Early Dark Energy models

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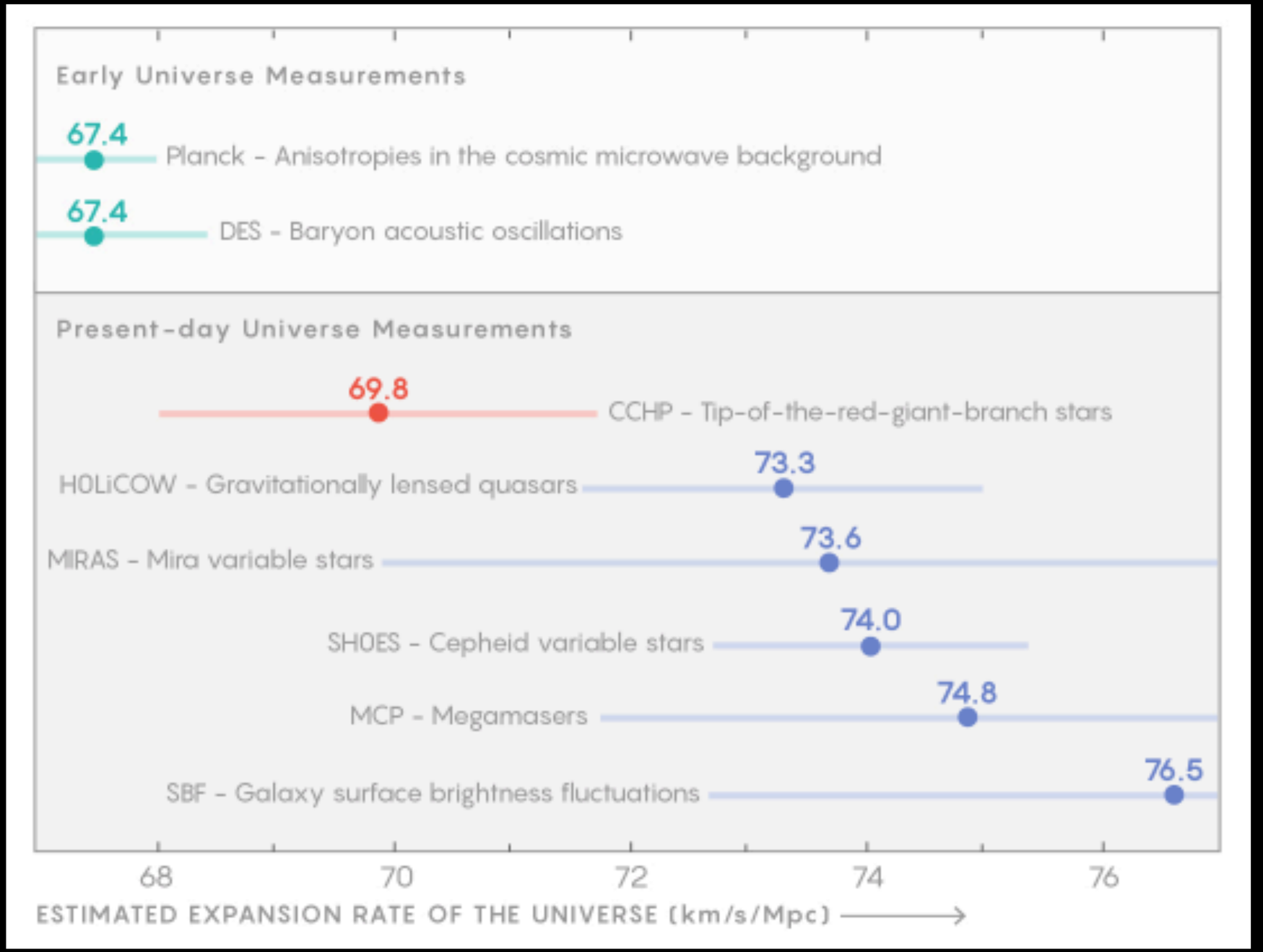
