East European Journal of Physics. **3.** 97-103 (2022)
DOI:10.26565/2312-4334-2022-3-13 ISSN 2312-4334

BIANCHI TYPE V TSALLIS HOLOGRAPHIC DARK ENERGY MODEL WITH HYBRID EXPANSION LAW[†]

Manash Pratim Das*, Chandra Rekha Mahanta
Department of Mathematics, Gauhati University, Guwahati (India)
**Corresponding Author: manashpratimdas22222@gmail.com, crmahanta@gauhati.ac.in*
Received July 25, 2022; revised August 23, 2022; accepted August 25, 2022

A number of recent cosmological observations have provided increasing evidence that currently the universe is undergoing a phase of accelerated expansion, the root cause of which is supposed to be due to an exotic component of the universe with large negative pressure, dubbed dark energy. Out of the various candidates of dark energy proposed in the literature, the holographic dark energy emerged from the Holographic Principle is drawing much attention in the research field. In this paper, we investigate a spatially homogeneous and anisotropic Bianchi Type V space-time filled with non-interacting Tsallis holographic dark energy (THDE) with Hubble horizon as the IR cutoff and pressureless cold dark matter within the framework of General Relativity. Exact solutions of the Einstein field equations are obtained by considering the average scale factor a to be a combination of a power law and an exponential law, the so called hybrid expansion law first proposed by Akarsu *et al*. (2014). We study the cosmological dynamics of various models for different values of the non-additive parameter δ that appeared in the Tsallis entropy and that for ξ that appeared in the exponential function of the hybrid expansion law. We find that our model exhibits present cosmological scenario.
Keywords: Tsallis Holographic Dark Energy, Bianchi Type V, Hybrid Expansion Law, Accelerated expansion
PACS: 98.80.jk, 04.20.jb

The powerful astrophysical observations such as Supernovae Type Ia [1-3], Cosmic Microwave Background [4, 5], Large Scale Structure [6]etc. strongly indicate that the present rate of cosmic expansion is accelerating. As till late 1990's it was believed that the expansion of the universe is decelerating, so the results from the above experiments made the cosmologists to think in a different way. The reason behind this mysterious acceleration is yet unknown, so universally it is accepted that the universe is dominated by a strange kind of energy fluid, dubbed dark energy, which occupies nearly 68.3% of the total content of the universe. Till then the cosmologists are trying to find the true nature of dark energy as well as the root cause of the observed cosmic acceleration. The simplest candidate which satisfies all the conditions for accelerating the expansion rate of the universe and which acts opposite to gravity is the cosmological constant Λ that Einstein introduced in his field equations. Theoretically, the cosmological constant is supposed to be $\Lambda = 8\pi G\rho_{vac}$. But the calculated value of ρ_{vac} is much larger than the value of Λ determined from observations, and therefore due to its non-evolving nature it faces the fine-tuning and cosmic coincidence problems and hence some alternative approaches have been adopted. Since then, a number of dark energy candidates have been considered in the literature to explain the late time acceleration of the universe. Among them quintessence [7], phantom [8], k-essence [9], tachyon [10], dilatonic ghost condensate model [11], Chaplygin gas models [12], braneworld models [13] etc. are the most studied candidates of dark energy.

Holographic dark energy model is another possible candidate which emerges from the famous holographic principle proposed to explain the thermodynamics of black hole physics. According to the holographic principle the number of degrees of freedom directly related to entropy of a physical system scales with the enclosing surface area of the system rather than with its volume [14]. Fischler and Susskind [15] later extended this principle to the cosmological setting with a new versionwhich states that the gravitational entropy within a closed surface should not be always larger than the particle entropy that passes through the past light-cone of that surface. Later several researchers proposed different IR cutoff which led to some new problems in physics. Tsallis and Cirto in 2013 put forwarded a new model of holographic dark energy known as Tsallis Holographic dark energy (THDE) model by using Tsallis generalized entropy, $S_\delta = \gamma A^\delta$, where γ is an unknown constant and δ is a non-additive parameter [16]. Thus, the energy density of the Tsallis holographic dark energy can be obtained as $\rho_{THDE} = DL^{2\delta-4}$, where D is an unknown parameter [17]. If the Hubble horizon is used as the IR cutoff i.e. $L = \frac{1}{H}$, then the energy density of the THDE is obtained as $\rho_{THDE} = DL^{-2\delta+4}$. In literature several researchers (Ghaffari*et al*. 2018 [18], Korunur 2019 [19], Sharma and Pradhan 2019 [20], Dubey *et al.* 2020 [21], Liu 2021 [22], Mohammadi *et al*. 2021 [23], Pandey *et al.* 2022 [24], Kumar *et al*; 2022 [25]). have studied different aspects of Tsallis Holographic dark energy.

