Equation of state for an interacting holographic dark energy model

Hungsoo Kim\textsuperscript{1}, Hyung Won Lee\textsuperscript{1} and Yun Soo Myung\textsuperscript{1,2}\textsuperscript{*}

\textsuperscript{1}Relativity Research Center, Inje University, Gimhae 621-749, Korea
\textsuperscript{2}Institute of Theoretical Science, University of Oregon, Eugene, OR 97403-5203, USA

Abstract

We investigate a model of the interacting holographic dark energy with cold dark matter (CDM). If the holographic energy density decays into CDM, we find two types of the effective equation of state. In this case we have to use the effective equations of state ($\omega_{\Lambda}^{\text{eff}}$) instead of the equation of state ($\omega_{\Lambda}$). For a fixed ratio of two energy densities, their effective equations of state are given by the same negative constant. Actually, the cosmic anti-friction arisen from the vacuum decay process may induce the acceleration with $\omega_{\Lambda}^{\text{eff}} < -1/3$. For a variable ratio, their effective equations of state are slightly different, but they approach the same negative constant in the far future. Consequently, we show that such an interacting holographic energy model cannot accommodate a transition from the dark energy with $\omega_{\Lambda}^{\text{eff}} \geq -1$ to the phantom regime with $\omega_{\Lambda}^{\text{eff}} < -1$.

\textsuperscript{*}e-mail address: ysmyung@physics.inje.ac.kr
1 Introduction

Supernova (SN Ia) observations suggest that our universe is accelerating and the dark energy contributes $\Omega_{DE} \simeq 0.75$ to the critical density of the present universe \[1\]. Also cosmic microwave background observations \[2\] imply that the standard cosmology is given by the inflation and FRW universe \[3\]. Although there exist a number of dark energy candidates, the two candidates are the cosmological constant and the quintessence scenario. The equation of state (EOS) for the latter is determined dynamically by the scalar or tachyon. In the study of dark energy \[4\], the first issue is whether or not the dark energy is a cosmological constant with $\omega_\Lambda = -1$. If the dark energy is shown not to be a cosmological constant, the next is whether or not the phantom-like state of $\omega_\Lambda < -1$ is allowed. Most theoretical models that can explain $\omega_\Lambda < -1$ confront with serious problems. The last one is whether or not $\omega_\Lambda$ is changing as the universe evolves.

On the other hand, there exists another model of the dynamical cosmological constant derived by the holographic principle. The authors in \[5\] showed that in quantum field theory, the UV cutoff $\Lambda$ could be related to the IR cutoff $L_\Lambda$ due to the limit set by introducing a black hole. In other words, if $\rho_\Lambda = \Lambda^4$ is the vacuum energy density caused by the UV cutoff, the total energy of system with the size $L_\Lambda$ should not exceed the mass of the black hole with the same size $L_\Lambda : L_\Lambda^3 \rho_\Lambda \leq 2L_\Lambda / G$. The newtonian constant $G$ is given by the Planck mass ($G = 1/M_p^2$). If the largest cutoff $L_\Lambda$ is chosen to be the one saturating this inequality, the holographic energy density is then given by $\rho_\Lambda = 3c^2 M_p^2 / 8\pi L_\Lambda^2$ with an undetermined constant $c$. Here we regard $\rho_\Lambda$ as the dynamical cosmological constant. Taking $L_\Lambda$ as the size of the present universe (Hubble horizon: $R_{HH}$), the resulting energy is close to the present dark energy \[6\]. Even though it may explain the data, this approach is not complete. This is because it fails to recover the EOS for a dark energy-dominated universe \[7\].

Usually, it is not an easy matter to determine the equation of state for a system with UV/IR cutoff. In order to find the EOS, we propose the two approaches. Firstly, the future event horizon of $R_{FH}$ is used for the IR cutoff $L_\Lambda$ instead of $R_{HH}$ \[8\]. In this case, one finds that $\rho_\Lambda \sim a^{-2(1-1/c)}$. It may describe the dark energy with $\omega_\Lambda = -1/3 - 2/3c$ ($c \geq 1$). For example, one obtains $\omega_\Lambda = -1$ for $c = 1$. The related issues appeared in Ref. \[9\] \[10\].

