Non-existence of extended holographic dark energy with the Hubble horizon

Yungui Gong and Jie Liu

College of Mathematics and Physics, Chongqing University of Posts and Telecommunications, Chongqing 400065, People’s Republic of China
E-mail: gongyg@cqupt.edu.cn and sxtyliujie@126.com

Received 14 July 2008
Accepted 26 August 2008
Published 18 September 2008

Abstract. The extended holographic dark energy model with the Hubble horizon as the infrared cutoff avoids the problem of the circular reasoning of the holographic dark energy model. We show that the infrared cutoff of the extended holographic dark energy model cannot be the Hubble horizon provided that the Brans–Dicke parameter $\omega$ satisfies the experimental constraint $\omega > 10^4$, and this is proved as a no-go theorem. The no-go theorem also applies to the case in which the dark matter interacts with the dark energy.

Keywords: dark energy theory, gravity

ArXiv ePrint: 0807.2000
1. Introduction

The current accelerating expansion of the universe was first discovered in 1998 by the observation of the type Ia supernovas [1]. The high redshift supernova Ia observation found strong evidence of a transition from deceleration in the past to acceleration at present [2, 3]. Evidence of the accelerating expansion of the universe was further provided by other complementary astronomical observations, such as the cosmic microwave background anisotropy and the large scale structure of the clusters of galaxies [4]–[6]. As a model independent tool, the energy conditions were correctly employed to analyze the observational data and conclude the existence of the accelerated expansion of the universe in [7, 8]. To explain the cosmic acceleration, an exotic energy component with negative pressure, dubbed dark energy, is introduced. Because the only observable effect of dark energy is through gravitational interaction, the nature of dark energy imposes a big challenge to theoretical physics. One simple dark energy candidate which is consistent with current observations is the cosmological constant. Due to the discrepancy of many orders of magnitude between the theoretical prediction and observation for the vacuum energy, lots of dynamical dark energy models were proposed. For a review of dark energy models, see [9].

The holographic dark energy (HDE) model is one of the interesting dynamical dark energy models. The HDE model is derived from the relationship between the ultraviolet (UV) and the infrared (IR) cutoffs proposed by Cohen et al in [10]. The UV–IR relationship was also obtained by Padmanabhan, arguing that the cosmological constant is the vacuum fluctuation of energy density [11]. Due to the limit set by the formation of a black hole, the UV–IR relationship gives an upper bound on the zero-point energy density \( \rho_h \leq 3L^{-2}/(8\pi G) \), which means that the maximum entropy is of the order of \( S_{\text{BH}}^{3/4} \). Here \( L \) is the scale of the IR cutoff. The zero-point energy density has the same order of magnitude as the matter energy density [12], and is named the HDE density by Li [13]. However, the original HDE model with the Hubble scale as the IR cutoff failed to explain the accelerating expansion of the universe [12]. Li solved the problem by discussing the possibilities of the particle and event horizons as the IR cutoff, and he found that only the event horizon identified as the IR cutoff leads to a viable dark energy model [13]. The HDE model using the event horizon as the IR cutoff was soon found to be consistent with the observational data in [14]. By considering the interaction between dark energy and matter in the HDE model with the event horizon as the IR cutoff, it was shown that the...
interacting HDE model realized the phantom crossing behavior [15]. Other discussions on the HDE model can be found in [16]–[25].

Since string theory is believed to be the theory of quantum gravity, Einstein’s theory of gravity needs to be modified according to string theory. In the low energy effective bosonic string, the dilaton field appears naturally. The scalar degree of freedom arises also upon compactification of higher dimensional theory. The simplest alternative which includes the scalar field in addition to the tensor field in general relativity is Brans–Dicke theory. Therefore, it is interesting to discuss the HDE model in the framework of Brans–Dicke theory. That was first done by Gong in [26], and the model is called the extended holographic dark energy (EHDE) model. The EHDE model was also discussed in [27]–[31]. Recently, it was claimed that the EHDE model with the Hubble horizon as the IR cutoff could solve the dark energy problem [29, 30]. The existence of the event horizon means that the universe must experience accelerated expansion, so the HDE and EHDE models with the event horizon as the IR cutoff face the problem of circular reasoning. If the Hubble horizon can be used as the IR cutoff in the EHDE model, then the EHDE model is more successful and interesting. In this paper, we carefully examine the EHDE model with the Hubble horizon as the IR cutoff and show that the model fails to solve the dark energy problem. We discuss the EHDE model with the Hubble horizon as the IR cutoff in section 2 and the interacting EHDE model in section 3.

