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Dilatonic Cosmology Model in the ω–ω' Plane

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Abstract In dilatonic cosmology model, we study the behavior of attractor solution in ω–ω' plane, which is defined by the equation of state parameter for the dark energy and its derivative with respect to N (the logarithm of the scale factor a). This is a good method which is useful to the study of classifying the dynamical dark energy models including "freezing" and "thawing" model. We find that our model belongs to "freezing" type model classified in ω–ω' plane. We show mathematically the property of attractor solutions which correspond to $\omega_\sigma = -1$, $\Omega_\sigma = 1$. The present values of energy density parameter Ω_{σ_0}, Ω_{m_0} and Ω_{r_0} are 0.715001, 0.284972 and 0.00002706 respectively, which meet the current observations well. Finally, we can obtain that the coupling between dilaton and matter affects the evolutive process of the Universe, but not the fate of the Universe.

Keywords Dilaton · Dark energy · Cosmology · Coupled quintessence · ω–ω' plane · Attractor

1 Introduction

Exploring the nature of the dark energy has been one of the most challenging problems in astronomy and physics today, since the observations of high-redshift Type Ia Supernova [1–4] and the Cosmic Microwave Background [5] are issued, which suggest that our universe is undergoing an accelerated expansion phase and spatially flat. Dark energy with negative pressure, which is an unclumped form of energy density pervading the Universe, contributes to about two thirds of the total energy density. In the observational cosmology, the equation

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of state parameter (EoS) of dark energy $\omega = \frac{p}{\rho}$ plays a central role, where p and ρ are its pressure and energy density, respectively. To fit the observations, the EoS of dark energy must satisfy $\omega < -\frac{1}{3}$. Perhaps the simplest explanation for these data is that the dark energy corresponds to a positive cosmological constant. However, the cosmological constant model suffers from two serious issues called "coincidence problem" and "fine-tuning problem", that is to say, we must answer the following two questions: why the cosmological constant is about 120 orders of magnitude smaller than its natural expectation and why does our universe begin the accelerated expansion recently? An alternative is a scalar field which has not yet reached its ground state. These scalar field models include Quintessence [6–44], K-essence [45–51], Tachyon [52–61], Phantom [62–72], Quintom [73–75] and so on. Quintessence model has been widely studied, and its state parameter ω which is time-dependent, is greater than -1. Such a model for a broad class of potentials can give the energy density converging to its present value for a wide set of initial conditions in the past and possess tracker behavior. In this paper, we regard dilaton in Weyl-scaled induced gravitational theory as a coupled Quintessence.

Motivations that make us consider dilatonic cosmology model are as follows: First, the dilaton is an essential element of string theories and the low-energy string effective action [76]. Second, dimensional compaction of Kaluza-Klein theories may naturally lead to the Weyl-scaled induced gravitational theory. Third, dilatonic gravities are expected to have such important cosmological applications as in the case of (hyper)extended inflation [77]. Fourth, Many authors have considered the coupled dark energy and obtained many interesting and important results [78–86]. In our previous paper [87], we have considered a dilatonic dark energy model, based on Weyl-scaled induced gravitational theory. We found that when the dilaton field was not gravitational clustered at small scales, the effect of dilaton can not change the evolutionary law of baryon density perturbation, and the density perturbation can grow from $z \sim 10^3$ to $z \sim 5$, which guarantees the structure formation. When dilaton energy is very small compared the matter energy, potential energy of dilaton field can be neglected. In this case, the solution of cosmological scale a has been found [88–90]. In another paper [91, 92], we have investigated the property of the attractor solutions and concluded that the coupling between dilaton and matter affects the evolutive process of the Universe, but not the fate of the Universe.

