A Holographic Energy Model

Peng Huang\textsuperscript{1} and Yong-Chang Huang\textsuperscript{1,2,3}\textsuperscript{†}

\textsuperscript{1}Institute of Theoretical Physics, Beijing University of Technology, Beijing 100124, China
\textsuperscript{2}Kavli Institute for Theoretical Physics, Chinese Academy of Sciences, Beijing 100080, China
\textsuperscript{3}CCAST (World Lab.), P.O. Box 8730, Beijing 100080, China

Abstract

We suggest a holographic energy model in which the energy coming from spatial curvature, matter and radiation can be obtained by using the particle horizon for the infrared cut-off. We show the consistency between the holographic dark-energy model and the holographic energy model proposed in this paper. Then, we give a holographic description of the universe.

Key words: holography principle, dark energy, cosmology

\textsuperscript{*}Electronic address: phuang@emails.bjut.edu.cn
\textsuperscript{†}Electronic address: ychuang@bjut.edu.cn
I. INTRODUCTION

The holographic dark energy model [1]-[6] is a phenomenological model which is simple and effective. Originally, Ref. [1] suggested that, in quantum field theory, due to the limit made by the formation of a black hole, an ultraviolet (UV) cut-off is related to an infrared (IR) cut-off. If \( \rho_D \) is the quantum zero-point energy density caused by a UV cut-off, the total energy in a region of size \( L \) should not exceed the mass of a black hole of the same size, then, \( L^3 \rho_D \leq L M_p^2 \), even general nonstationary black holes are investigated [7][8]. Thus one has \( \rho_D = 3C^2 M_p^2 L^{-2} \), here, \( C \) is a numerical constant introduced for convenience and \( M_p \) is Planck mass [2]. If one supposes that there is no interaction between dark energy and matter, an inevitable result is to use the future event horizon for infrared (IR) cut-off, only by doing this can we deduce the correct equation of state (EOS) to obtain an accelerated universe. The holographic dark energy model developed from this viewpoint is as follows [3]

\[
\rho_D = 3C^2 M_p^2 L^{-2},
\]

where \( C \) is a positive numerical parameter which is in favour of \( C = 1 \) [2, 3], \( M_p \) is the Plank mass, \( L_E = a(t)r_E(t) \), the definition of \( r_E(t) \) is \( \int_0^{r_E(t)} \frac{dr}{\sqrt{1-k r^2}} = \frac{R_E(t)}{a(t)} = \int_0^{\infty} \frac{dt}{a(t)} \), and \( R_E(t) \) is future event horizon, \( k=1, 0, -1 \) corresponds to the closed, flat and open universe, respectively.

The index of the EOS of dark energy derived from Eq.(1) is [3]

\[
\omega_D = -\frac{1}{3} \left( 1 + \frac{2}{C} \sqrt{\Omega_D} \cos \frac{\sqrt{k} R_E(t)}{a(t)} \right),
\]

so, in the early universe, when \( \Omega_D \to 0 \), one has \( \omega_{DE} \to -\frac{1}{3} \); in the dark-energy-dominated era, \( \Omega_D \to 1 \) and \( \omega_D \to -1 \), namely, dark energy evolves towards the cosmological constant.

It is profound that a simple combination of the Planck scale and IR cut-off \( L_E \) gives an energy density comparable to the observed dark energy. This can be understood in terms of the holographic principle [9][10][11], saying that the area of any surface limits the information content of adjacent spacetime regions at \( 1.4 \times 10^{69} \) bits per square meter [11], which is thought to be manifest in an underlying quantum theory of gravity. Such a basic principle should have the property that it is universal and does not hold only for special objects. Thus, since the dark energy has already shown its holographic character, a natural generalization is that the remnant kinds of energy in the universe should also have their holographic characters which people don’t know yet.

In this paper, we will show that the energy coming from spatial curvature, matter and radiation together is holographic and appears when we use the particle horizon for the IR cut-off, furthermore, we give a holographic description of the universe.

