Cosmological analysis of Barrow holographic dark energy model considering the Granda-Oliveros infrared cutoff

Author:
Miguel Sabogal G.[1]

B.Sc Advisor:
Alexander Oliveros G.[2]

[1]Last year student, Physics Department, Universidad del Atlántico

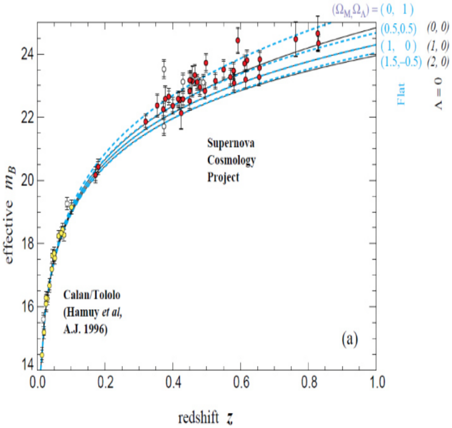
[2]Associate Professor, Physics Department, Universidad del Atlántico

September 8, 2021

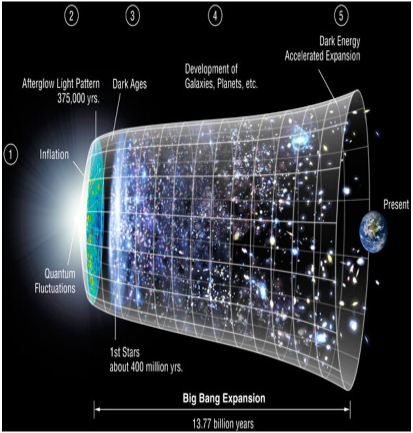
Content

Universidad del Atlántico

Modern cosmology



(a) The supernova data plotted in terms of brightness (bolometric magnitude) versus redshift.



(b) Credit: NASA/ LAMBDA Archive/ WMAP Science Team.

Figure 1: (*a*) Evidence of the accelerated expansion of the universe from [1]. (*b*) Λ-CDM model.

Modern cosmology

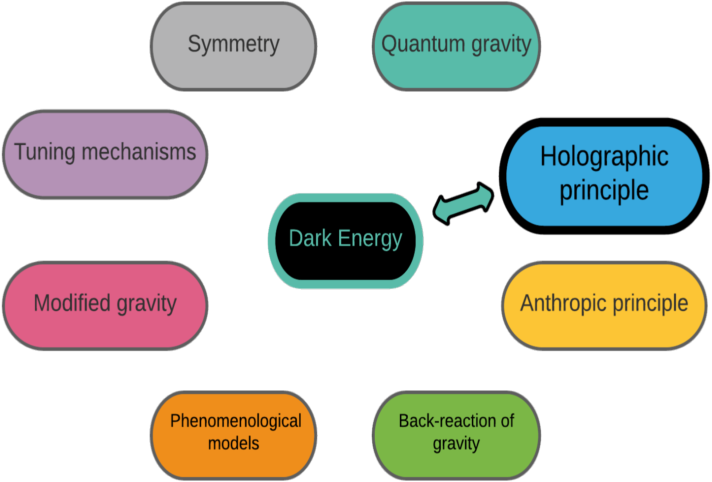


Figure 2: Models that try to explain the Dark Energy problem, review in [2].

Holographic principle

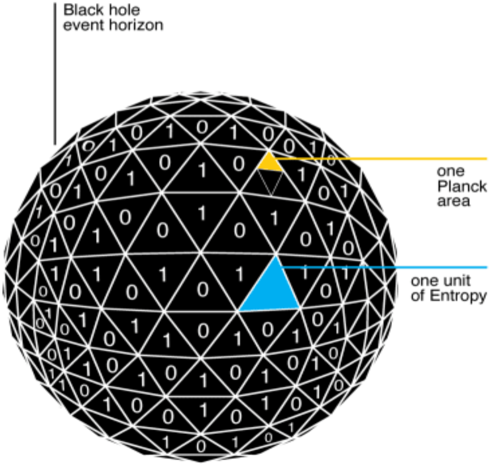
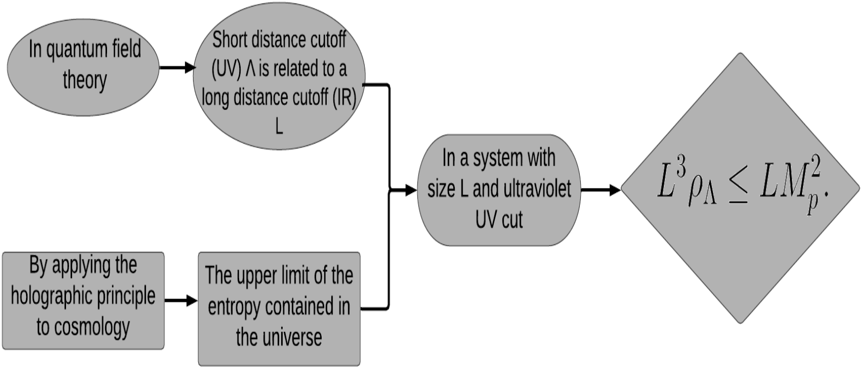