2. EHDE model

The Brans–Dicke Lagrangian in the Jordan frame is given by

\[
L_{BD} = \frac{\sqrt{-g}}{16\pi} \left[ \phi R - \omega g^{\mu\nu} \frac{\partial_\mu \phi \partial_\nu \phi}{\phi} \right] - L_m(\psi, g_{\mu\nu}).
\]  

On the basis of the flat Friedmann–Robertson–Walker metric, we get the evolution equations of the universe from the action (1):

\[
H^2 + H \frac{\dot{\phi}}{\phi} - \frac{\omega}{6} \left( \frac{\dot{\phi}}{\phi} \right)^2 = \frac{8\pi}{3\phi} \rho,
\]

\[
\ddot{\phi} + 3H \dot{\phi} = \frac{8\pi}{2\omega + 3} (\rho - 3p),
\]

\[
\dot{\rho} + 3H (\rho + p) = 0.
\]

Combining the above equations, we also get

\[
\frac{\ddot{a}}{a} = H \frac{\dot{\phi}}{\phi} - \frac{\omega}{3} \left( \frac{\dot{\phi}}{\phi} \right)^2 - \frac{8\pi}{3\phi} \frac{3\omega p + (\omega + 3)p}{3 + 2\omega},
\]

\[
\dot{H} = 2H \frac{\dot{\phi}}{\phi} - \frac{\omega}{2} \left( \frac{\dot{\phi}}{\phi} \right)^2 - \frac{8\pi}{2\omega + 3} \frac{\omega (\rho + p) + 2\rho}{3 + 2\omega}.
\]
In Brans–Dicke theory, the scalar field $\phi$ takes the role of $1/G$, so the EHDE density with the Hubble horizon as the IR cutoff is

$$\rho_h = \frac{3c^2\phi H^2}{8\pi}.$$  \hspace{1cm} (7)

Let us consider the special power law solution $\phi/\phi_0 = (a/a_0)^n$, or $\dot{\phi}/\phi = nH$ first. Using equations (2), (3) and (6), we get the consistency condition for this solution

$$\frac{p}{\rho} = \frac{n\omega + n - 1}{n\omega - 3}.$$  \hspace{1cm} (8)

Substituting the power law solution into the Friedmann equation (2), we get

$$\rho = \rho_m + \rho_h = \frac{3\dot{\phi}}{8\pi} \left( 1 + n - \frac{\omega}{6} n^2 \right) H^2.$$  \hspace{1cm} (9)

Substituting equation (7) into equation (9), we obtain

$$\rho_m = \frac{3\dot{\phi}}{8\pi} H^2 \left( 1 + n - c^2 - \frac{\omega}{6} n^2 \right),$$  \hspace{1cm} (10)

and

$$r = \frac{\Omega_m}{\Omega_h} = \frac{1 + n - c^2 - \omega n^2/6}{c^2}.$$  \hspace{1cm} (11)

Therefore, this solution is the tracking solution in which the dark energy tracks the matter. When $n = 3/\omega$, the ratio $r$ reaches the maximum value

$$r_{\max} = \frac{1 - c^2 + 3/(2\omega)}{c^2}.$$  \hspace{1cm} (12)

On the other hand, if

$$n = \frac{3 \pm \sqrt{9 + 6\omega(1 - c^2)}}{\omega},$$  \hspace{1cm} (13)

then we get the dark energy dominated solution with $r = 0$. For the dark energy dominated solution, the deceleration parameter is

$$q = 2 + \frac{3 \pm \sqrt{9 + 6\omega(1 - c^2)}}{\omega} \pm \frac{\sqrt{3} c^2}{\sqrt{3 + 2\omega(1 - c^2)}}.$$  \hspace{1cm} (14)

If $c^2 = 1$, we get $n = 0$ and $n = 6/\omega$. So $q = 1$ and $q = 3 + 6/\omega$, respectively. To get late time acceleration, we require $-2 < \omega < 0$ [26] which is in violation of the current experimental constraint $\omega > 10^4$ [32, 33]. If $c^2 \neq 1$, then $q < 0$ requires that $c^2$ is very close to $1 + 3/(2\omega)$ when $\omega \gg 1$. However, equation (11) tells us that $r \sim 0$ if $c^2 \sim 1 + 3/(2\omega)$. This means that we cannot recover the early matter dominated epoch. Therefore, if the Brans–Dicke scalar field takes the power law form $\phi/\phi_0 = (a/a_0)^n$, the EHDE model with the Hubble horizon as the IR cutoff exists only when $\omega < 0$.