The arrangement of the paper is as follows. In Sec.2 we suggest a holographic energy model in which the energy coming from spatial curvature, matter and radiation together can be obtained by using the particle horizon to make the IR cut-off; in Sec.3 we study the consistency between the two holographic energy models and give a holographic description of the universe; the last section is the summary and conclusion.
II. HOLOGRAPHIC ENERGY FROM SPATIAL CURVATURE, MATTER AND RADIATION

Assuming a ΛCDM model ($\Omega = 1$), Seven-Year WMAP Observations give the result

$$0.0133 < \Omega_K < 0.0084 (95\% CL),$$

(3)

this limit weakens significantly if dark energy is allowed to be dynamical, in fact a closed universe with a small positive curvature ($\Omega_K \sim 0.01$) is compatible with observations, [12]-[14], we now do our investigating in the closed universe; for the open universe with a negative spatial curvature the results can be very similarly obtained from the investigations on those for the closed universe.

In the closed universe, we know that

$$\rho_K \sim a(t)^{-2}, \quad \rho_M \sim a(t)^{-3}, \quad \rho_R \sim a(t)^{-4},$$

(4)

where the subscripts $K$, $M$ and $R$ are shortly denoted as the spatial curvature, matter and radiation, respectively. And we notice the character of $\rho \propto a^{-3(1+\omega)}$ that is obtained from the Friedmann equation, from which we can get the corresponding indexes of $\rho_K$, $\rho_M$, $\rho_R$ in their EOS as follows

$$\omega_K = -\frac{1}{3}, \quad \omega_M = 0, \quad \omega_R = \frac{1}{3}.$$  

(5)

Therefore, we can use the general energy density $\rho_{KMR}$ to denote the sum of the three energy densities of (4), then, the index $\omega_{KMR}$ in the EOS of $\rho_{KMR}$ evolves from $\frac{1}{3}$ in the early universe to $-\frac{1}{3}$ in the dark-energy-dominated era, thus, when there exists a holographic description for $E_{KMR}$ ($E_{KMR}$ is short for energy coming from spatial curvature, matter and radiation together), the deduced $\omega_{KMR}$ must satisfy this evolvement.

Similar to the research of establishing the holographic dark energy model, $\rho_{KMR}$ also suffer the limitation made by the formation of a black hole, and then an ultraviolet cut-off corresponding to $\rho_{KMR}$ in a region of size $L$ is related to an infrared cut-off corresponding to a black hole of the same size, which is just

$$\rho_{KMR} = 3C'^2 M_p^2 L^{-2},$$

(6)

where the similar parameter $C'$ is introduced for convenience. Then, the task is to find a suited infrared cut-off $L$ which can not only give the correct evolvement of $\omega_{KMR}$ but also make the value of $\rho_{KMR}$ match the experimental data.

It has been pointed out that [15], if one uses the Hubble radius to provide the IR cut-off and supposes that there is no interaction between dark energy and matter, the deduced EOS is just for pressureless matter. So the Hubble radius is not a good choice for the holographic description of $E_{KMR}$. And the event horizon has been used for the holographic description of dark energy, so, we now investigate the particle horizon radius for the IR cut-off. In this case, Eq. (6) turns to

$$\rho_p = 3C'^2 M_p^2 L_p^{-2},$$

(7)

the definition of $L_p$ is

$$L_p = a(t)r_p(t),$$

(8)
$r_p(t)$ is defined by

$$
\int_0^{r_p(t)} \frac{dr}{\sqrt{1 - kr^2}} = \frac{R_p(t)}{a(t)} = \int_0^t \frac{dt}{a(t)},
$$

or

$$\sqrt{kr_p(t)} = \sin \frac{\sqrt{kR_p(t)}}{a(t)} = \sin y_p, \quad (10)
$$

where $k=1, 0, -1$ corresponds to closed, flat and open universe, respectively, and $y_p = \frac{\sqrt{kR_p(t)}}{a(t)}$.