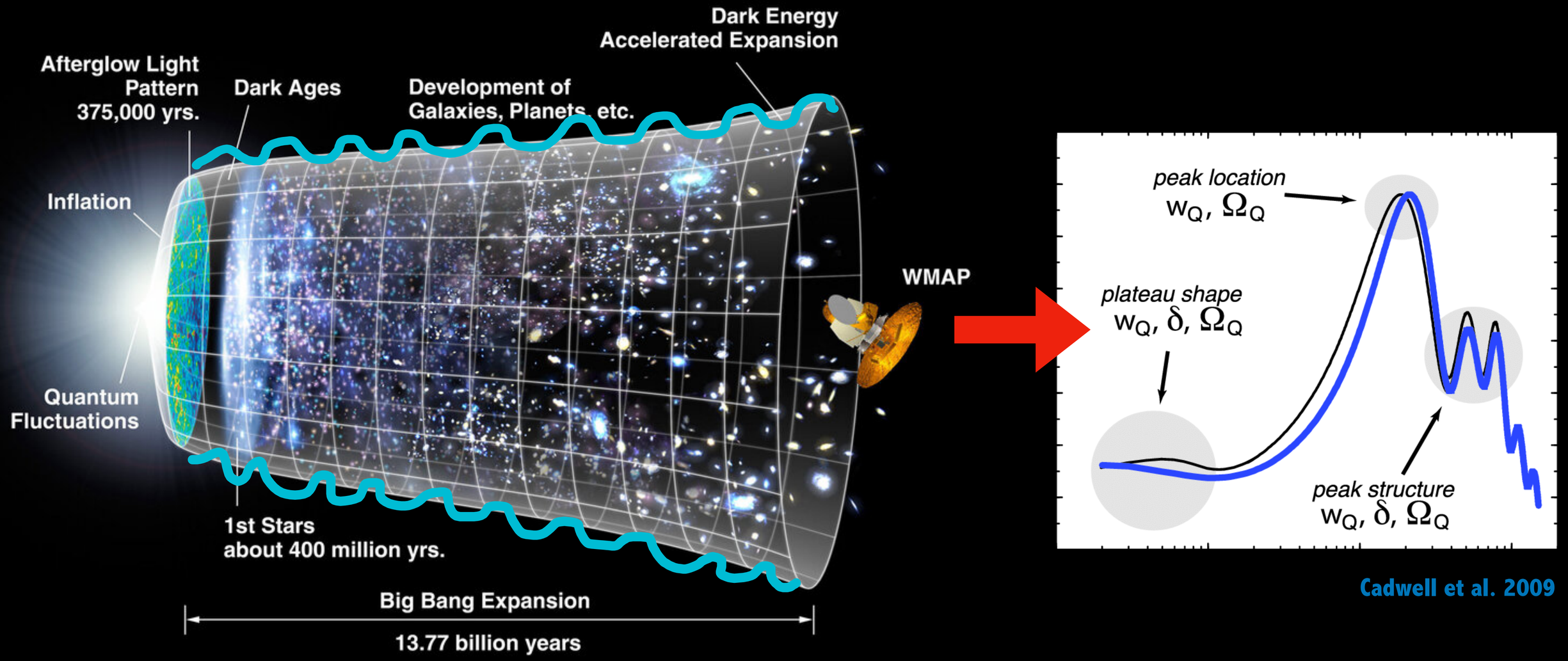
Work done in collaboration with Prof. Leonardo Castañeda (OAN)

