Physical Science International Journal
5(4): 267-275, 2015, Article no.PSIJ.2015.027
ISSN: 2348-0130

SCIENCEDOMAIN *international*
www.sciencedomain.org

SCIENCEDOMAIN

A Natural Solution to the Dark Energy Problem

Man Ho Chan[1*]

[1] *Department of Physics, The Chinese University of Hong Kong, Shatin, Hong Kong, P.R. China.*

Article Information
DOI: 10.9734/PSIJ/2015/14201
Editor(s):
(1) Roberto Oscar Aquilano, Department of Science and Technology, School of Exact Science, National University of Rosario (UNR), Argentina.
(2) David F. Mota, Institute of Theoretical Astrophysics, University of Oslo, Norway.
Reviewers:
(1) Salahe Eddine Ennadifi, Department of Physics, Laboratory of High Energy Physics, Mohammed V University, Morocco.
(2) Anonymous, South Korea.
(3) Anonymous, India.
(4) Anonymous, Italy.
(5) Anonymous, Venezuela.
(6) Anonymous, Canada.
Complete Peer review History:
http://www.sciencedomain.org/review-history.php?iid=835id=33aid=7740

Original Research Article

Received: 23 September 2014
Accepted: 18 November 2014
Published: 10 January 2015

Abstract

Recent observations indicate that the acceleration of our universe expansion is slowing down, which challenge the standard ΛCDM model. In this article, we show that the existence of particles with imaginary energy density can explain the observed slowing down acceleration and provide a complete solution to the origin of dark energy. This model can give good agreements with observational constraints by 28 data from supernovae between redshift $z = 0.07 - 2.3$.

Keywords: Dark energy; cosmology; tachyons; general relativity; supernavoe.

1 Introduction

The ΛCDM model is the most robust scenario to describe the evolution of our universe. The existence of dark energy or cosmological constant provides the acceleration of universe expansion which is

**Corresponding author: E-mail: mhchan@phy.cuhk.edu.hk*

confirmed by the data from supernovae [1,2]. This model can also sucessfully explain the large-scale structure of the universe and the flatness of the universe that revealed from the Cosmic Microwave Background (CMB) [3,4].

However, some recent observations begin to challenge this standard model in cosmology [5,6]. For example, the current value of the cosmological constant is so small, which is 120 orders of magnitude smaller than the theoretical anticipated value. Also, we are so surprised that the dark energy is just starting to dominate the total energy density. These two problems are known as the Fine Tuning Problem and the Coincidence Problem respectively [7]. Although some tiny modifications such as the quintessence model and the modified gravity model may help to alleviate the problem, the complexity of the required models is further increased. Moreover, the ΛCDM model predicts that the deceleration parameter should approach to a constant ($q \approx -0.55$) while recent observations from supernovae indicate that the acceleration of expansion of our universe is decreasing [8-11]. For example, numerical calculations from SNIa data obtain $q = -0.38 \pm 0.05$ [12], and recently $q = -0.2086^{+0.0374}_{-0.0380}$ [13]. Some calculations even obtain a positive deceleration parameter [14,6]. All the above problems indicate that the ΛCDM model may not be the ultimate model to describe our universe.

Furthermore, the origin of the dark energy is still unknown. The acceleration of universe expansion may be driven by some unknown scalar fields (see [15] for a review), effect from higher dimensions [16] or some other recent proposed models [17-29]. In particular, the existence of Tachyonic field is one of the popular models to explain the origin of dark energy [30-40]. The existence of tachyon is first derived from quantum field theory. Generally speaking, tachyon is a hypothetical particle that always moves faster than the speed of light. Although this kind of particles can never be directly discovered, they can be inferred indirectly from observations. For example, some works have already shown that neutrino can be a tachyon [41-43]. Many theoretical works show that tachyonic particles could be stable for a long period of time [44-46]. The energy of a tachyon with rest mass m is given by $E = \gamma mc^2$, where γ is the Lorentz factor. Since a tachyonic particle travels faster than light, γ would be an imaginary number. Traditional theory of tachyon suggests that m is also an imaginary number so that the energy E would be real to observe [47]. However, it is also possible that m is a real number so that E is an imaginary number [48,49]. In this article, I suggest that if there exists some tachyons with imaginary value of energy, the evolution of our universe might be affected. In the following sections, I show that the existence of tachyons in our universe can naturally explain the acceleration of universe expansion. If the energy density of tachyons is a complex number, the spatial dimensions would also be a complex number so that the Friedmann equation is self-consistent [49]. If the real part of the spatial dimensions is our observable universe, it can be shown that the evolution of the imaginary part of the spatial dimensions could affect the real universe and contribute to a dark energy term in the evolution. I also show that the new tachyonic Friedmann equation can satisfy current observations from 28 supernovae data and explain the slowing down acceleration in the universe expansion.

