

Revisiting Metastable DE and Tensions In the Estimation of Cosmological Parameters

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Outline

- Introduction
- Metastable Dark Energy models
- Cosmological Probes
- Results and Discussion
- Summary

Introduction

- Accelerating expansion of universe.
 - Dark energy or modified Gravity
- Λ CDM model:
 - Simplest and best known candidate
 - Problems:
 1. Fine-tuning problem
 2. Cosmic coincident problem
 3. H_0 tension
- Cosmological models:
 - Evolving Scalar fields
 - Modifications to GR
 - ...

Metastable Dark Energy models

- DE decays into other dark sector component of the universe
- The rate of the decay depends only on its ‘intrinsic’ properties

I. Exponential decaying DE: $\dot{\rho}_{\text{DE}} = -\Gamma\rho_{\text{DE}}$

II. DE decays into DM:

$$\dot{\rho}_{\text{DE}} = -\Gamma\rho_{\text{DE}} \quad \text{and} \quad \dot{\rho}_{\text{DM}} + 3H\rho_{\text{DM}} = \Gamma\rho_{\text{DE}}$$

Shafieloo, A., Hazra, D. K., Sahni, V., & Starobinsky, A. A. 2017

Metastable Dark Energy models

Assuming FLRW metric and spatially flat universe, the Hubble parameter:

I. Metastable DE model I:

$$H^2(z) = H_0^2(z) \left[\Omega_{m,0}(1+z)^3 + (1 - \Omega_{m,0}) \exp \left(\frac{\Gamma}{H_0} \int_0^z \frac{dz'}{E(z')(1+z')} \right) \right]$$

II. Metastable DE model II:

$$H^2(z) = H_0^2(z) \left[\Omega_{DE}(z) + \Omega_{DM}(z) + \Omega_{b,0}(1+z)^3 \right]$$

III. Λ CDM model :

$$H^2(z) = H_0^2(z) \left[\Omega_{m,0}(1+z)^3 + (1 - \Omega_{m,0}) \right]$$

Cosmological probes

1. Type Ia Supernovae: “Pantheon” sample, 1048 Data, $0.01 < z < 2.3$
2. Baryonic Acoustic Oscillations:

z	D_V/r_d	$D_M \times (r_{d,\text{fid}}/r_d)$ (Mpc)	$H \times (r_d/r_{d,\text{fid}})$ (km/s/Mpc)	$D_A \times (r_{d,\text{fid}}/r_d)$ (Mpc)	Ref.
0.106	3.047 ± 0.137	-	-	-	Beutler et al. (2011)
0.150	4.480 ± 0.168	-	-	-	Ross et al. (2015)
0.38	-	1512 ± 24	81.2 ± 2.4	-	Alam et al. (2017a)
0.51	-	1975 ± 30	90.9 ± 2.4	-	
0.61	-	2307 ± 37	99.0 ± 2.5	-	
0.978	-	-	113.72 ± 14.63	1586.18 ± 284.93	Zhao et al. (2018)
1.230	-	-	131.44 ± 12.42	1769.08 ± 159.67	
1.526	-	-	148.11 ± 12.75	1768.77 ± 96.59	
1.944	-	-	172.63 ± 14.79	1586.18 ± 146.46	
2.4	-	5393.4 ± 176.8	227.56 ± 5.6	-	
					Des Bourbonx et al. (2017)

3. Cosmic Microwave Background (Planck 2018) Distance Prior:

$$R \equiv \sqrt{\Omega_m H_0^2 r(z_*)}/c \quad , \quad l_a \equiv \pi r(z_*)/r_s(z_*)$$

Cosmological probes

In our analysis, we totally consider 4 kinds of data combinations:

1. Pantheon+BAO(6dFGS+SDSS DR7 MGS+BOSS DR12)
2. Pantheon+BAO(6dFGS+SDSS DR7 MGS+BOSS DR12+eBOSS DR14)
3. Pantheon+BAO(6dFGS+SDSS DR7 MGS+BOSS DR12+eBOSS DR14+Lya)
4. Pantheon+BAO(6dFGS+SDSS DR7 MGS+BOSS DR12+eBOSS DR14+Lya)+CMB

The constraint results are obtained with Markov Chain Monte Carlo (MCMC) estimation using CosmoMC ([Lewis & Bridle 2002](#))