CoCo 2021: Cosmology in Colombia, September 8th, 2021


Early Universe Measurements
67.4
Planck – Anisotropies in the cosmic microwave background
67.4
DES – Baryon acoustic oscillations
Present-day Universe Measurements
69.8
CCHP – Tip-of-the-red-giant-branch stars
73.3
H0LiCOW – Gravitationally lensed quasars
73.6
MIRAS – Mira variable stars
74.0
SH0ES – Cepheid variable stars
74.8
MCP – Megamasers
76.5
SBF – Galaxy surface brightness fluctuations
68
70
72
74
76
ESTIMATED EXPANSION RATE OF THE UNIVERSE (km/s/Mpc)

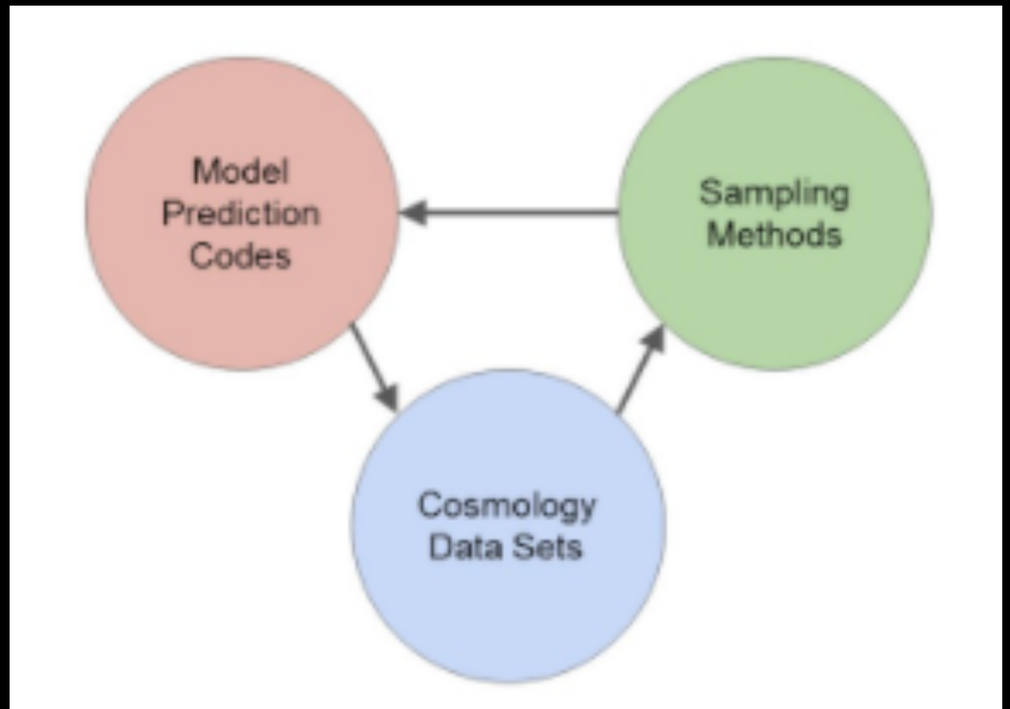


Cadwell et al. 2009

CosmoSIS

* CosmoSIS is a cosmological parameter estimation code. Version 1.6.

* It consolidates and connects together existing code for predicting cosmic observables, and makes mapping out experimental likelihoods with a range of different techniques much more accessible.

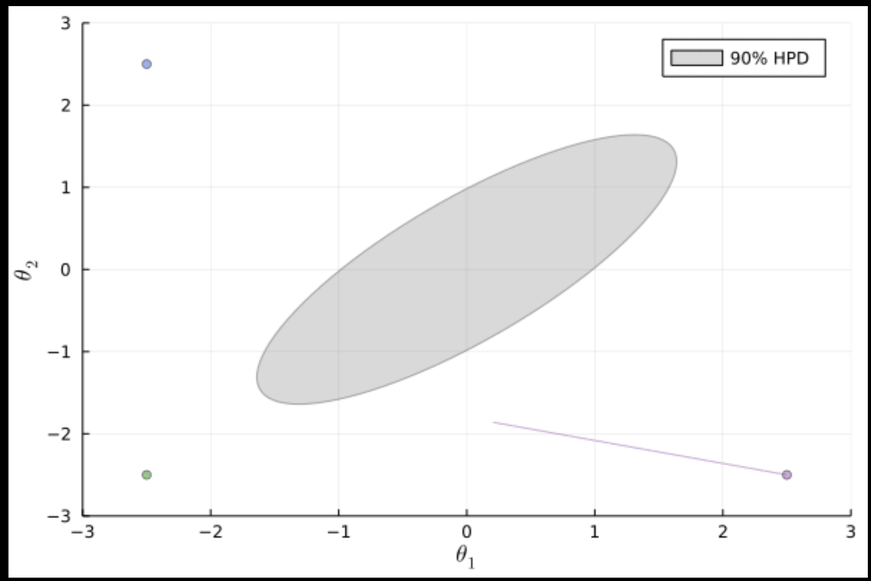


Zuntz et al. 2014

Sampler: EMCEE

Monte-Carlo Markov Chain that uses an ensemble of 'walkers' that explore the parameter space. Each walker chooses another walker at random and proposes along the line connecting the two of them using the Metropolis acceptance rule. The proposal scale is given by the separation of the two walkers.