Although there are plenty of theoretical researches showing that the tachyonic field can explain the origin of dark energy, most of the models depend strongly on the arbitariness of the tachyonic potential functions [5]. In our model, we do not require any tachyonic potential functions to explain the origin of dark energy.

2 The Tachyonic Friedmann Equations

The original Friedmann equation without cosmological constant in a flat universe is given by

$$\dot{a}^2 = \frac{8\pi G}{3} \left(\rho_m + \rho_r\right) a^2, \tag{2.1}$$

where a is the cosmic scale factor, ρ_m and ρ_r are the energy density of matter and radiation respectively. In the following discussion, we neglect the radiation term for simplicity because it would not have a significant effect on the late time of universe expansion. If the total matter energy density includes tachyonic particles with imaginary value of energy density, we can write $\rho_m = \rho_n + \rho_t i$, where ρ_n and ρ_t are the energy density of normal matter and imaginary part of the energy density of tachyonic matter respectively. Since the right hand side of the Friedmann equation is a complex number, the only way for it to be consistent is that the cosmic scale factor is also a complex number, which is given by $a = a_r + a_i i$. In fact, the no-boundary proposal in pre-Big Bang theory suggests the possibility of the imaginary value of time [50]. If this is true, it is also possible that the spatial dimensions are also complex. This complexified cosmology has been discussed by many papers recently [51-53].

The evolution of the energy density is controlled by the fluid equation, which is given by

$$\frac{d}{dt}(a^3\rho) = -\frac{P}{c^2}\frac{d(a^3)}{dt}, \tag{2.2}$$

where ρ and P are the density and pressure due to every component of the universe. Since $P \approx 0$ for normal matter (including dark matter), we get $\rho_n = \rho_{n0}a^{-3}$, where ρ_{n0} is the present energy density of normal matter. For tachyonic matter, although the 'pressure' may be unphysical in nature, the pressure term serves an effect of gravity in the Friedmann equation. From statistical mechanics, the pressure would be $P = \rho_t/3$ if the speed of the tachyonic particles is just exceeding the speed of light (ultra-relativistic regime). Therefore, Eq. (2) gives $\rho_t = \rho_{t0}a^{-4}$, where ρ_{t0} is the imaginary part of the present energy density of tachyonic matter.

By writing $y = \rho_{t0}/\rho_{n0}$, $\Omega_{t0} = \rho_{t0}/\rho_{re}$, $\Omega_{n0} = \rho_{n0}/\rho_{re}$, $x = a_i/a_r$, and using Eq. (1), we can get

$$\dot{a}_r = \sqrt{\frac{4\pi G\rho_{re}}{3}\Omega_{n0}a_r^{-1}\left(f(x,y) + \sqrt{[f(x,y)]^2 + [g(x,y)]^2}\right)}, \tag{2.3}$$

where

$$f(x,y) = \frac{1}{1+x^2} + \frac{2xy}{a_r(1+x^2)^2} \tag{2.4}$$

and

$$g(x,y) = \frac{x}{1+x^2} + \frac{y(1-x^2)}{a_r(1+x^2)^2}. \tag{2.5}$$

Here, we call ρ_{re} the reference density, which determines the value of Hubble constant. Also, we have the evolution of the imaginary part:

$$\dot{a}_i = \frac{4\pi G\Omega_{n0}\rho_{re}}{3\dot{a}_r a_r}\left[\frac{-x}{1+x^2} + \frac{y(1-x^2)}{a_r(1+x^2)^2}\right]. \tag{2.6}$$