Recently, some authors have investigated the evolution of Quintessence dark energy models in the ω–ω' plane [93–95], where ω' is the time variation of ω with respect to N. According to different regions in the ω–ω' phase plane, these models can be classified two types which are call "thawing" and "freezing" models. In what follows, we shall study the cosmological dynamics of dilatonic dark energy model in the ω–ω' plane. In the exponential potential $Ae^{-\beta\sigma}$, the evolutive behaviors of dynamics of dilatonic cosmology model in the ω–ω' plane, the energy density parameter of dark energy Ω_σ, matter energy density Ω_m and radiation energy density Ω_r with respect to N are shown mathematically. Our results show that the critical point with $\omega \sim -1$ is a late-time attractor, where dilaton field becomes ultimately frozen, as shown in the Fig. 1. The evolution of Ω_σ shows also that there exists a late-time attractor solution, which corresponds to $\Omega_\sigma = 1$.

2 Basic Equations

To deduce the field equation of induced gravitational theory, let us consider the action of Jordan-Brans-Dicke theory firstly

$$S = \int d^4X\sqrt{-\gamma}\left[\phi\tilde{R} - \varpi\gamma^{\mu\nu}\frac{\partial_\mu\phi\partial_\nu\phi}{\phi} - \Lambda(\phi) + \tilde{L}_{\text{fluid}}(\psi)\right], \tag{1}$$

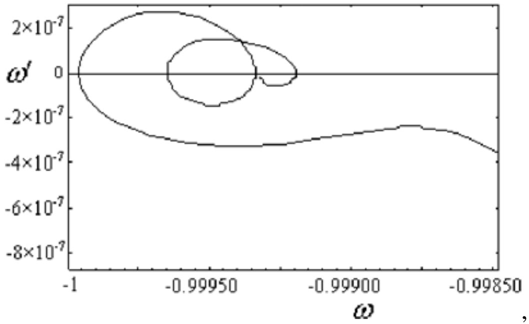

Fig. 1 The attractive property of dilatonic cosmology model with exponential potential $W(\sigma)=Ae^{-\beta\sigma}$ in ω–ω' plane. We set $\alpha=3.78\times10^{-5}$, $\beta=0.005$ and $A=1.0$

,

where the lagrangian density of cosmic fluid $\tilde{L}_{\text{fluid}}(\psi)=\frac{1}{2}\gamma^{\mu\nu}\partial_\mu\psi\partial_\nu\psi-V(\psi)$, γ is the determinant of $\gamma_{\mu\nu}$ which is Jordan metric, ϖ is the dimensionless coupling parameter, R is the contracted $R_{\mu\nu}$. The metric sign convention is $(-,+,+,+)$. The quantity $\Lambda(\phi)$ is a nontrivial potential of ϕ field. When $\Lambda(\phi)\neq 0$ the action of equation (1) describes the induced gravity. The energy density of cosmic fluid $\widetilde{\rho}=\frac{1}{2}(\frac{d\psi}{dt})^2+V(\psi)$ and the pressure $\widetilde{p}=\frac{1}{2}(\frac{d\psi}{dt})^2-V(\psi)$.

However it is often useful to write the action in terms of the conformally related Einstein metric. We introduce the dilaton field σ and conformal transformation as follows

$$\phi=\frac{1}{2}e^{\alpha\sigma}, \tag{2}$$

$$\gamma_{\mu\nu}=e^{-\alpha\sigma}g_{\mu\nu}, \tag{3}$$

where $\alpha=\sqrt{\frac{\kappa^2}{2\varpi+3}}$ with $\varpi>3500$ [96] being an important parameter in Weyl-scaled induced gravitational theory, σ is dilaton field, $g_{\mu\nu}$ is the Pauli metric which can really represent the massless spin-two graviton and should be considered to be physical metric [97]. From the solar system tests, the current constrain is $\alpha^2<0.001$ [98]. The new constrain on the parameter is $\alpha^2<0.0001$ [99], which seems to argue against the existence of long-range scalars. Perhaps such a pessimistic interpretation of the limit is premature [97, 98]. We work in units $\kappa^2\equiv 8\pi G=1$.

