Observational Constraint for Rényi Dark Energy Model

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Introduction

- Holographic Dark Energy (HDE) is an attempt to propose dark energy density in terms of infrared length

$$\rho_\Lambda = 3C^2 M_{\mathrm{Pl}}^2 L^{-2} \ , \tag{1}$$

  where C is a numerical constant, $M_{\mathrm{Pl}} = (8\pi G)^{-1/2}$, and L is the infrared length related to some quantities describing universe.

- Manoharan, et al [2208.08736] proposed a method to generate a dark energy density proposoal for a given entropy S, the corresponding dark energy density can given in the form of (with unit $G = 1$)

$$\rho_\Lambda = C^2 \left[\left(-\frac{3}{8\pi^2} \int \frac{1}{r_A^4} dS \right) - \frac{3}{8\pi r_A^2} \right] \tag{2}$$

  where the last term $3/8\pi r_A$ is introduced to cancel out the Friedmann equation coming from standard Bekenstein–Hawking entropy, and $r_A = 1/H$ is the radius of the apparent horizon.

Setup

- We consider a generalization of Bekenstein–Hawking entropy so called Renyi entropy

$$S_R = \frac{1}{\gamma} \ln\left(1 + \gamma \frac{A}{4G}\right) \ . \tag{3}$$

$A \equiv 4\pi r_A^2$

- We apply this entropy to the (2), we obtain

$$\rho_\Lambda = -\frac{3C^2}{8\pi^2}\left[\pi^2 \lambda \ln\left(1 + \frac{H^2}{\pi\lambda}\right)\right] + \tilde{\Lambda} \tag{4}$$

where $\tilde{\Lambda}$ is an integration constant

Datasets

Observational Hubble Data (OHD)

- The OHD compilation provides direct measurements of the expansion rate,

$$H_{\rm obs}(z_i) \pm \sigma_{H,i},$$

  at several redshifts.
- The data are read from `OHD.txt`, which contains

$$\{z_i,\ H_{\rm obs}(z_i),\ \sigma_{H,i}\}.$$

- The theoretical values $H_{\rm th}(z_i)$ are obtained by numerically solving the modified Friedmann equation.
- Assuming independent Gaussian uncertainties, the likelihood contribution is

$$\chi^2_{\rm OHD} = \sum_i \left[\frac{H_{\rm th}(z_i) - H_{\rm obs}(z_i)}{\sigma_{H,i}}\right]^2.$$

- This dataset mainly constrains the late-time expansion history and the Hubble constant H_0.

Datasets

DESI Baryon Acoustic Oscillations

- The analysis uses 13 correlated BAO observables:
- The relevant distance measures are

$$D_M(z) = c\int_0^z \frac{dz'}{H(z')}, \qquad D_H(z) = \frac{c}{H(z)},$$

  and

$$D_V(z) = \left[z D_M^2(z) D_H(z)\right]^{1/3}.$$

- The sound horizon at the drag epoch is fixed to

$$r_d = 147.09 \text{ Mpc}.$$

- The correlated BAO likelihood is

$$\chi^2_{\rm BAO} = \Delta\mathbf{D}^{\mathsf{T}}\mathbf{C}^{-1}_{\rm BAO}\Delta\mathbf{D},$$

  where $\Delta\mathbf{D} = \mathbf{D}_{\rm th} - \mathbf{D}_{\rm obs}$.

Pantheon+ Type Ia Supernovae

- The Pantheon+ dataset contains

$$\{z_i,\ \mu_{\mathrm{obs},i},\ \sigma_{\mu,i}\}.$$

- For a spatially flat universe,

$$D_L(z) = (1+z)D_M(z), \qquad \mu_{\mathrm{th}}(z) = 5\log_{10}\left(\frac{D_L(z)}{\mathrm{Mpc}}\right) + 25.$$