We can discover that the holographic energy density $\rho_p$ is just $\rho_{KMR}$.

To see this, firstly, we derive the concrete form of the EOS of $\rho_p$ from Eq.(7). Using the definitions $\Omega_p = \frac{\rho_p}{\rho_c}$ and $\rho_c = 3M_p^2H^2$, we can get from Eq.(7) the following result

$$HL_p = \frac{C'}{\sqrt{\Omega_p}}, \quad (11)
$$

Using Eq.(8-11) we obtain

$$\dot{L}_p = HL_p + a \dot{r}_p(t)
= \frac{C'}{\sqrt{\Omega_p}} + a \cos y_p \frac{d}{dt} \int_0^t \frac{dt}{a}
= \frac{C'}{\sqrt{\Omega_p}} + \cos y_p, \quad (12)
$$

so the rate of change of the $\rho_p$ with time is

$$\frac{d\rho_p}{dt} = -6C'2M_p^2L_p^{-3} \dot{L}_p = -2H\rho_p(1 + \frac{1}{C'}\sqrt{\Omega_p}\cos y_p). \quad (13)
$$

On the other hand, because of the conservation of the energy–momentum tensor, the evolution of the holographic energy density $\rho_p$ is governed by

$$\frac{d}{da}(a^3\rho_p) = -3a^2p_p, \quad (14)
$$

where $p_p$ denotes the pressure coming from $\rho_p$, thus we obtain $p_p = -\frac{1}{3} \frac{d\rho_p}{a \ln a} - \rho_p$, and the EOS of the holographic energy $\rho_p$ is characterized by the index

$$\omega_p = \frac{p_p}{\rho_p} = -\frac{1}{3\rho_p} \frac{d\rho_p}{a \ln a} - 1 = -\frac{1}{3H\rho_p} \frac{d\rho_p}{dt} - 1, \quad (15)
$$

inserting Eq.(13) to Eq.(15), finally, we get

$$\omega_p = -\frac{1}{3}(1 - \frac{2}{C'}\sqrt{\Omega_p}\cos \frac{R_p}{a(t)}), \quad (16)
$$

where $k = 1$ is taken.
We can see that when $C' = 1$ then in the early universe $\Omega_p \to 1$ because $\Omega_D \to 0$ at that time; when it is the dark-energy-dominated era, $\Omega_p$ must be close to zero, we thus can see from Eq.(16) that $\omega_p$ evolves from $\frac{1}{3}$ in the early universe to $-\frac{1}{3}$ in the dark-energy-dominated era which is the same as $\omega_{KMR}$ (see the discussion below Eq.(5)). But is it reasonable that $C' = 1$? In fact we can see $C'$ is also in favor of 1 if we notice that the total energy in a region of size $L_p$ is $\frac{4\pi}{3}L_p^3\rho_{KMR}$, and the mass of a black hole of the same size $L_p$ is $4\pi M_p^2 L_p$, in the extreme case we can equate these two quantities, we can find that

$$\rho_{KMR} = 3M_p^2L_p^{-2}$$

which shows $C' = 1$ and is consistent with the holographic dark energy model.

Secondly, let’s study the magnitude of $\rho_p$.

Huang and Li [3] give a useful expression

$$\rho = \frac{C}{\sqrt{\Omega_D}}.$$  \hfill (18)

Comparing Eq.(18) with Eq.(11) deduced in this paper, we find that they have the same mathematical structure except for $\Omega_p$ and $\Omega_D$, respectively. We know that $\Omega_D = 0.73 \pm 0.04$ from the first year WMAP observations [12], when $\rho_p$ is just $\rho_{KMR}$ and together with the fact that $\rho_{KMR}$ now is dominated by $\rho_M$ nowadays, we have the result that $\Omega_p \approx \Omega_M = 0.27 \pm 0.04$ [12], inserting the values of $\Omega_p$ and $\Omega_D$ into Eq.(18) and Eq.(11), respectively, we can derive that $L_E$ and $L_p$ are at the same order of magnitude, and according to Eq.(11) and Eq.(7) we can discover that the magnitudes of $\rho_D$ and $\rho_p$ are at the same order of magnitude. Thus, since the magnitude of $\rho_D$ matches the experimental data well in the holographic dark energy model, the magnitude of $\rho_p$ also matches the experimental data well if we equate it to $\rho_{KMR}$.