In this paper, we study the spatially homogeneous and anisotropic Bianchi Type V space-time filled with non-interacting Tsallis holographic dark energy (THDE) and cold dark matter. The paper is organized as follows: in Sect. **"METRIC AND FIELD EQUATIONS"**, we derive the cosmic evolution equations from the Einstein field equations in the background of Bianchi Type V line element. We solve the field equations in Sect. **"COSMOLOGICAL SOLUTIONS OF THE FILED EQUATIONS"** by considering the hybrid expansion law proposed by Akarsu *et al* (2014) [26]. In

[†]*Cite as:* M.P. Das, and C.R. Mahanta, East Eur. J. Phys. **3**, 97 (2022), https://doi.org/10.26565/2312-4334-2022-3-13

Sect. **"RESULTS AND DISCUSSION"** we study cosmological dynamics of our model for $\delta = 1$, $1 < \delta < 2$ and for $\delta = 2$. Finally, we conclude the paper in Sect. **"CONCLUSION"** with a brief discussion.

METRIC AND FIELD EQUATIONS

We consider the spatially homogeneous and anisotropic Bianchi Type V space-time characterized by the line element

$$ds^2 = -dt^2 + A^2dx^2 + e^{2mx}(B^2dy^2 + C^2dz^2) \tag{1}$$

where *A*, *B*, *C* are functions of cosmic time *t* only and *m* is a constant.

We assume that the universe is filled with cold dark matter and non-interacting Tsallis holographic dark energy (THDE) with energy-momentum tensors T_{ij} and $\bar{T}_{ij}$resepectively

$$T_{ij} = \rho_m u_i u_j \tag{2}$$

$$\bar{T}_{ij} = (\rho_{THDE} + p_{THDE})u_i u_j + g_{ij}p_{THDE} \tag{3}$$

where ρ_{THDE} and p_{THDE} are the energy density and the pressure of the THDE respectively.

Einstein's field equations in natural units ($8\pi G = 1, c = 1$) are given by

$$R_{ij} - \frac{1}{2}g_{ij}R = -(T_{ij} + \bar{T}_{ij}) \tag{4}$$

where R_{ij} is the Ricci tensor, $R$is the Ricci scalar and$g_{ij}$is the metric tensor.

The THDE density with Hubble horizon as the IR cutoff is

$$\rho_{THDE} = DH^{-2\delta+4} \tag{5}$$

where D is an unknown parameter.

For $\delta = 1$, the THDE density becomes the usual holographic dark energy density. For $\delta = 2$, ρ_{THDE} =constant, i.e., the dark energy behaves like cosmological constant.

Now, in comoving coordinate system the equations (4) with (2) and (3) for the metric (1) lead to the following system of field equations:

$$\frac{\ddot{B}}{B} + \frac{\ddot{C}}{C} + \frac{\dot{B}\dot{C}}{BC} - \frac{m^2}{A^2} = -p_{THDE} \tag{6}$$

$$\frac{\ddot{C}}{C} + \frac{\ddot{A}}{A} + \frac{\dot{C}\dot{A}}{CA} - \frac{m^2}{A^2} = -p_{THDE} \tag{7}$$

$$\frac{\ddot{A}}{A} + \frac{\ddot{B}}{B} + \frac{\dot{A}\dot{B}}{AB} - \frac{m^2}{A^2} = -p_{THDE} \tag{8}$$

$$\frac{\dot{A}\dot{B}}{AB} + \frac{\dot{B}\dot{C}}{BC} + \frac{\dot{C}\dot{A}}{CA} - \frac{3m^2}{A^2} = \rho_m + \rho_{THDE} \tag{9}$$

$$2\frac{\dot{A}}{A} - \frac{\dot{B}}{B} - \frac{\dot{C}}{C} = 0 \tag{10}$$

where an over dot denotes differentiation with respect to cosmic time t.