Parameter	Type	Meaning	Default
walkers	integer	number of walkers in the space	
samples	integer	number of jumps to attempt per walker	
nsteps	integer	number of sample steps taken in between writing output	
random_start	bool	whether to start the walkers at random points in the prior instead of near the start. Usually a bad idea	N
start_points	string	a file containing starting points for the walkers. If not specified walkers are initialized randomly from the prior distribution.	(empty)
covmat	string	a file containing a covariance matrix for initializing the walkers.	(empty)



PASP, 125, 925, 306-312

CosmoSIS + EMCEE sampler hyperparameters

* **Walkers:** 64

* **Samples:** 1000

* **Nsteps:** 20

* **Random start:** False

* **Additional packages:** Consistency, CAMB, Growth Structure, SLTD

* **Minimum acceptance fraction:** 0.25

Model 1

Toy model with quadratic dependence with the scale factor a.

$$\omega = \omega_a + \omega_b \cdot a^2$$

Scolnic et al. 2018

Chuang et al. 2011; Beutler et al. 2012

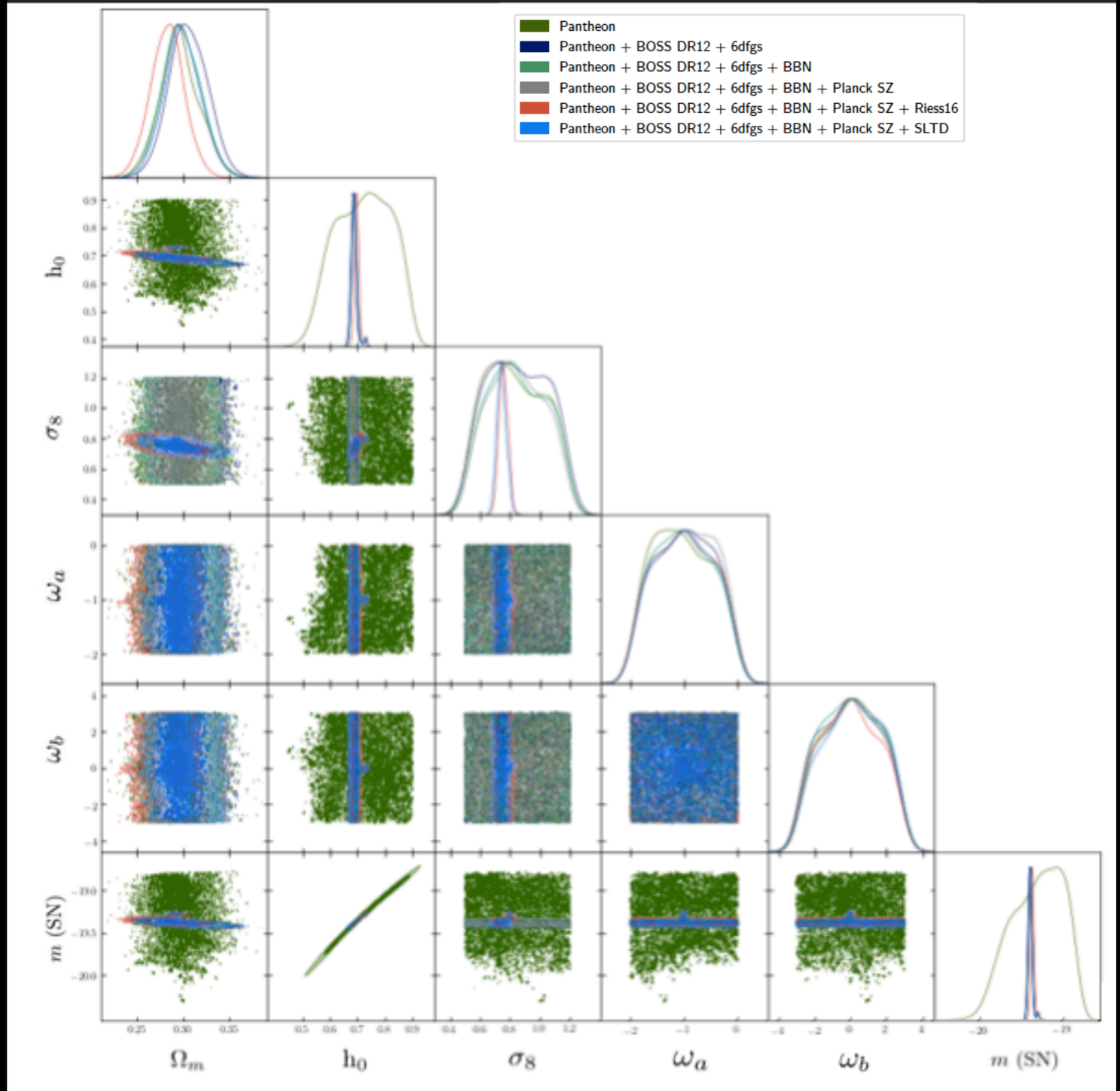
Alam et al. 2015

Beringer et al. 2012

Ade et al. 2013 Planck Collaboration

Riess et al. 2016

Suyu et al. 2018; Bonvin et al. 2017



Model 1

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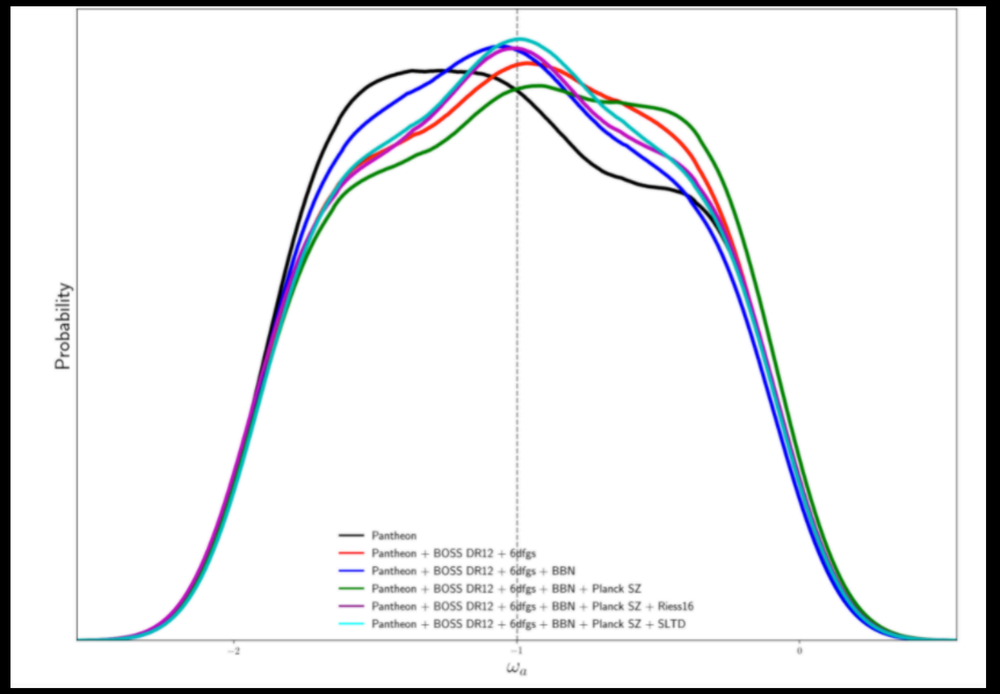