We can also see this from another point of view. Noticing that the particle horizon is comparable to the Hubble horizon nowadays, we insert $L_p^{-1} \sim H_0 = 1.51 \times 10^{-42} GeV$ [12] and $M_p \approx 2.43 \times 10^{18} GeV$ into Eq.(7), we get the result that $\rho_p \sim 10^{-47} GeV^4$, which is just at the same order of the magnitude of $\rho_{KMR}$, so we again find that the magnitude of $\rho_p$ matches experimental data well.

Therefore, since the evolution of the EOS of $\rho_p$ is the same as that for $\rho_{KMR}$ and the magnitude of $\rho_p$ matches experimental data well if we equate it to $\rho_{KMR}$, we can now see that the holographic energy density $\rho_p$ is just $\rho_{KMR}$. So we have the conclusion that the energy coming from spatial curvature, matter and radiation together can be described by the holographic $E_{KMR}$ whose energy density $\rho_p$ is given by Eq.(7), we then can change the index $p$ as $KMR$ for comfortable, consequently, we have

$$\rho_{KMR} = 3C'^2 M_p^2 L_p^{-2}$$ \hfill (19)

with the parameter $C'$ in favor of 1.

Maybe someone has the conclusion that this holographic energy model can only be established in a universe in which a particle horizon can be found. The implying behind this is that this model will fail when one faces universe models without particle horizon. In fact, it is well motivated that our universe does not begin with a singular point but is a cosmological egg with a little scale factor $a(0)$ ($a(0)$ approaches zero but is not equal to zero), i.e., a rather hot egg with very high temperature, density and curvature. Therefore, there must exist a particle horizon, which can be seen from the definition $R_p = a \int_0^t \frac{dt}{a(t)}$ of the radius of the particle horizon.
III. THE CONSISTENCY BETWEEN THE TWO HOLOGRAPHIC ENERGY MODELS AND THE HOLOGRAPHIC DESCRIPTION OF THE UNIVERSE

From the discussion of the parameter $C'$ in the Sec.2, we know that it is also in favor of $C' = 1$ as that in the holographic dark energy model[2][3], which shows the consistency between these two holographic energy models. We here give furthermore discussions on the consistency. From the result in the Sec.2, it is convenient to set $C'$ equal to $C$, then, taking a derivative of the total energy density of the universe with respect to time $t$, we have

$$\frac{d}{dt}\rho_{\text{total}} = \frac{d}{dt}\rho_{\text{DE}} + \frac{d}{dt}\rho_{\text{KMR}}$$

$$= -6C^2 M_p^2 L_{E}^{-3} \dot{L}_E - 6C^2 M_p^2 L_{p}^{-3} \dot{L}_p.$$  \hfill (20)

And Ref.[3] gives an expression

$$\dot{L}_E = HL_E - \cos y_E.$$  \hfill (21)

Inserting Eq.(12) and Eq.(21) into Eq.(20), we obtain

$$\frac{d}{dt}\rho_{\text{total}} = -\frac{2\rho_{\text{DE}}}{L_E}(HL_E - \cos y_E) + \frac{-2\rho_{\text{KMR}}}{L_p}(HL_p + \cos y_p),$$  \hfill (22)

using Eq.(11) and Eq.(18), Eq.(22) can be rewritten as

$$\frac{d}{dt}\rho_{\text{total}} = -2H\rho_{\text{DE}}(1 - \frac{1}{C}\sqrt{\Omega_{DE}\cos y_E}) - 2H\rho_{\text{KMR}}(1 + \frac{1}{C}\sqrt{\Omega_{KMR}\cos y_p})$$

$$= -2H\rho_{\text{total}} + \frac{2}{C}H(\frac{\rho_{DE}^3}{\sqrt{\rho_c}} \cos y_E - \frac{\rho_{KMR}^3}{\sqrt{\rho_c}} \cos y_p).$$  \hfill (23)