We may wonder whether the EHDE model with the Hubble horizon as the IR cutoff exists if we consider more general solutions. In order to analyze the system, let us take
Non-existence of extended holographic dark energy with the Hubble horizon

\[ y = H^{-1} \dot{\phi}/\phi; \] then equation (2) becomes

\[ \rho = \rho_m + \rho_h = \frac{3\dot{\phi}}{8\pi} H^2 \left( 1 + y - \frac{\omega}{6} y^2 \right). \]  

(15)

Substituting equation (7) into equation (15), we get

\[ \rho_m = \frac{3\dot{\phi}}{8\pi} H^2 \left( 1 + y - c^2 - \frac{\omega}{6} y^2 \right), \]

(16)

and

\[ r = \frac{\Omega_m}{\Omega_h} = \frac{1 + y - c^2 - \omega y^2/6}{c^2}. \]

(17)

Since \( \rho_m \geq 0 \) and \( \omega > 0 \), so

\[ 3 - \sqrt{9 + 6\omega(1 - c^2)} \leq y \leq \frac{3 + \sqrt{9 + 6\omega(1 - c^2)}}{\omega}, \]

(18)

and

\[ c^2 \leq 1 + \frac{3}{2\omega}. \]

(19)

Again when \( y = 3/\omega \), \( r \) reaches the maximum value,

\[ r_{\text{max}} = \frac{1 - c^2 + 3/(2\omega)}{c^2}. \]

(20)

To recover the matter dominated universe, either \( c^2 \) or \( \omega \) must be very small. Let \( x = \ln a \); with the help of equations (2) and (6), equation (3) is rewritten as

\[ y' = \frac{[\omega y^2 - 6y - 6(1 - c^2)][(\omega + 1)y - 1]}{2[3 + 2\omega(1 - c^2)]}, \]

(21)

where \( y' = dy/dx \). Take \( y' = 0 \); we get three fixed points

\[ y_{1c} = \frac{3 + \sqrt{9 + 6\omega(1 - c^2)}}{\omega}, \quad y_{2c} = \frac{3 - \sqrt{9 + 6\omega(1 - c^2)}}{\omega}, \quad y_{3c} = \frac{1}{1 + \omega}. \]

(22)

From the definition (7) of the HDE and the energy conservation equation (4) of the dark energy, we get the equation of state parameter of the dark energy

\[ w_h = \frac{3 - (4\omega + 3) y + \omega(\omega + 1)y^2}{3[3 + 2\omega(1 - c^2)]}. \]

(23)

From equation (5), we get the deceleration parameter

\[ q = -\frac{\ddot{a}}{aH^2} = \frac{1}{2} + \frac{\omega(\omega + 1)y^2 - 2\omega(1 + c^2)y + 3}{2[3 + 2\omega(1 - c^2)]}. \]

(24)

If \( c^2 \leq \sqrt{3(1 + 1/\omega)} - 1 \), then \( q \) is never less than \( 1/2 \).

Substituting the fixed points \( y_{1c} \) and \( y_{2c} \) into equation (17), we get \( r = 0 \). These two fixed points correspond to the power law solution (13) discussed above. The deceleration parameters are given by equation (14).
Table 1. The properties of the fixed points for the EHDE model without interaction.

| Points | Stability | \( r \) | \( q \) |
|--------|-----------|---------|---------|
| \( y_{1c} \) | Unstable | 0 | \( > 2 \) |
| \( y_{2c} \) | Stable if \( c^2 > (2\omega + 3)(3\omega + 4)/6(\omega + 1)^2 \) | 0 | Can be negative |
| \( y_{3c} \) | Stable if \( c^2 < (2\omega + 3)(3\omega + 4)/6(\omega + 1)^2 \) | \( > (1 - c^2)/c^2 \) | \( > 1/2 \) |

For the first fixed point \( y_{1c} \), equation (14) tells us that \( q > 2 \). This fixed point corresponds to the deceleration solution. By linearizing equation (21) around the fixed point \( y_{1c} \), we get

\[
y' = \frac{2\sqrt{9 + 6\omega(1 - c^2)[3 + 2\omega + (\omega + 1)\sqrt{9 + 6\omega(1 - c^2)}]}}{\omega} y. \tag{25}
\]

Therefore, the fixed point \( y_{1c} \) corresponds to an unstable fixed point which is not interesting.

