Int J Theor Phys (2010) 49: 2935–2944
DOI 10.1007/s10773-010-0486-z

Correspondence Between Interacting New Agegraphic and Tachyon Dark Energy Models

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Received: 9 July 2010 / Accepted: 1 September 2010 / Published online: 15 September 2010

Abstract In this paper we consider a correspondence between the interacting new agegraphic dark energy density and tachyon energy density in non-flat universe. Then we reconstruct the potential and the dynamics of the tachyon field which describe tachyon cosmology.

1 Introduction

Recent cosmological observations indicate that our universe is in accelerated expansion. These observations are those which is obtained by SNe Ia [1], WMAP [2], SDSS [3] and X-ray [4]. This acceleration is triggered by more than 70% of dark energy. There are many proposals to explain the role of dark energy. It seems that the best one is cosmological constant [5–8] which is fit with observational data but it suffers from two kind of problems [9], i.e. "fine tuning" (why is the current vacuum energy density so small) and "coincidence problem" (why are the densities of vacuum energy and dark matter nearly equal today since they scale very differently during the expansion history). An alternative proposal for dark energy is the dynamical dark energy scenario. The dynamical nature of dark energy, at least in an effective level, can originate from various fields, such is a canonical scalar field (quintessence) [10–13], a phantom field, that is a scalar field with a negative sign of the kinetic term [14–18], or the combination of quintessence and phantom in a unified model named quintom [19–28]. But we should note that the mainstream viewpoint regards the scalar field dark energy models as an effective description of an underlying theory of dark energy. In addition, other proposals on dark energy include interacting dark energy models [29–33], braneworld models [34–36], and Chaplygin gas models [37–39], etc. One should realize, nevertheless, that almost these models are settled at the phenomenological level, lacking theoretical root.

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Although we are lacking a quantum gravity theory today, we still can make some attempts to probe the nature of dark energy according to some principles of quantum gravity. An interesting attempt in this direction is the so-called "holographic dark energy" proposal [40–57]. Such a paradigm has been constructed in the light of holographic principle of quantum gravity [58, 59], and thus it presents some interesting features of an underlying theory of dark energy. More recently a new dark energy model, dubbed agegraphic dark energy has been proposed [60] (see also [61–67]), which takes into account the Heisenberg uncertainty relation of quantum mechanics together with the gravitational effect in general relativity.

In this paper, we consider the issue of the tachyon as a source of the dark energy. The tachyon is an unstable field which has become important in string theory through its role in the Dirac-Born-Infeld (DBI) action which is used to describe the D-brane action [68–74]. It has been noticed that the cosmological model based on effective lagrangian of tachyon matter

$$L = -V(T)\sqrt{1 - T_{,\mu}T^{,\mu}} \tag{1}$$

with the potential $V(T) = \sqrt{A}$ exactly coincides with the Chaplygin gas model [75, 76]. In the other hand, it has been pointed out that the Chaplygin gas model can be described by a quintessence field with well-connected potential [37–39].

Most discussions on dark energy rely on the assumption that it evolves independently of dark matter. Given the unknown nature of both dark energy and dark matter there is nothing in principle against their mutual interaction and it seems very special that these two major components in the universe are entirely independent. Indeed, this possibility has received a lot of attention recently [77–85] and in particular, it has been shown that the coupling can alleviate the coincidence problem [86]. Furthermore, it was argued that the appropriate coupling between dark components can influence the perturbation dynamics and the cosmic microwave background (CMB) spectrum and account for the observed CMB low l suppression [87]. It was shown that in a model with interaction the structure formation has a different fate as compared with the non-interacting case [87]. It was also discussed that with strong coupling between dark energy and dark matter, the matter density perturbation is stronger during the universe evolution till today, which shows that the interaction between dark energy and dark matter enhances the clustering of dark matter perturbation compared to the noninteracting case in the past. Therefore, the coupling between dark components could be a major issue to be confronted in studying the physics of dark energy. However, so long as the nature of these two components remain unknown it will not be possible to derive the precise form of the interaction from first principles. Therefore, one has to assume a specific coupling from the outset [88–90] or determine it from phenomenological requirements [91, 92]. Nevertheless, different Lagrangians have been proposed in support of it.

In the present paper, we suggest a correspondence between the interacting new agegraphic dark energy scenario [61] and tachyon dark energy model. We show this agegraphic description of tachyon dark energy in the non-flat universe and reconstruct the potential and the dynamics of the scalar field which describe the tachyon cosmology.