Results and Discussion

➤ Λ CDM model

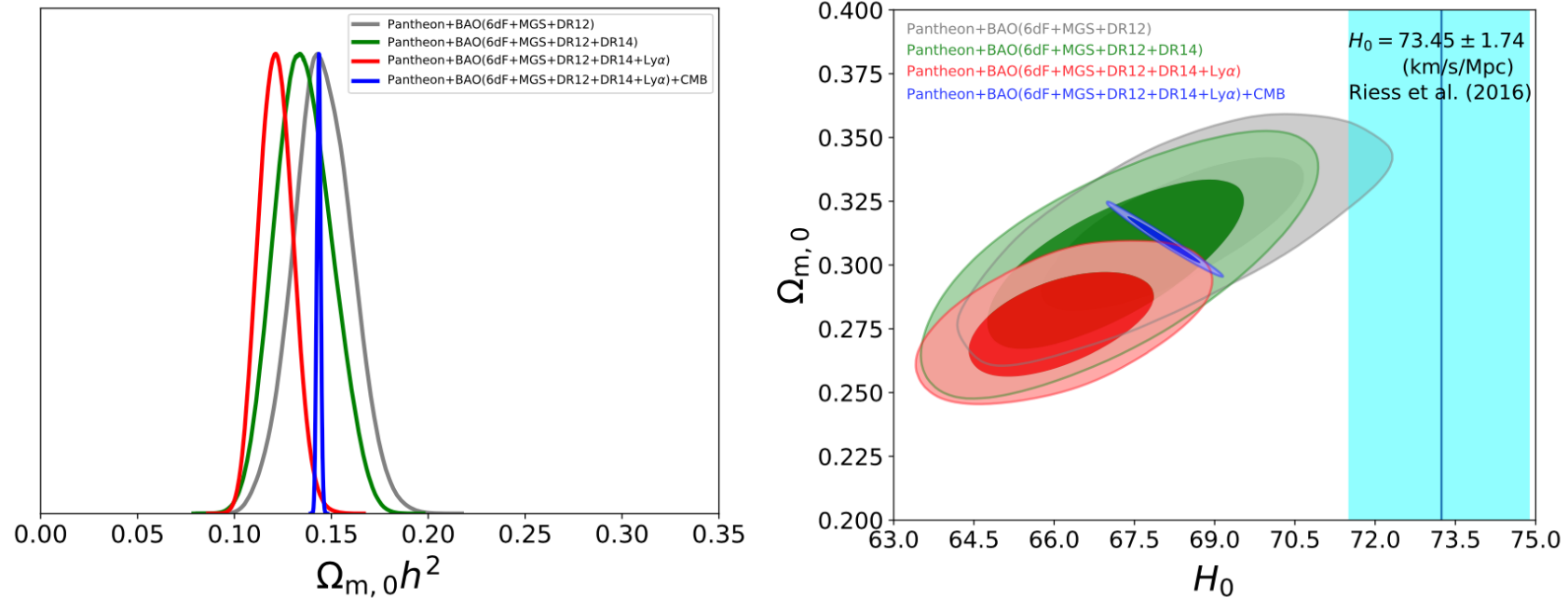


Figure 1. Observed constraints on standard Λ CDM. Left plot gives the 1D likelihood for $\Omega_{m,0}h^2$ and right plots shows the 1 σ and 2 σ contours for $\Omega_{m,0}$ vs H_0 . The cyan shadow in the right plot give H_0 results from Riess et al. (2016) and we show the constrain results from different data sets in different color.

Results and Discussion

➤ Metastable DE model I:

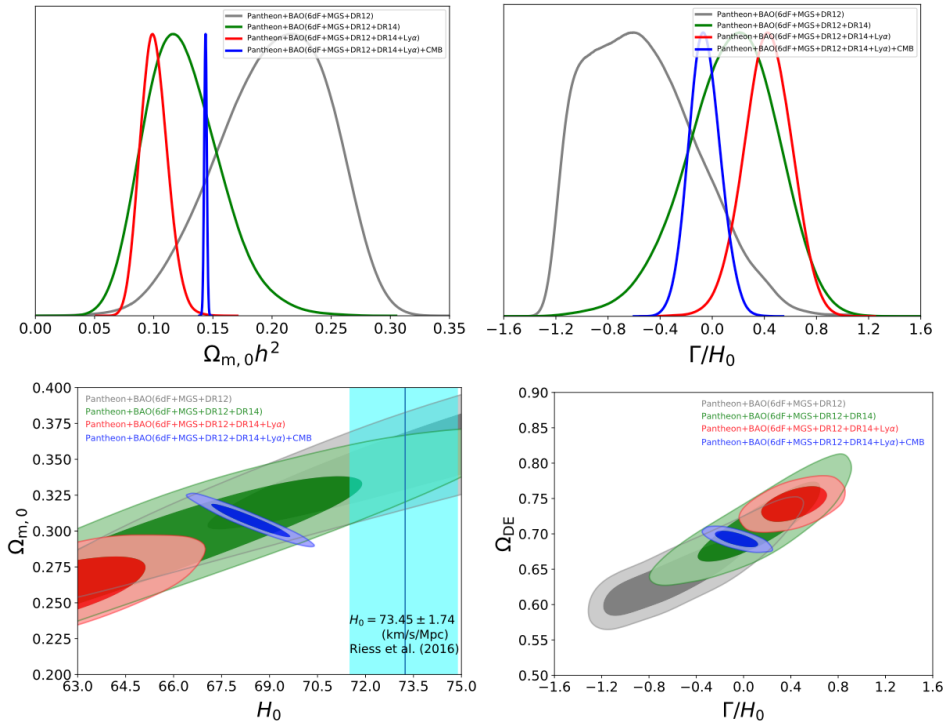


Figure 2. Observed constraints on model I. The upper two plots show the marginalized 1D likelihood for $\Omega_{m,0}h^2$ (left) and Γ/H_0 (right). The lower two plots show the marginalized 1σ and 2σ contours for matter density vs Hubble constant (left) and Ω_{DE} vs Γ/H_0 (right). Different color denotes for the constraint results from different data sets.

$$\dot{\rho}_{DE} = -\Gamma\rho_{DE}$$

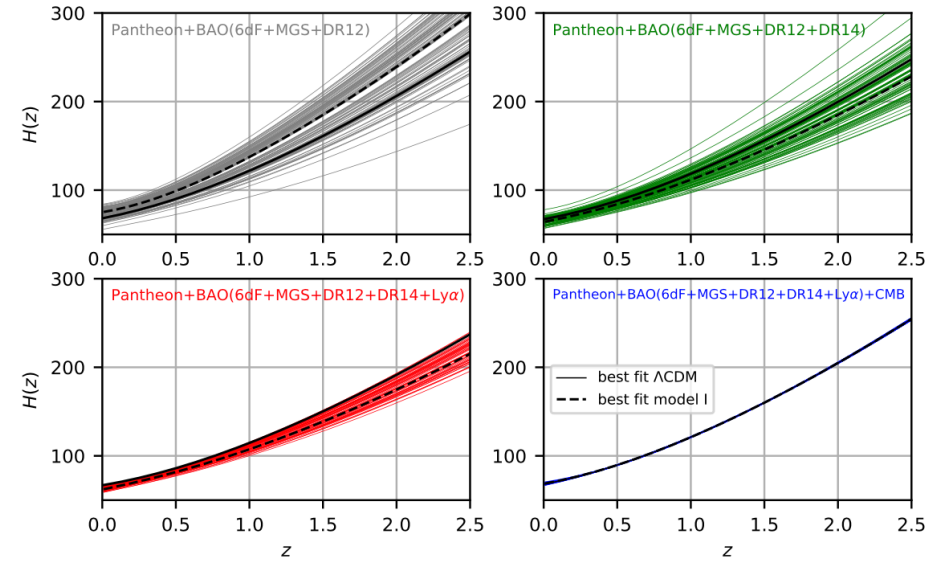


Figure 3. The Hubble parameter $H(z)$ for the metastable DE model I obtained with different data combinations. The solid black lines and the dashed black lines show $H(z)$ from the best fit of the Λ CDM model and the metastable DE model I with same data set, respectively.

Results and Discussion

➤ Metastable DE model II:

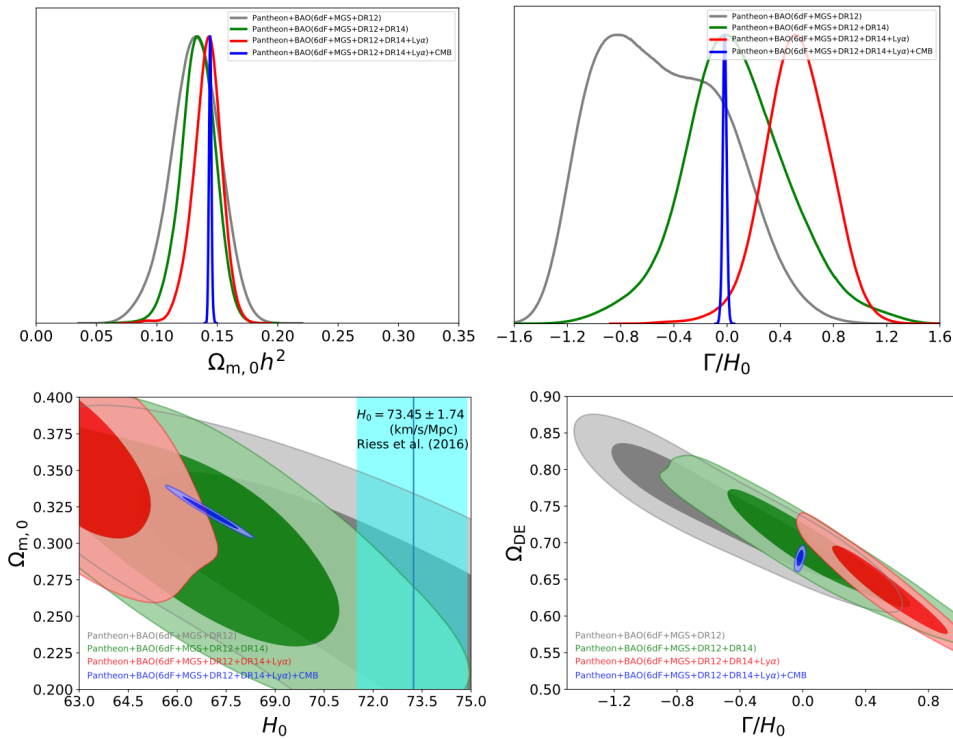


Figure 7. The constrain results for Model II. The upper two plots show the marginalized 1D likelihood for $\Omega_{m,0}h^2$ (left) and Γ/H_0 (right). The lower two plots show the marginalized 1σ and 2σ regions for matter density vs Hubble constant (left) and Ω_{DE} vs Γ/H_0 (right). Different color denotes for the constraint results from different data sets.

$$\dot{\rho}_{DE} = -\Gamma\rho_{DE}$$

$$\dot{\rho}_{DM} + 3H\rho_{DM} = \Gamma\rho_{DE}$$

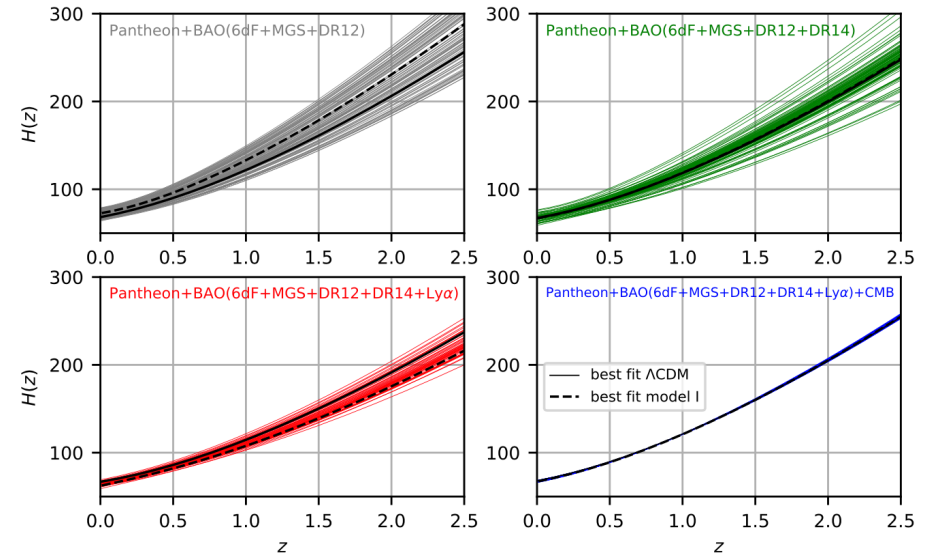


Figure 8. The Hubble parameter $H(z)$ for the metastable DE model II obtained with different data combinations. The solid black lines and the dashed black lines show $H(z)$ from the best fit of the Λ CDM model and the metastable DE model II with the same data set, respectively.

Summary

1. For Λ CDM model, Using latest data sets of SNe Ia, BAO and CMB, the H_0 tension between CMB and BAO measurements from Ly α becomes larger.
2. Metastable DE models cannot reduce this H_0 tension
3. Including the CMB distance prior to our analysis shows that both model I and model II are consistent with Λ CDM model
4. the results from Pantheon in combination with BAO(6dF+MGS+DR12+DR14+Ly α) support that DE density is decaying

In the recent work of [*Riess et al. \(2019\)*](#), they showed a larger H_0 tension between locally measurement and the value inferred from Planck CMB based on Λ CDM. It is therefore extremely important to understand the nature of these tensions.

Thank you~

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