By differentiating Eq. (1) and combining with Eq. (2), the acceleration equation is given by

$$\ddot{a}_r = -\frac{4\pi G\Omega_{m0}\rho_{re}}{3a_r^2}\left[\frac{1-x^2}{(1+x^2)^2} + \frac{2y(3x-x^3)}{a_r(x^6+3x^4+3x^2+1)}\right]. \tag{2.7}$$

Assuming $a_r = 0$ initially and $a_r = 1$ at present, the only free parameters in this model are Ω_{t0}, Ω_{m0} and the initial a_i. The reference density ρ_{re} can be calculated from these free parameters when the model is compared with observational data.

3 Comparing the Results with Observations

There are a few constraints we need to satisfy. They are the Hubble constant as a function of redshift $H(z)$, the deceleration parameter $q = -a_r\ddot{a}_r/\dot{a}_r$ and the minimum age of universe t_0. In particular, we do not compare with the data obtained from CMB because the spectrum calculated is highly dependent on the form of the Friedmann equation. Therefore, in this section, we mainly compare the results with observations from the data of supernovae.

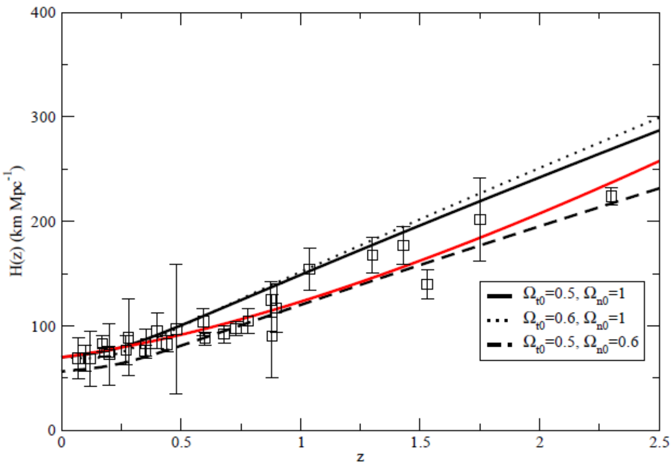

Figure 1: Our model (black lines) is fitted with $H(z)$ data [54]. We set $a_i(t=0)=-1$ in all fits. The ΛCDM model with $\Omega_m=0.3$ and $\Omega_\Lambda=0.7$ is shown in red line.

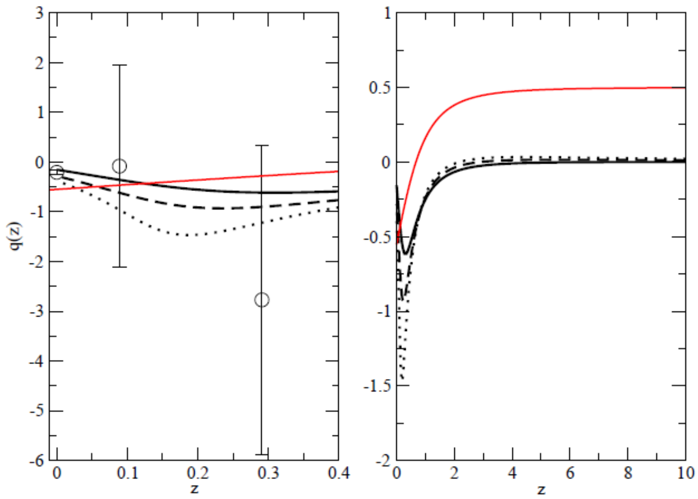

Figure 2: Left: Our model (black lines) is fitted with the $q(z)$ data for $0\le z\le 0.4$ [55,13]. Right: $q(z)$ vs z for $0\le z\le 10$ in our model. We set $\Omega_{n0}=1$ and $a_i=-1$ in all fits. Different lines in both figures correspond to $\Omega_{t0}=0.5$ (solid line), $\Omega_{t0}=0.6$ (dashed line) and $\Omega_{t0}=0.7$ (dotted line). The ΛCDM model with $\Omega_m=0.3$ and $\Omega_\Lambda=0.7$ is shown in red line.