Figure 3: Schematic representation of the holographic principle applied to a black hole, where $S_B = (A/A_0)$. Taken from [3].

Holographic dark energy



Taking the largest value of L allowed saturates the above inequality, resulting in:

(1) $$\rho_\Lambda = 3c^2 M_p^2 L^2.$$

Barrow new entropy and Barrow holographic dark energy

Barrow, inspired by representations of the Covid-19 virus, demonstrated that quantum gravitational effects can introduce intricate fractal features into the surface of a black hole [4]

$$S_B = \left(\frac{A}{A_0}\right)^{1+\Delta/2}, \tag{2}$$

where Δ could take the values between $0 \leq \Delta \leq 1$, A is the standard area of the horizon and A_0 is the Planck area.

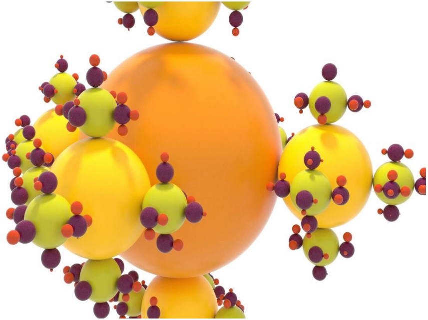


Figure 4: Diagram of the fractal shapes in the structure of a black hole, taken from [4]

Applying the holographic principle in a cosmological scenario, but using Barrow's entropy, Saridakis [5] obtains:

$$\rho_\Lambda = 3c^2 M_p^2 L^{2-\Delta}. \tag{3}$$

Granda-Oliveros infrared cutoff

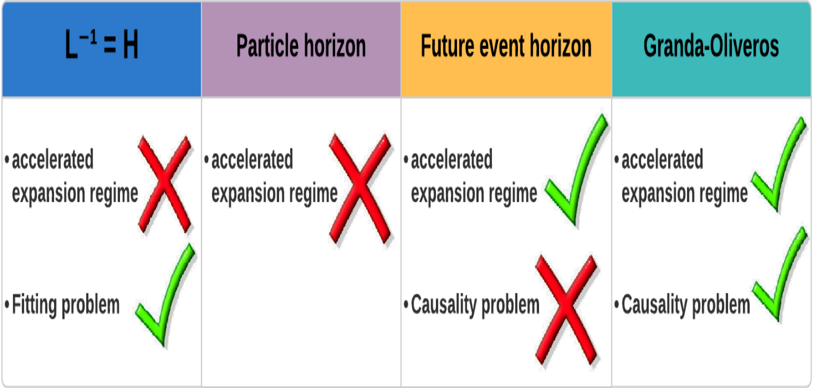


Figure 5: Pro and cons of differents IR cut-off

In [6] Granda and Oliveros proposed a new infrared cut-off:

$$L^{-1} = \sqrt{\alpha H^2 + \beta \dot{H}}, \tag{4}$$

Friedmann equations

Taking into account:

- Einstein's field equations
- The Friedmann-Robertson-Walker (FRW) metric with $k = 0$ (flat, homogeneous and isotropic universe).
- The content of the universe at large-scale as a perfect fluid.
- $H_0 = 67.37$ km/s/Mpc , $\Omega_{m_0} = 0.315$ and $\Omega_{r_0} = 4.6 \times 10^{-5}$.
- Barrow holographic dark energy density
- And the Granda-Oliveros infrared cutoff,

The Friedmann equations of the model were obtained, the first one is:

$$H^2 = \frac{8\pi G}{3}\rho_{m_0} a^{-3} + \frac{8\pi G}{3}\rho_{r_0} a^{-4} + \left(\alpha H^2 + \beta \dot{H}\right)^{1-\frac{1}{2}\Delta} \tag{5}$$

Where a is the scale factor, $H = \dot{a}/a$ the Hubble parameter, G the gravitational constant and $c = 1$.