Because $\rho_c = \rho_D + \rho_M + \rho_R - \rho_K$ coming from one of Friedmann equations and $\rho_{\text{total}} = \rho_D + \rho_M + \rho_R + \rho_K = \rho_D + \rho_{\text{KMR}}$, we can have

$$\frac{d}{dt}\rho_{\text{total}} = -2H\rho_c - 4H\rho_K + \frac{2}{C}H(\frac{\rho_{DE}^3}{\sqrt{\rho_c}} \cos y_E - \frac{\rho_{KMR}^3}{\sqrt{\rho_c}} \cos y_p)$$

$$= -2H\rho_c[1 + 2\Omega_K - \frac{1}{C}\Omega_{DE}^3 \cos y_E + \frac{1}{C}\Omega_{KMR}^3 \cos y_p],$$  \hfill (24)

letting this equation equate zero to obtain the extremum point, we have

$$1 + 2\Omega_K - \frac{1}{C}\Omega_{DE}^3 \cos y_E + \frac{1}{C}\Omega_{KMR}^3 \cos y_p = 0.$$  \hfill (25)

One can know from the holographic dark energy model[3] that the expansion of the universe will never have a turning point so that the universe will not re-collapse; the dark energy will dominate our universe and $\Omega_{DE} \rightarrow 1^+$, thus, we can have $\Omega_{KMR} \rightarrow 0^+$ and $\Omega_K \rightarrow 0^+$; furthermore, the universe evolves towards a de Sitter universe, where $y_E = \int_{t}^{\infty} \frac{dt}{a} \propto \int_{t}^{\infty} \frac{dt}{e^{Ht}} = \frac{1}{H} e^{-Ht}$, when the dark energy evolves towards the cosmological constant and when the considered time is large enough,
then $y_E \to 0$. Thus, we can see from above discussions in this paragraph that $\Omega_{DE} = 1$ is the solution of Eq.(25), which implies $C = 1$.

On the other hand, because a lot of general physical processes should satisfy quantitative causal relation with no-loss-no-gain character \[16\][17], e.g., Ref.[18] uses the no-loss-no-gain homeomorphic map transformation satisfying the quantitative causal relation to gain exact strain tensor formulas in Weitzenböck manifold. In fact, some changes (cause) of some quantities in Eq.(25) must result in the relative some changes (result) of the other quantities in Eq.(25) so that Eq.(25)’s right side keep no-loss-no-gain, i.e., zero, namely, Eq.(25) also satisfies the quantitative causal relation. Hence the investigations are consistent.

So, when we consider the holographic $E_{KMR}$ model and the holographic dark energy model simultaneously, we can see $C = 1$; on the other hand, when we only consider the holographic $E_{KMR}$ model, the parameter also have the same result. This shows the consistency between the two holographic energy models. More commonly, we know that the dark energy and $E_{KMR}$ can be obtained by using respective horizon for their IR cut-off, this correspondence between the energy and the horizon both in the holographic dark energy model and in the holographic $E_{KMR}$ model also shows the consistency between the two models. This consistency implies that the holographic descriptions of the energies may be on the correct way to describe the universe. Based on this consideration, we can now say that a closed physical universe is holographic, it makes up of two holographic components:

(i) Holographic dark energy: $\rho_D = 3C^2 M_p^2 L_E^{-2}$;

(ii) Holographic $E_{KMR}$: $\rho_{KMR} = 3C^2 M_p^2 L_P^{-2}$.