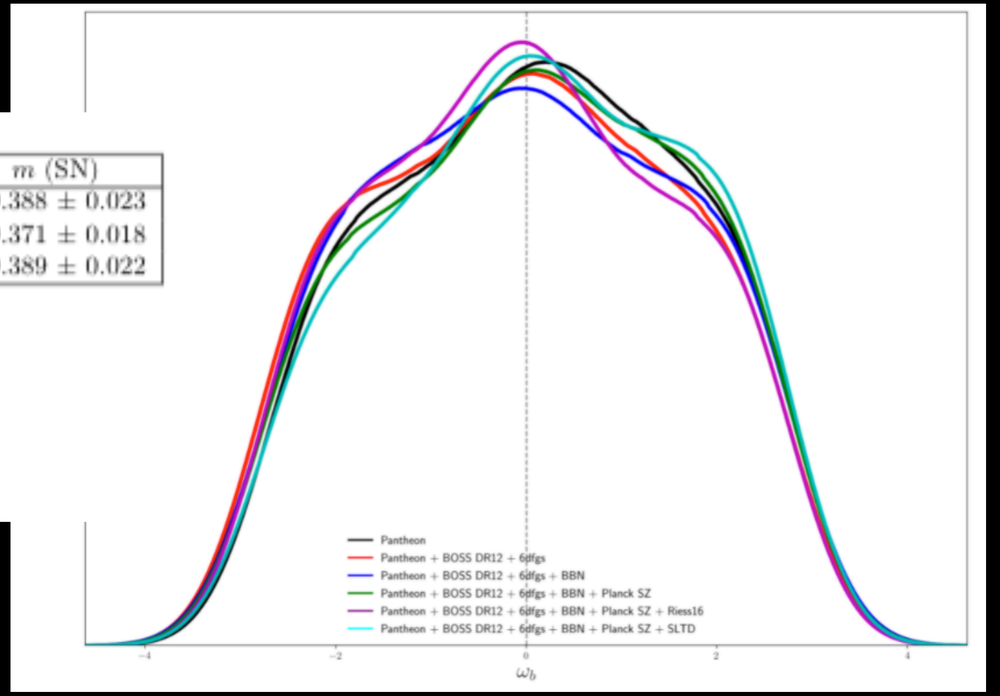

	Ω_m	h_0	σ_8	Ω_ϕ	ω_a	ω_b	m (SN)
Test 4	0.299 ± 0.021	0.687 ± 0.009	0.98 ± 0.35	0.701 ± 0.021	-0.693 ± 0.798	0.692 ± 2.048	-19.388 ± 0.023
Test 5	0.286 ± 0.022	0.695 ± 0.007	0.748 ± 0.025	0.714 ± 0.022	-0.568 ± 0.823	-1.991 ± 0.576	-19.371 ± 0.018
Test 6	0.297 ± 0.017	0.688 ± 0.009	0.743 ± 0.036	0.703 ± 0.017	-1.246 ± 0.449	1.998 ± 2.98	-19.389 ± 0.022

Test 4: Pantheon + BOSSDR12 + 6DFGS + BBN + Planck SZ.
Test 5: Pantheon + BOSSDR12 + 6DFGS + BBN + Planck SZ + Riess16.
Test 6: Pantheon + BOSSDR12 + 6DFGS + BBN + Planck SZ + SLTD.