Hubble parameter varying Δ

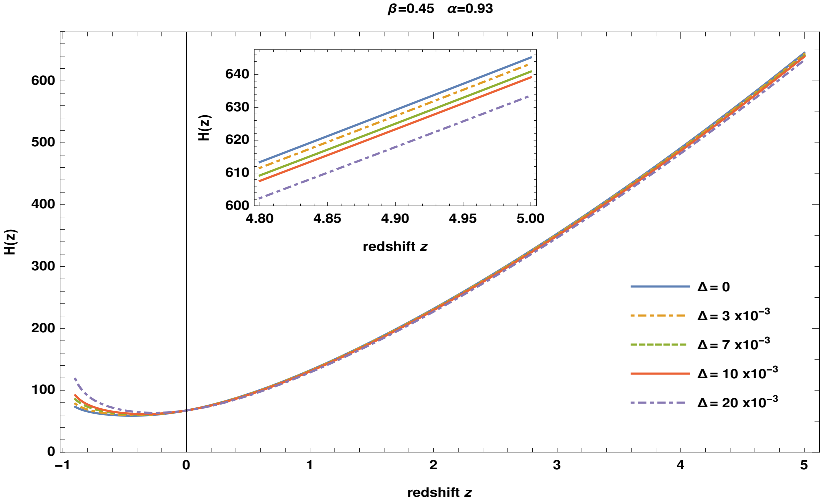


Figure 6: Hubble parameter as a function of the redshift z, varying Δ.

Hubble parameter at high redshift

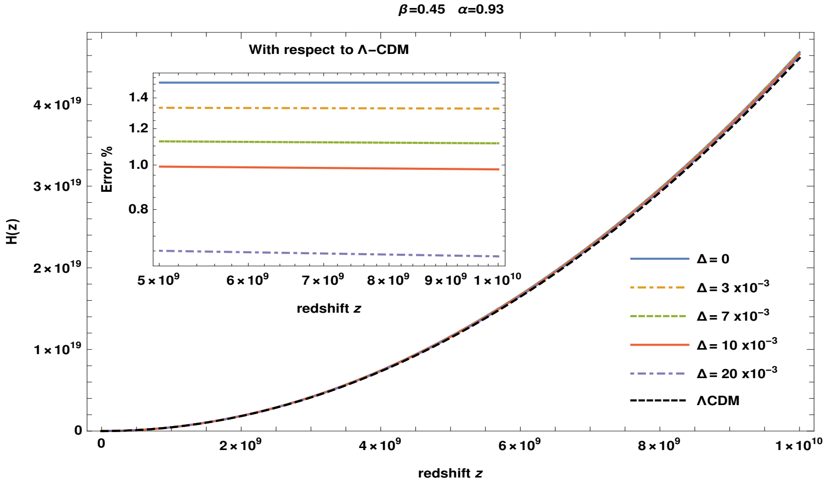


Figure 7: Hubble parameter as a function of the redshift z, varying Δ and Λ-CDM model at high redshift, the inside figure corresponds to the percentage error between the models.