2 Tachyon Field as New Agegraphic Dark Energy in Non-flat Universe

We consider the non-flat Friedmann-Robertson-Walker universe with line element

$$ds^2 = -dt^2 + a^2(t)\left(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right), \tag{2}$$

where k denotes the curvature of space $k = 0, 1, -1$ for flat, closed and open universe respectively. A closed universe with a small positive curvature ($\Omega_k \sim 0.01$) is compatible with observations [93–96]. We use the Friedmann equation to relate the curvature of the universe to the energy density. The first Friedmann equation is given by

$$H^2 + \frac{k}{a^2} = \frac{1}{3M_p^2}\Big[\rho_\Lambda + \rho_{\rm m}\Big], \tag{3}$$

where k denotes the curvature of space $k = 0, 1, -1$ for flat, closed and open universe respectively. Define as usual

$$\Omega_{\rm m} = \frac{\rho_m}{\rho_{cr}} = \frac{\rho_{\rm m}}{3M_p^2H^2}, \qquad \Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{cr}} = \frac{\rho_\Lambda}{3M_p^2H^2}, \qquad \Omega_k = \frac{k}{a^2H^2} \tag{4}$$

Let us first review the origin of the agegraphic dark energy model. Following the line of quantum fluctuations of spacetime, Karolyhazy et al. [97–99] argued that the distance t in Minkowski spacetime cannot be known to a better accuracy than $\delta t = \beta t_p^{2/3} t^{1/3}$ where β is a dimensionless constant of order unity. Based on Karolyhazy relation, Maziashvili discussed that the energy density of metric fluctuations of the Minkowski spacetime is given by [100, 101]

$$\rho_\Lambda \sim \frac{1}{t_p^2 t^2} \sim \frac{M_p^2}{t^2}, \tag{5}$$

where t_p is the reduced Planck time and t is a proper time scale. On these basis, Cai wrote down the energy density of the original agegraphic dark energy as [60]

$$\rho_\Lambda = \frac{3n^2 M_p^2}{T_A^2}, \tag{6}$$

where T_A is the age of the universe,

$$T_A = \int_0^a \frac{da}{Ha}, \tag{7}$$

and the numerical factor $3n^2$ is introduced to parameterize some uncertainties, such as the species of quantum fields in the universe, the effect of curved space-time, and so on. However, to avoid some internal inconsistencies in the original agegraphic dark energy model, the so-called "new agegraphic dark energy" was proposed, where the time scale is chosen to be the conformal time η instead of the age of the universe [61]. The new agegraphic dark energy contains some new features different from the original agegraphic dark energy and overcome some unsatisfactory points. For instance, the original agegraphic dark energy suffers from the difficulty to describe the matter-dominated epoch while the new agegraphic dark energy resolved this issue [61]. The energy density of the new agegraphic dark energy can be written

$$\rho_\Lambda = \frac{3n^2 M_p^2}{\eta^2}, \tag{8}$$

where the conformal time η is given by

$$\eta = \int \frac{dt}{a} = \int \frac{da}{a^2 H}. \tag{9}$$

Using definitions $\Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{cr}}$ and $\rho_{cr} = 3M_p^2 H^2$, we get

$$H\eta = \frac{n}{\sqrt{\Omega_\Lambda}} \tag{10}$$

we obtain the equation of state for the agegraphic energy density when there is an interaction between agegraphic energy density ρ_Λ and a Cold Dark Matter (CDM) with $w_m = 0$. The continuity equations for dark energy and CDM are

$$\dot{\rho}_\Lambda + 3H(1+w_\Lambda)\rho_\Lambda = -Q, \tag{11}$$

$$\dot{\rho}_{\rm m} + 3H\rho_{\rm m} = Q, \tag{12}$$

where the quantity Q expresses the interaction between the dark components. The interaction term Q should be positive, i.e. $Q > 0$, which means that there is an energy transfer from the dark energy to dark matter. The positivity of the interaction term ensures that the second law of thermodynamics is fulfilled [102]. At this point, it should be stressed that the continuity equations imply that the interaction term should be a function of a quantity with units of inverse of time (a first and natural choice can be the Hubble factor H) multiplied with the energy density. Therefore, the interaction term could be in any of the following forms: (i) $Q \propto H\rho_T$ [86, 102], (ii) $Q \propto H\rho_b$ [103, 104], or (iii) $Q \propto H(\rho_T + \rho_b)$ [105, 106]. The freedom of choosing the specific form of the interaction term Q stems from our incognizance of the origin and nature of dark energy as well as dark matter. Moreover, a microphysical model describing the interaction between the dark components of the universe is not available nowadays. Here we consider $Q = \Gamma\rho_\Lambda$. This is a decaying of the agegraphic energy component into CDM with the decay rate Γ. Taking a ratio of two energy densities as $u = \rho_{\rm m}/\rho_\Lambda$, the above equations lead to

$$\dot{u} = 3Hu\left[w_\Lambda + \frac{1+u}{u}\frac{\Gamma}{3H}\right] \tag{13}$$