From equation (10), integrating and suppressing the constant of integration, we get

$$A^2 = BC \tag{11}$$

The conservation of energy-momentum yields

$$\dot{\rho}_m + \dot{\rho}_{THDE} + 3H(\rho_m + \rho_{THDE} + p_{THDE}) = 0 \tag{12}$$

But the continuity equation for the cold dark matter is

$$\dot{\rho}_m + 3H\rho_m = 0 \tag{13}$$

And the continuity equation of the THDE is

$$\dot{\rho}_{THDE} + 3H(\rho_{THDE} + p_{THDE}) = 0 \tag{14}$$

The equation of state parameter for THDE is

$$\omega_{THDE} = \frac{p_{THDE}}{\rho_{THDE}} \tag{15}$$

Therefore, from (5), (14) and (15), we have

$$\omega_{THDE} = -1 - (-2\delta + 4)\frac{\dot{H}}{3H^2} \tag{16}$$

COSMOLOGICAL SOLUTIONS OF THE FILED EQUATIONS

From equations (6) - (9), we derive

$$B(t) = M_1 a \exp\left(N \int a^{-3} dt\right) \tag{17}$$

$$C(t) = M_2 a \exp\left(-N \int a^{-3} dt\right) \tag{18}$$

where M_1, M_2 and N are relevant constants used in the derivation and $a = (ABC)^{\frac{1}{3}}$ is the average scale factor.

In order to obtain a complete solution of the field equations, we consider the hybrid expansion law proposed by Akarsu *et al*. (2014) [24] as

$$a(t) = a_0 \left(\frac{t}{t_0}\right)^{\gamma} e^{\xi\left(\frac{t}{t_0}-1\right)} \tag{19}$$

where a_0 and t_0 are the present values of the scale factor and age of the universe respectively.

The value of γ is in the range $(0,1)$ and behavior of the universe at late time is determined by the value of ξ. In this work we take $\gamma = 0.5$ and investigate the behavior of the Tsallis holographic dark energy for different values of ξ.
Using (19) in (17) and (18), we get

$$B(t) = M_1 \left(kt^{3\gamma} e^{\frac{3\xi t}{t_0}}\right)^{\frac{1}{3}} \exp\left(NF(t)\right) \tag{20}$$

$$C(t) = M_2 \left(kt^{3\gamma} e^{\frac{3\xi t}{t_0}}\right)^{\frac{1}{3}} \exp\left(-NF(t)\right) \tag{21}$$

where $F(t) = \int \left(kt^{3\gamma} e^{\frac{3\xi t}{t_0}}\right)^{-1} dt$ and k is a non zero constant.
Now, from (11) using (20) and (21), we get

$$A(t) = (M_1 M_2)^{\frac{1}{2}} \left(kt^{3\gamma} e^{\frac{3\xi t}{t_0}}\right)^{\frac{1}{3}} \tag{22}$$

RESULTS AND DISCUSSION

For the metric given in (1), the directional Hubble parameters are obtained as

$$H_1 = \frac{\dot{A}}{A} = \left(\frac{\gamma}{t} + \frac{\xi}{t_0}\right) \tag{23}$$

$$H_2 = \frac{\dot{B}}{B} = \left(\frac{\gamma}{t} + \frac{\xi}{t_0}\right) + NF'(t) \tag{24}$$

$$H_3 = \frac{\dot{C}}{C} = \left(\frac{\gamma}{t} + \frac{\xi}{t_0}\right) - NF'(t) \tag{25}$$

Hence the mean Hubble parameter (H) is obtained as

$$H = \frac{1}{3}\left(\frac{\dot{A}}{A} + \frac{\dot{B}}{B} + \frac{\dot{C}}{C}\right) = \frac{\gamma}{t} + \frac{\xi}{t_0} \tag{26}$$

