe is experiencing an accelerated expansion. The evidence of the accelerated expansion of the universe is proved by numerous and complementary cosmological observations, like the Supernovae Ia (SNIa) (Perlmutter et al. 1999; Astier et al. 2006), the Cosmic Microwave Background (CMB) anisotropies, observed mainly by WMAP (Wilkinson Microwave Anisotropy Probe) (Bennett et al. 2003; Spergel et al. 2003), the Large Scale Structure (LSS) (Tegmark et al. 2004; Abazajian et al. 2004, 2005) and X-ray (Allen et al. 2004) experiments.

In the framework of standard Freidmann-Robertson-Walker (FRW) cosmology, a missing energy component with negative pressure (called Dark Energy (DE)) is the source of this expansion. Careful analysis of cosmological observations, in particular of WMAP data (Spergel et al. 2003; Bennett et al. 2003; Peiris et al. 2003) indicates that the two-thirds of the total energy of the universe is been occupied by the DE whereas DM occupies almost the rest (the baryonic matter representing only a few percent of the total).

The nature of DE is still unknown, and scientists have proposed many candidates in order to describe it (see Padmanabhan 2003; Peebles and Ratra 2003; Copeland et al. 2006 and references therein for good reviews).

The time-independent cosmological constant, Λ, as vacuum energy density, with equation of state (EoS) parameter $\omega = -1$ is the earliest, most famous and simplest theoretical candidate for DE.

Cosmologists know that the cosmological constant suffers from two well-known difficulties: the fine-tuning and the cosmic coincidence problems (Copeland et al. 2006). The former asks why the vacuum energy density is so small (an order of 10^{-123} smaller than what we observe) (Weinberg 1989) and the latter says why vacuum energy and DM are nearly equal today (which is an incredible coincidence if there are no internal connections between them).

The alternative candidates for DE problem are the dynamical DE scenarios with no longer constant but time-varying EoS, ω. According to some analysis on the SNe Ia observational data, it has been shown that the time-varying DE models give a better fit compared with a cosmological constant. There are two different categories for dynamical DE scenarios: (i) scalar fields, including quintessence (Wetterich 1988; Ratra and Peebles 1988), K-essence (Chiba et al. 2000; Armendariz-Picon et al. 2000, 2001), phantoms (Caldwell 2002; Nojiri and Odintsov 2003a, 2003b), tachyon (Sen 2002b; Padmanabhan 2002; Padmanabhan and Choudhury 2002), dilaton (Gasperini et al. 2002; Piazza and Tsujikawa 2004; Arkani-Hamed et al. 2004), quintom (Elizalde et al. 2004; Nojiri et al. 2005; Anisimov 2005) and so forth, and (ii) interacting DE models, including Chaplygin gas models (Kamenshchik et al. 2001; Setare 2007a; Bento et al. 2002), braneworld models (Deffayet et al. 2002; Sahni and Shtanov 2003), holographic DE (HDE) (Cohen et al. 1999; Hořava and Minic 2000; Setare 2006, 2007b, 2007c, 2007d, 2007e, 2007f) and agegraphic DE (ADE) models (Cai 2007; Wei and Cai 2008). For a good review about the problem of DE, including a survey of some theoretical models, see Li et al. (2011).

An important advance in the studies of black hole theory and string theory is the suggestion of the so called holographic principle. According to the holographic principle, the number of degrees of freedom of a physical system should be finite and should scale with its bounding area rather than with its volume ('t Hooft 1993) and it should be constrained by an infrared cut-off (Cohen et al. 1999). The holographic DE (HDE), based on the holographic principle proposed by Fischler and Susskind (1998), is one of the most interesting DE candidates and it has been widely studied in literature (Huang and Li 2004; Hsu 2004; Wang et al. 2005b; Guberina et al. 2005, 2006; Gong 2004; Jamil and Farooq 2010a; Jamil et al. 2009a, 2009b, 2010, 2011; Sadjadi and Jamil 2011; Sheykhi and Jamil 2011a, 2011b, Sheykhi 2009, 2010; Elizalde et al. 2005; Setare 2006, 2007a, 2007c, 2007d; Setare and Jamil 2010b, 2010c, 2011; Karami et al. 2010, 2011; Farooq et al. 2010b; Sheykhi et al. 2010; Setare and Shafei 2006; Setare and Vagenas 2008; Zhang and Wu 2007, 2005; Zhang 2006; Enqvist et al. 2005; Shen et al. 2005). HDE models have also been constrained and tested by various astronomical observations (Zhang and Wu 2005, 2007; Huang and Li 2004; Enqvist et al. 2005; Wang and Xu 2010; Micheletti 2010; Zhang 2009; Feng et al. 2005; Kao et al. 2005; Shen et al. 2005) as well as by the anthropic principle (Huang and Li 2005).

Applying the holographic principle to cosmology, the upper bound of the entropy contained in the universe can be obtained (Fischler and Susskind 1998). Following this line (Li 2004) suggested the following constraint on its energy density:

$$\rho_\Lambda \leq 3c^2 M_p^2 L^{-2}, \tag{1}$$

where c is a numerical constant, L denotes the IR cut-off radius, $M_p = (8\pi G)^{-1/2}$ is the reduced Planck mass (G represents the gravitational constant) and the equality sign holds only when the holographic bound is saturated. Obviously, in the derivation of HDE, the black hole entropy S_{BH} plays an important role. As it is well known, $S_{BH} = A/(4G)$, where $A \approx L^2$ is the area of horizon and G is the gravitational constant. However, in literature, this entropy-area relation can be modified to (Banerjee and Majhi 2008; Banerjee and Ranjan Majhi 2008; Banerjee and Modak 2009; Majhi 2009; Jamil and Farooq 2010b; Wei et al. 2010; Easson et al. 2010; Mohseni Sadjadi and Jamil 2010; Jamil and Sheykhi 2011):

$$S_{BH} = \frac{A}{4G} + \tilde{\alpha} \log\left(\frac{A}{4G}\right) + \tilde{\beta}, \tag{2}$$

where $\tilde{\alpha}$ and $\tilde{\beta}$ are dimensionless constants of order of unity. These corrections can appear in the black hole entropy in Loop Quantum Gravity (LQG). They can also be due to thermal equilibrium fluctuation, quantum fluctuation, or mass and charge fluctuations. The quantum corrections provided to the entropy-area relationship leads to the curvature correction in the Einstein-Hilbert action and vice versa (Zhu and Ren 2009; Cai et al. 2009; Nojiri and Odintsov 2001). Using the corrected entropy-area relation (2), the energy density of the entropy-corrected HDE (ECHDE) can be written as (Wei 2009):

$$\rho_\Lambda = 3\alpha M_p^2 L^{-2} + \gamma_1 L^{-4} \log\left(M_p^2 L^2\right) + \gamma_2 L^{-4}, \tag{3}$$

where γ_1 and γ_2 are dimensionless constants of order unity. In the limiting case $\gamma_1 = \gamma_2 = 0$, (3) yields the well-known HDE density.