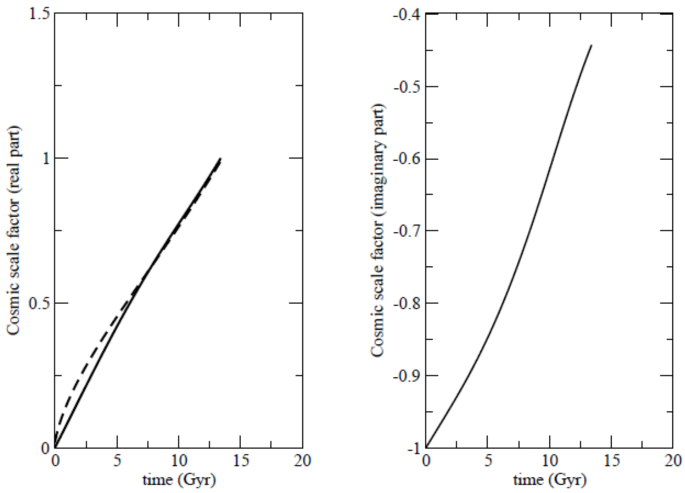

Figure 3: The time evolution of a_r and a_i in our model. The solid line and dashed line represent our model ($\Omega_{t0} = 0.5$, $\Omega_{n0} = 1$, $a_i = -1$) and the ΛCDM model respectively ($\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$).

In Fig. 1 and Fig. 2, we fit our model with 28 observational data from supernovae. We find that our model gives good agreements with both $H(z)$ data for $z \leq 2.5$ [54] and $q(z)$ data for $z \leq 0.4$ [55,13] (high-redshift data for deceleration parameter are not reliable). Moreover, we find that the initial a_i must be a negative value if Ω_{t0} is positive. Otherwise, no acceleration of the universe would be resulted. For the ΛCDM model, it generally agrees with the $H(z)$ data. However, it does not match the present deceleration parameter, which indicates a slowing down acceleration.

In Fig. 3, we plot the real and imaginary parts of the cosmic scale factor as a function of time. For $\Omega_{t0} = 0.5$, $\Omega_{n0} = 1$ and initial $a_i = -1$, the age of universe obtained in our model is about 13.4 Gyr, which is very closed to that predicted by CMB (13.7 Gyr). Nevertheless, it is still compatible with the minimum age of universe estimated from the ages of the oldest star HE 1523-0901, which is $(13.4 \pm 0.8 \pm 1.8)$ Gyr [56]. Besides, the reference density is $\rho_{re} \approx 1.7 \times 10^{-29}$ g cm^{-3}, which is about twice the critical density in the ΛCDM model. In fact, the difference of the evolution between our model and the ΛCDM model is very small except for high redshift ($z \geq 3$). Therefore, observations from high redshift quasars may be able to further identify which model is better.

4 Discussion

The claim of having tachyons with imaginary value of energy density in this model is very controversial. We have no promising experimental evidence for the existence of tachyon and the matter with imaginary energy density. This assumption is only speculative but not yet confirmed. However, the origin of dark energy and dark energy pressure in the ΛCDM model is also a mystery in standard physics. Strictly speaking, both models possess similar simplicity. The ΛCDM model requires the existence of positive dark energy and negative dark energy pressure while our model assumes the existence of imaginary value of energy density and pressure. Moreover, both models can generate an acceleration of universe expansion and give good agreements with $H(z)$ data from supernovae.