The deceleration parameter and the jerk parameter are obtained as

$$q(t) = -\frac{\ddot{a}}{aH^2} = -1 + \frac{\gamma t_0^2}{(\xi t + \gamma t_0)^2} \tag{27}$$

$$j(t) = \frac{\dddot{a}}{aH^3} = 1 + \frac{(2t_0 - 3\xi t - 3\gamma t_0)\gamma t_0^2}{(\xi t + \gamma t_0)^3} \tag{28}$$

From equation (27) and (28), it is obvious that the universe transitioned from decelerating to accelerating phase. The scalar of expansion θ, the spatial volume$V$, the shear scalar σ^2 and the anisotropy parameter A_m for this model are obtained as

$$\theta = 3H = 3\left(\frac{\gamma}{t} + \frac{\xi}{t_0}\right) \tag{29}$$

$$\sigma^2 = \frac{1}{2}\left[\sum_{i=1}^{3} H_i^2 - \frac{1}{3}\theta^2\right] = \frac{N^2}{\left(kt^{3\gamma}e^{\frac{3\xi t}{t_0}}\right)^2} \tag{30}$$

$$V = a^3 = \left(a_0\left(\frac{t}{t_0}\right)^{\gamma} e^{\xi\left(\frac{t}{t_0}-1\right)}\right)^3 \tag{31}$$

$$A_m = \frac{1}{3}\sum_{i=1}^{3}\frac{(H_i - H)^2}{H^2} = \frac{2N^2}{3}\frac{\left(kt^{3\gamma}e^{\frac{3\xi t}{t_0}}\right)^{-2}}{\left(\frac{\gamma}{t}+\frac{\xi}{t_0}\right)^2} \tag{32}$$

Using (26) in (5) we get

$$\rho_{THDE} = D\left(\frac{\gamma}{t}+\frac{\xi}{t_0}\right)^{-2\delta+4} \tag{33}$$

Again using (26) in (13), we get

$$\rho_m = C\left[t^{-3\gamma}e^{-\frac{\xi t}{t_0}}\right] \tag{34}$$

where C is a constant of integration.
Hence, the total energy density and EoS parameter are

$$\Omega = \Omega_m + \Omega_{THDE} = \frac{C\left[t^{-3\gamma}e^{-\frac{\xi t}{t_0}}\right] + D\left(\frac{\gamma}{t}+\frac{\xi}{t_0}\right)^{-2\delta+4}}{3\left(\frac{\gamma}{t}+\frac{\xi}{t_0}\right)^2} \tag{35}$$

$$\omega_{THDE} = -1 + (-2\delta+4)\frac{\gamma t_0^2}{3(\gamma t_0 + \xi t)^2} \tag{36}$$

Cosmology for $\delta = 1$:
For $\delta = 1$, the THDE density, total energy density and EoS parameter become

$$\rho_{THDE} = D\left(\frac{\gamma}{t}+\frac{\xi}{t_0}\right)^2 \tag{37}$$

$$\Omega = \frac{D}{3} + \frac{C\left[t^{-3\gamma}e^{-\frac{\xi t}{t_0}}\right]}{3\left(\frac{\gamma}{t}+\frac{\xi}{t_0}\right)^2} \tag{38}$$

$$\omega_{THDE} = -1 + \frac{2\gamma t_0^2}{3(\gamma t_0 + \xi t)^2} \tag{39}$$

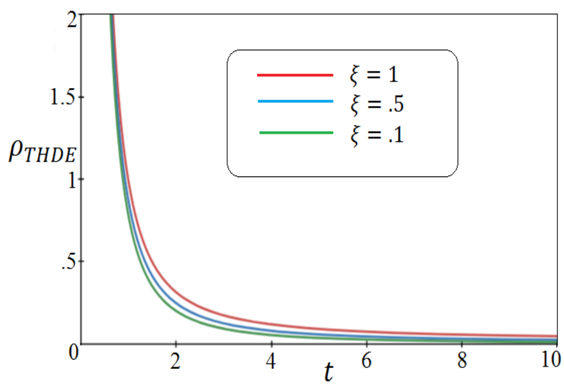

Figure 1. The plot of THDE density vs. cosmic time t with $D = 3, \gamma = 0.5$ and $\xi = 1, 0.5, 0.1$

The Figure 1 exhibits that the Tsallis holographic dark energy density decreases for any value of ξ while for smaller value of ξ, the THDE density decreases rapidly.