The first term on (3) corresponds to the usual holographic energy density. The second and the third terms are due to entropy corrections: since they can be comparable to the first term only when L is very small, the corrections given by them make sense only at the early evolutionary stage of the universe. When the universe becomes large, (3) reduce to that of the ordinary HDE.

Inspired by the HDE models, in this paper we propose to consider another possibility: the IR cut-off radius L is given by the average radius of Ricci scalar curvature, $R^{-1/2}$, so that we have the DE density $\rho_\Lambda \propto R$. We remember that the Ricci scalar can be written as:

$$R = 6\left(\dot{H} + 2H^2 + \frac{k}{a(t)^2}\right), \tag{4}$$

where $H = \dot{a}(t)/a(t)$ is the Hubble parameter, $\dot{H}$ is the derivative of the Hubble parameter with respect to the cosmic time t, $a(t)$ is a dimensionless scale factor and k is the curvature parameter which can assume the values $-1, 0, +1$ which yield, respectively, an open, a flat or a closed FRW universe.

Substituting L with $R^{-1/2}$, we can write the energy density of Ricci ECHDE (R-ECHDE) as:

$$\rho_\Lambda = 3\alpha M_p^2 R + \gamma_1 R^2 \log\left(M_p^2/R\right) + \gamma_2 R^2, \tag{5}$$

where α, γ_1 and γ_2 are three constants, $M_p = (8\pi G)^{-1/2}$ is the modified Planck mass (G is the gravitational constant). Many authors applied the entropy correction terms in an interacting/non-interacting and flat/non-flat universe with modified IR-cutoff (for example see Khodam-Mohammadi and Malekjani 2011a, 2011b; Khodam-Mohammadi 2011).

This paper is organized as follows. In Sect. 2, we describe the physical contest we are working in and we derive the EoS parameter ω_Λ, the deceleration parameter q and Ω'_D for our model in a non-flat universe. In Sect. 3, we establish a correspondence between our model and the tachyon, K-essence, dilaton and quintessence fields. In Sect. 4 we write the Conclusions of this paper.

2 Interacting model in a non-flat universe

Observational evidence suggest that our universe is not perfectly flat but it has a small positive curvature, which implies a closed universe. The tendency of a closed universe is shown in cosmological (in particular CMB) experiments (Bennett et al. 2003; Spergel et al. 2003, 2007; Tegmark et al. 2004; Seljak et al. 2006; Sievers et al. 2003; Netterfield et al. 2002; Benoît et al. 2003a, 2003b). Moreover, the measurements of the cubic correction to the luminosity-distance relation of Supernova measurements reveal a closed universe (Caldwell and Kamionkowski 2004; Wang et al. 2005a). For the above reasons, we prefer to consider a non-flat universe.

Within the framework of the standard Friedmann-Robertson-Walker (FRW) cosmology, the line element for non-flat universe is given by:

$$ds^2 = -dt^2 + a^2(t) \times \left(\frac{dr^2}{1-kr^2} + r^2\left(d\theta^2 + \sin^2\theta d\varphi^2\right)\right). \tag{6}$$

The corresponding Friedmann equation takes the form:

$$H^2 + \frac{k}{a^2} = \frac{1}{3M_p^2}(\rho_\Lambda + \rho_m), \tag{7}$$

where ρ_Λ and ρ_m are the energy densities of DE and DM, respectively.

We also define the fractional energy densities for matter, curvature and DE, respectively, as:

$$\Omega_m = \frac{\rho_m}{\rho_{cr}} = \frac{\rho_m}{3M_p^2H^2}, \tag{8}$$

$$\Omega_k = \frac{\rho_k}{\rho_{cr}} = \frac{k}{H^2a^2}, \tag{9}$$

$$\Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{cr}} = \frac{\rho_\Lambda}{3M_p^2H^2}, \tag{10}$$

where $\rho_{cr} = 3M_p^2H^2$ represents the critical density. The parameter Ω_k represents the contribution to the total density from the spatial curvature. Recent observations support a closed universe with a small positive curvature $\Omega_k \cong 0.02$ (Spergel et al. 2007).

Using (8), (9) and (10) it is possible to write the Friedmann (7) in the following form:

$$\Omega_m + \Omega_\Lambda = 1 + \Omega_k. \tag{11}$$

In order to preserve the Bianchi identity or local energy-momentum conservation law, i.e. $\nabla_\mu T^{\mu\nu} = 0$, the total energy density $\rho_{tot} = \rho_\Lambda + \rho_m$ must satisfy the following equation:

$$\dot{\rho}_{tot} + 3H(1+\omega)\rho_{tot} = 0, \tag{12}$$

where $\omega = p_{tot}/\rho_{tot}$ is the total EoS. By assuming an interaction between DE and DM, the two energy densities ρ_Λ and ρ_m are conserved separately and the conservation equations take the following form:

$$\dot{\rho}_\Lambda + 3H\rho_\Lambda(1 + w_\Lambda) = -Q, \tag{13}$$

$$\dot{\rho}_m + 3H\rho_m = Q. \tag{14}$$

Q represents the interaction term which can be, in general, an arbitrary function of cosmological parameters, like the Hubble parameter H and energy densities ρ_m and ρ_Λ, i.e. $Q(H\rho_m, H\rho_\Lambda)$. The simplest choice for Q is:

$$Q = 3b^2H(\rho_m + \rho_\Lambda), \tag{15}$$

with b^2 a coupling parameter between DM and DE (Amendola and Tocchini-Valetini 2001, 2002; Setare and Jamil 2010a, 2010b; Sheykhi and Jamil 2011b; Farooq et al. 2010a; Jamil and Farooq 2010a; Jamil and Saridakis 2010; Zimdahl et al. 2001, 2003) although more general interaction terms can be used (Jamil and Rashid 2008b). However, since the nature of DM and DE remains unknown, different Lagrangians have been proposed to generate this interaction term. Positive values of b^2 indicate transition from DE to matter and vice versa for negative values of b^2. Sometimes b^2 is taken in the range [0, 1] (Zhang and Zhu 2006). The case with $b^2 = 0$ represents the non-interacting FRW model while $b^2 = 1$ yields the complete transfer of energy from DE to matter. Recently, it is reported that this interaction is observed in the Abell cluster A586 showing a transition of DE into DM and vice versa (Bertolami et al. 2007; Jamil and Rashid 2008a). However the strength of this interaction is not clearly identified (Feng et al. 2007).