However, recent observations from supernovae indicate that the acceleration of universe expansion is slowing down. Our model sucessfully predicts this phenomenon while the ΛCDM model predicts that a constant deceleration parameter should be approaching. Although there are some solutions suggested such as assuming a time-dependent cosmological constant or redshift-dependent equation of state of dark energy to reconcile the tension [6], these assumptions simultaneously increase the complexity of the model. Also, we need to explain the origin of the time-dependent variation. In our model, the acceleration of our universe is slowing down because a_i is a restoring function which finally gives $x = 0$ in a long run. By Eq. (7), we can see that our universe will enter to the deceleration regime again when x becomes very small.

Furthermore, both models obtain the same order of magnitude of energy density ratios ($\rho_{t0}/\rho_{n0} \approx 0.5$ and $\rho_\Lambda/\rho_m \approx 2.3$) at present. However, we have $\rho_{t0}/\rho_{n0} \approx 500$ and $\rho_\Lambda/\rho_m \approx 10^{-9}$ at $z = 1000$. The extremely small ρ_Λ/ρ_m at high redshift suggests that the ΛCDM model requires serious fine-tuning at high redshift and thus suffers much more from the Coincidence Problem. Therefore, based on the above facts, it can be concluded that our model is better than the ΛCDM model to describe our universe.

We haven't tested our model with the CMB spectrum because the CMB calculations are dependent on the form of the Friedmann equation. This can be done if the standard Friedmann equation in the spectrum calculation is fully replaced by our equations in this model. Further verification and investigation by using the CMB data including empirical fits with the free parameters in this model are needed.

In this model, we assume that the scale factor is a complex number in order to make the Friedmann equation consistent. In principle, the Einstein equation, the matter-energy tensor and line element in General Relativity would also be complex. However, in this model, we assume that only the real part of the scale factor a_r describes our observable universe. This assumption can be justified by the following example. Consider the line element $ds^2 = c^2dt^2 - a^2(dx^2 + dy^2 + dz^2)$, where a is a complex number. Suppose $dt = dy = dz = 0$, we have $ds = adx$. Since the lengths (ds and dx) observed are real, the observed scale factor a should be the real part a_r. Therefore, although the line element $ds^2 = dt^2 - a^2(dx^2 + dy^2 + dz^2)$ is complex in our model, the observed line element should be $ds^2 = dt^2 - a_r^2(dx^2 + dy^2 + dz^2)$. Thus, the complex scale factor would not affect the observed real physical quantities because they depend on the real part of the scale factor only.

Moreover, as mentioned above, only real values are observable and the energy of tachyons is purely imaginary. Therefore we cannot directly observe the tachyons and the violation of causality. Also, most probably there is no direct interaction between the dark energy and the ordinary matter except the global effect from General Relativity. Therefore, we believe that there is also no direct interaction between the tachyonic matter and ordinary matter, and clearly no violation of causality can be seen.

5 Conclusion

The dark energy term can be obtained naturally if there exists some matter containing imaginary energy density. This result also agrees with the recent observations of the slowing down acceleration of our universe expansion and the Hubble constant $H(z)$ from 28 supernovae data. This model can be tested in the future by using the data from Cosmic Microwave Background (CMB) if the model is incorporated into the CMB spectrum calculations.

Competing Interests

The author declares that no competing interests exist.

References

[1] Riess AG, et al. [Supernova Search Team Collaboration], Observational evidence from supernovae for an accelerating universe and a cosmological constant, Astron. J. 1998;116:1009.

[2] Perlmutter S, et al. [Supernova Cosmology Project Collaboration], Measurement of Ω and Λ from 42 high-redshift supernavoe, Astrophys. J. 1999;517:565.

[3] Eisenstein DJ, et al. [SDSS Collaboration], Detection of the baryon acoustic peak in the large-scale correlation function of sdss luminous red galaxies, Astrophys. J. 2005; 633:560.

[4] Ade PAR, et al. [Planck Collaboration], Planck 2013 results. I. Overview of products and scientific results, arXiv:1303.5062; 2013.

[5] Keresztes Z, Gergely LA, Kamenshchik AY, Gorini V, Polarski D. Will the tachyonic universe survive the big brake? Phys. Rev. D 82, 123534; 2010.

[6] Lin J, Wu P, Yu H. Re-examining the role of curvature in the slowing down acceleration scenario, Phy. Rev. D 87, 043502; 2013.