When $t \to 0$, $R_p = \lim_{t \to 0} a(t) \int_0^t \frac{dt}{a(t)} \to 0$, and $\rho_{KMR} \sim R_p^{-2} \to \infty$, it corresponds to the big bang; when $\int_0^t \frac{dt}{a(t)} \sim \int_0^\infty \frac{dt}{a(t)}$, the magnitude of $\rho_D$ and $\rho_{KMR}$ is comparable to each other, the particle horizon and the event horizon are both comparable to the Hubble horizon, and this is the duration we stay at present; when $t$ is large enough, the universe is dark energy dominated, so the universe looks like a de Sitter universe that $H \sim \frac{\Lambda}{M_p}$ and $a(t) \sim e^{Ht}$, thus, $\rho_{DE} \sim M_p^2 (e^{Ht} \sin^2 \frac{\Lambda}{H} \int_0^\infty \frac{dt}{e^{Ht}})^{-2} \sim \Lambda$ (from Eq.(11)) and $\rho_{KMR} \sim M_p^2 (e^{Ht} \sin^2 \int_0^t \frac{dt}{e^{Ht}})^{-2} \sim M_p^2 e^{-2Ht}$ (from Eq.(19)) during this time, namely, the dark energy evolves towards the cosmological constant and the $E_{KMR}$ density decays vary fast, however, still has a non-vanishing value which is proportional to $e^{-2Ht}$.

A deduction from the holographic description of the universe is that there must be both dark energy and $E_{KMR}$ as long as the two horizons exist in a given closed universe. Thus, for example, a closed de Sitter universe with only a positive cosmological constant, in which the two horizons appear, can not exist as a real physical universe but be a good approximation for the real physical universe during dark energy dominated era since the $E_{KMR}$ decays so fast.
IV. SUMMARY AND CONCLUSION

The motivation to study the holographic characteristic of the energy coming from spatial curvature, matter and radiation is that the holographic principle is believed to be a basic principle which must be manifest in an underlying quantum theory of gravity, and such a basic principle should have the property of universality and does not holds only for special object, thus, since the dark energy has already shown its holographic character, a natural generalization is that the remnant kinds of energy in the universe should also have their holographic characters. In the holographic dark-energy model [2][3], using an event horizon for the IR cut-off is an inevitable choice, only by doing this can we get the correct equation of state to accelerate the expansion of the universe. In order to give a holographic model of the remnant energy in the universe, similarly, we must find a suitable IR cut-off that can give the correct equation of the state for these remnant energy, we can find that the particle horizon is also an inevitable choice.

It is well known that the early universe is radiation-dominanted, and the energy coming from spatial curvature decays slower than those from radiation and matter when the universe is expanding, which can be seen from Eq.(4), so the index $\omega$ of the EOS of the general energy density $\rho_{KMR}$, which denotes the energy $E_{KMR}$ density coming from spatial curvature, matter and radiation, must evolve from $\frac{1}{3}$ in the early time of the universe to $-\frac{1}{3}$ when the universe is dark-energy-dominanted. Similar to using the event horizon for the IR cut-off in the holographic dark energy model, we then investigate the particle horizon for the IR cut-off in the holographic dark energy model, we denote the new holographic energy density got by this way as $\rho_p$, we find that the index $\omega$ of the deduced EOS of $\rho_p$ shows the expected behavior as that for $\rho_{KMR}$, and the magnitude of $\rho_p$ also matches experimental data well, and we have the conclusion that $E_{KMR}$ can be obtained by using the particle horizon for the IR cut-off, and then we have established the holographic $E_{KMR}$ model.