Observations of the CMB and of galactic clusters show that the coupling parameter $b^2 < 0.025$, i.e. a small but positive constant of order of the unity (Ichiki and Keum 2008; Amendola et al. 2007). A negative coupling parameter is avoided due to violation of thermodynamical laws.

We now want to derive the expression for the EoS parameter ω_Λ for our model.

Using (7), the Ricci scalar can be written as:

$$R = 6\left(\dot{H} + H^2 + \frac{\rho_m + \rho_\Lambda}{3M_p^2}\right). \tag{16}$$

From the Friedmann (7) we obtain that:

$$\dot{H} = \frac{k}{a^2} - \frac{1}{2M_p^2}\big(\rho_m + \rho_\Lambda(1+\omega_\Lambda)\big). \tag{17}$$

Adding (7) and (17), we obtain:

$$\dot{H} + H^2 = \frac{\rho_m + \rho_\Lambda}{3M_p^2} - \frac{1}{2M_p^2}\big(\rho_m + \rho_\Lambda(1+\omega_\Lambda)\big). \tag{18}$$

Therefore, the Ricci scalar can be written as:

$$R = \frac{\rho_m + \rho_\Lambda}{M_p^2} - \frac{3\rho_\Lambda\omega_\Lambda}{M_p^2}. \tag{19}$$

From (19) we can easily derive the expression of the EoS parameter ω_Λ:

$$\omega_\Lambda = -\frac{RM_p^2}{3\rho_\Lambda} + \frac{\rho_\Lambda + \rho_m}{3\rho_\Lambda} = -\frac{RM_p^2}{3\rho_\Lambda} + \frac{\Omega_\Lambda + \Omega_m}{3\Omega_\Lambda}. \tag{20}$$

Substituting the expression of the energy density given in (5) and using (11) we obtain:

$$\omega_\Lambda = -\frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}. \tag{21}$$

We now want to derive the expression for the evolution of energy density parameter Ω_Λ.

From (13), it is possible to obtain the following expression for the EoS parameter ω_Λ:

$$\omega_\Lambda = -1 - \frac{\dot{\rho}_\Lambda}{3H\rho_\Lambda} - \frac{Q}{3H\rho_\Lambda}. \tag{22}$$

Using the expression of Q given in (15), the derivative of the DE density ρ_Λ can be written as:

$$\dot{\rho}_\Lambda = 3H\left[-\rho_\Lambda - (\rho_m + \rho_\Lambda)\left(b^2 + \frac{1}{3}\right) + \frac{RM_p^2}{3}\right]. \tag{23}$$

Dividing by the critical density $\rho_c = 3H^2M_p^2$, (23) can be written as:

$$\begin{aligned}\frac{\dot{\rho}_\Lambda}{\rho_c} &= \dot{\Omega}_\Lambda + 2\Omega_\Lambda\frac{\dot{H}}{H}\\ &= 3H\left[-\Omega_\Lambda - (1+\Omega_k)\left(b^2 + \frac{1}{3}\right) + \frac{R}{9H^2}\right].\end{aligned} \tag{24}$$

From (4), we can see that the term $\frac{R}{9H^2}$ is equivalent to:

$$\frac{R}{9H^2} = \frac{2}{3}\left(\frac{\dot{H}}{H^2} + 2 + \Omega_k\right). \tag{25}$$

From (24) and substituting (25), it is possible to obtain the derivative of Ω_Λ with respect to the cosmic time t:

$$\begin{aligned}\dot{\Omega}_\Lambda &= 2\frac{\dot{H}}{H}(1-\Omega_\Lambda)\\ &\quad + 3H\left[-\Omega_\Lambda - (1+\Omega_k)\left(b^2 - \frac{1}{3}\right) + \frac{2}{3}\right].\end{aligned} \tag{26}$$

Since $\Omega'_\Lambda = \frac{d\Omega_\Lambda}{dx} = \frac{1}{H}\dot{\Omega}_\Lambda$ (where $x = \ln a$), we derive:

$$\begin{aligned}H\Omega'_\Lambda &= 2H'(1-\Omega_\Lambda)\\ &\quad + 3H\left[-\Omega_\Lambda - (1+\Omega_k)\left(b^2 - \frac{1}{3}\right) + \frac{2}{3}\right],\end{aligned} \tag{27}$$

which yields to:

$$\begin{aligned}\Omega'_\Lambda &= \frac{2}{H}(1-\Omega_\Lambda)\\ &\quad + 3\left[-\Omega_\Lambda - (1+\Omega_k)\left(b^2 - \frac{1}{3}\right) + \frac{2}{3}\right].\end{aligned} \tag{28}$$

In the above Equation we used the fact that:

$$H' = \frac{a'}{a} = 1. \tag{29}$$

For completeness, we also derive the deceleration parameter q:

$$q = -\frac{\ddot{a}a}{\dot{a}^2} = -1 - \frac{\dot{H}}{H^2}. \tag{30}$$

q, combined with the Hubble parameter H and the dimensionless density parameters, form a set of very useful parameters for the description of the astrophysical observations. Taking the derivative respect to the cosmic time t of the Friedmann (7) and using (11), (13) and (14), it is possible to write (30) as:

$$q = \frac{1}{2}[1 + \Omega_k + 3\Omega_\Lambda \omega_\Lambda]. \tag{31}$$

Substituting the expression of the EoS parameter ω_Λ given in (21), we obtain that:

$$q = 1 - \frac{1}{2}\frac{M_p^2 \Omega_\Lambda}{3\alpha M_p^2 + \gamma_1 R \log(M_p^2/R) + \gamma_2 R} + \Omega_k. \tag{32}$$

We can derive the important quantities of the R-ECHDE model in the limiting case, for a flat dark dominated universe in HDE model, i.e. when $\gamma_1 = \gamma_2 = 0$, $\Omega_\Lambda = 1$ and $\Omega_k = 0$.

The energy density given in (5) reduces to:

$$\rho_\Lambda = 3\alpha M_p^2 R. \tag{33}$$

From FRW (7) we find:

$$H = \frac{6\alpha}{12\alpha - 1}\left(\frac{1}{t}\right), \tag{34}$$

$$R = \frac{36\alpha}{(12\alpha - 1)^2}\left(\frac{1}{t^2}\right). \tag{35}$$

At last, the EoS parameter ω_Λ and deceleration parameter q reduce to:

$$\omega_\Lambda = \frac{1}{3} - \frac{1}{9\alpha}, \tag{36}$$

$$q = 1 - \frac{1}{6\alpha}. \tag{37}$$

From (36), we see that in the limiting case, the EoS parameter of DE becomes a constant value in which for $\alpha < 1/12$, $\omega_\Lambda < -1$, where the phantom divide can be crossed. Since the Ricci scalar diverges at $\alpha = 1/12$, this value of α can not be taken into account. From (37), the acceleration is started at $\alpha \leq 1/6$ where the quintessence regime is started ($\omega_\Lambda \leq -1/3$).