Deceleration parameter varying Δ

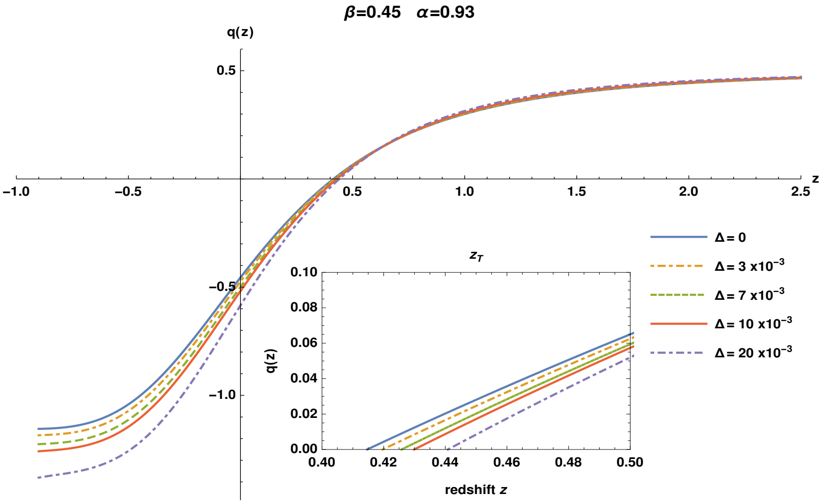


Figure 8: Deceleration parameter as a function of redshift z, varying Δ.

Deceleration parameter varying β

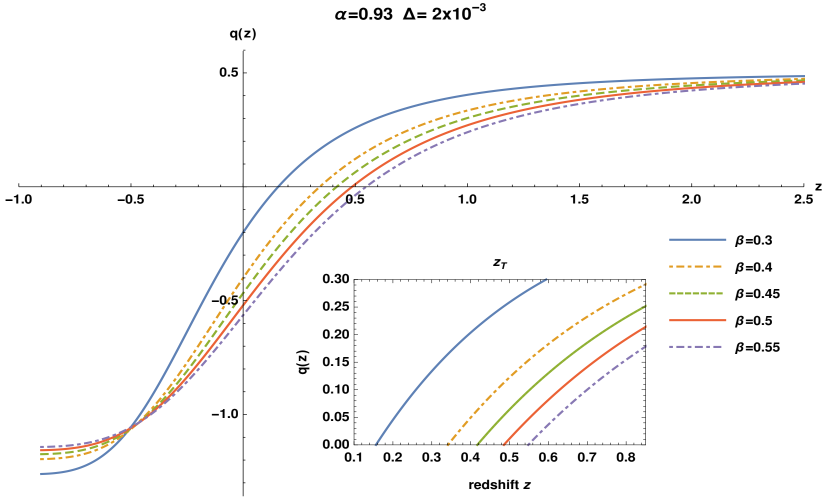


Figure 9: Deceleration parameter as a function of redshift z, varying β.

Deceleration parameter varying α

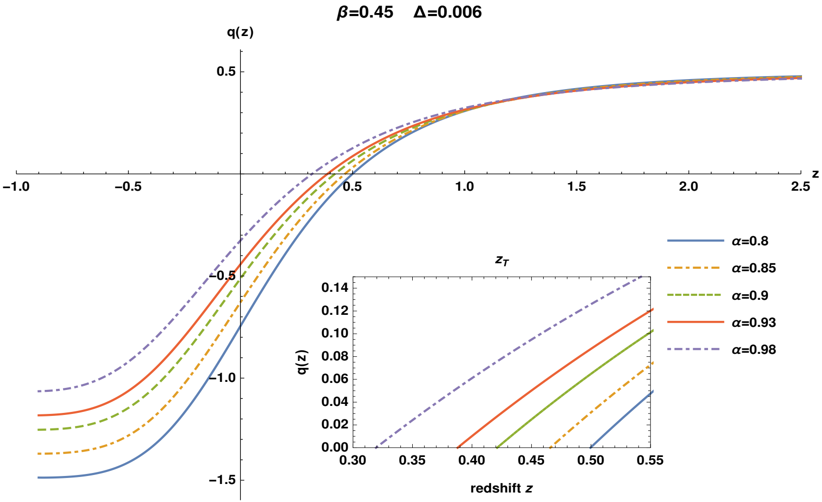


Figure 10: Deceleration parameter as a function of redshift z, varying α.