Here as in [107], we choose the following relation for decay rate

$$\Gamma = 3b^2(1+u)H \tag{14}$$

with the coupling constant b^2. Following [108], if we define

$$w_\Lambda^{\rm eff} = w_\Lambda + \frac{\Gamma}{3H}, \qquad w_m^{\rm eff} = -\frac{1}{u}\frac{\Gamma}{3H}. \tag{15}$$

Then, the continuity equations can be written in their standard form

$$\dot{\rho}_\Lambda + 3H(1+w_\Lambda^{\rm eff})\rho_\Lambda = 0, \tag{16}$$

$$\dot{\rho}_m + 3H(1+w_m^{\rm eff})\rho_m = 0 \tag{17}$$

Using (8), (10), (15), (16), one can obtain the equation of state as

$$w_\Lambda = -\left(1 - \frac{2}{3na}\sqrt{\Omega_\Lambda} + \frac{\Gamma}{3H}\right) \tag{18}$$

Then using (14), (4) we can rewrite the above equation as following

$$w_\Lambda = -\left(1 - \frac{2}{3na}\sqrt{\Omega_\Lambda} + \frac{b^2(1+\Omega_k)}{\Omega_\Lambda}\right), \tag{19}$$

then we can see that w_Λ can cross the phantom divide if $\frac{b^2(1+\Omega_k)}{\Omega_\Lambda} > \frac{2}{3na}\sqrt{\Omega_\Lambda}$. The energy density and pressure for the tachyon field are as following [71–74]

$$\rho_T = \frac{V(T)}{\sqrt{1-\dot{T}^2}}, \qquad P_T = -V(T)\sqrt{1-\dot{T}^2} \tag{20}$$

where $V(T)$ is the tachyon potential energy. The barotropic index for the tachyon is

$$w_T = \dot{T}^2 - 1 \tag{21}$$

If we establish the correspondence between the agegraphic dark energy and tachyon energy density, then using (8), (20) we have

$$\rho_\Lambda = 3n^2 M_p^2 \eta^{-2} = \frac{V(T)}{\sqrt{1-\dot{T}^2}}. \tag{22}$$

Also using (21), (19), one can write

$$w_\Lambda = -1 + \frac{2}{3na}\sqrt{\Omega_\Lambda} - \frac{b^2(1+\Omega_k)}{\Omega_\Lambda} = \dot{T}^2 - 1 \tag{23}$$

then

$$\dot{T} = \sqrt{\frac{2}{3na}\sqrt{\Omega_\Lambda} - \frac{b^2(1+\Omega_k)}{\Omega_\Lambda}} \tag{24}$$

Now using (22) we can obtain the tachyon potential energy as

$$V(T) = 3n^2 M_p^2 \eta^{-2}\sqrt{1 - \frac{2}{3na}\sqrt{\Omega_\Lambda} + \frac{b^2(1+\Omega_k)}{\Omega_\Lambda}} \tag{25}$$

Differentiating (3) with respect to the cosmic time t, one find

$$\dot{H} = \frac{\dot{\rho}}{6HM_p^2} + \frac{k}{a^2} \tag{26}$$

where $\rho = \rho_m + \rho_\Lambda$ is the total energy density. Now we write continuity equation for dark energy and cold dark matter as

$$\dot{\rho} = -3H(1+w)\rho \tag{27}$$

where

$$w = \frac{w_\Lambda \rho_\Lambda}{\rho} = \frac{\Omega_\Lambda w_\Lambda}{1+\frac{k}{a^2H^2}} \tag{28}$$

Substitute $\dot{\rho}$ into (26), we obtain

$$w = \frac{2/3(\frac{k}{a^2} - \dot{H})}{H^2 + \frac{k}{a^2}} - 1 \tag{29}$$

Using (28), (29), one can rewrite the new agegraphic energy equation of state as

$$w_\Lambda = \frac{-1}{3\Omega_\Lambda H^2}\left(2\dot{H} + 3H^2 + \frac{k}{a^2}\right) \tag{30}$$