Secondly, one may introduce an interaction between the holographic energy density with $R_{HH}$ and CDM. Here the EOS for the holographic energy density is less important because the interaction changes it \[11\]. Recently, the authors in \[12\] introduced an interacting holographic dark energy model. They derived the phantom-like EOS of $\omega_\Lambda < -1$ for a model that an interaction exists between holographic energy with $L_\Lambda = R_{FH}$ and CDM.
They insisted that this model can describe even the phantom regime with $\omega_\Lambda < -1$. This implies that the interacting holographic model can accommodate a transition of the dark energy from a normal state to a phantom regime. Although the decay process leads to the case that the effective EOS of CDM becomes negative, but this process does not change the nature of holographic energy into the phantom-like matter significantly. Hence it is hard to accept their argument because they consider the process of decaying from the holographic energy density into CDM.

In this work we examine this issue carefully. We will show that the interacting holographic dark energy model cannot describe a phantom regime of $\omega_{\text{eff}}^\Lambda < -1$ when using the effective EOS. A key of this system is an interaction between holographic energy and CDM. Their contents are changing due to energy transfer from holographic energy to CDM until the two components are comparable. If there exists a source/sink in the right hand side of the continuity equation, we must be careful to define the EOS. In this case the effective EOS is the only candidate to represent the state of the mixture of two components arisen from decaying of the holographic energy into CDM. This is quite different from the non-interacting case. Hence we remark an important usage which is useful for our study

-effective EOS $\implies$ an interacting two fluid model,

EOS $\implies$ a noninteracting two fluid model.

2 Interacting model

Let us imagine a universe made of CDM with $\omega_m = 0$, but obeying the holographic principle. In addition, we propose that the holographic energy density exists with $\omega_\Lambda \geq -1$. If one introduces a form of the interaction $Q = \Gamma \rho_\Lambda$, their continuity equations take the forms

$$\dot{\rho}_\Lambda + 3H(1 + \omega_\Lambda)\rho_\Lambda = -Q, \quad (1)$$
$$\dot{\rho}_m + 3H\rho_m = Q. \quad (2)$$

This implies that the mutual interaction could provide a mechanism to the particle production. Actually this is a decaying of the holographic energy component into CDM with the decay rate $\Gamma$. Taking a ratio of two energy densities as $r = \rho_m / \rho_\Lambda$, the above equations lead to

$$\dot{r} = 3Hr \left[ \omega_\Lambda + \frac{1 + r}{r} \frac{\Gamma}{3H} \right]. \quad (3)$$
which means that the evolution of the ratio depends on the explicit form of interaction. In this work we choose the same notation as in Ref. [12], \( \Gamma = 3b^2(1+r)H \) with the coupling constant \( b^2 \). Even if one starts with \( \omega_m = 0 \) and \( \omega_\Lambda = -1 \), this process is necessarily accompanied by the different equations of state \( \omega_m^{\text{eff}} \) and \( \omega_\Lambda^{\text{eff}} \). The decaying process impacts their equations of state and particularly, it provides the negatively effective EOS of CDM. Actually, an accelerating phase could arise from a largely effective non-equilibrium pressure \( \Pi_m \) defined as \( \Pi_m \equiv -\frac{\Gamma}{3H} \frac{\rho_\Lambda}{\rho_m} \). Then the two equations (1) and (2) are translated into those of the two dissipatively imperfect fluids

\[
\dot{\rho}_\Lambda + 3H \left[ 1 + \omega_\Lambda + \frac{\Gamma}{3H} \right] \rho_\Lambda = \dot{\rho}_\Lambda + 3H \left[ (1 + \omega_\Lambda) \rho_\Lambda + \Pi_\Lambda \right] = 0, \tag{4}
\]

\[
\dot{\rho}_m + 3H \left[ 1 - \frac{1}{r} \frac{\Gamma}{3H} \right] \rho_m = \dot{\rho}_m + 3H (\rho_m + \Pi_m) = 0. \tag{5}
\]