For the second fixed point \( y_{2c} \), equation (14) tells us that \( q \) can be negative when \( c^2 \approx 1 + 3/(2\omega) \). However, when \( c^2 \approx 1 + 3/(2\omega) \), \( y \approx y_{1c} \approx y_{2c} \) and \( r = 0 \). The universe is always in the dark energy dominated era and the matter dominated era does not exist. By linearizing equation (21) around the fixed point \( y_{2c} \), we get

\[
y' = -\frac{2\sqrt{9 + 6\omega(1 - c^2)[3 + 2\omega - (\omega + 1)\sqrt{9 + 6\omega(1 - c^2)}]}}{\omega} y. \tag{26}
\]

When \( (2\omega + 3)(3\omega + 4)/6(\omega + 1)^2 < c^2 \leq 1 + 3/2\omega \), the fixed point corresponds to a stable fixed point.

For the third fixed point, we get

\[
r = \frac{1 - c^2}{c^2} + \frac{6 + 5\omega}{6(1 + \omega)^2c^2} > \frac{1 - c^2}{c^2}, \tag{27}
\]

and the deceleration parameter

\[
q = \frac{1}{2} + \frac{1}{2(\omega + 1)} > \frac{1}{2}. \tag{28}
\]

This fixed point corresponds to the deceleration solution too. By linearizing equation (21) around the fixed point \( y_{3c} \), we get

\[
y' = -\frac{(2\omega + 3)(3\omega + 4) - 6(\omega + 1)^2c^2}{2(\omega + 1)[3 + 2\omega(1 - c^2)]} y. \tag{29}
\]

When \( c^2 < (2\omega + 3)(3\omega + 4)/6(\omega + 1)^2 \), the fixed point becomes the stable fixed point. The analysis of the fixed points is summarized in table 1. To better understand the above discussion, we take the parameters \( c^2 = 0.1, 1, c^2 \approx 1 + 3/2\omega, \omega = 1, 10 \) and 1000, and then solve equation (21) numerically. The evolutions of \( r = \Omega_m/\Omega_h \) and \( q \) are plotted in figure 1. The results in figure 1 support the above analysis.

From the above discussion, we know that the transition from deceleration in the past which is matter dominated to acceleration at present which is dark energy dominated does not happen in the EHDE model with the Hubble horizon as the IR cutoff.
result is somewhat expected because Brans–Dicke theory reduces to Einstein theory when \( \omega \to \infty \). In Einstein theory, we know that the HDE model with the Hubble horizon as the IR cutoff does not exist. So we expect the EHDE model with the Hubble horizon as the IR cutoff not to exist either if \( \omega \gg 1 \). Therefore, we have the following no-go theorem: There is no viable EHDE model with the Hubble horizon as the IR cutoff if the Brans–Dicke parameter \( \omega \) satisfies the experimental constraint \( \omega > 10^{10} \). This no-go theorem also applies to the situation when we consider the interaction between dark matter and dark energy.

3. Interacting EHDE model

By introducing the interaction between dark matter and dark energy, the conservation equations become

\[
\dot{\rho}_m + 3H\rho_m = Q, \tag{30}
\]

\[
\dot{\rho}_h + 3H(1+w_h)\rho_h = -Q, \tag{31}
\]

where \( Q \) stands for the interaction term. We take \( Q = \Gamma H\rho_h \) with \( \Gamma > 0 \) being the interaction rate. Because the Friedmann equation (2) is unchanged, the ratio \( r \) between \( \Omega_m \) and \( \Omega_h \) still satisfies equation (17) and the range of the variable \( y \) is still restricted by equation (18). The above discussion tells us that for \( \omega \gg 1 \), we need to require \( c^2 \ll 1 \) to get an early matter dominated universe. The differential equation of the variable \( y \) now becomes

\[
y' = \frac{\omega(\omega + 1)y^3 - (6 + 7\omega)y^2 + 2[(3 + 3\omega - \omega\Gamma)c^2 - 3\omega]y + 6(1 - c^2 + \Gamma c^2)}{2[3 + 2\omega(1 - c^2)]}. \tag{32}
\]
The fixed points are derived by setting $y' = 0$. In this case, there are no analytical expressions for the fixed points. We need to find them numerically. Note that the fixed points $y_{1c}$ and $y_{2c}$ in equation (22) are no longer fixed points when the interaction between dark components is present. In other words, the late time attractors do not correspond to $r = 0$ due to the interaction. The equation of state parameter $w_h$ is

$$w_h = \frac{\omega(\omega + 1)y^2 - (4\omega + 3)y + 3 - (2\omega + 3)\Gamma}{3[3 + \Gamma(1 - c^2)]}. \tag{33}$$

The deceleration parameter is

$$q = \frac{1}{2} + \frac{\omega(\omega + 1)y^2 - 2\omega(1 + c^2)y + 3 - 2\omega c^2 \Gamma}{2[3 + \Gamma(1 - c^2)]}. \tag{34}$$

With the extra term $\Gamma$, it is now easier to get $q < 0$.