Model 1

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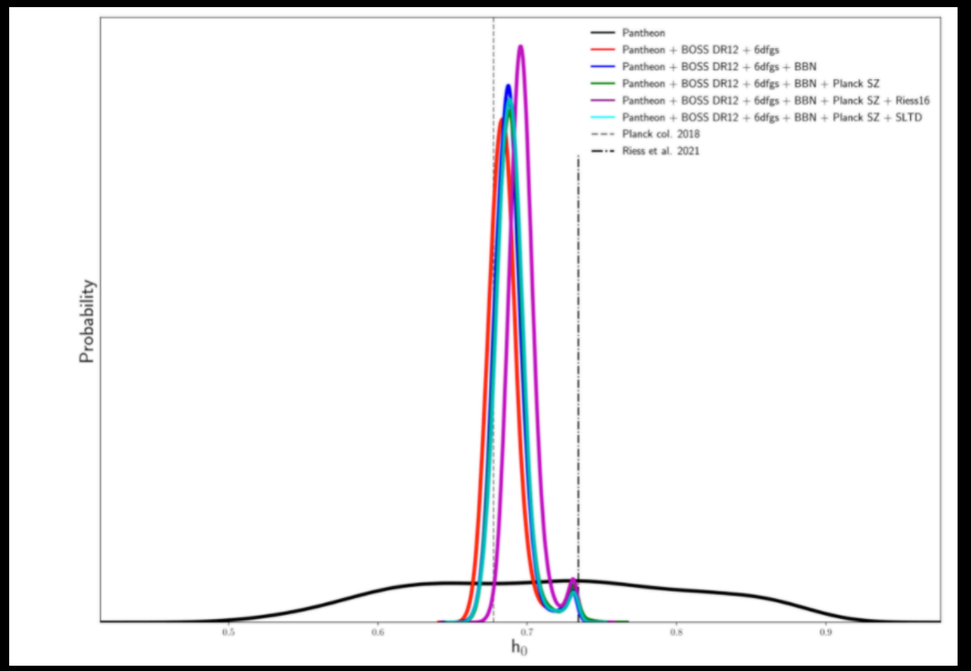
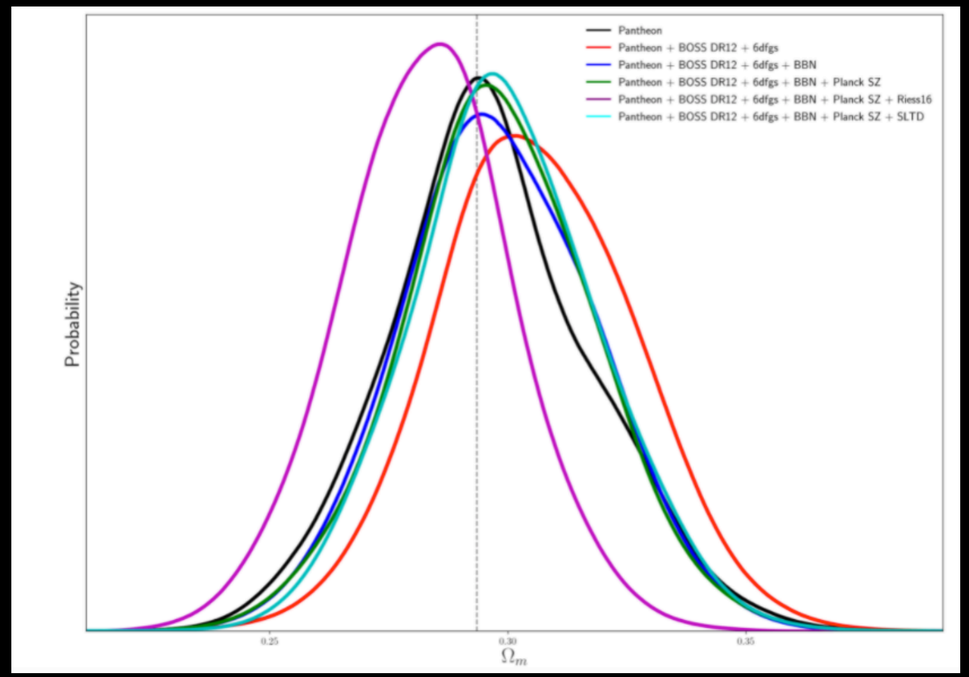
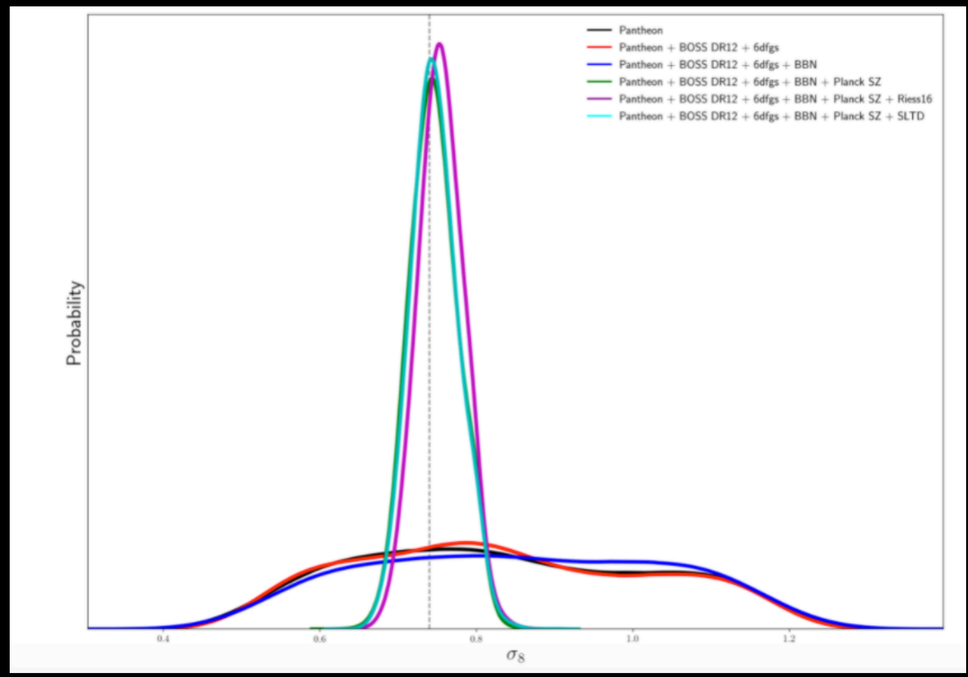