\( \Pi_\Lambda > 0 \) shows a decaying of holographic energy density via the cosmic frictional force, while \( \Pi_m < 0 \) induces a production of the CDM via the cosmic anti-frictional force simultaneously [13, 14]. This is a sort of the vacuum decay process to generate a particle production within the two fluid model [15]. As a result, a mixture of two components will be created. From Eqs.(1) and (5), turning on the interaction term, we define their effective equations of state as

\[
\omega_\Lambda^{\text{eff}} = \omega_\Lambda + \frac{\Gamma}{3H}, \quad \omega_m^{\text{eff}} = -\frac{1}{r} \frac{\Gamma}{3H}. \tag{6}
\]

On the other hand, the first Friedmann equation is given by

\[
H^2 = \frac{8\pi}{3M_p^2} \left[ \rho_\Lambda + \rho_m \right]. \tag{7}
\]

Differentiating Eq.(7) with respect to the cosmic time \( t \) and then using Eqs.(1) and (2), one finds the second Friedmann equation as

\[
\dot{H} = -\frac{3}{2} H^2 \left[ 1 + \frac{\omega_\Lambda}{1 + r} \right]. \tag{8}
\]

Let us introduce

\[
\Omega_m = \frac{8\pi\rho_m}{3M_p^2 H^2}, \quad \Omega_\Lambda = \frac{8\pi\rho_\Lambda}{3M_p^2 H^2} \tag{9}
\]

which allows to rewrite the first Friedmann equation as

\[
\Omega_m + \Omega_\Lambda = 1. \tag{10}
\]

\[1\] It seems that the deceleration parameter of \( q = -1 - \frac{\dot{H}}{H^2} \) is independent of the interaction factor \( \Gamma(\sim b^2) \). However, using Eq.(12), one finds that \( q = 1 - b^2/2 - \Omega_\Lambda/2 - \Omega_\Lambda^{3/2}/c \). Even for \( r = \text{const} \), using Eq.(4) leads to \( \omega_\Lambda = -b^2(1+r)^2/r \). This means that the acceleration will be determined by \( H \) through \( \omega_\Lambda \).
Then we can express $r$ and its derivative ($\dot{r}$) in terms of $\Omega_\Lambda$ as

$$
\begin{align*}
  r &= \frac{1 - \Omega_\Lambda}{\Omega_\Lambda}, \\
  \dot{r} &= -\frac{\dot{\Omega}_\Lambda}{\Omega_\Lambda^2}.
\end{align*}
$$

(11)

Here we get an important relation of $\Omega_\Lambda = 1/(1 + r)$ between $\Omega_\Lambda$ and $r$.

### 3 Holographic energy density with the future event horizon

In the case of $\rho_\Lambda$ with $L_\Lambda = 1/H$, we always have a fixed ratio of two energy densities. This provides the same negative EOS for both two components [11, 14]. In order to study a variable ratio of two energy densities, we need to introduce the future event horizon [8, 9]

$$
L_\Lambda = R_{FH} \equiv a \int_t^\infty (dt/a) = a \int_a^\infty (da/Ha^2).
$$

(12)

In this case the first Friedmann equation takes the form (11) with $\rho_\Lambda = \frac{3c^2M_p^2}{8\pi R_{FH}^2}$. From this we derive a reduced equation

$$
R_{FH} = \frac{c\sqrt{1+r}}{H} = \frac{c}{H\sqrt{\Omega_\Lambda}}.
$$

(13)

Considering the definition of holographic energy density $\rho_\Lambda$, one finds also

$$
\dot{\rho}_\Lambda = 2H\rho_\Lambda \left[ -1 + \frac{1}{R_{FH}H} \right] = -3H\rho_\Lambda \left[ 1 - \frac{1}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c} \right].
$$

(14)