This case is very similar to power-law expansion of scale factor of Granda and Oliveros (2008), in which $a(t) = t^{6\alpha/(12\alpha-1)}$.

3 Correspondence between R-ECHDE and scalar fields

In this section we establish a correspondence between the interacting Ricci scale model and the tachyon, K-essence, dilaton and quintessence scalar field models. The importance of this correspondence is that the scalar field models are an effective description of an underlying theory of DE. Therefore, it is worthwhile to reconstruct the potential and the dynamics of scalar fields according the evolutionary form of Ricci scalar model. For this purpose, first we compare the energy density of Ricci scale model (i.e. (5)) with the energy density of corresponding scalar field model. Then, we equate the equations of state of scalar field models with the EoS parameter of Ricci scalar model (i.e. (21)).

3.1 Interacting tachyon model

Recently, huge interest has been devoted to the study of the inflationary model with the help of the tachyon field, since it is believed the tachyon can be assumed as a possible source of DE (Bagla et al. 2003; Shao et al. 2007; Calcagni and Liddle 2006; Copeland et al. 2005).

The tachyon is an unstable field which can be used in string theory through its role in the Dirac-Born-Infeld (DBI) action to describe the D-bran action (Sen 2002a, 1999; Bergshoeff et al. 2000; Klusoň 2000; Kutasov and Niarchos 2003). Tachyon might be responsible for cosmological inflation in the early evolutionary stage of the universe, due to tachyon condensation near the top of the effective scalar potential. A rolling tachyon has an interesting EoS whose parameter smoothly interpolates between -1 and 0. This discovery motivated to take DE as a dynamical quantity, i.e. a variable cosmological constant and model inflation using tachyons. The effective Lagrangian for the tachyon field is given by:

$$L = -V(\phi)\sqrt{1 - g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi}, \tag{38}$$

where $V(\phi)$ represents the potential of tachyon and $g^{\mu\nu}$ is the metric tensor. The energy density ρ_ϕ and pressure p_ϕ for the tachyon field are given, respectively, by:

$$\rho_\phi = \frac{V(\phi)}{\sqrt{1 - \dot{\phi}^2}}, \tag{39}$$

$$p_\phi = -V(\phi)\sqrt{1 - \dot{\phi}^2}. \tag{40}$$

Instead, the EoS parameter of tachyon scalar field is given by:

$$w_\phi = \frac{p_\phi}{\rho_\phi} = \dot{\phi}^2 - 1. \tag{41}$$

In order to have a real energy density for tachyon field, it is required that $-1 < \dot{\phi} < 1$. Consequently, from (41), the EoS parameter of tachyon is constrained to $-1 < \omega_\phi < 0$. Hence, the tachyon field can interpret the accelerated expansion of the universe, but it can not enter the phantom regime, i.e. $\omega_\Lambda < -1$.

Comparing (5) and (39), we obtain an expression for the potential $V(\phi)$ of the tachyon:

$$V(\phi)=\rho_\Lambda\sqrt{1-\dot\phi^2}. \tag{42}$$

Instead, equating (21) and (41), we obtain an expression for the kinetic energy term $\dot\phi^2$:

$$\begin{aligned}\dot\phi^2&=1+\omega_\Lambda\\&=1-\frac{M_p^2/3}{3\alpha M_p^2+\gamma_1 R\log(M_p^2/R)+\gamma_2 R}\\&\quad+\frac{(1+\Omega_k)}{3\Omega_\Lambda}.\end{aligned} \tag{43}$$

Using (42) and (43), it is possible to write the potential of the tachyon as:

$$\begin{aligned}V(\phi)&=\rho_\Lambda\sqrt{-\omega_\Lambda}\\&=\rho_\Lambda\sqrt{\frac{M_p^2/3}{3\alpha M_p^2+\gamma_1 R\log(M_p^2/R)+\gamma_2 R}-\frac{(1+\Omega_k)}{3\Omega_\Lambda}}.\end{aligned} \tag{44}$$

We can derive from (43) and (44) that the kinetic energy $\dot\phi^2$ and the potential $V(\phi)$ may exist if it is satisfied the condition:

$$-1\le\omega_\Lambda\le 0, \tag{45}$$

which implies that the phantom divide can not be crossed in a universe with an accelerated expansion.

Using $\dot\phi=\phi' H$ and (43), we get:

$$\begin{aligned}\phi'&=\frac{1}{H}\\&\quad\times\sqrt{1-\frac{M_p^2/3}{3\alpha M_p^2+\gamma_1 R\log(M_p^2/R)+\gamma_2 R}+\frac{(1+\Omega_k)}{3\Omega_\Lambda}}.\end{aligned} \tag{46}$$

Then, from (46), it is possible to obtain the evolutionary form of the tachyon scalar field as:

$$\begin{aligned}&\phi(a)-\phi(a_0)\\&\quad=\int_{a_0}^{a}\frac{da}{aH}\\&\quad\quad\times\sqrt{1-\frac{M_p^2/3}{3\alpha M_p^2+\gamma_1 R\log(M_p^2/R)+\gamma_2 R}+\frac{(1+\Omega_k)}{3\Omega_\Lambda}},\end{aligned} \tag{47}$$

where a_0 is the present value of the scale factor. Here, we have established an interacting entropy-corrected holographic tachyon DE model and reconstructed the potential and the dynamics of the tachyon field.

In the limiting case for flat dark dominated universe for $\gamma_1=\gamma_2=0$, $\Omega_\Lambda=1$ and $\Omega_k=0$, the scalar field and potential of the tachyon are, respectively:

$$\phi(t)=\sqrt{\frac{12\alpha-1}{9\alpha}}t, \tag{48}$$

$$V(\phi)=\frac{4M_p^2}{(12\alpha-1)}\sqrt{\alpha(1-3\alpha)}\frac{1}{\phi^2}, \tag{49}$$

which are a result of the power-law expansion. In this correspondence, the scalar field exist provided that $\alpha>1/12$, which shows that the phantom divide can not be achieved.

