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RENYI HOLOGRAPHIC DARK ENERGY MODEL IN *f(R)* GRAVITY WITH HUBBLE'S IR CUT-OFF[†]

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In the present study, a homogeneous and anisotropic LRS Bianchi type-I universe model is considered with an interacting dark matter and Renyi holographic dark energy model (RHDE) in $f(R)$ gravity. The deceleration parameter (DP) shows a signature flipping for a universe which was decelerating in past and accelerating at present epoch. Therefore, the DP is a most physically justified parameter to analyze the solution of cosmological model. In order to find an exact solution of the field equations of the model, the shear scalar is considered to be proportional to the expansion scalar. We have considered $f(R)=bR^n$, the depiction model of $f(R)$ which is the function of Ricci scalar R. The physical and geometrical characteristics of the universe model have been studied.
Keywords: *f*(*R*) *Gravity; RHDE; dark matter; Cosmology; Bianchi type-I space-time*
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INTRODUCTION

Observational cosmic data show that our Universe is currently expanding at a faster rate [1–5]. Dark energy (DE), which has negative pressure and accounts for 70% of the exotic component, is what propels the universe's cosmic expansion [6–9]. To investigate the universe and its accelerated expansion, modified theories of gravity provide an alternative approach. Some appropriate characteristics of modified theories of gravity are found in [10]. In the literature, several modified theories, including $f(R)$ gravity [11–15], $f(T)$ gravity [16–20], and $f(G)$ gravity [21–23] have been proposed with the changes of the Einstein–Hilbert action. Many researchers have worked on modified theories of gravity in recent past on different aspects of Cosmology [24-34]. In fact, the Ricci scalar $f(R)$ theory uses a conventional Einstein-Hilbert action that contains an arbitrary function *R*. The authors of Nojiri et al. [35] provided a comprehensive overview of modified theories of gravitation. Theoretical models of workable dark energy are described in [36]. The Noether symmetry technique is used to show spherically symmetric solutions in [37]. The exact solutions of static spherically symmetric space-times in $f(R)$ gravity coupled to nonlinear electrodynamics have been studied by Hollenstein and Lobo [38]. $f(R)$ gravity has been studied by a number of researchers in various cosmological contexts [39–53].

Holographic dark energy (HDE) has a variety of characteristics that have been studied in [54–58]. In [59–61], the holographic concept serves as the foundation for the potential of HDE. The HDE theory is also a helpful approach for addressing the DE conundrum in [62]. It was put forth based on the quantum characteristics of black holes (BH), which have been thoroughly studied in the literature to research quantum gravity. Studying the cosmic ramifications of holographic dark energy is more natural because Newton's gravitational constant is made dynamical in the Scalar Tensor Theory. According to [63], the holographic principle refers to a system's entropy, which is determined by its surrounding surface area rather than its volume. If we assume that the infrared (IR) cutoff is equal to the size of the universe, then the holographic energy density is rather near to the dark energy density. We can discover the cosmological characteristics of the vacuum energy with the aid of the HDE theory. The decreased Planck mass $M_p^2=8\pi G$ and the numerical constant d are used to calculate the HDE energy density $\rho_{de}=3d^2M_p^2L^{-2}$. Numerous investigations have examined the interaction of holographic dark energy with matter using various IR cutoffs, including particle horizons, future horizons, and Hubble horizons. The authors of [64] suggested an IR cut-off made up of local Hubble scale values and temporal derivative Hubble scales. Sheykhi et al. in [65] explore the astrophysical implications of New Holographic DE (NHDE) by using the Hubble radius $L=H^{-1}$ as the system's IR cutoff. Many extended entropy formalisms have been used to investigate cosmological and gravitational events, but Tsallis and Renyi entropies offer the most accurate universe model. Sharma-Mittal HDE is compatible with the expansion of the universe and it is stable whenever it dominates the cosmos. The horizon is assigned to the Tsallis and Renyi entropies to investigate the cosmic ramifications. The generalized entropies

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In Figure 5, it is shown that the equation of state parameter initially reflects the quintessence region and that as time goes on, it evolves around the ΛCDM model. The equation of state parameter behaves like a cosmological constant $\omega_r = -1$ as the universe expands, which is consistent with recent theoretical results.