It can be easily integrated to give $\rho_\Lambda \sim a^{-3(1+\omega_\Lambda^{\text{eff}})}$ with $\omega_\Lambda^{\text{eff}} = -1/3 - 2\sqrt{\Omega_\Lambda}/3c$ only for $r=\text{const}$ ($\Omega_\Lambda=\text{const}$). On the other hand, differentiating Eq.(13) with respect to the cosmic time $t$ leads to two important relations. Using Eqs.(3) and (8), one finds the holographic energy equation of state

$$
\omega_\Lambda = -\frac{1}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c} - \frac{b^2}{\Omega_\Lambda}.
$$

(15)

The other is cast in a form of differential equation for $\Omega_\Lambda$

$$
\frac{1}{\Omega_\Lambda^2} \frac{d\Omega_\Lambda}{dx} = (1 - \Omega_\Lambda) \left[ \frac{1}{\Omega_\Lambda} + \frac{2}{c\sqrt{\Omega_\Lambda}} - \frac{3b^2}{\Omega_\Lambda(1 - \Omega_\Lambda)} \right]
$$

(16)

with $x = \ln a$. Plugging the solution to Eq.(16) into Eq.(15), one can determine the evolution of equation of state. These equations were also derived in Ref. [12].
As a simple example, we first consider a fixed ratio of two energy densities. In this case of \( r = \text{const} \), we obtain from Eq. (3)

\[
\omega_\Lambda = \frac{1 + r}{r} \frac{\Gamma}{3H} = -\frac{b^2}{\Omega_\Lambda(1 - \Omega_\Lambda)}
\]

(17)

which means that \( \omega_\Lambda = 0 \), if there is no interaction (\( \Gamma = 0 \)). Substituting this into Eq. (6), one obtains the same effective EOS for both components

\[
\omega^\text{eff}_\Lambda = -\frac{b^2}{1 - \Omega_\Lambda} = \omega^\text{eff}_m.
\]

(18)

Furthermore, from Eq. (16) one finds a relation which is valid for \( \Omega_\Lambda = \text{const} \)

\[
1 - \frac{\sqrt{\Omega_\Lambda}}{c} = \frac{3}{2} \left( 1 - \frac{b^2}{1 - \Omega_\Lambda} \right).
\]

(19)

Using the above relation, one arrives at

\[
\omega^\text{eff}_\Lambda = -\frac{1}{3} - \frac{2\sqrt{\Omega_\Lambda}}{3c} = \omega^\text{eff}_m.
\]

(20)

We confirm from Eq. (14) that the effective equation of state (20) is correct. This is very similar to the case that the Hubble horizon is chosen for the IR cutoff. Using another notation of \( \omega^\text{eff}_\Lambda = \omega_\Lambda/(1 + r) \), one finds the same expression as in the case found for the Hubble horizon [11]. At this stage we emphasize that in the presence of interaction, the true equation of state for the holographic energy density is given by not \( \omega_\Lambda \) but \( \omega^\text{eff}_\Lambda \).

Now we are in a position to discuss a variable ratio of two energy densities. From Eqs. (6) and (15), we have the effective equation of state

\[
\omega^\text{eff}_\Lambda(x) = \omega_\Lambda(x) + \frac{b^2}{\Omega_\Lambda(x)} = -\frac{1}{3} - \frac{2\sqrt{\Omega_\Lambda(x)}}{3c}.
\]

(21)

It seems that \( \omega^\text{eff}_\Lambda(x) \) is independent of the decay rate \( \Gamma \). However, a solution \( \Omega_\Lambda(x) \) to the evolution equation (16) which includes the \( b^2 \)-term determines how the effective equation of state \( \omega^\text{eff}_\Lambda(x) \) is changing under the evolution of the universe. In this process the interaction impacts on both the holographic energy density and the CDM. Accordingly, their contents are changing due to energy transfer from the holographic energy to the CDM until two components are comparable. As is shown Fig. 1, \( \Omega_\Lambda(x) \) is a monotonically increasing function of \( x = \ln a \). For the noninteracting case of \( b^2 = 0 \), we find that \( \Omega_\Lambda(x) \to 1 \) as \( x \) increases, while for the interaction case of \( b^2 = 0.2 \), \( \Omega_\Lambda(x) \to 0.8 \). The first case is obvious because the holographic energy with the future event horizon dominates
Figure 1: The evolution of density parameter $\Omega_\Lambda(x)$ as a monotonically increasing function of $x = \ln a$. Here we choose $c = 1.0$ and $b^2 = 0.2$ for an interacting case, while $c = 1.0, b^2 = 0$ for a noninteracting case. For the noninteracting case, it shows that $\Omega_\Lambda(x) \to 1$ as $x$ increases, but for the interacting case $\Omega_\Lambda(x) \to 0.8$ as $x$ increases. The latter is possible because two components become comparable after the interaction.