Therefore one can rewrite (24), (25) respectively as

$$\dot{T}^2 = 1 - \frac{1}{3\Omega_\Lambda H^2}\left(2\dot{H} + 3H^2 + \frac{k}{a^2}\right) \tag{31}$$

$$V(T) = \frac{3n^2 M_p^2}{H\eta^2}\sqrt{\frac{2\dot{H} + 3H^2 + \frac{k}{a^2}}{3\Omega_\Lambda}} \tag{32}$$

Using (10) we get

$$V(T) = HM_p^2\sqrt{3\Omega_\Lambda\left(2\dot{H} + 3H^2 + \frac{k}{a^2}\right)} \tag{33}$$

In similar to the [109–113], we can define $\dot{T}^2$ and $V(T)$ in terms of single function $f(T)$ as

$$-1 = 1 - \frac{1}{3\Omega_\Lambda f^2(T)}\left[2f'(T) + 3f^2(T) + \frac{k}{a^2}\right] \tag{34}$$

$$V(T) = f(T)M_p^2\sqrt{3\Omega_\Lambda\left[2f'(T) + 3f^2(T) + \frac{k}{a^2}\right]} \tag{35}$$

Hence, the following solution are obtained

$$T = it, \qquad H = f(it) \tag{36}$$

From (34) we get

$$\frac{k}{a^2} = 3f^2(T)(2\Omega_\Lambda - 1) - 2f'(T) \tag{37}$$

Substitute the above $\frac{k}{a^2}$ into (35), we obtain the tachyon potential as

$$V(T) = 3\sqrt{2}M_p^2\Omega_\Lambda f^2(T) \tag{38}$$

One can check that the solution (36) satisfies the following tachyon field equation

$$\frac{\ddot{T}}{1-\dot{T}^2} + 3H\dot{T} + \frac{V'}{V} = 0 \tag{39}$$

Therefore by the above condition and using (38), $f(T)$ in our model must satisfy following relation

$$3if(T) + \frac{2f'(T)}{f(T)} = 0 \tag{40}$$

Elementary algebra now gives the $f(T)$ to be of the form

$$f(T) = \frac{2}{3iT} \tag{41}$$

In this case, we can determine the potential to be

$$V(T) = \frac{-4\sqrt{2}}{3}M_p^2\Omega_\Lambda\frac{1}{T^2} \tag{42}$$

For the tachyon self-interaction, there are a number of models which one can consider, some being motivated by non-perturbative string theory and others purely by phenomenology. The authors of [114] have studied a wide range of potentials, they have shown that in the presence of a tachyon field T with potential $V(T)$ and a barotropic perfect fluids, the cosmological dynamics depends on the asymptotic behavior of the quantity $\lambda = \frac{-M_p V'}{V^{3/2}}$. If λ is a constant, which corresponds to an inverse square potential $V(T) \propto T^{-2}$, there exists one stable critical point that gives an acceleration of the universe at late times. In fact Ω_Λ is not constant, the differential equation for Ω_Λ is

$$\frac{d\Omega_\Lambda}{dx} = \frac{\dot{\Omega}_\Lambda}{H} = 3\Omega_\Lambda(1+\Omega_k-\Omega_\Lambda)\left[1-\frac{2}{3na}\sqrt{\Omega_\Lambda}+\frac{b^2(1+\Omega_k)}{\Omega_\Lambda}\right] \tag{43}$$

where $x = \ln a$. The above equation describes the behavior of the new agegraphic dark energy completely, in the spatially flat case, i.e. $k = 0$:

$$\frac{d\Omega_\Lambda}{dx} = \frac{\dot{\Omega}_\Lambda}{H} = 3\Omega_\Lambda(1-\Omega_\Lambda)\left[1-\frac{2}{3na}\sqrt{\Omega_\Lambda}\right] \tag{44}$$

From (36) one can see that Ω_Λ depend to T, therefore, the potential (42) does not only vary as T^{-2}, but at late time Ω_Λ increases to 1. Then it is interesting that in our model, at late time where $\Omega_\Lambda = 1$, we obtain $V(T) \propto T^{-2}$, similar to the result of [114]. In fact only in this case potential is as $V(T)$. The additional dependence through Ω_Λ makes it dependent not only on the tachyon field but through H^2, on the matter component as well. With this result we can claim that only the potentials which have the above form are consistent with the agegraphic approach of tachyon dark energy model. From (30), (33) we have

$$V(T) = HM_p^2\sqrt{-9\Omega_\Lambda^2 H^2 w_\Lambda} = 3H^2M_p^2\Omega_\Lambda\sqrt{-w_\Lambda} \tag{45}$$