According to the conformal transformation (2), (3), we can rewrite (1) as follows

$$S=\int d^4X\sqrt{-g}\left[\frac{1}{2}R(g_{\mu\nu})-\frac{1}{2}g^{\mu\nu}\partial_\mu\sigma\partial_\nu\sigma-W(\sigma)+L_{\text{fluid}}(\psi)\right], \tag{4}$$

where $L_{\text{fluid}}(\psi)=\frac{1}{2}g^{\mu\nu}e^{-\alpha\sigma}\partial_\mu\psi\partial_\nu\psi-e^{-2\alpha\sigma}V(\psi)$. The conventional Einstein gravity limit occurs as $\sigma\to 0$ for an arbitrary ϖ or $\varpi\to\infty$ with an arbitrary σ. When $W(\sigma)=0$, it will result in the Einstein-Brans-Dicke theory.

By varying action (4) and working in FRW universe, we obtain the field equations of Weyl-scaled induced gravitational theory:

$$H^2=\frac{1}{3}\left[\frac{1}{2}\dot{\sigma}^2+W(\sigma)+e^{-\alpha\sigma}\rho\right], \tag{5}$$

$$\ddot{\sigma}+3H\dot{\sigma}+\frac{dW}{d\sigma}=\frac{1}{2}\alpha e^{-\alpha\sigma}(\rho-3p), \tag{6}$$

$$\dot{\rho}+3H(\rho+p)=\frac{1}{2}\alpha\dot{\sigma}(\rho+3p), \tag{7}$$

where H is Hubble parameter. For radiation $\rho_r = 3p_r$, we get $\rho_r \propto \frac{e^{\alpha\sigma}}{a^4}$ from (7). For matter $p_m = 0$, we get $\rho_m \propto \frac{e^{\frac{1}{2}\alpha\sigma}}{a^3}$ from (7). Taking these results into (5), we obtain

$$H^2 = H_i^2\left[\frac{\frac{1}{2}\dot{\sigma}^2 + W(\sigma)}{\rho_{c,i}} + \Omega_{m,i}e^{-\frac{1}{2}\alpha\sigma}\left(\frac{a_i}{a}\right)^3 + \Omega_{r,i}\left(\frac{a_i}{a}\right)^4\right], \tag{8}$$

where $H_i^2 = \frac{\rho_{c,i}}{3}$, $\rho_{c,i}$ is the critical energy density of the universe at initial time t_i. H_i, $\Omega_{m,i}$, $\Omega_{r,i}$ denote the Hubble parameter, matter energy density parameter, radiation energy density parameter at initial time t_i respectively. We define our starting point as the equipartition epoch, at which $\Omega_{m,i} = \Omega_{r,i} = 0.5$ and consider the initial scale factor $a_i = 1$ for convenience. According to the transformation $N = \ln a$, we have

$$H = H_i\left[\frac{\frac{1}{2}\dot{\sigma}^2 + W(\sigma)}{\rho_{c,i}} + \Omega_{m,i}e^{-\frac{1}{2}\alpha\sigma}e^{-3N} + \Omega_{r,i}e^{-4N}\right]^{\frac{1}{2}}. \tag{9}$$

3 Dilaton Cosmological Dynamics in the ω–ω' Plane

The effective density ρ_σ and effective pressure p_σ can be expressed as follows

$$\rho_\sigma = \frac{1}{2}\dot{\sigma}^2 + W(\sigma), \tag{10}$$

$$p_\sigma \equiv \omega_\sigma\rho_\sigma = \frac{1}{2}\dot{\sigma}^2 - W(\sigma). \tag{11}$$

According to (6) which is the scalar field equation of motion, we get

$$-\frac{\dot{\rho}_\sigma}{H} = 3\dot{\sigma}^2 - \frac{\alpha\dot{\sigma}\rho_m e^{-\alpha\sigma}}{2H}, \tag{12}$$

where $\rho_m = \rho_{m_0}e^{\frac{1}{2}\alpha\sigma}a^{-3}$ with ρ_{m_0} is the matter energy density at initial time t_0.