Figure 2: The evolution of density parameter $\Omega_m(x)$ as a monotonically increasing function of $x = \ln a$. Here we choose $c = 1.0$ and $b^2 = 0.2$ for an interacting case, while $c = 1.0, b^2 = 0$ for a noninteracting case. For the noninteracting case, it shows that $\Omega_m(x) \to 1$ as $x$ increases, but for the interacting case $\Omega_m(x) \to 0.8$ as $x$ increases. The latter is possible because two components become comparable after the interaction.

in the future. Further the latter shows that two components become comparable, due to the interaction.

On the other hand, the effective equation of state for CDM is given differently by

$$\omega_m(x) = -\frac{b^2}{1 - \Omega_\Lambda(x)}.$$  \hfill (22)

This arises because a relation of Eq.(20) is no longer valid for the dynamic evolution of a variable ratio.

We could conjecture the lower bound of $\omega_\Lambda(x)$ by requiring the holographic principle. According to this principle, the total entropy $S = S_m + S_\Lambda$ of the universe is bounded by the Bekenstein-Hawking entropy of $S_{BH} = \pi L_\Lambda^2$. Here we choose $L_\Lambda = R_{FH} = c/H\sqrt{\Omega_\Lambda}$. That is, one has $S \leq S_{BH}$. For simplicity, we assume that the entropy of the universe is given roughly by the one saturating the bound ($S \sim S_{BH}$). If one requires the second law of thermodynamics (the entropy of the universe does not decrease, as the universe evolves), one has a relation of $\dot{S}_{BH} \geq 0$ which gives $\dot{R}_{FH} = c/\sqrt{\Omega_\Lambda} - 1 \geq 0$. This implies that $c \geq \sqrt{\Omega_\Lambda}$. Applying this to Eq. (21) leads to the lower bound: $\omega_\Lambda(x) \geq -1$. Accordingly it seems to be impossible to have $\omega_\Lambda(x)$ crossing $-1$. That is, the phantom-like equation of state ($\omega_\Lambda(x) < -1$) is not allowed, even if one includes an interaction between the
Figure 2: The effective equations of state for holographic energy and CDM versus $x = \ln a$. Here we choose $c = 1$ and $b^2 = 0.2$ for simplicity. Although the two effective EOS show different behaviors during evolution of the universe, these approach shortly the same value which is larger than $-1$ in the future. This is possible because the two components become comparable after the interaction.

holographic energy density and CDM. This feature can be confirmed from the numerical computations using Eqs. (16) and (21) (see Fig. 2). It shows that the effective EOS of $\omega^\text{eff}_\Lambda$ for the holographic energy is always larger than $-1$ during the whole evolution of the universe. As was shown at Fig. 5 in Ref. [12], $\omega_\Lambda = \omega^\text{eff}_\Lambda - b^2/\Omega_\Lambda(x)$ is smaller than $-1$ in the far future. In this case, however, we have to use $\omega^\text{eff}_\Lambda$ instead of $\omega_\Lambda$ for a description of the interacting case.