Substitute w_Λ into the above equation

$$V(T) = 3H^2M_p^2\Omega_\Lambda\sqrt{1-\frac{2}{3n}(1+z)\sqrt{\Omega_\Lambda}+\frac{b^2(1+\Omega_k)}{\Omega_\Lambda}} \tag{46}$$

3 Conclusions

Within the different candidates to play the role of the dark energy, tachyon, has emerged as a possible source of dark energy for a particular class of potentials [115–121].

In the other hand some experimental data have implied that our universe is not a perfectly flat universe and recent papers have favoured a universe with spatial curvature [93–95]. As a matter of fact, we want to remark that although it is believed that our universe is flat, a contribution to the Friedmann equation from spatial curvature is still possible if the number of e-foldings is not very large [122]. Cosmic Microwave Background (CMB) anisotropy data provide the most stringent constraints on cosmic curvature k. Assuming that dark energy is a cosmological constant, the three-year WMAP data give $\Omega_k = -0.15 \pm 0.11$, and this improves dramatically to $\Omega_k = -0.005 \pm 0.006$, with the addition of galaxy survey data from the SDSS [96]. The effect of allowing non-zero curvature on constraining some dark energy models has been studied by [123–129]. Recently Clarkson et al. [130] have shown that ignoring Ω_k induces errors in the reconstructed dark energy equation of state, $w(z)$, that grow very rapidly with redshift and dominate the $w(z)$ error budget at redshifts ($z \succeq 0.9$) even if Ω_k is very small. Due to these considerations and motivated by the recent works [62–64] on the new agegraphic dark energy model, we generalize their work to the non-flat case.

In this paper we have associated the interacting new agegraphic dark energy in non-flat universe with a tachyon field which describe the tachyon cosmology. Studying the interaction between the dark energy and ordinary matter will open a possibility of detecting the dark energy. It should be pointed out that evidence was recently provided by the Abell Cluster A586 in support of the interaction between dark energy and dark matter [131, 132]. We have shown that the new agegraphic dark energy can be described by the tachyon field in a certain way. Then a correspondence between the new agegraphic dark energy and tachyon model of dark energy has been established, and the potential of the agegraphic tachyon field and the dynamics of the field have been reconstructed. For the agegraphic tachyon model constructed in the present paper, the tachyon potential can be determined by (42).

Acknowledgement This work has been supported financially by Research Institute for Astronomy and Astrophysics of Maragha, Iran.