To solve equation (32), we need to specify $\omega$, $c^2$ and $\Gamma$. From the above discussions, it is necessary that $c^2 \ll 1$ so that it is possible for the universe to have experienced the transition from the matter dominated to the dark energy dominated case. If $\Gamma$ is order unity, then $\Gamma c^2 \ll 1$ and the effect of the interaction becomes negligible. So the late time attractor is approximately the same as that without interaction, i.e., the fixed point is $y_e \sim 1/\omega$. However, the dark energy would not dominate if $\Gamma c^2 \ll 1$ as shown in equation (27). To illustrate the point, we take $c^2 = 0.1$ and assume that $\Gamma$ is a constant for simplicity. In figure 2, we show the dynamical behavior of $y$ for $\omega = 1$ and 1000, and
Non-existence of extended holographic dark energy with the Hubble horizon

Figure 3. The dynamical evolutions of $r$ for different $\Gamma$ and $\omega$; we take $c^2 = 0.1$.

Figure 4. The dynamical evolutions of $q$ for different $\Gamma$ and $\omega$; we take $c^2 = 0.1$.

$\Gamma = 1$ and 1000. If $\Gamma = 1$, the fixed points are $y_c = 0.001$ for $\omega = 1000$ and $y_c = 0.53$ for $\omega = 1$. The results support our argument that $y_c \approx 1/(1 + \omega)$. If $\Gamma = 1000$, the fixed points are $y_c = 0.00295$ for $\omega = 1000$ and $y_c = 2.687$ for $\omega = 1$. Now the fixed points are $y_c \approx 3/\omega$. In figures 3 and 4, we show the evolution of $r$ and $q$ for the same choices of $\omega$ and $\Gamma$. From figure 3, it is clear that there is no dark energy dominated period. We also see that $r$ is almost independent of $\Gamma$ if $\omega \gg 1$. This can be easily understood. If $\omega \gg 1$, then $-\sqrt{6(1 - c^2)/\omega} \lesssim y \lesssim \sqrt{6(1 - c^2)/\omega}$. So $y$ is almost zero. Furthermore, the fixed point $y_c \sim 1/\omega$, so $r \sim (1 - c^2)/c^2$ which is independent of $\Gamma$. From figure 4, we see that there is no transition from deceleration to acceleration.
In conclusion, the no-go theorem also applies for the interaction case. Whether there is interaction between the dark components or not, the EHDE model with the Hubble horizon as the IR cutoff is not a viable dark energy model if the Brans–Dicke parameter $\omega$ satisfies the experimental constraint $\omega \gg 1$. The no-go theorem breaks down if $\omega < 0$. For a more general Brans–Dicke theory with variable $\omega$, the current solar system constraint can be relaxed [34]. If $\omega$ is a function of the scalar field and $\omega(\phi)$ increases with time, we may get a different result. The HDE model in the context of a general scalar–tensor theory of gravity will be considered in future work.

Acknowledgments

The work was supported by NNSFC under grant No 10605042. Y G Gong thanks for hospitality the Abdus Salam International Center for Theoretical Physics where part of the work was done.