Stability factor is

$$\vartheta_r^2 = -\frac{8\pi}{3d^2\beta}\left(\frac{\tau^2}{1-\tau}\right)\frac{\left(1+\pi\delta\tau^2\right)}{\left[\frac{\pi\delta}{\left(1+\pi\delta\tau^2\right)}+\frac{2}{\tau}\right]}\left\{\frac{1}{2}f+\ddot{F}+\frac{3}{(m+2)\tau}\left\{\begin{array}{l}-\beta\left(\frac{1-\tau}{\tau}\right)\left\{\left[\beta m+\frac{2m\left(3m-\beta(m+2)+6\right)}{(m+2)\tau}\right]F+2\dot{F}\right\}\\+\left[\beta m+\frac{m\left(3m-\beta(m+2)+6\right)}{(m+2)\tau}\right]\dot{F}+2\ddot{F}\end{array}\right\}\right\} \tag{33}$$

where

$$\dddot{F} = \left\{\begin{array}{l}-bn(n-1)\beta\left(\frac{-6}{M_1}\right)^{n-1}(\tau_1)^{n-3}\left(\frac{1-\tau}{\tau^n}\right)\\ \left\{\left(\frac{1-\tau}{\tau^2}\right)\left\{2\tau_2\tau_3+\frac{M_2}{\tau}\left[2M_2\left(\frac{3-2\tau}{\tau}\right)+\beta M_1(2-\tau)\right]+(n-2)\tau_1\tau_3\right\}\right.\\ \left.+\left\{\tau_1\left[2M_2\left(\frac{1-\tau}{\tau^2}\right)+\tau_2\left(\frac{2-\tau}{\tau}\right)\right]+(n-2)\left(\frac{1-\tau}{\tau}\right)\tau_2^2\right\}\left\{(n-3)M_2\left(\frac{1-\tau}{\tau^2\tau_1}\right)+\left(1+n\left(\frac{1-\tau}{\tau}\right)\right)\right\}\right\}\end{array}\right\},$$

and

$$\tau_1 = \left(\beta M_1 + \frac{M_2}{\tau}\right),\ \tau_2 = \left(\beta M_1 + \frac{2M_2}{\tau}\right),\ \tau_3 = \left[2M_2\left(\frac{3-\tau}{\tau}\right)+\beta M_1\right].$$

From Figure 6, it is clear that the universe is unstable because RHDE has a negative stability factor during the universe's expansion.

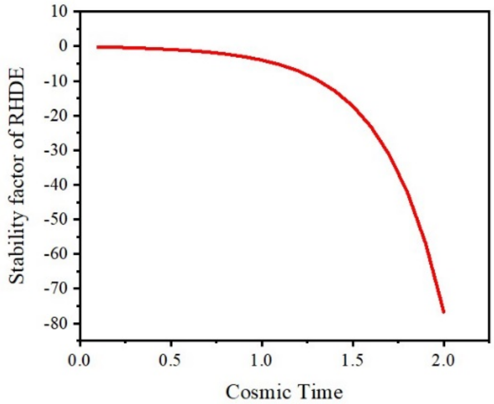

Figure 6. Stability factor of RHDE versus cosmic time for $\beta = 3$, $c = 1$, $d = 1.2$, $\delta = 4$, $m = 2$, $n = 2$ and $b = 1$.

CONCLUSION

In the present study, a homogeneous and anisotropic LRS Bianchi type I universe model is considered with an interacting dark matter and RHDE in $f(R)$ gravity.

- It is found that the energy density of RHDE is always positive and decreases as a function of cosmic time t.
- As time goes on, the equation of state parameter evolves around the ΛCDM model, which is familiar from the universe's current accelerated expansion. The equation of state parameter initially represents the quintessence area [87-88].
- The average scale factor and the spatial volume increase with increasing cosmic time.
- Expansion scalar is constant because of $t \to \infty$. It implies that the universe expands more quickly initially and then less quickly as time goes on.
- The deceleration parameter is negative during the entire universe's expansion, which is consistent with the usual accelerating expansion [89-90].
- The stability factor has been negative during the universe's expansion, indicating that the cosmos is unstable.
- As cosmic time lengthens, recent theoretical observations are consistent with this scenario.

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ГОЛОГРАФІЧНА МОДЕЛЬ ТЕМНОЇ ЕНЕРГІЇ РЕНЬЇ У f(R) ГРАВІТАЦІЇ З ІЧ-ОБРІЗАННЯМ ХАББЛА

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У цьому дослідженні розглядається однорідна та анізотропна модель Всесвіту LRS Bianchi типу I із взаємодіючою темною матерією та голографічною моделлю темної енергії Реньї (RHDE) у *f*(*R*) гравітації. Параметр уповільнення (DP) показує характерне перевертання для Всесвіту, який уповільнювався в минулому та прискорювався в нинішню епоху. Таким чином, DP є найбільш фізично виправданим параметром для аналізу рішення космологічної моделі. Щоб знайти точний розв'язок польових рівнянь моделі, скаляр зсуву вважається пропорційним скаляру розширення. Ми розглянули $f(R) = bR^n$, моделлю зображення *f*(*R*) якої є функція скаляра Річчі *R*. Досліджено фізико-геометричні характеристики моделі Всесвіту.

Ключові слова: *f*(*R*) *гравітація; RHDE; темна матерія; космологія; простір-час Бьянкі типу I*