Furthermore, we study the consistency between the two holographic energy models. We show that the both holographic models have consistent requirements for the parameter $C$, and in the both models the relative correspondences between the energy and the horizon naturally shows their consistency. This consistency implies that the holographic description of the energy is on the correct way to describe the universe. Motivating by this point of view, we propose the holographic description of the universe. According to this description, a closed accelerated physical universe is holographic and made up by two holographic components: the holographic dark energy and the holographic $E_{KMR}$, the evolution of the universe depends on the evolution of the two components. The novel natures of this paper are not only that we first suggest a holographic energy model, in which the energy coming from spatial curvature, matter and radiation can be obtained by using the particle horizon for the infrared cut-off, but also that a holographic description of the universe is obtained, according to the description, there must be both the holographic dark energy and the holographic $E_{KMR}$ in the universe with the particle horizon and the event horizon according to the holographic description of the universe, so we argue the de Sitter universe, which has both the two horizons can not exist as a real physical universe but be a good approximation for the real physical universe during dark energy dominated era since the $E_{KMR}$ decays so fast.

We want to highlight that different components of the observed energy density are associated with different holographic screens. The dark energy is associated with one screen (the event horizon) which is presented in Eq.(11) while the remnant energy densities are associated with another screen
(the particle horizon) given in Eq. (19) seriously in this paper. It needs to be pointed out that, in
general, FRW universe models don’t have simultaneously a particle horizon and a event horizon,
they may have one or other but not both at the same time. There is no future event horizon in
the decelerated universe, there is also no particle horizon in the accelerated universe. However, the
particle horizon can always be found in any universe once we take a short cutoff in the definition.
Furthermore, the percentage of the $\rho_{KMR}$ in the total energy density $\rho_t$ is decreasing while the
expansion of the universe is proceeding, and the $\rho_{KMR}$-dominated epoch is turning to the dark-
energy-dominated epoch, which denotes our universe changes from decelerating to accelerating,
thus, in this picture, the universe have the both horizons at the same time.

For a lot of further investigations, it is valuable to investigate, e.g., the all relative investigations
about the holographic $E_{KMR}$, which are similar to those about the holographic dark energy in
different models, and so on.

[1] A. G. Cohen, D. B. Kaplan and A. E. Nelson, Phys. Rev. Lett., 82 (1999) 4971.
[2] M. Li, Phys. Lett., B 603 (2004) 1.
[3] Q. G. Huang and M. Li, JCAP, 08 (2004) 013.
[4] R. Horvatic, Phys. Rev., D70 (2004) 087301
[5] Y. Gong, Phys. Rev., D70 (2004) 064029
[6] D. Pavon and W. Zimdahl, Phys. Lett., B 628 (2005) 206
[7] J. C. Hua and Y. C. Huang, Europhysics Letters, 85 (2009) 30007
[8] Y. C. Huang, R. X. Xu and X. H. Meng, Modern Astrophysics and Cosmology, Science Press, New
York, in press.
[9] G. ’t Hooft, gr-qc/9321026, published in Salam- festschrift: a collection of talks, eds. A. Ali, J. Ellis
and S. Randjbar-Daemi (World Scientific, 1993)
[10] L. Susskind, J. Math. Phys. 36 (1995) 6377
[11] R. Bousso, Rev. Mod. Phys. 74 (2002) 825
[12] C. L. Bennett et al, Astrophys. J. Suppl., 148 (2003) 1
[13] M. Tegmark et al, Phys. Rev., D69 (2004) 103501
[14] A. G. Riess et al., Astrophys. J., 607 (2004) 665
[15] S. D. H. Hsu, Phys. Lett. B 594 (2004) 13
[16] Y. C. Huang, X. G. Lee and M. X. Shao. Mod. Phys. Lett., A21(2006) 1107; Y. C. Huang and Q. H.
Huo, Physics Letters B, 662(2008) 290.
[17] Y. C. Huang, C. X. Yu, Phys. Rev. D 75, 044011 (2007); L. Liao and Y. C. Huang, Ann. Phys. (N.
Y.), 322 (2007) 2469; Y. C. Huang, L. Liao and X. G. Lee, European Physical Journal C, 60(2009)
481.
[18] Y. C. Huang and B. L. Lin, Phys. Lett., A299 (2002) 644.