References

[1] Riess A G et al, 1998 Astron. J. 116 1009 [SPIRES]
[2] Perlmutter S et al, 1999 Astrophys. J. 517 565 [SPIRES]
[3] Wood-Vasey W M et al, 2007 Astrophys. J. 666 694 [SPIRES]
[4] Davis T M et al, 2007 Astrophys. J. 666 716 [SPIRES]
[5] Astier P et al, 2006 Astron. Astrophys. 447 31 [SPIRES]
[6] Eisenstein D J et al, 2005 Astrophys. J. 633 560 [SPIRES]
[7] Spergel D N et al, 2007 Astrophys. J. Suppl. 170 377
[8] Gong Y G and Wang A, 2007 Phys. Lett. B 652 63 [SPIRES]
[9] Sahni V and Starobinsky A A, 2000 Int. J. Mod. Phys. D 9 373 [SPIRES]
[10] Padmanabhan T, 2003 Phys. Rep. 380 235 [SPIRES]
[11] Peebles P J E and Ratra B, 2003 Rev. Mod. Phys. 75 559 [SPIRES]
[12] Hsu S D H, 2004 Phys. Lett. B 603 1 [SPIRES]
[13] Li M, 2004 Phys. Lett. B 594 13 [SPIRES]
[14] Huang Q G and Gong Y G, 2004 J. Cosmol. Astropart. Phys. JCAP08(2004)006 [SPIRES]
[15] Wang B, Gong Y G and Abdalla E, 2005 Phys. Lett. B 624 141 [SPIRES]
[16] Gong Y G, Wang B and Zhang Y Z, 2005 Phys. Rev. D 72 043510 [SPIRES]
[17] Wang B, Gong Y G, Wang A, Wu Q and Zhang Y Z, 2007 J. Cosmol. Astropart. Phys. JCAP08(2007)018 [SPIRES]
[18] Padmanabhan T, 2003 Class. Quantum Grav. 20 L107 [SPIRES]
[19] Padmanabhan T, 2005 Int. J. Mod. Phys. D 15 1753 [SPIRES]
[20] Li M, 2004 Phys. Lett. B 603 1 [SPIRES]
[21] Huang Q G and Gong Y G, 2004 J. Cosmol. Astropart. Phys. JCAP08(2004)006 [SPIRES]
[22] Wang B, Gong Y G and Abdalla E, 2005 Phys. Lett. B 624 141 [SPIRES]
[23] Gong Y G, Wang B and Zhang Y Z, 2005 Phys. Rev. D 72 043510 [SPIRES]
[24] Kao H-C, Lee W-L and Lin F-L, 2005 Phys. Rev. D 71 123518 [SPIRES]
[25] Copeland E J, Sami M and Tsujikawa S, 2006 Class. Quantum Grav. 23 37
[26] Setare M R, 2005 Phys. Rev. D 71 123518 [SPIRES]
[27] Setare M R, 2006 Phys. Lett. B 636 80 [SPIRES]
[28] Setare M R, 2007 Phys. Lett. B 653 116 [SPIRES]
[29] Setare M R, 2007 Eur. Phys. J. C 50 991 [SPIRES]
[30] Ito M, 2005 Europhys. Lett. 71 712 [SPIRES]
[31] Nojiri S and Odintsov S D, 2006 Gen. Rel. Grav. 38 1285 [SPIRES]
[32] Setare M R, 2006 Phys. Rev. D 74 125011 [SPIRES]
[33] Gubser B, Horvat R and Nikolic H, 2006 Phys. Lett. B 636 80 [SPIRES]
[34] Saridakis E, 2008 Phys. Lett. B 660 138 [SPIRES]
[35] Saridakis E, 2008 Phys. Lett. B 661 335 [SPIRES]
Non-existence of extended holographic dark energy with the Hubble horizon

Saridakis E, 2008 J. Cosmol. Astropart. Phys. JCAP04(2008)020 [SPIRES]
[23] Hu B and Ling Y, 2006 Phys. Rev. D 73 123510 [SPIRES]
Li H, Guo Z K and Zhang Y Z, 2006 Int. J. Mod. Phys. D 15 869 [SPIRES]
[24] Sadjadi H M, 2007 J. Cosmol. Astropart. Phys. JCAP02(2007)026 [SPIRES]
Guo Z K, Ohta N and Tsujikawa S, 2007 Phys. Rev. D 76 023508 [SPIRES]
[25] Zhang X and Wu F Q, 2005 Phys. Rev. D 72 043524 [SPIRES]
Zhang X and Wu F Q, 2007 Phys. Rev. D 76 023502 [SPIRES]
[26] Gong Y G, 2004 Phys. Rev. D 70 064029 [SPIRES]
[27] Kim H, Lee H W and Myung Y S, 2006 Phys. Lett. B 632 665 [SPIRES]
[28] Setare M R, 2007 Phys. Lett. B 644 99 [SPIRES]
[29] Banerjee N and Pavón D, 2007 Phys. Lett. B 647 477 [SPIRES]
[30] Nayak B and Singh L P, 2008 arXiv:0803.2930
[31] Xu L and Lu J, 2008 arXiv:0804.2925
[32] Will C M, 2006 Living Rev. Rel. 9 3
[33] Bertotti B, Iess L and Tortora P, 2003 Nature 425 374 [SPIRES]
[34] Clifton T, Mota D F and Barrow J D, 2005 Mon. Not. R. Astron. Soc. 358 601