[7] Perivolaropoulos L. Six Puzzles for LCDM Cosmology, arXiv:0811.4684; 2008.

[8] Shafieloo A, Sahni V, Starobinsky AA. Is cosmic acceleration slowing down? Phys. Rev. D 80, 101301; 2009.

[9] Guimarães ACC, Lima JAS. Could the cosmic acceleration be transient? A cosmographic evaluation, Class. Quanum Grav. 28, 125026; 2011.

[10] Li Z, Wu P, Yu H. Examining the cosmic acceleration with the latest Union2 supernova data, Phys. Lett. B 695, 2011;1.

[11] Cardenas VH, Bernal C, Bonilla A. Cosmic slowing down of acceleration using f_{gas}, arXiv:1306.0779; 2013.

[12] Kumar S. Observational constraints on Hubble constant and deceleration parameter in power-law cosmology, Mon. Not. R. Astron. Soc. 2012;422:2532.

[13] Rani S, Altaibayeva A, Shahalam M, Singh JK, Myrzakulov R. Constraints on cosmological parameters in power-law cosmology, arXiv:1404.6522; 2014.

[14] Wu P,Yu H. Is the present cosmic expansion decelerating? arXiv:1012.3032; 2010.

[15] Copeland EJ, Sami M, Tsujikawa S. Dynamics of Dark Energy, Int. J. Mod. Phys. 2006;D 15,1753.

[16] El-Nabulsi AR. Dark energy in five-dimensional Brans-Dicke cosmology with dimentsional reduction, Research in Astron. Astrophy. 2011;11:888.

[17] El-Nabulsi AR. Accelerated expansion from a modified-quadratic gravity, Astrophys. Space Sci. 2010;332:491.

[18] Bhatt JR, Desai BR, Ma E, Rajasekaran G, Sarkar U. Neutrino condensate as origin of dark energy, Phys. Lett. 2010;B 687, 75.

[19] El-Nabulsi AR. A modified gravity theory with time-dependent exponent, Eur. Phys. J. Plus. 2011;126:114.

[20] Hajdukovic DS. Quantum Vacuum and Virtual Gravitational Dipoles: The solution to the Dark Energy Problem? arXiv: 2012;1201.4594.

[21] El-Nabulsi AR. Some late-time cosmological aspects of a Gauss-Bonnet gravity with nonminimal coupling a la Brans-Dicke: solutions and perspectives, Canadian Journal of Physics. 2013;91:300.

[22] El-Nabulsi AR. Crossing the phantom divide line from a generalized time-dependent Hubble parameter and its dynamical evolution a la Riccati, Canadian Journal of Physics. 2013;91:623.

[23] Pani P, Sotiriou TP, Vernieri D. Gravity with auxiliary fields, Phys. Rev. 2013;D 88,121502.

[24] Kaloper N, Padilla A. Sequestering the Standard Model Vacuum Energy, Phys. Rev. Lett. 2014;112; 091304.

[25] Burdyuzha V. Testing of Dark Energy and a Solution of the Cosmological Constant Problem, arXiv:1401.4686; 2014.

[26] Rinaldi M. Through the looking GLASS: HST spectroscopy of faint galaxies lensed by the Frontier Fields cluster MACS0717.5+3745, arXiv:1404.0532; 2014.

[27] Davis TM. Cosmological constraints on dark energy, arXiv:1404.7266; 2014.

[28] Smoot GF. See Saw Inflation/Dark Matter/Dark Energy/Baryogenesis, arXiv:1405.2776; 2014.

[29] Ayaita Y, Baldi M, Führer F, Puchwein E, Wetterich C. Nonlinear growing neutrino cosmology, arXiv:1407.8414; 2014.

[30] Hao J, Li X. Reconstructing the equation of state of the tachyon, Phys. Rev. D 66, 087301; 2002.

[31] Bagla JS, Jassal HK, Padmanabhan T. Cosmology with tachyon field as dark energy, Phys. Rev. D 67, 063504; 2003.