3.2 Interacting K-essence model

A model in which the kinetic term of the scalar field appears in the Lagrangian in a non-canonical way is called K-essence model. The idea of the K-essence scalar field was motivated from the Born-Infeld action of string theory and it is used to explain the late time acceleration of the universe (Sen 2002c; Lambert and Sachs 2003). The general scalar field action for the K-essence model as a function of ϕ and $\chi=\dot\phi/2$ is given by Chiba et al. (2000), Armendariz-Picon et al. (2000, 2001):

$$S=\int d^4x\sqrt{-g}\,p(\phi,\chi), \tag{50}$$

where the Lagrangian density $p(\phi,\chi)$ corresponds to a pressure density. According to this Lagrangian, the pressure $p(\phi,\chi)$ and the energy density of the field ϕ can be written, respectively, as:

$$p(\phi,\chi)=f(\phi)\big(-\chi+\chi^2\big), \tag{51}$$

$$\rho(\phi,\chi)=f(\phi)\big(-\chi+3\chi^2\big). \tag{52}$$

Hence, the EoS parameter of K-essence scalar field is given by:

$$\omega_K=\frac{p(\phi,\chi)}{\rho(\phi,\chi)}=\frac{\chi-1}{3\chi-1}. \tag{53}$$

From (53), one can see the phantom behavior of K-essence scalar field ($w_K<-1$) when the parameter χ lies in the interval $1/3<\chi<1/2$.

In order to consider the K-essence field as a description of the interacting R-ECHDE density, we establish the correspondence between the K-essence EoS parameter, ω_K, and the interacting R-ECHDE EoS parameter, ω_Λ.

The expression for χ can be found equating (21) and (53), obtaining:

$$\chi = \frac{w_\Lambda - 1}{3w_\Lambda - 1} = \frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}. \tag{54}$$

Moreover, equating (5) and (52), we obtain:

$$f(\phi) = \frac{\rho_\Lambda}{\chi(3\chi - 1)}. \tag{55}$$

Using $\dot{\phi}^2 = 2\chi$ and $\dot{\phi} = \phi' H$, we derive:

$$\phi' = \frac{\sqrt{2}}{H}\sqrt{\frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}}. \tag{56}$$

Integrating (56), we find the evolutionary form of the K-essence scalar field:

$$\phi(a) - \phi(a_0) = \sqrt{2}\int_{a_0}^{a} \frac{da}{aH} \times \sqrt{\frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}}, \tag{57}$$

where a_0 is the present value of the scale factor.

In the limiting case of $\gamma_1 = \gamma_2 = 0$, $\Omega_\Lambda = 1$ and $\Omega_k = 0$, in a flat dark dominated universe, the scalar field and potential of K-essence field reduce to:

$$\phi(t) = \sqrt{\frac{2(1+6\alpha)}{3}}\,t, \tag{58}$$

$$f(\phi) = \frac{36\alpha M_p^2}{(12\alpha - 1)^2}\frac{1}{\phi^2}, \tag{59}$$

which are a result of power-law expansion. Moreover, we see that our universe may behave in all accelerated regimes (phantom and quintessence), since all values of α are permitted.

3.3 Interacting dilaton model

A dilaton scalar field, originated from the lower-energy limit of string theory (Piazza and Tsujikawa 2004), can also be assumed as a source of DE.

The process of compactification of the string theory from higher to four dimensions introduces the scalar dilaton field which is coupled to curvature invariants. The coefficient of the kinematic term of the dilaton can be negative in the Einstein frame, which means that the dilaton behaves as a phantom-like scalar field. The pressure (Lagrangian) density and the energy density of the dilaton DE model are given, respectively, by Gasperini et al. (2002), Arkani-Hamed et al. (2004), Elizalde et al. (2008):

$$p_D = -\chi + ce^{\lambda\phi}\chi^2, \tag{60}$$

$$\rho_D = -\chi + 3ce^{\lambda\phi}\chi^2, \tag{61}$$

where c and λ are positive constants and $2\chi = \dot{\phi}^2$. The negative coefficient of the kinematic term of the dilaton field in Einstein frame makes a phantom-like behavior for dilaton field. The EoS parameter for the dilaton scalar field is given by:

$$\omega_D = \frac{p_D}{\rho_D} = \frac{-1 + ce^{\lambda\phi}\chi}{-1 + 3ce^{\lambda\phi}\chi}. \tag{62}$$

In order to consider the dilaton field as a description of the interacting R-ECHDE density, we establish the correspondence between the dilaton EoS parameter, w_D, and the EoS parameter ω_Λ of the R-ECHDE model. By equating (21) and (62), it is possible to find:

$$ce^{\lambda\phi}\chi 7 = \frac{\omega_\Lambda - 1}{3\omega_\Lambda - 1} = \frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}. \tag{63}$$

Using $\dot{\phi}^2 = 2\chi$, we can rewrite (63) as:

$$e^{\lambda\phi/2}\dot{\phi} = \sqrt{\frac{2}{c}} \times \sqrt{\frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}}. \tag{64}$$

Integrating (64) with respect to a, we obtain:

$$e^{\frac{\lambda\phi(a)}{2}} = e^{\frac{\lambda\phi(a_0)}{2}} + \frac{\lambda}{\sqrt{2c}}\int_{a_0}^{a}\frac{da}{aH} \times \sqrt{\frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}}. \tag{65}$$

The evolutionary form of the dilaton scalar field is written as:

$$\phi(a) = \frac{2}{\lambda}\ln\left[e^{\frac{\lambda\phi(a_0)}{2}} + \right] + \frac{\lambda}{\sqrt{2c}}\int_{a_0}^{a}\frac{da}{aH} \times\sqrt{\frac{-1 - \frac{M_p^2/3}{3\alpha M_p^2+\gamma_1 R\log(M_p^2/R)+\gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}}{-1 - \frac{M_p^2}{3\alpha M_p^2+\gamma_1 R\log(M_p^2/R)+\gamma_2 R} + \frac{(1+\Omega_k)}{\Omega_\Lambda}}}. \quad (66)$$

In the limiting case of $\gamma_1 = \gamma_2 = 0$, $\Omega_\Lambda = 1$ and $\Omega_k = 0$, in a flat dark dominated universe, the scalar field of dilaton field reduces to the following form:

$$\phi(t) = \frac{2}{\lambda}\ln\left[\lambda t\sqrt{\frac{1+6\alpha}{6c}}\right]. \quad (67)$$

We see that all values of α are permitted and, therefore, by this correspondence, the universe may behave in phantom and quintessence regime.