References

1. Perlmutter, S., et al. (Supernova Cosmology Project Collaboration) Astrophys. J. **517**, 565 (1999)
2. Bennett, C.L., et al.: Astrophys. J. Suppl. **148**, 1 (2003)
3. Tegmark, M., et al. (SDSS Collaboration) Phys. Rev. D **69**, 103501 (2004)
4. Allen, S.W., et al.: Mon. Not. R. Astron. Soc. **353**, 457 (2004)
5. Einstein, A.: Cosmological considerations in the General Theory of Relativity. Sitz.ber. Preuss. Akad. Wiss. Berl. (Math. Phys.) 142 (1917)
6. Weinberg, S.: Rev. Mod. Phys. **61**, 1 (1989)
7. Sahni, V., Starobinsky, A.: Int. J. Mod. Phys. D **9**, 373 (2000). arXiv:astro-ph/9904398
8. Peebles, P.J., Ratra, B.: Rev. Mod. Phys. **75**, 559 (2003). arXiv:astro-ph/0207347
9. Steinhardt, P.J.: Critical Problems in Physics. Princeton University Press, Princeton (1997)
10. Ratra, B., Peebles, P.J.E.: Phys. Rev. D **37**, 3406 (1988)
11. Wetterich, C.: Nucl. Phys. B **302**, 668 (1988)
12. Liddle, A.R., Scherrer, R.J.: Phys. Rev. D **59**, 023509 (1999). arXiv:astro-ph/9809272
13. Zlatev, I., Wang, L.M., Steinhardt, P.J.: Phys. Rev. Lett. **82**, 896 (1999)
14. Caldwell, R.R.: Phys. Lett. B **545**, 23 (2002)
15. Caldwell, R.R., Kamionkowski, M., Weinberg, N.N.: Phys. Rev. Lett. **91**, 071301 (2003)
16. Nojiri, S., Odintsov, S.D.: Phys. Lett. B **562**, 147 (2003). arXiv:hep-th/0303117
17. Onemli, V.K., Woodard, R.P.: Phys. Rev. D **70**, 107301 (2004). arXiv:gr-qc/0406098
18. Setare, M.R., Sadeghi, J., Amani, A.R.: Phys. Lett. B **666**, 288 (2008)
19. Feng, B., Wang, X.L., Zhang, X.M.: Phys. Lett. B **607**, 35 (2005)
20. Guo, Z.K., et al.: Phys. Lett. B **608**, 177 (2005)
21. Li, M.-Z., Feng, B., Zhang, X.-M.: J. Cosmol. Astropart. Phys. **002**, 0512 (2005)
22. Feng, B., Li, M., Piao, Y.-S., Zhang, X.: Phys. Lett. B **634**, 101 (2006)
23. Zhao, W., Zhang, Y.: Phys. Rev. D **73**, 123509 (2006)
24. Setare, M.R., Sadeghi, J., Amani, A.R.: Phys. Lett. B **660**, 299 (2008)
25. Sadeghi, J., Setare, M.R., Banijamali, A., Milani, F.: Phys. Lett. B **662**, 92 (2008)
26. Setare, M.R., Saridakis, E.N.: Phys. Lett. B **668**, 177 (2008)
27. Setare, M.R., Saridakis, E.N.: arXiv:0807.3807 [hep-th]
28. Setare, M.R., Saridakis, E.N.: J. Cosmol. Astropart. Phys. **0809**, 026 (2008)
29. Amendola, L.: Phys. Rev. D **62**, 043511 (2000). astro-ph/9908023
30. Comelli, D., Pietroni, M., Riotto, A.: Phys. Lett. B **571**, 115 (2003). hep-ph/0302080
31. Zhang, X.: Mod. Phys. Lett. A **20**, 2575 (2005). astro-ph/0503072
32. Szydlowski, M., Kurek, A., Krawiec, A.: Phys. Lett. B **642**, 171 (2006). astro-ph/0604327
33. Setare, M.R.: J. Cosmol. Astropart. Phys. **0701**, 023 (2007). astro-ph/0604327
34. Deffayet, C., Dvali, G.R., Gabadadze, G.: Phys. Rev. D **65**, 044023 (2002). astro-ph/0105068
35. Sahni, V., Shtanov, Y.: J. Cosmol. Astropart. Phys. **0311**, 014 (2003). astro-ph/0202346