[32] Copeland EJ, Garousi MR, Sami M, Tsujikawa S. What is needded of a tachyon if it is to be the dark energy? Phys. Rev. D 71, 043003; 2005.

[33] Calcagni G, and Liddle AR, Tachyon dark energy models: Dynamics and constraints, Phys. Rev. D 74, 043528; 2006.

[34] Setare MR, Sadeghi J, Amani AR. Interacting tachyon dark energy in non-flat universe, Phys. Lett. B 673, 241; 2009.

[35] El-Nabulsi RA. Exact solution of a tachyon oscillating cosmology with a supergravity tracking potential, Eur. Phys. J. Plus. 2013;128:55.

[36] Chen X, Gong Y. The limit on w' for tachyon dark energy, arXiv:1309.2044;2013.

[37] Sadeghi J, Khurshudyan M, Hakobyan M, Farahani H. Mutually interacting Tachyon dark energy with variable G and $Lambda$, arXiv:1309.7496; 2013.

[38] Smolyaninov II. Metamaterial Model of Tachyonic Dark Energy, Galaxies. 2014;2:72.

[39] Aghamohammadi A. Resembling holographic dark energy with f(R) gravity as scalar field and ghost dark energy with tachyon scalar fields, arXiv:1401.4453; 2014.

[40] Keresztes Z, Gergely LA. Combined cosmological tests of a bivalent tachyonic dark energy scalar field model, arXiv:1408.3736; 2014.

[41] Chodos A, Hauser AI, Kostelecký VA. The neutrino as a tachyon, Phys. Lett. B 150, 431; 1985.

[42] R. Ehrlich, Tachyonic neutrinos and the neutrino masses, Astroparticle Phys. 2013;41:1.

[43] Ehrlich R. Possible evidence for a 5.86 PeV cosmic ray enhancement, arXiv:1307.3944; 2013.

[44] Li JL, Wu JP. Dynamics of tachyon field in spatially curved FRW universe, Phys. Lett. B 686, 221; 2010.

[45] Bros J, Epstein H, Moschella U. Scalar Tachyons in the de Sitter Universe, Letters in Mathematical Physics. 2010;93:203.

[46] Konoplya RA. Superluminal neutrinos and the tachyon's stability in the rotating Universe, Phys. Lett. B 706, 451; 2012.

[47] Pecina-Cruz JN. The Imaginary Mass of the Neutrino, physics/0604003; 2006.

[48] Trojan E. Tachyonic Dirac sea, hep-ph/1201.6560; 2012.

[49] Jentschura UD, Wundt BJ. ISRN High Energy Physics. 2013; 374612.

[50] J. B. Hartle, and S. W. Hawking, Wave function of the Universe, Phys. Rev. D 28, 2960; 1983.

[51] R. Erdem, A symmetry for vanishing cosmological constant in an extra-dimensional toy model, Phys. Lett. B 621, 11; 2005.

[52] Ma DZ, Wu X, Zhong SY. Effects of the cosmological constant on chaos in an FRW scalar field universe, Res. Astron. Astrophys. 9, 1185; 2009.

[53] Barvinsky AO, Kamenshchik AY. Selection rules for the Wheeler-DeWitt equation in quantum cosmology, Phys. Rev. D 89, 043526; 2014.

[54] Farooq O, Ratra B. Hubble Parameter Measurement Constraints on the Cosmological Deceleration-Acceleration Transition Redshift, Astrophys. J. 766, L7; 2013.

[55] Cai R, Tuo Z. Detecting the cosmic acceleration with current data, Phys. Lett. B 706, 116; 2011.

[56] M. Roos, Chaplygain gas in decelerating DGP gravity and the age of the oldest star, Phys. Lett. B 666, 420; 2008.

©2015 Chan; This is an Open Access article distributed under the terms of the Creative Commons Attribution License http://creativecommons.org/licenses/by/4.0, which permits unrestricted use, distribution, and reprod-uction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here (Please copy paste the total link in your browser address bar)
www.sciencedomain.org/review-history.php?iid=835&id=33&aid=7740