Because $\frac{\dot{\rho}_\sigma}{H} = \frac{d\rho_\sigma}{dN}$, $\dot{\sigma} = \sqrt{2[\rho_\sigma - W(\sigma)]}$ and $W(\sigma) = \frac{1}{2}(1-\omega_\sigma)\rho_\sigma$, the above equation becomes

$$-\frac{d\rho_\sigma}{dN} \equiv n_\sigma\rho_\sigma = 3\rho_\sigma(1+\omega_\sigma) - \frac{\alpha\rho_{m_0}e^{-\frac{1}{2}\alpha\sigma-3N}\sqrt{\rho_\sigma(1+\omega_\sigma)}}{2H}. \tag{13}$$

Equation (13) is the continuity equation of dilaton scalar field in dilatonic cosmology model. The evolutive equation of dilaton field can be expressed as follows

$$\frac{d\sigma}{dN} = \frac{\dot{\sigma}}{H} = \frac{\sqrt{6[\rho_\sigma - W(\sigma)]}}{H} = \frac{\sqrt{(1+\omega_\sigma)\rho_\sigma}}{H}. \tag{14}$$

Now, we define a new function

$$\Delta(a) \equiv \frac{d(\ln W(\sigma))}{d(\ln\rho_\sigma)} = 1 + \frac{1}{1-\omega_\sigma} \times \frac{-d\omega_\sigma/dN}{\frac{1}{\rho_\sigma}(d\rho_\sigma/dN)}. \tag{15}$$

So, we can rewrite (13) as

$$\frac{d\omega_\sigma}{dN} = \left[3(1-\omega_\sigma^2) - \alpha\rho_{m_0}\frac{(1-\omega_\sigma)e^{-\frac{1}{2}\alpha\sigma-3N}\sqrt{(1+\omega_\sigma)\rho_\sigma}}{2H}\right] \times [\Delta - 1] \tag{16}$$

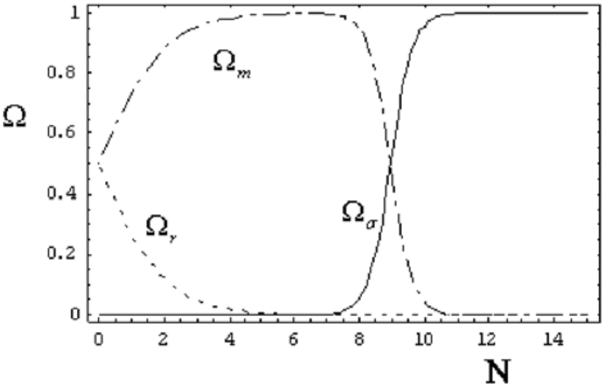

Fig. 2 The evolution of energy density parameter Ω_σ (*real line*), Ω_m (*dot-dashed line*) and Ω_r (*dot line*) with respect to N in dilatonic cosmology model with exponential potential $W(\sigma) = Ae^{-\beta\sigma}$ when $\alpha = 3.78 \times 10^{-5}$, $\beta = 0.005$ and $A = 1.0$. The current values of Ω_σ, Ω_m and Ω_r are 0.715001, 0.284972 and 0.00002706 respectively

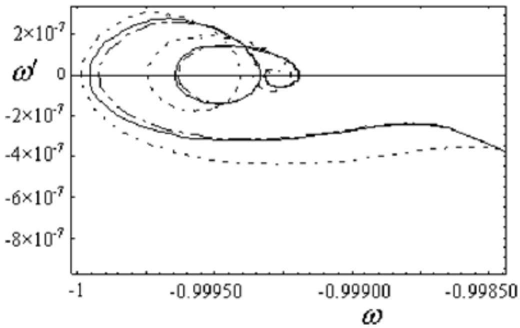

Fig. 3 The comparison of attractive property of dilatonic cosmology model with exponential potential $W(\sigma) = Ae^{-\beta\sigma}$ in different initial condition $\omega_i = -0.92$ (*dot line*), $\omega_i = -0.94$ (*real line*) and $\omega_i = -0.98$ (*dot-dashed line*), when $\alpha = 3.78 \times 10^{-5}$, $\beta = 0.005$ and $A = 1.0$