Equation of state varying Δ

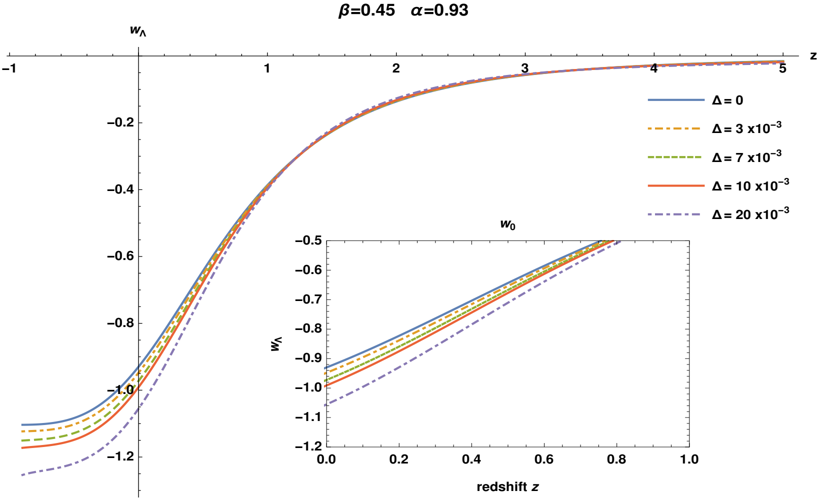


Figure 11: Equation of state for Dark Energy as a function of redshift z, varying Δ.

Equation of state varying β

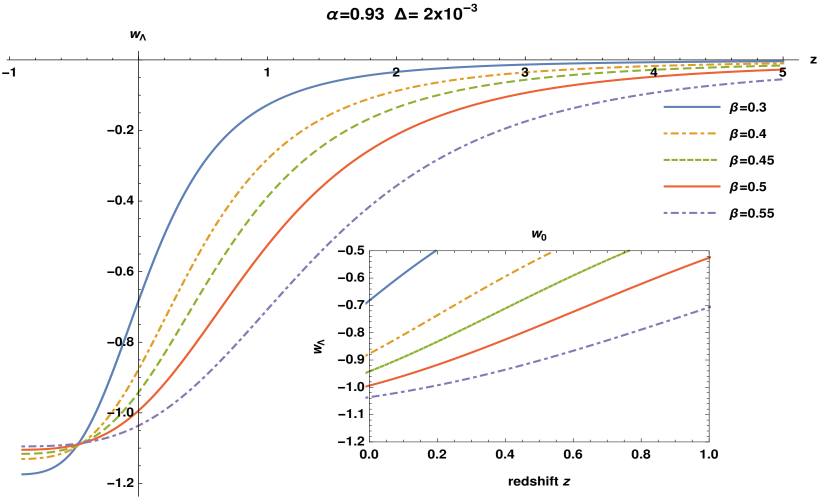


Figure 12: Equation of state for Dark Energy as a function of redshift z, varying β.

Equation of state varying α

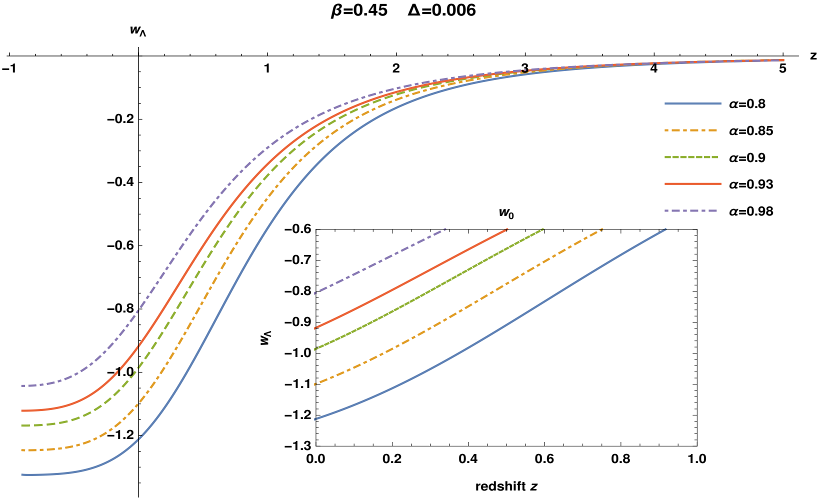


Figure 13: Equation of state for Dark Energy as a function of redshift z, varying α.