From Figures 2 and 3, we observe that the holographic dark energy dominates the universe and approaches flat, isotropic universe at late times for large value of ξ. For small value of ξ ($\ll 1$), the dark energy dominates the universe lately and the universe never reaches isotropic background.

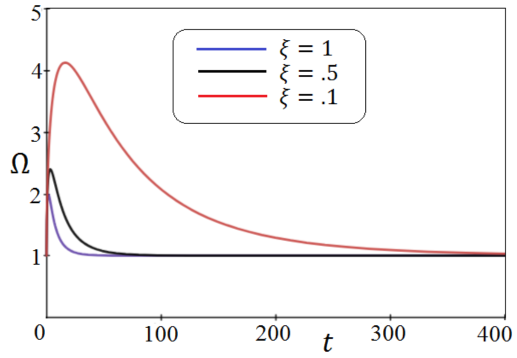

Figure 2. The plot of total energy density vs. cosmic time t with $D = 3, C = 1, t_0 = 13.8, \ \gamma = 0.5$ and $\xi = 1, 0.5, 0.1$

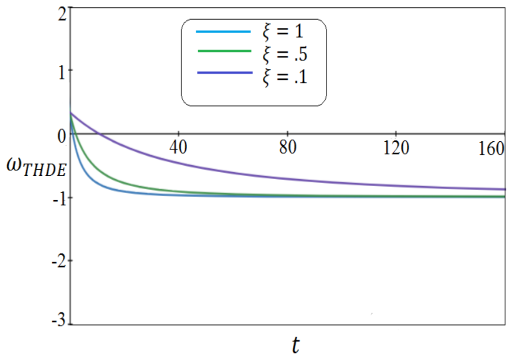

Figure 3. The plot of EoS parameter vs. cosmic time t with $t_0 = 13.8, \ \gamma = 0.5$ and $\xi = 1, 0.5, 0.1$

Cosmology for $1 < \delta < 2$ **:**

In this case the value of δ lies between 1 and 2. We choose $\delta = 1.3$ and plot the graphs of the total energy density Ω versus the cosmic time t for $\xi = 12, 14, 15$ (Fig. 4).

From the graph, it is obvious that the total energy density approaches the present isotropic background for $\xi \approx 14$ and for smaller value of ξ it never approaches isotropic background. However, for relatively larger value of ξ, the total energy density will tend to 1 not at present time but at late time.

Hence we draw the graph of THDE density and EoS parameter vs. cosmic time t for $\xi = 14$ (Fig. 5).

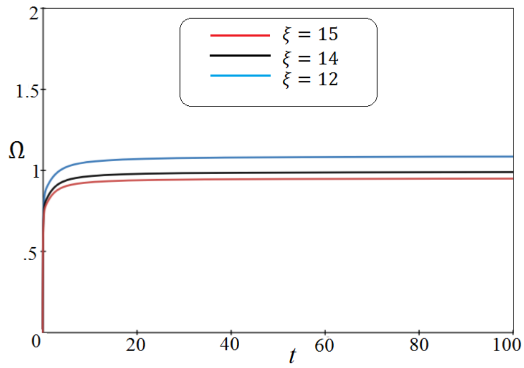

Figure 4. The plot of total energy density vs. cosmic time t with $D = 3, C = 1, t_0 = 13.8, \delta = 1.3, \ \gamma = 0.5$ and $\xi = 12, 14, 15$

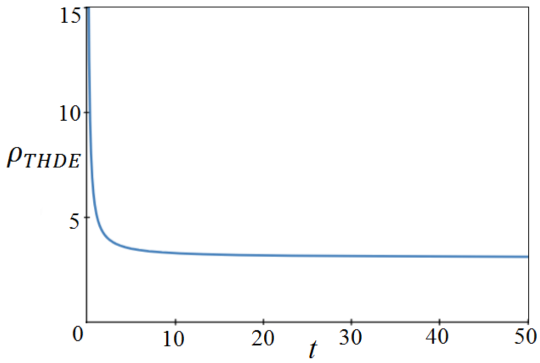

Figure 5. The plot of THDE density vs. cosmic time t with $D = 3, C = 1, t_0 = 13.8, \delta = 1.3, \ \gamma = 0.5$ and $\xi = 14$

Like the previous case ($\delta = 1$), here also THDE density decreases but it never tends to zero at late times (Fig. 6).