3.4 Quintessence

Quintessence is described by an ordinary time-dependent and homogeneous scalar field ϕ which is minimally coupled to gravity, but with a particular potential $V(\phi)$ that leads to the accelerating universe. The action for quintessence is given by Copeland et al. (2006):

$$S = \int d^4x\sqrt{-g}\left[-\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right]. \quad (68)$$

The energy momentum tensor $T_{\mu\nu}$ of the field is derived by varying the action given in (68) with respect to the metric tensor $g^{\mu\nu}$:

$$T_{\mu\nu} = \frac{2}{\sqrt{-g}}\frac{\delta S}{\delta g^{\mu\nu}}, \quad (69)$$

which yields to:

$$T_{\mu\nu} = \partial_\mu\phi\partial_\nu\phi - g_{\mu\nu}\left[\frac{1}{2}g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi + V(\phi)\right]. \quad (70)$$

The energy density ρ_Q and pressure p_Q of the quintessence scalar field ϕ are given, respectively, by:

$$\rho_Q = -T_0^0 = \frac{1}{2}\dot{\phi}^2 + V(\phi), \quad (71)$$

$$p_Q = T_i^i = \frac{1}{2}\dot{\phi}^2 - V(\phi). \quad (72)$$

The EoS parameter for the quintessence scalar field is given by:

$$\omega_Q = \frac{p_Q}{\rho_Q} = \frac{\dot{\phi}^2 - 2V(\phi)}{\dot{\phi}^2 + 2V(\phi)}. \quad (73)$$

We find from (73) that, when $\omega_Q < -1/3$, the universe accelerates for $\dot{\phi}^2 < V(\phi)$.

Here we establish the correspondence between the interacting scenario and the quintessence DE model: equating (73) with the EoS parameter given in (21), i.e. $\omega_Q = \omega_\Lambda$, and equating (71) and (5), i.e. $\rho_Q = \rho_\Lambda$, we obtain:

$$\dot{\phi}^2 = (1+\omega_\Lambda)\rho_\Lambda, \quad (74)$$

$$V(\phi) = \frac{1}{2}(1-\omega_\Lambda)\rho_\Lambda. \quad (75)$$

Substituting (22) into (74) and (75), the kinetic energy term $\dot{\phi}^2$ and the quintessence potential energy $V(\phi)$ can be easily found as follow:

$$\dot{\phi}^2 = \rho_\Lambda\left(1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}\right), \quad (76)$$

$$V(\phi) = \frac{\rho_\Lambda}{2}\left(1 + \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} - \frac{(1+\Omega_k)}{3\Omega_\Lambda}\right). \quad (77)$$

From (76), using $\dot{\phi} = \phi' H$, it is possible to obtain the evolutionary form of the quintessence scalar field as:

$$\phi(a) - \phi(a_0) = \int_{a_0}^{a}\frac{da}{a}\left\{\sqrt{3M_p^2\Omega_\Lambda} \times\left(1 - \frac{M_p^2/3}{3\alpha M_p^2 + \gamma_1 R\log(M_p^2/R) + \gamma_2 R} + \frac{(1+\Omega_k)}{3\Omega_\Lambda}\right)^{1/2}\right\}, \quad (78)$$

where a_0 is the present value of the scale factor. In the limiting case of $\gamma_1 = \gamma_2 = 0$, $\Omega_\Lambda = 1$ and $\Omega_k = 0$, in a flat dark dominated universe, the scalar field and potential of quintessence reduce to:

$$\phi(t) = \frac{6\alpha M_p}{\sqrt{3\alpha(12\alpha-1)}}\ln(t), \quad (79)$$

$$V(\phi) = \frac{6\alpha(6\alpha+1)}{(12\alpha-1)^2}M_p^2\exp\left[\frac{-\sqrt{3\alpha(12\alpha-1)}}{3\alpha M_p}\phi\right]. \quad (80)$$

The potential exists for all values of $\alpha > 1/12$ (quintessence regime). The potential has also been obtained by power-law expansion of scale factor.

4 Conclusions

In this paper, we considered the entropy-corrected version of the HDE model which is in interaction with DM in the non-flat FRW universe (and with IR cut-off equivalent to the Ricci scalar R). The HDE model is an attempt to probe the nature of DE within the framework of quantum gravity. We considered the logarithmic correction term to the energy density of HDE model. The addition of correction terms to the energy density of HDE is motivated from the Loop Quantum Gravity (LQG), which is one of the most promising theories of quantum gravity. Using the expression of this modified energy density, we obtained the EoS parameter, deceleration parameter and evolution of energy density parameter for the interacting R-ECHDE model. We found that for the appropriate model parameters (even in limiting case,$\gamma_1 = \gamma_2 = \Omega_k = 0$, $\Omega_\Lambda = 1$), the phantom divide may be crossed, $\omega_\Lambda < -1$, and the present acceleration expansion ($q < 0$) is achieved where the quintessence regime is started. Moreover, we established a correspondence between the interacting R-ECHDE model and the tachyon, K-essence, dilaton and quintessence scalar field models in the hypothesis of non-flat FRW universe.

These correspondences are important to understand how various candidates of DE are mutually related to each other. The limiting case of flat dark dominated universe without entropy correction were studied in each scalar field and we see that the EoS parameter is constant in this case and we calculate the scalar field and its potential which can be obtained by idea of power-law expansion of scalar field.

In order to make a comparison between our model and another works in LECHDE-scalar field model, we concentrate our attention in a recent article (Amani et al. 2012). The authors considered a scalar-tensor cosmological model with the non-minimal kinetic coupling terms and discussed its cosmological implications with respect to the entropy corrected holographic dark energy. Our results differ from their results in that their analysis involves two coupling parameters and a cosmological event horizon while ours deal with a Ricci scale and no couplings. Such scalar field models have interesting property of explaining the phantom crossing while the reconstructed scalar potential has interesting physical implications in cosmology.