Finally, we wish to comment on the following case. One may require that $\omega_\Lambda$ itself be larger than $-1$, since the holographic principle is compatible with the dominant energy condition of $\rho_\Lambda \geq |p_\Lambda|$. In this case, we have $\omega_\Lambda \geq -1$ and thus it may provide the upper bound on the parameter $b^2$. This condition may work for the noninteracting picture. However, we have to use $\omega^\text{eff}_\Lambda$ for the interacting picture. The reason is clear because the interaction makes a mixture of two fluid which is different from CDM and holographic energy. If one requires this dominant energy condition on this mixture instead, then one finds the known bound of $\omega^\text{eff}_\Lambda \geq -1$, which is already obtained by imposing the entropy relation.
4 Discussions

We discuss a few of pictures of the vacuum decay in cosmology. We usually introduce a source/sink to mediate an interaction between holographic energy and CDM in the continuity equations [13]. This picture is called the decaying vacuum cosmology which may be related to the vacuum fluctuations [16]. Here we wish to describe three different pictures.

The first picture is that the equation of state is fixed by $p_\Lambda = -\rho_\Lambda$ for all time [17]. As a result of decaying the holographic energy into the CDM, the energy density of CDM takes a different form of $\rho_m \sim a^{-3+\epsilon}$ with a positive constant $\epsilon$. This means that CDM will dilute more slowly compared to its standard form of $\rho_m \sim a^{-3}$. However, this picture seems to focus on the CDM sector.

The second is that the EOS for $\rho_\Lambda$ is indeterminate in the beginning but a ratio of two energy densities is fixed. In this case the holographic energy itself is changing as a result of decaying into the CDM. Requiring the total energy-momentum conservation, its change must be compensated by the corresponding change in the CDM sector [11]. The two matters turn into the imperfect fluids. The decaying process continues until two components are comparable. Here we note that the effective EOS for the holographic energy and CDM will be the same negative constant by the interaction. In this sense, the works in [18, 14] are between the first picture and second one, because they set $\omega_\Lambda = -1$ initially and determine $\omega_\Lambda^{\text{eff}} = -\epsilon/3 = \omega_m^{\text{eff}}$ with $L_\Lambda = 1/H$ or $R_{\text{FH}}$ finally.

The third picture corresponds to the case that a ratio of two energy densities is changing as the universe evolves [7, 8]. It works well for the presence of both the holographic energy and CDM without interaction. In this case the energy-momentum conservation is required for each matter separately [8]. Recently, it was proposed that this picture is valid even for the case including an interaction between the holographic energy with $R_{\text{FH}}$ and CDM [12]. They used $\omega_\Lambda$ to show that $\rho_\Lambda$ can describe the phantom regime. However, we have to use $\omega_\Lambda^{\text{eff}}$ when considering the interaction. As are shown in Fig. 2, two equations of state take different forms initially. However, two effective EOS will take the same negative value which is larger than $-1$ in the far future.

Hence, the vacuum decay picture is still alive even for a dynamical evolution in the interacting holographic dark energy model. This implies that one cannot generate a phantom-like mixture of $\omega_\Lambda^{\text{eff}} < -1$ from an interaction between the holographic energy and CDM. In other words, decaying from the holographic energy into the CDM never leads to the phantom regime. Fig. 1 shows clearly that the density parameter of holographic energy is decreased from 1 to 0.8 when introducing an interaction of $b^2 = 0.2$. 

9
Furthermore, from the graphs in Fig. 2, one recognizes the changes from the noninteracting case to the interacting one in the far future: $\omega_\Lambda = -1.0 \rightarrow \omega^\text{eff}_\Lambda = -0.9$ and $\omega_m = 0 \rightarrow \omega^\text{eff}_m = -0.9$. This means that although the CDM was changed drastically, the holographic energy density preserves its nature.

Consequently, it is not true that after an inclusion of the interaction, the holographic energy density can describe the phantom regime.

Acknowledgment

Y. Myung thanks Steve Hsu, Roman Buny, and Brian Murray for helpful discussions. H. Kim and H. Lee were in part supported by KOSEF, Astrophysical Research Center for the Structure and Evolution of the Cosmos. Y. Myung was in part supported by the SRC Program of the KOSEF through the Center for Quantum Spacetime (CQUeST) of Sogang University with grant number R11-2005-021.