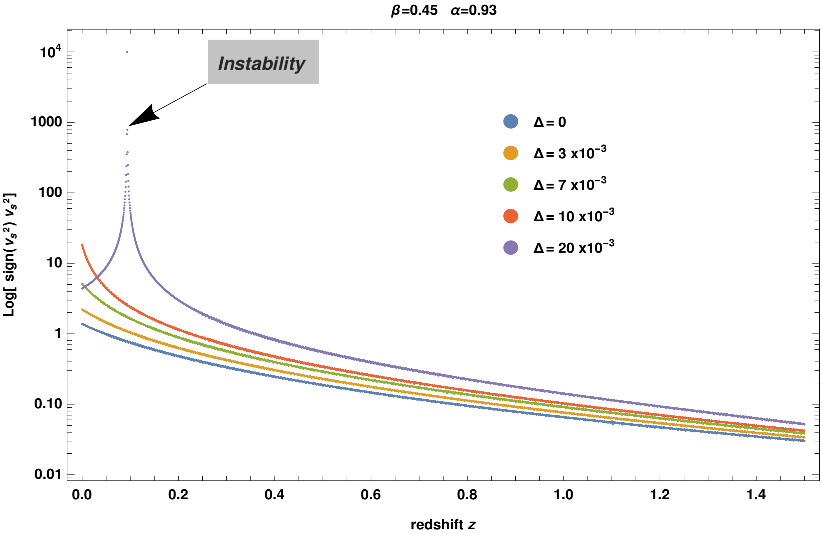


Figure 14: On a logarithmic scale, the speed of sound squared by its sign, as a function of the redshift z, for different values of Δ.

The evolution of densities

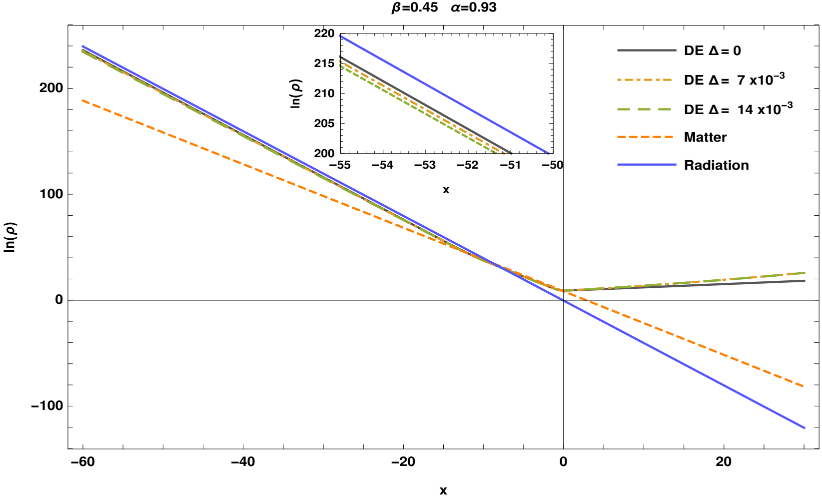


Figure 15: The evolution of the densities of matter, dark energy and radiation, for different values of Δ.

Conclusions

- With the proposed model it is possible to obtain a regime of accelerated expansion of the universe in late times.
- The values for the Hubble parameter of the proposed model and the Lambda-CDM, show a similar behavior of at least 1.5% at high redshifts.
- As the α and β parameters, the new deformation parameter Δ significantly affects the values of z_T and w_0.
- The model is stable under perturbations since the early epoch until present and later time, however, it presents a zone of instability as the value of Δ increases, suggesting that it can not take values very far from zero.
- The model exhibit an era of radiation dominance, followed by non-relativistic matter and the current era of dark energy dominance.

Future work

- We will use the current cosmological observational data in order to extract constraints for α, β and Δ on the new scenario of Barrow holographic dark energy considering the Granda-Oliveros infrared cutoff.

- We will study the phenomenology of Barrow holographic dark energy with a GO infrared cutoff in CLASS

Referencias

[1] Perlmutter, Saul, et al. "Measurements of Ω and Λ from 42 high-redshift supernovae." The Astrophysical Journal 517.2 (1999): 565.

[2] Li, Miao, et al. "Dark energy." Communications in Theoretical Physics, vol. 56, no. 3, pp. 525–604, sep 2011.

[3] Baggioli, Matteo. "Gravity, holography and applications to condensed matter." arXiv preprint arXiv:1610.02681 (2016).

[4] J. D. Barrow, "The area of a rough black hole" , Physics Letters B, vol 808, p.135643 .2020.

[5] E. N. Saridakis, "Barrow holographic dark energy," Phys. Rev. D, vol. 102, p. 123525, Dec 2020.

[6] L. N. Granda and A. Oliveros, Phys. Lett. B 669, 275 (2008).