where

$$\Delta = \frac{\pm W'(\sigma)/W(\sigma)}{3H\sqrt{\frac{1+\omega_\sigma}{\rho_\sigma}} - \frac{\alpha\rho_{m0} e^{-\frac{1}{2}\alpha\sigma - 3N}}{2\rho_\sigma}} \tag{17}$$

and the sign "′" denotes the derivative of $W(\sigma)$ with respect to σ. Equation (16) is the scalar field equation of motion in dilatonic cosmology model. For the dilaton field rolling down its potential, the $\pm$ sign before $W'(\sigma)$ corresponds to $W'(\sigma) > 0$ or $W'(\sigma) < 0$. The size of the parameter $\alpha = \sqrt{\frac{1}{2\varpi+3}}$ denotes the coupling intensity.

Now we consider the exponential potential $W(\sigma) = Ae^{-\beta\sigma}$. The system decided by (16) admits these critical points $\omega_\sigma = 1$, $\omega_\sigma \sim -1$, $\Delta = 1$. When $\Delta = 1$, ω_σ varies very slowly where the dilaton field is tracking and the ratio of kinetic energy to potential energy of the dilaton field becomes a constant. When $\omega_\sigma \sim -1$, it corresponds to a late time attractor where the dilaton field becomes ultimately frozen, as shown in the Fig. 1. Figure 2 shows the evolution of the energy density parameter Ω_σ Ω_m and Ω_r with respect to N. Since $T_i \simeq 5.64(\Omega_0 h^2)$ eV $\simeq 2.843 \times 10^4$ K, $T_0 \simeq 2.7$ K, $a_i = 1$, the scale factor at the present epoch a_0 would nearly be 1.053×10^4, then we know $N_0 = \ln a_0 = 9.262$. According to N_0, we obtain the current value of energy density parameter $\Omega_{\sigma_0} \simeq 0.715001$, $\Omega_{m_0} = 0.284972$ and $\Omega_{r_0} = 0.00002706$, which meet the current observations well. Figure 3 shows the effect of different initial conditions $\omega_0 = 0.80, \ -0.82, \ -0.83$ on the property of attractor. We also investigate the effect of different value of $\alpha = 10^{-9}$ and 2.49×10^{-7}, the critical point always tends to -1, as shown in Fig. 4.

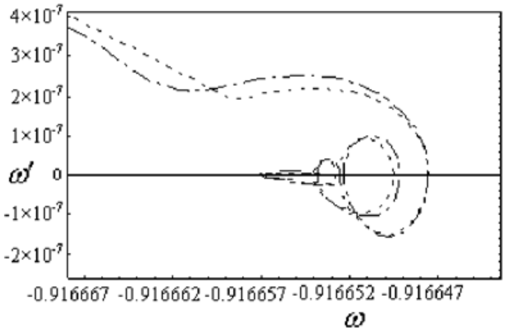

Fig. 4 The effect of α on the property of attractor in the ω–ω' plane. We take two different values $\alpha = 3.78 \times 10^{-5}$ (*dot line*) and $\alpha = 1.58 \times 10^{-4}$ (*dot-dashed line*). It can hardly change the evolutive process of attractor in the ω–ω'