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References

Abazajian, K., et al.: Astron. J. **128**, 502 (2004)
Abazajian, K., et al.: Astron. J. **129**, 1755 (2005)
Allen, S.W., et al.: Mon. Not. R. Astron. Soc. **353**, 457 (2004)
Amendola, L., Tocchini-Valetini, D.: Phys. Rev. D **64**, 043509 (2001)
Amendola, L., Tocchini-Valetini, D.: Phys. Rev. D **66**, 043528 (2002)
Amendola, L., Campos, G.C., Rosenfeld, R.: Phys. Rev. D **75**, 083506 (2007)
Anisimov, A.: J. Cosmol. Astropart. Phys. **6**, 6 (2005)
Arkani-Hamed, N., Creminelli, P., Mukohyama, S., Zaldarriaga, M.: J. Cosmol. Astropart. Phys. **4**, 1 (2004)
Armendariz-Picon, C., Mukhanov, V., Steinhardt, P.J.: Phys. Rev. Lett. **85**, 4438 (2000)
Armendariz-Picon, C., Mukhanov, V., Steinhardt, P.J.: Phys. Rev. D **63**, 103510 (2001)
Astier, P., et al.: Astron. Astrophys. **447**, 31 (2006)
Bagla, J.S., Jassal, H.K., Padmanabhan, T.: Phys. Rev. D **67**, 063504 (2003)
Banerjee, R., Majhi, B.R.: Phys. Lett. B **662**, 62 (2008)
Banerjee, R., Modak, S.K.: J. High Energy Phys. **5**, 63 (2009)
Banerjee, R., Ranjan Majhi, B.: J. High Energy Phys. **6**, 95 (2008)
Bennett, C.L., et al.: Astrophys. J. **148**, 1 (2003)
Benoît, A., et al.: Astron. Astrophys. **399**, L19 (2003a)
Benoît, A., et al.: Astron. Astrophys. **399**, L25 (2003b)
Bento, M.C., Bertolami, O., Sen, A.A.: Phys. Rev. D **66**, 043507 (2002)
Bergshoeff, E.A., et al.: J. High Energy Phys. **5**, 9 (2000)
Bertolami, O., Gil Pedro, F., Le Delliou, M.: Phys. Lett. B **654**, 165 (2007)
Cai, R.-G.: Phys. Lett. B **657**, 228 (2007)
Cai, R.-G., Cao, L.-M., Hu, Y.-P.: Class. Quantum Gravity **26**, 15 (2009)
Calcagni, G., Liddle, A.R.: Phys. Rev. D **74**, 043528 (2006)
Caldwell, R.R.: Phys. Lett. B **545**, 23 (2002)
Caldwell, R.R., Kamionkowski, M.: J. Cosmol. Astropart. Phys. **9**, 9 (2004)
Chiba, T., Okabe, T., Yamaguchi, M.: Phys. Rev. D **62**, 023511 (2000)
Cohen, A.G., Kaplan, D.B., Nelson, A.E.: Phys. Rev. Lett. **82**, 4971 (1999)
Copeland, E.J., et al.: Phys. Rev. D **71**, 043003 (2005)
Copeland, E.J., Sami, M., Tsujikawa, S.: Int. J. Mod. Phys. D **15**, 1753 (2006)
Deffayet, C., Dvali, G., Gabadadze, G.: Phys. Rev. D **65**, 044023 (2002)
Easson, D.A., Frampton, P.H., Smoot, G.F.: arXiv:1003.1528 [hep-th] (2010)
Elizalde, E., Nojiri, S., Odintsov, S.D.: Phys. Rev. D **70**, 043539 (2004)
Elizalde, E., Nojiri, S., Odintsov, S.D., Wang, P.: Phys. Rev. D **71**, 103504 (2005)
Elizalde, E., et al.: Eur. Phys. J. C Part. Fields **53**, 447 (2008)
Enqvist, K., Hannestad, S., Sloth, M.S.: J. Cosmol. Astropart. Phys. **2**, 4 (2005)
Farooq, M.U., Jamil, M., Rashid, M.A.: Int. J. Theor. Phys. **49**, 2278 (2010a)
Farooq, M.U., Jamil, M., Rashid, M.A.: Int. J. Theor. Phys. **49**, 2334 (2010b)
Feng, B., Wang, X., Zhang, X.: Phys. Lett. B **607**, 35 (2005)
Feng, C., Wang, B., Gong, Y., Su, R.-K.: J. Cosmol. Astropart. Phys. **9**, 5 (2007)
Fischler, W., Susskind, L.: (arXiv:hep-th/9806039) (1998)
Gasperini, M., Piazza, F., Veneziano, G.: Phys. Rev. D **65**, 023508 (2002)
Gong, Y.: Phys. Rev. D **70**, 064029 (2004)
Granda, L.N., Oliveros, A.: Phys. Lett. B **669**, 275 (2008)
Guberina, B., Horvat, R., Stefancic, H.: J. Cosmol. Astropart. Phys. **5**, 1 (2005)
Guberina, B., Horvat, R., Nikolić, H.: Phys. Lett. B **636**, 80 (2006)
Hořava, P., Minic, D.: Phys. Rev. Lett. **85**, 1610 (2000)
Hsu, S.D.H.: Phys. Lett. B **594**, 13 (2004)
Huang, Q.G., Li, M.: J. Cosmol. Astropart. Phys. **8**, 13 (2004)
Huang, Q.G., Li, M.: J. Cosmol. Astropart. Phys. **3**, 1 (2005)
Ichiki, K., Keum, Y.Y.: J. Cosmol. Astropart. Phys. **6**, 5 (2008)
Jamil, M., Farooq, M.U.: Int. J. Theor. Phys. **49**, 42 (2010a)
Jamil, M., Farooq, M.U.: J. Cosmol. Astropart. Phys. **3**, 2 (2010b)