36. Setare, M.R., Saridakis, E.N.: J. Cosmol. Astropart. Phys. **0903**, 002 (2009). astro-ph/0202346
37. Kamenshchik, A.Y., Moschella, U., Pasquier, V.: Phys. Lett. B **511**, 265 (2001). gr-qc/0103004
38. Setare, M.R.: Eur. Phys. J. C **52**, 689 (2007)
39. Setare, M.R. Int. J. Mod. Phys. D **18**, 419 (2009)
40. Cohen, A.G., Kaplan, D.B., Nelson, A.E.: Phys. Rev. Lett. **82**, 4971 (1999)
41. Horava, P., Minic, D.: Phys. Rev. Lett. **85**, 1610 (2000)
42. Thomas, S.D.: Phys. Rev. Lett. **89**, 081301 (2002)
43. Hsu, S.D.H.: Phys. Lett. B **594**, 13 (2004)
44. Li, M.: Phys. Lett. B **603**, 1 (2004)
45. Enqvist, K., Sloth, M.S.: Phys. Rev. Lett. **93**, 221302 (2004)
46. Ke, K., Li, M.: Phys. Lett. B **606**, 173 (2005)
47. Huang, Q.G., Li, M.: J. Cosmol. Astropart. Phys. **0503**, 001 (2005)
48. Elizalde, E., Nojiri, S., Odintsov, S.D., Wang, P.: Phys. Rev. D **71**, 103504 (2005)
49. Kim, H., Lee, H.W., Myung, Y.S.: Phys. Lett. B **632**, 605 (2006)
50. Hu, B., Ling, Y.: Phys. Rev. D **73**, 123510 (2006)
51. Li, H., Guo, Z.K., Zhang, Y.Z.: Int. J. Mod. Phys. D **15**, 869 (2006)
52. Setare, M.R.: Phys. Lett. B **642**, 1 (2006)
53. Setare, M.R.: Phys. Lett. B **644**, 99 (2007)
54. Setare, M.R., Zhang, J., Zhang, X.: J. Cosmol. Astropart. Phys. **0703**, 007 (2007)
55. Setare, M.R.: Phys. Lett. B **648**, 329 (2007)
56. Zhao, W.: Phys. Lett. B **655**, 97 (2007)
57. Li, M., Lin, C., Wang, Y.: J. Cosmol. Astropart. Phys. **0805**, 023 (2008)
58. 't Hooft, G.: arXiv:gr-qc/9310026
59. Susskind, L.: J. Math. Phys. **36**, 6377 (1995)
60. Cai, R.G.: Phys. Lett. B **657**, 228 (2007)
61. Wei, H., Cai, R.G.: Phys. Lett. B **660**, 113 (2008)
62. Neupane, I.P.: Phys. Lett. B **673**, 111 (2009)
63. Kim, K.Y., Lee, H.W., Myung, Y.S.: Phys. Lett. B **660**, 118 (2008)
64. Zhang, J., Zhang, X., Liu, H.: Eur. Phys. J. **C54**, 303 (2008)
65. Kim, K.Y., Lee, H.W., Myung, Y.S., Park, M.I.: Mod. Phys. Lett. A **23**, 3049 (2008)
66. Wu, J.P., Ma, D.Z., Ling, Y.: Phys. Lett. B **663**, 152 (2008)
67. Cui, J., Zhang, L., Zhang, J., Zhang, X.: arXiv:0902.0716 [astro-ph]
68. Sen, A.: J. High Energy Phys. **0204**, 048 (2002)
69. Sen, A.: J. High Energy Phys. **0207**, 065 (2002)
70. Sen, A.: Mod. Phys. Lett. A **17**, 1797 (2002). arXiv:hep-th/0312153
71. Sen, A.: J. High Energy Phys. **9910**, 008 (1999)
72. Bergshoeff, E.A., de Roo, M., de Wit, T.C., Eyras, E., Panda, S.: J. High Energy Phys. **0005**, 009 (2000)
73. Kluson, J.: Phys. Rev. D **62**, 126003 (2000)
74. Kutasov, D., Niarchos, V.: Nucl. Phys. B **666**, 56 (2003)
75. Frolov, A., Kofman, L., Starobinsky, A.: Phys. Lett. B **545**, 8 (2002)
76. Gorini, V., Kamenshchik, A., Moschella, U., Pasquier, V., Starobinsky, A.: astro-ph/0504576
77. Amendola, L.: Phys. Rev. D **60**, 043501 (1999)
78. Amendola, L., Tocchini-Valentini, D.: Phys. Rev. D **64**, 043509 (2001)
79. Amendola, L., Valentini, D.T.: Phys. Rev. D **66**, 043528 (2002)
80. Zimdahl, W., Pavon, D., Chimento, L.P.: Phys. Lett. B **521**, 133 (2001)
81. Zimdahl, W., Pavon, D.: Gen. Relativ. Gravit. **35**, 413 (2003)
82. Setare, M.R.: J. Cosmol. Astropart. Phys. **0701**, 023 (2007)
83. Setare, M.R.: Phys. Lett. B **654**, 1 (2007)
84. Setare, M.R.: Phys. Lett. B **642**, 421 (2006)
85. Wang, B., Lin, C.Y., Pavon, D., Abdalla, E.: Phys. Lett. B **662**, 1 (2008)
86. Pavon, D., Zimdahl, W.: Phys. Lett. B **628**, 206 (2005)
87. Wang, B., Zang, J., Lin, Ch.-Y., Abdalla, E., Micheletti, S.: Nucl. Phys. B **778**, 69 (2007)
88. Das, S., Corasaniti, P.S., Khoury, J.: Phys. Rev. D **73**, 083509 (2006)
89. Amendola, L., Tsujikawa, S., Sami, M.: Phys. Lett. B **632**, 155 (2006)
90. Amendola, L., Quercellini, C.: Phys. Rev. D **68**, 023514 (2003)
91. Chimento, L.P., Jakubi, A.S., Pavon, D., Zimdahl, W.: Phys. Rev. D **67**, 083513 (2003)
92. del Campo, S., Herrera, R., Pavón, D.: Phys. Rev. D **70**, 043540 (2004)
93. Bennet, C.L., et al.: Astrophys. J. Suppl. **148**, 1 (2003)
94. Spergel, D.N.: Astrophys. J. Suppl. **148**, 175 (2003)
95. Ichikawa, K., et al.: astro-ph/0605481
96. Tegmark, M., et al.: Phys. Rev. D **69**, 103501 (2004)