4 Conclusions

Caldwell and Linder classified the quintessence models into two types "thawing" and "freezing" model according to the different regions in ω–ω' plane and gave the limit of quintessence [93]. Maybe, in dilatonic cosmology model we can also make the same delimitation according to different initial conditions. For the "thawing" type model, the dilaton field has been frozen by Hubble damping at a value displace from its minimum until recently, when it starts to roll down to the minimum. For the "freezing" model, the dilaton field which was already rolling down towards its potential minimum, prior to the onset of acceleration, but which slows down and creeps to a halt as it comes to dominate the Universe. We find our dilaton model belongs to the "freezing" type model where $\omega \to -1$, $\omega' \to 0$. We investigate the cosmological dynamics of dilaton model with exponential potential $Ae^{-\beta\sigma}$ in the ω–ω' plane and examine the energy density parameter Ω_σ, Ω_σ, Ω_m and Ω_r with respect to N. According to $N_0 = \ln a_0 \doteq 9.262$, we obtain the current values of energy density parameter Ω_σ, Ω_m and Ω_r are 0.715001, 0.284972 and 0.00002706 respectively, which meet the current observations well. These numerical results show that the critical point with $\omega = -1$ is the late-time attractor, where dilaton field becomes ultimately frozen and $\Omega_\sigma = 1$. While our model avoids the "Big Rip" singularity, it also suffers from the "fine-tuning" problem. Lastly, we consider the effect of initial conditions ω_i and the parameter α on the property of attractor solution, as shown in Figs. 3, 4. When we set $\omega_i = -0.68, \ -0.70, \ -0.72$ and $\alpha = 10^{-9}, \ 2.49 \times 10^{-7}$, the evolutive behavior of dilatonic attractor changes so tiny that it can be neglected. This result is consonant with our previous viewpoint that the coupling between dilaton field and matter affects the evolutive process of the Universe, but not the fate of the Universe [91].

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References

1. Riess, A.G., et al.: Astrophys. J. **607**, 665 (2004)
2. Riess, A.G.: Astron. J. **116**, 1009 (1998)
3. Perlmutter, S., et al.: Astrophys. J. **517**, 565 (1999)
4. Bahcall, N.A., et al.: Science **284**, 1481 (1999)
5. Spergel, D.N., et al.: Astrophys. J. Suppl. **148**, 175 (2003)
6. Bagla, J.S., Jassal, H.K., Padmamabhan, T.: Phys. Rev. D **67**, 063504 (2003)
7. Amendola, L., Quartin, M., Tsujikawa, S., Waga, I.: Phys. Rev. D **74**, 023525 (2006)