- The absolute-magnitude offset $\mathcal{M}$ is treated as a nuisance parameter and marginalized analytically:

$$\widehat{\mathcal{M}} = \frac{\sum_i \Delta_i/\sigma_{\mu,i}^2}{\sum_i 1/\sigma_{\mu,i}^2}, \qquad \Delta_i = \mu_{\mathrm{th},i} - \mu_{\mathrm{obs},i}.$$

- The supernova contribution to the total chi-square is

$$\chi^2_{\mathrm{SN}} = \sum_i \frac{\left(\Delta_i - \widehat{\mathcal{M}}\right)^2}{\sigma_{\mu,i}^2}.$$

Compressed Planck CMB Likelihood

- The compressed CMB data vector is

$$\mathbf{v}_{\rm CMB} = (\theta_s, \omega_b, \omega_m), \qquad \mathbf{v}_{\rm CMB}^{\rm obs} = (0.01041, 0.02223, 0.14208).$$

- Its components are

$$\theta_s = \frac{r_s(z_*)}{D_M(z_*)}, \qquad \omega_b = \Omega_{b0} h^2, \qquad \omega_m = \Omega_{m0} h^2,$$

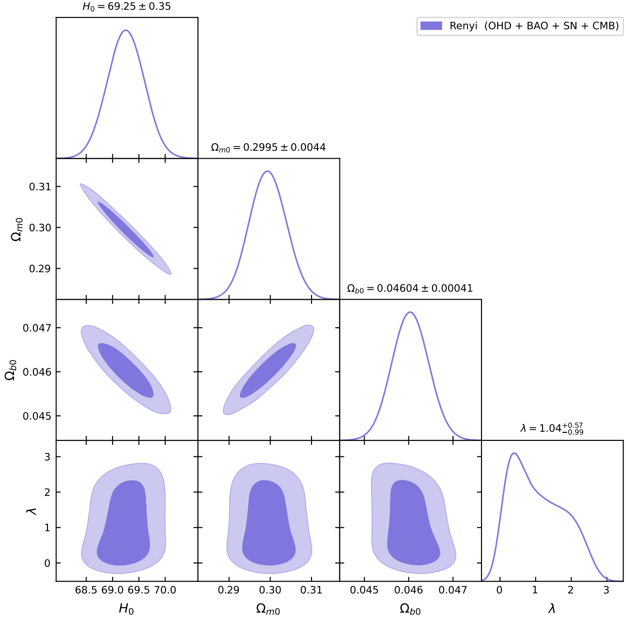
  where $h = H_0/(100\ \mathrm{km\,s^{-1}\,Mpc^{-1}})$.

- Parameter correlations are included through the inverse covariance matrix:

$$\chi^2_{\rm CMB} = \Delta\mathbf{v}^{\mathsf{T}} \mathbf{C}^{-1}_{\rm CMB} \Delta\mathbf{v}, \qquad \Delta\mathbf{v} = \mathbf{v}_{\rm CMB}^{\rm th} - \mathbf{v}_{\rm CMB}^{\rm obs}.$$

- The compressed likelihood follows the Planck/Cobaya convention.

Some results



Some results

Parameter	Median with 68% confidence interval
$H_0\ [\mathrm{km\,s^{-1}\,Mpc^{-1}}]$	$69.252^{+0.347}_{-0.347}$
Ω_{m0}	$0.2994^{+0.0045}_{-0.0044}$
Ω_{b0}	$0.0460^{+0.0004}_{-0.0004}$
λ	$0.923^{+1.025}_{-0.713}$
$w_{\mathrm{DE}}(0)$	$-1.0131^{+0.0021}_{-0.0014}$
q_0	$-0.5642^{+0.0069}_{-0.0066}$

Model	k	$\chi^2_{\min}$	AIC	BIC
Rényi HDE	4	794.226	802.226	824.118
ΛCDM	3	792.669	798.669	815.088
Δ(Rényi HDE$-\Lambda$CDM)	–	$+1.557$	$+3.558$	$+9.031$

- The positive $\Delta\mathrm{AIC}$ and $\Delta\mathrm{BIC}$ indicate that ΛCDM is statistically preferred, particularly according to the BIC.

THANK YOU!!