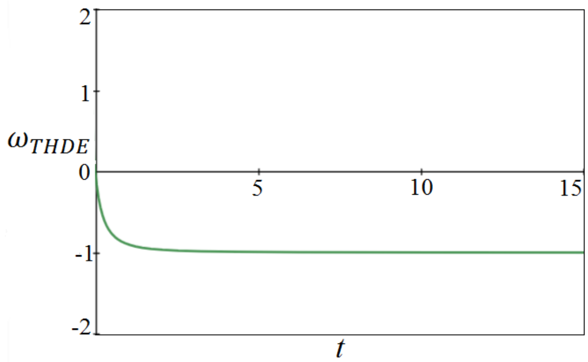

Figure 6. The plot of EoS parameter vs. cosmic time t with $t_0 = 13.8, \delta = 1.3, \ \gamma = .5$ and $\xi = 14$

From the above graph we see that the dark energy started to dominate the universe from the early era and behaves like cosmological constant at late times.

Cosmology for $\delta = 2$:

For $\delta = 2$, the Tsallis holographic dark energy becomes constant throughout the evolution, and the universe is highly anisotropic at late time. The expression of THDE density, total energy density and EoS parameter for $\delta = 2$ are obtained as

$$\rho_{THDE} = D \quad (40)$$

$$\Omega = \frac{C\left[t^{-3\gamma}e^{-\frac{\xi t}{t_0}}\right]+D}{3(\frac{\gamma}{t}+\frac{\xi}{t_0})^2} \quad (41)$$

$$\omega_{THDE} = -1 \quad (42)$$

From the Figure 7, it is clear that in this case the universe approaches flat and isotropic background for $\xi = 14$.

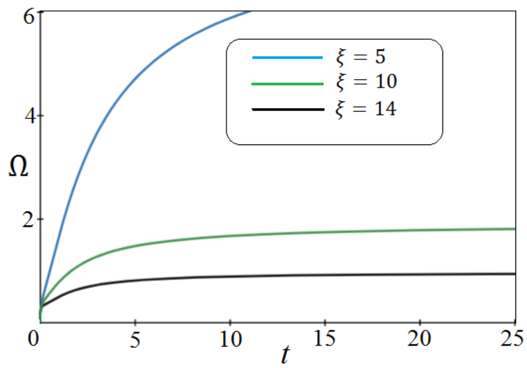

Figure 7. The plot of total energy density vs. cosmic time t with $t_0 = 13.8, \delta = 2, \gamma = 0.5$ and $\xi = 14, 10, 5$

CONCLUSION

In this paper, we study a spatially homogeneous and anisotropic Bianchi Type V universe filled with cold dark matter and non-interacting Tsallis holographic dark energy with Hubble horizon as the IR cutoff. Exact solutions of the Einstein field equations are obtained by considering the hybrid expansion law proposed by Akarsu *et al*. (2014) [24]. We study the cosmological dynamics of our model for $\delta = 1, 1 < \delta < 2$ and 2. We find that

- For $\delta = 1$, the THDE density (usual holographic dark energy density) decreases for any value of ξ and decreases rapidly for relatively smaller value of ξ. Also, the universe approaches a flat and isotropic universe at late times for any value of ξ while the universe approaches dark energy dominated era lately for $\xi \ll 1$.
- For $\delta = 1.3$, the universe approaches present isotropic background for $\xi \approx 14$. At this value, the THDE dark energy density decreases but does not tend to 0 at late times. Also, the dark energy dominates the universe from very early era.
- For $\delta = 2$, the THDE density is constant throughout the evolution of the universe and the dark energy behaves like cosmological constant. In this case also, the universe approaches isotropic background for $\xi \approx 14$.