8. Elizalde, E., Nojiri, S., Odintsov, S.D.: arXiv:hep-th/0405034
9. Nojiri, S., Odintsov, S.D., Sasaki, M.: Phys. Rev. D **70**, 043539 (2004)
10. Nojiri, S., Odintsov, S.D.: arXiv:hep-th/0601213
11. Nojiri, S., Odintsov, S.D.: Phys. Lett. B **639**, 144 (2006)
12. Nojiri, S., Odintsov, S.D., Stefancic, H.: arXiv:hep-th/0608168
13. Nojiri, S., Odintsov, S.D.: Phys. Lett. B **562**, 147 (2003), arXiv:hep-th/0303117
14. Nojiri, S., Odintsov, S.D.: Phys. Rev. D **70**, 103522 (2004), arXiv:hep-th/0408170
15. Nojiri, S., Odintsov, S.D., Tsujikawa, S.: arXiv:hep-th/0501025
16. Nojiri, S., Odintsov, S.D.: Phys. Rev. D **72**, 023003 (2005), arXiv:hep-th/0505215
17. Nojiri, S., Odintsov, S.D.: arXiv:hep-th/0506212
18. Nojiri, S., Odintsov, S.D.: arXiv:hep-th/0611071
19. Boisseau, B., et al.: Phys. Rev. Lett. **85**, 2236 (2000), arXiv:gr-qc/0001066
20. Esposito-Farese, G., Polarski, D.: Phys. Rev. D **63**, 063504 (2001), arXiv:gr-qc/0009034
21. Zhang, X.: Mod. Phys. Lett. A **20**, 2575 (2005), arXiv:astro-ph/0503072
22. Zhang, X.: Phys. Lett. B **611**, 1 (2005), arXiv:astro-ph/0503075
23. Setare, M.R.: Phys. Lett. B **642**, 1 (2006), arXiv:hep-th/0609069
24. Setare, M.R.: arXiv:hep-th/0609104
25. Setare, M.R.: arXiv:hep-th/0610190
26. Wetterich, C.: Nucl. Phys. B **302**, 668 (1998)
27. Copeland, E.J., Sami, M., Tsujikawa, S.: arXiv:hep-th/0603057
28. Ferreira, P.G., Joyce, M.: Phys. Rev. D **58**, 023503 (1998)
29. Frieman, J., Hill, C.T., Stebbinsand, A., Waga, I.: Phys. Rev. Lett. **75**, 2077 (1995)
30. Brax, P., Martin, J.: Phys. Rev. D **61**, 103502 (2000)
31. Barreiro, T., Copeland, E.J., Nunes, N.J.: Phys. Rev. D **61**, 127301 (2000)
32. Zlatev, I., Wang, L., Steinhardt, P.J.: Phys. Rev. Lett. **82**, 896 (1999)
33. Padmanabhan, T., Choudhury, T.R.: Phys. Rev. D **66**, 081301 (2002)
34. Sen, A.: J. High Energy Phys. **0204**, 048 (2002)
35. Armendariz-Picon, C., Damour, T., Mukhanov, V.: Phys. Lett. B **458**, 209 (1999)
36. Feinstein, A.: Phys. Rev. D **66**, 063511 (2002)
37. Fairbairn, M., Tytgat, M.H.: Phys. Lett. B **546**, 1 (2002)
38. Frolov, A., Kofman, L., Starobinsky, A.: Phys. Lett. B **545**, 8 (2002)
39. Kofman, L., Linde, A.: J. High Energy Phys. **0207**, 004 (2004)
40. Acatrinei, C., Sochichiu, C.: Mod. Phys. Lett. A **18**, 31 (2003)
41. Alexander, S.H.: Phys. Rev. D **65**, 0203507 (2002)
42. Padmanabhan, T.: Phys. Rev. D **66**, 021301 (2002)
43. Mazumadar, A., Panda, S., Perez-Lorenzana, A.: Nucl. Phys. B **614**, 101 (2001)
44. Sarangi, S., Tye, S.H.: Phys. Lett. B **536**, 185 (2002)
45. Armendáriz-Picón, C., Mukhanov, V., Steinhardt, P.J.: Phys. Rev. Lett. **85**, 4438 (2000)
46. Armendáriz-Picón, C., Mukhanov, V., Steinhardt, P.J.: Phys. Rev. D **63**, 103510 (2001)
47. Chiba, T.: Phys. Rev. D **66**, 063514 (2002)
48. Malquarti, M., Copeland, E.J., Liddle, A.R., Trodden, M.: Phys. Rev. D **67**, 123503 (2003)
49. Sherrer, R.J.: Phys. Rev. Lett. **93**, 011301 (2004)
50. Chimento, L.P.: Phys. Rev. D **69**, 123517 (2004)
51. Melchiorri, A., Mersini, L., Odman, C.J., Trodden, M.: Phys. Rev. D **68**, 043509 (2003)
52. Sen, A.: J. High Energy Phys. **0207**, 065 (2002)
53. Garousi, M.R.: Nucl. Phys. B **584**, 284 (2000)
54. Garousi, M.R.: J. High Energy Phys. **0305**, 058 (2003)
55. Bergshoeff, E.A., de Roo, M., de Wit, T.C., Eyras, E., Panda, S.: J. High Energy Phys. **0005**, 009 (2000)
56. Kluson, J.: Phys. Rev. D **62**, 126003 (2000)
57. Gibbons, G.W.: Phys. Lett. B **537**, 1 (2002)
58. Sami, M., Chingangbam, P., Qureshi, T.: Phys. Rev. D **66**, 043530 (2002)
59. Sami, M.: Mod. Phys. Lett. A **18**, 691 (2003)
60. Piao, Y.S., Cai, R.G., Zhang, X.M., Zhang, Y.Z.: Phys. Rev. D **66**, 121301 (2002)
61. Kofman, L., Linde, A.: J. High Energy Phys. **0207**, 004 (2002)
62. Lu, H.Q.: Int. J. Mod. Phys. D **14**, 355 (2005), arXiv:hep-th/0312082
63. Lu, H.Q., Huang, Z.G., Fang, W., Ji, P.Y.: arXiv:hep-th/0504038
64. Fang, W., Lu, H.Q., Huang, Z.G., Zhang, K.F.: Int. J. Mod. Phys. D **15**, 199 (2006), arXiv:hep-th/0409080
65. Fang, W., Lu, H.Q., Huang, Z.G.: arXiv:hep-th/0606032
66. Li, X.Z., Hao, J.G.: Phys. Rev. D **69**, 107303 (2004)
67. Chiba, T., Okabe, T., Yamaguchi, M.: Phys. Rev. D **62**, 023511 (2000)