Jamil, M., Rashid, M.A.: Eur. Phys. J. C **58**, 111 (2008a)
Jamil, M., Rashid, M.A.: Astrophys. J. **56**, 429 (2008b)
Jamil, M., Saridakis, E.N.: J. Cosmol. Astropart. Phys. **7**, 28 (2010)
Jamil, M., Sheykhi, A.: Int. J. Theor. Phys. **50**, 625 (2011)
Jamil, M., Saridakis, E.N., Setare, M.R.: Phys. Lett. B **679**, 172 (2009a)
Jamil, M., Farooq, M.U., Rashid, M.A.: Eur. Phys. J. C **61**, 471 (2009b)
Jamil, M., Sheykhi, A., Farooq, M.U.: Int. J. Mod. Phys. D **19**, 1831 (2010)
Jamil, M., et al.: Int. J. Theor. Phys. **579** (2011)
Kamenshchik, A., Moschella, U., Pasquier, V.: Phys. Lett. B **511**, 265 (2001)
Kao, H.C., Lee, W.L., Lin, F.L.: Phys. Rev. D **71**, 123518 (2005)
Karami, K., Khaledian, M.S., Felegary, F., Zarmi, Z.: Phys. Lett. B **686**, 216 (2010)
Karami, K., Khaledian, M.S., Jamil, M.: Phys. Scr. **83**, 025901 (2011)
Khodam-Mohammadi, A.: Mod. Phys. Lett. A **26**, 2487 (2011)
Khodam-Mohammadi, A., Malekjani, M.: Commun. Theor. Phys. **55**, 942 (2011a)
Khodam-Mohammadi, A., Malekjani, M.: arXiv:1101.1632 [gr-qc] (2011b)
Klusoň, J.: Phys. Rev. D **62**, 126003 (2000)
Kutasov, D., Niarchos, V.: Nucl. Phys. B **666**, 56 (2003)
Lambert, N.D., Sachs, I.: Phys. Rev. D **67**, 025005 (2003)
Li, M.: Astrophys. J. **603**, 1 (2004)
Li, M., Li, X.-D., Wang, S., Wang, Y.: Commun. Theor. Phys. **56**, 525 (2011)
Majhi, B.R.: Phys. Rev. D **79**, 044005 (2009)
Micheletti, S.M.R.: J. Cosmol. Astropart. Phys. **4**, 9 (2010)
Mohseni Sadjadi, H., Jamil, M.: Europhys. Lett. **926**, 69001 (2010)
Netterfield, C.B., et al.: Astrophys. J. **571**, 604 (2002)
Nojiri, S., Odintsov, S.D.: Int. J. Mod. Phys. A **16**, 3273 (2001)
Nojiri, S., Odintsov, S.D.: Astrophys. J. **565**, 1 (2003a)
Nojiri, S., Odintsov, S.D.: Phys. Lett. B **562**, 147 (2003b)
Nojiri, S., Odintsov, S.D., Tsujikawa, S.: Phys. Rev. D **71**, 063004 (2005)
Padmanabhan, T.: Phys. Rev. D **66**, 021301 (2002)
Padmanabhan, T.: Phys. Rep. **380**, 235 (2003)
Padmanabhan, T., Choudhury, T.R.: Phys. Rev. D **66**, 081301 (2002)
Peebles, P.J., Ratra, B.: Rev. Mod. Phys. **75**, 559 (2003)
Peiris, H.V., et al.: Astrophys. J. Suppl. Ser. **148**, 213 (2003)
Perlmutter, S., et al.: Astrophys. J. **517**, 565 (1999)
Piazza, F., Tsujikawa, S.: J. Cosmol. Astropart. Phys. **7**, 4 (2004)
Ratra, B., Peebles, P.J.E.: Phys. Rev. D **37**, 3406 (1988)
Sadjadi, H.M., Jamil, M.: Gen. Relativ. Gravit. **43**, 1759 (2011)
Sahni, V., Shtanov, Y.: J. Cosmol. Astropart. Phys. **11**, 14 (2003)
Seljak, U., Slosar, A., McDonald, P.: J. Cosmol. Astropart. Phys. **10**, 14 (2006)
Sen, A.: J. High Energy Phys. **10**, 8 (1999)
Sen, A.: J. High Energy Phys. **7**, 65 (2002a)
Sen, A.: J. High Energy Phys. **4**, 48 (2002b)
Sen, A.: Mod. Phys. Lett. A **17**, 1797 (2002c)
Setare, M.R.: Phys. Lett. B **642**, 421 (2006)
Setare, M.R.: Eur. Phys. J. C **52**, 689 (2007a)
Setare, M.R.: Phys. Lett. B **653**, 116 (2007b)
Setare, M.R.: Phys. Lett. B **648**, 329 (2007c)
Setare, M.R.: Phys. Lett. B **644**, 99 (2007d)
Setare, M.R.: Eur. Phys. J. C **50**, 991 (2007e)
Setare, M.: Phys. Lett. B **654**, 1 (2007f)
Setare, M.R., Jamil, M.: Phys. Lett. B **690**, 1 (2010a)
Setare, M.R., Jamil, M.: J. Cosmol. Astropart. Phys. **2**, 10 (2010b)
Setare, M.R., Jamil, M.: Europhys. Lett. **92**, 49003 (2010c)
Setare, M.R., Jamil, M.: Gen. Relativ. Gravit. **43**, 293 (2011)
Setare, M.R., Shafei, S.: J. Cosmol. Astropart. Phys. **9**, 11 (2006)
Setare, M.R., Vagenas, E.C.: Phys. Lett. B **666**, 111 (2008)
Shao, Y., Gui, Y.-X., Wang, W.: Mod. Phys. Lett. A **22**, 1175 (2007)
Shen, J., Wang, B., Abdalla, E., Su, R.-K.: Phys. Lett. B **609**, 200 (2005)
Sheykhi, A.: Phys. Lett. B **681**, 205 (2009)
Sheykhi, A.: Astrophys. J. **27**, 025007 (2010)
Sheykhi, A., Jamil, M.: Gen. Relativ. Gravit. **43**, 2661 (2011a)
Sheykhi, A., Jamil, M.: Phys. Lett. B **694**, 284 (2011b)
Sheykhi, A., et al.: arXiv:1005.4541 [gen-ph] (2010)
Sievers, J.L., et al.: Astrophys. J. **591**, 599 (2003)
Spergel, D.N., et al.: Astrophys. J. Suppl. Ser. **148**, 175 (2003)
Spergel, D.N., et al.: Astrophys. J. Suppl. Ser. **170**, 377 (2007)
Tegmark, M., et al.: Phys. Rev. D **69**, 103501 (2004)
't Hooft, G.: arXiv:gr-qc/9310026 [gr-qc] (1993)
Wang, Y., Xu, L.: Phys. Rev. D **81**, 083523 (2010)
Wang, B., Gong, Y., Su, R.-K.: Phys. Lett. B **605**, 9 (2005a)
Wang, B., Gong, Y., Abdalla, E.: Astrophys. J. **624**, 141 (2005b)
Wei, H.: Commun. Theor. Phys. **52**, 743 (2009)
Wei, H., Cai, R.G.: Phys. Lett. B **660**, 113 (2008)
Wei, S.W., Liu, Y.X., Wang, Y.Q., Guo, H.: arXiv:1002.1550 [hep-th] (2010)
Weinberg, S.: Rev. Mod. Phys. **61**, 1 (1989)
Wetterich, C.: Nucl. Phys. B **302**, 668 (1988)
Zhang, X.: Phys. Rev. D **74**, 103505 (2006)
Zhang, X.: Phys. Rev. D **79**, 103509 (2009)
Zhang, X., Wu, F.Q.: Phys. Rev. D **72**, 043524 (2005)
Zhang, X., Wu, F.Q.: Phys. Rev. D **76**, 023502 (2007)
Zhang, H., Zhu, Z.H.: Phys. Rev. D **73**, 043518 (2006)
Zimdahl, W., Pavón, D., Chimento, L.P.: Phys. Lett. B **521**, 133 (2001)
Zimdahl, W., Pavón, D.: Gen. Relativ. Gravit. **35**, 413 (2003)
Zhu, T., Ren, J.R.: Eur. Phys. J. C **62**, 413 (2009)
Amani, A.R., Sadeghi, J., Farajollahi, H., Pourali, M.: Can. J. Phys. **90**, 61 (2012)