ORCID IDs

Manash Pratim Das, https://orcid.org/0000-0002-1179-8068, **Chandra Rekha Mahanta**, https://orcid.org/0000-0002-8019-8824

REFERENCES

[1] S. Perlmutter, G. Aldering, M. Della Valle, S. Deustua, R.S. Ellis, S. Fabbro, A. Fruchter, et al, "Discovery of supernovae explosion at half the age of the universe", Nature, **391**, 51 (1998). https://doi.org/10.1038/34124
[2] S. Perlmutter, G. Aldering, G. Goldhaber, R.A. Knop, P. Nugent, P.G. Castro, S. Deustua, et al, "Measurement of Ω and *Λ* from 42 High-Red shift Supernovae", Astrophys. J. **517**, 565 (1999). https://doi.org/10.1086/307221
[3] A.G. Riess, A.V. Filippenko, P. Challis, A. Clocchiatti, A. Diercks, P.M. Garnavich, R.L. Gilliland, et al, "Observational evidence from supernovae for an accelerating universe and a cosmological constant", Astron. J. **116**, 1009 (1998). https://doi.org/10.1086/300499
[4] C.L. Bennett, M. Halpern, G. Hinshaw, N. Jarosik, A. Kogut, M. Limon, S.S. Meyer, et al, "First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Preliminary Maps and Basic Results", Astrophys. J. **148**, 1 (2003). https://doi.org/10.1086/377253
[5] D.N. Spergel, L. Verde, H.V. Peiris, E. Komatsu, M.R. Nolta, C.L. Bennett, M. Halpern, et al, "First-Year Wilkinson Microwave Anisotropy Probe (WMAP)*Observations: Determination of Cosmological Parameters", Astrophys. J. Suppl. Ser. **148**, 175 (2003). https://doi.org/10.1086/377226
[6] L. Verde, A.F. Heavens, W.J. Percival, S. Matarrese, C.M. Baugh, J. Bland-Hawthorn, T. Bridges, et al, "The 2dF Galaxy Redshift Survey: the bias of galaxies and the density of the Universe", Mon. Not. R. Astron. Soc. **335**, 432 (2002). https://doi.org/10.1046/j.1365-8711.2002.05620.x
[7] V. Sahni, and A.A. Starobinsky, "The Case for a Positive Cosmological Lambda-term", Int. J. Mod. Phys. D, **9**, 373 (2000). https://doi.org/10.1142/S0218271800000542
[8] Caldwell, R. R., "A phantom menace? Cosmological consequences of dark energy component with super- negative equation of state", Phys. Lett. B, **545**, 23 (2002). https://doi.org/10.1016/S0370-2693(02)02589-3
[9] C. Armendariz-Picon, V. Mukhanov, and P.J. Steinhardt, "Essentials of k-essence", Phys. Rev. D, **63**, 103510 (2001). https://doi.org/10.1103/PhysRevD.63.103510