68. Amendola, L., Tsujikawa, S., Sami, M.: Phys. Lett. B **632**, 155 (2006)
69. Amendola, L.: Phys. Rev. Lett. **93**, 181102 (2004)
70. Singh, P., Sami, M., Dadhich, N.: Phys. Rev. D **68**, 023522 (2003)
71. Carroll, S.M., Hoffman, M., Trodden, M.: Phys. Rev. D **68**, 023509 (2003)
72. Gannouji, R., Polarski, D., Ranquet, A., Starobinsky, A.A.: arXiv:astro-ph/0606287
73. Hao, W., Cai, R.G., Zeng, D.F.: Class. Quantum Gravity **22**, 3189 (2005)
74. Guo, Z.K., Piao, Y.S., Zhang, X.M., Zhang, Y.Z.: Phys. Lett. B **608**, 177 (2005)
75. Feng, B.: arXiv:astro-ph/0602156
76. Polchinski, J.: String Theory. Cambridge University Press, Cambridge (1998)
77. Kolb, E.W., Salopek, D., Turner, M.S.: Phys. Rev. D **42**, 3925 (1990)
78. Amendola, L., Quercellini, C.: Phys. Rev. D **68**, 023514 (2003)
79. Doran, M., Jächel, J.: Phys. Rev. D **66**, 043519 (2002)
80. Nunes, N.J., Mota, D.F.: Mon. Not. R. Astron. Soc. **368**, 751 (2006)
81. Manera, M., Mota, D.F.: Mon. Not. R. Astron. Soc. **371**, 1373 (2006)
82. Neupane, I.P.: arXiv:hep-th/0602097
83. Neupane, I.P., Carter, B.M.N.: J. Cosmol. Astropart. Phys. **0606**, 004 (2006)
84. Neupane, I.P., Carter, B.M.N.: Phys. Lett. B **638**, 94 (2006)
85. Piazza, F., Tsujikawa, S.: J. Cosmol. Astropart. Phys. **0407**, 004 (2004)
86. Gumjudpai, B., Naskar, T., Sami, M., Tsujikawa, S.: J. Cosmol. Astropart. Phys. **0506**, 007 (2005)
87. Lu, H.Q., Huang, Z.G., Fang, W., Zhang, K.F.: arXiv:hep-th/0409309
88. Lu, H.Q., Cheng, K.S.: Astrophys. Space Sci. **235**, 207 (1996)
89. Huang, Z.G., Lu, H.Q., Pan, P.P.: Astrophys. Space Sci. **295**, 493 (2005)
90. Gong, Y.G.: arXiv:gr-qc/9809015
91. Huang, Z.G., Lu, H.Q., Fang, W.: Class. Quantum Gravity **23**, 6215 (2006), arXiv:hep-th/0604160
92. Huang, Z.G., Lu, H.Q.: Int. J. Mod. Phys. D **15**, 1501 (2006)
93. Caldwell, R.R., Linder, E.V.: Phys. Rev. Lett. **95**, 141301 (2005)
94. Bludman, S.A., Roos, M.: Phys. Rev. D **65**, 043503 (2002)
95. Guo, Z.K., Piao, Y.S., Zhang, X.M., Zhang, Y.Z.: arXiv:astro-ph/0608165
96. Will, C.M.: Living Rev. Rel. **4**, 4 (2001)
97. Cho, Y.M.: Phys. Rev. Lett. **68**, 3133 (1992)
98. Damour, T., Nordtvedt, K.: Phys. Rev. Lett. **70**, 2217 (1993)
99. Bertotti, B., Iess, L., Tortora, P.: Nature **425**, 374 (2003)