97. Karolyhazy, F.: Nuovo Cimento A **42**, 390 (1966)
98. Karolyhazy, F., Frenkel, A., Lukacs, B.: In: Shimony A., Feschbach H. (eds.) Physics as Natural Philosophy. MIT Press, Cambridge (1982)
99. Karolyhazy, F., Frenkel, A., Lukacs, B.: In: Penrose R., Isham C.J. (eds.) Quantum Concepts in Space and Time. Clarendon, Oxford (1986)
100. Maziashvili, M.: Int. J. Mod. Phys. D **16**, 1531 (2007)
101. Maziashvili, M.: Phys. Lett. B **652**, 165 (2007)
102. Pavon, D., Wang, B.: Le Chatelier-Braun principle in cosmological physics. arXiv:0712.0565 [gr-qc]
103. Amendola, L., Camargo Campos, G., Rosenfeld, R.: Phys. Rev. D **75**, 083506 (2007). arXiv: astro-ph/0610806
104. Guo, Z.K., Ohta, N., Tsujikawa, S.: Phys. Rev. D **76**, 023508 (2007). arXiv:astro-ph/0702015
105. Wang, B., Lin, C.Y., Abdalla, E.: Phys. Lett. B **637**, 357 (2006). arXiv:hep-th/0509107
106. Karwan, K.: J. Cosmol. Astropart. Phys. **0805**, 011 (2008). arXiv:0801.1755 [astro-ph]
107. Wang, B., Gong, Y., Abdalla, E.: Phys. Lett. B **624**, 141 (2005)
108. Kim, H., Lee, H.W., Myung, Y.S.: Phys. Lett. B **632**, 605 (2006)
109. Nojiri, S., Odintsov, S.D.: Gen. Relativ. Gravit. **38**, 1285 (2006)
110. Capozziello, S., Nojiri, S., Odintsov, S.D.: Phys. Lett. B **632**, 597 (2006)
111. Nojiri, S., Odintsov, S.D.: hep-th/0611071
112. Nojiri, S., Odintsov, S.D., Stefancic, H.: Phys. Rev. D **74**, 086009 (2006)
113. Setare, M.R.: Eur. Phys. J. C **50**, 991 (2007)
114. Copeland, E.J., Garousi, M.R., Sami, M., Tsujikawa, S.: Phys. Rev. D **71**, 043003 (2005)
115. Padmanabhan, T.: Phys. Rev. D **66**, 021301 (2002)
116. Bagla, J.S., Jassal, H.K., Padmanabhan, T.: Phys. Rev. D **67**, 063504 (2003)
117. Feinstein, A.: Phys. Rev. D **66**, 063511 (2002)
118. Abramo, L.R.W., Finelli, F.: Phys. Lett. B **575**, 165 (2003)
119. Aguirregabiria, J.M., Lazkoz, R.: Phys. Rev. D **69**, 123502 (2004)
120. Guo, Z.K., Zhang, Y.Z.: J. Cosmol. Astropart. Phys. **0408**, 010 (2004)
121. Chimento, L.P.: Phys. Rev. D **69**, 123517 (2004)
122. Huang, Q.G., Li, M.: J. Cosmol. Astropart. Phys. **0408**, 013 (2004)
123. Polarski, D., Ranquet, A.: Phys. Lett. B **627**, 1 (2005)
124. Franca, U.: Phys. Lett. B **641**, 351 (2006)
125. Ichikawa, K., Takahashi, T.: Phys. Rev. D **73**, 083526 (2006)
126. Gong, Y., Wang, A.: Phys. Rev. D **75**, 043520 (2007)
127. Ichikawa, K., Takahashi, T.: J. Cosmol. Astropart. Phys. **0702**, 001 (2007)
128. Wright, E.L.: astro-ph/0701584
129. Zhao, G., et al.: astro-ph/0612728
130. Clarkson, C., Cortes, M., Bassett, B.A.: J. Cosmol. Astropart. Phys. **0708**, 011 (2007)
131. Bertolami, O., Pedro, F. Gil, Le Delliou, M.: Phys. Lett. B **654**, 165 (2007). arXiv:astro-ph/0703462
132. Le Delliou, M., Bertolami, O., Pedro, F. Gil: AIP Conf. Proc. **957**, 421 (2007). arXiv:0709.2505 [astro-ph]