[10] A. Sen, "Rolling Tachyon", J. High Energy Phys., **204**, 48 (2002). https://doi.org/10.1088/1126-6708/2002/04/048
[11] M. Gasperini, F. Piazza, and G. Veneziano, "Quintessence as a runaway dilaton", Phys. Rev. D, **65**, 023508 (2001). https://doi.org/10.1103/PhysRevD.65.023508
[12] M.C. Bento, O. Bertolami, and A.A. Sen, "Generalized Chaplygin gas, accelerated expansion and dark-matter unification", Phys. Rev. D, **66**, 043507 (2002). https://doi.org/10.1103/PhysRevD.66.043507
[13] C. Deffayet, G. Dvali, and G. Gabadadze, "Accelerated universe from gravity leaking to extra dimension" Phys. Rev. D, **65**, 044023 (2002). https://doi.org/10.1103/PhysRevD.65.044023
[14] G.'t Hooft, "Dimensional Reduction in Quantum Gravity", (1993). https://doi.org/10.48550/arXiv.gr-qc/9310026
[15] W. Fischler, and L. Susskind, "Holography and Cosmology", (1998). https://doi.org/10.48550/arXiv.hep-th/9806039
[16] C. Tsallis, and L.J.L.Cirto, "Black hole thermodynamical entropy", Eur. Phys. J. C, **73**, 2487 (2013). https://doi.org/10.1140/epjc/s10052-013-2487-6
[17] M. Tavayef, A. Sheykhi, K. Bamba, and H. Moradpour, "Tsallis holographic dark energy", Physics Letters B, **781**, 195 (2018). https://doi.org/10.1016/j.physletb.2018.04.001
[18] S. Ghaffari, "Holographic dark energy model in the DGP braneworld with time varying holographic parameter", New astronomy, **67**, 76 (2019). https://doi.org/10.1016/j.newast.2018.09.002
[19] M. Korunur, "Tsallis holographic dark energy in Bianchi type-III spacetime with scalar fields", Mod. Phys. Lett. A, **34**, 1950310 (2019). https://doi.org/10.1142/S0217732319503103
[20] U.K. Sharma, and A. Pradhan, "Diagnosing Tsallis holographic dark energy models with statefinder and$\omega - \omega'$ pair", Mod. Phys. Lett. A, **34**, 1950101 (2019). https://doi.org/10.1142/S0217732319501013
[21] V.C. Dubey, A.K. Mishra, S. Srivastava, and U.K. Sharma, "Tsallis holographic dark energy models in axially symmetric space time", Int. J. Geom. Meth. Modern Phys. **17**, 2050011 (2020).https://doi.org/10.1142/S0219887820500115
[22] Y. Liu, "Tachyon model of Tsallis holographic dark energy", Eur. Phys. J. Plus, **136**, 579 (2021). https://doi.org/10.1140/epjp/s13360-021-01573-y
[23] A. Mohammadi, T. Golanbari, K. Bamba, and I.P. Lobo, "Tsallis holographic dark energy for inflation", Phys. Rev. D, **103**, 083505 (2021). https://doi.org/10.1103/PhysRevD.103.083505
[24] B.D. Pandey, P.S. Kumar, Pankaj, and U.K. Sharma, "New Tsallis holographic dark energy", Eur. Phys. J. C, **82**, 233 (2022). https://doi.org/10.1140/epjc/s10052-022-10171-w
[25] P.S. Kumar, Pankaj, and U.K. Sharma, "Quintessence model of Tsallis holographic dark energy", New Astronomy, **96**, 101829 (2022). https://doi.org/10.1016/j.newast.2022.101829
[26] Ö. Akarsu, S. Kumar, R. Myrzakulov, M. Sami, and L. Xu, "Cosmology with hybrid expansion law: scalar field reconstruction of cosmic history and observational constraints", J. Cosmol. Astropart. Phys. **01**, 022 (2014). https://doi.org/10.1088/1475-7516/2014/01/022

ГОЛОГРАФІЧНА МОДЕЛЬ ТЕМНОЇ ЕНЕРГІЇ БІАНЧІ ТИПУ V ЦАЛЛІСА З ГІБРИДНИМ ЗАКОНОМ РОЗШИРЕННЯ

Манаш Пратім Дас, Чандра Рекха Маханта
Факультет математики, Університет Гаухаті, Гувахаті (Індія)

Кілька останніх космологічних спостережень надали все більше доказів того, що в даний час Всесвіт переживає фазу прискореного розширення, першопричиною якого, як припускають, є екзотичний компонент Всесвіту з великим негативним тиском, який називається темною енергією. З різних кандидатів темної енергії, запропонованих у літературі, голографічна темна енергія, яка виникла з голографічного принципу, привертає велику увагу в галузі досліджень. У цій статті ми досліджуємо просторово однорідний та анізотропний простір-час Б'янкі типу V, заповнений невзаємодіючою голографічною темною енергією Цалліса (THDE) з горизонтом Хаббла як межею інфрачервоного випромінювання та холодною темною матерією без тиску в рамках загальної теорії відносності. Отримано точні розв'язки рівнянь поля Ейнштейна, розглядаючи середній масштабний коефіцієнт a як комбінацію степеневого та експоненціального законів, так званого гібридного закону розширення, вперше запропонованого Акарсу та ін. (2014). Ми вивчаємо космологічну динаміку різних моделей для різних значень неадитивного параметра δ, який з'явився в ентропії Цалліса, і для ξ, який з'явився в експоненціальній функції гібридного закону розширення. Ми виявили, що наша модель демонструє поточний космологічний сценарій.
Ключові слова: голографічна темна енергія Цалліса, тип Б'янкі V, закон гібридного розширення, прискорене розширення