References

[1] S. J. Perlmutter et al., Astrophys. J. 517, 565(1999) [astro-ph/9812133]; A. G. Riess et al., Astron. J. 116, 1009 (1998) [astro-ph/9805201]; A. G. Riess et al., Astrophys. J. 607, 665(2004) [astro-ph/0402512].

[2] H. V. Peiris et al., Astrophys. J. Suppl. 148 (2003) 213 [astro-ph/0302225]; C. L. Bennett et al., Astrophys. J. Suppl. 148 (2003) 1 [astro-ph/0302207]; D. N. Spergel et al., Astrophys. J. Suppl. 148 (2003) 175 [astro-ph/0302209].

[3] A. H. Guth, Phys. Rev. D 23, 347 (1981); A. D. Linde, Phys. Lett. B 108, 389 (1982); A. Albrecht and P. J. Steinhardt, Phys. Rev. Lett. 48, 1220 (1982).

[4] A. Upadhye, M. Ishak, and P. J. Steinhardt, Phys. Rev. D 72, 063501 (2005) [astro-ph/0411803].

[5] A. Cohen, D. Kaplan, and A. Nelson, Phys. Rev. Lett. 82, 4971 (1999) [arXiv:hep-th/9803132].

[6] P. Horava and D. Minic, Phys. Rev. Lett. 85, 1610 (2000) [arXiv:hep-th/0001145]; S. Thomas, Phys. Rev. Lett. 89, 081301 (2002).

[7] S. D. Hsu, Phys. Lett. B 594, 13 (2004) [hep-th/0403052].
[8] M. Li, Phys. Lett. B 603, 1 (2004) [hep-th/0403127].

[9] Q-C. Huang and Y. Gong, JCAP 0408, 006 (2004) [astro-ph/0403590]; Y. Gong, Phys. Rev. D 70, 064029 (2004) [hep-th/0404030]; B. Wang, E. Abdalla and Ru-Keng Su, [hep-th/0404057]; K. Enqvist and M. S. Sloth, Phys. Rev. Lett. 93, 221302 (2004) [hep-th/0406019]; S. Hsu and A. Zee, [hep-th/0406142]; K. Ke and M. Li, [hep-th/0407056]; P. F. Gonzalez-Diaz, [hep-th/0411070]; H. Kim, H. W. Lee, and Y. S. Myung, [hep-th/0501118]; Phys. Lett. B 628, 11 (2005) [gr-qc/0507010]; X. Zhang, astro-ph/0504586; X. Zhang and F.-Q. Wu, [astro-ph/0506310].

[10] Y. S. Myung, Phys. Lett. B 610, 18 (2005) [hep-th/0412224]; Mod. Phys. Lett. A 27, 2035 (2005) [hep-th/0501023]; A. J. M. Medved, [hep-th/0501100].

[11] D. Pavon and W. Zimdahl, Phys. Lett. B 628, 206 (2005) [gr-qc/0505020]; W. Zimdahl, [gr-qc/0505056].

[12] B. Wang, Y. Gong, and E. Abdalla, Phys. Lett. B 624, 141 (2005)[hep-th/0505069].

[13] W. Zimdahl, D. Pavon, and L. P. Cimento, Phys. Lett. B 521, 133 (2001) [astro-ph/0105479].

[14] Y. S. Myung, Phys. Lett. B 626, 1 (2005) [hep-th/0502128].

[15] W. Zimdahl, D. J. Schwarz, A. B. Balakin, and D. Pavon, Phys. Rev. D 64, 063501 (2001) [astro-ph/0009353]; A. B. Balakin, D. Pavon, D. J. Schwarz, and W. Zimdahl, New J. Phys. 5, 085 (2003) [astro-ph/0302150].

[16] T. Padmanabhan, [astro-ph/0411044].

[17] P. Wang and X. Meng, Class. Quant. Grav. 22, 283(2005) [astro-ph/0408495].

[18] R. Horvat, Phys. Rev. D 70, 087301 (2004) [astro-ph/0404204].