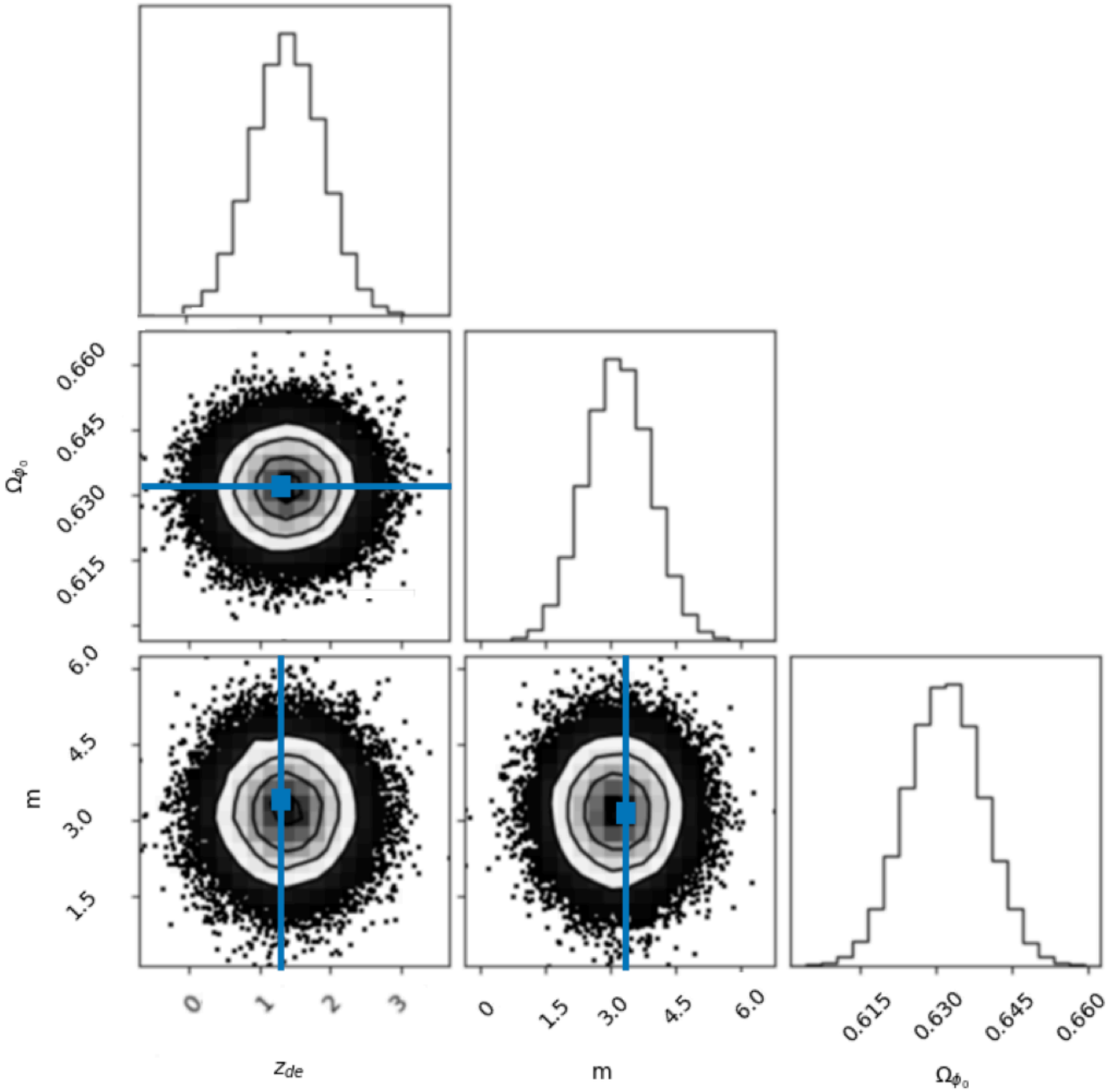
Model 2. First method

* Ω_ϕ should be strictly positive, [0,1] in the Concordance model.

* Negative values of **m** lead to an inverted transition between the radiation and the De-Sitter attractors (the latter occurring first than the former), which is not consequent with the thermal history of the Universe. On the other hand, **m = 0** produces no transition whatsoever, then, **m** is strictly positive in the framework of the Standard Model.

* The redshift of matter - dark energy equality, z_{DE} has already occurred since the Universe is experiencing an accelerated expansion $0 < z_{de} < 1.5$. The upper limit takes into account that cosmic structure was formed during the matter domination epoch, and that has been observed through different with different surveys to-date 2dFGRS, 6dFGS, WiggleZ and the Sloan Digital Sky Survey SDSS.

García et al. 2021



Model 2. First method

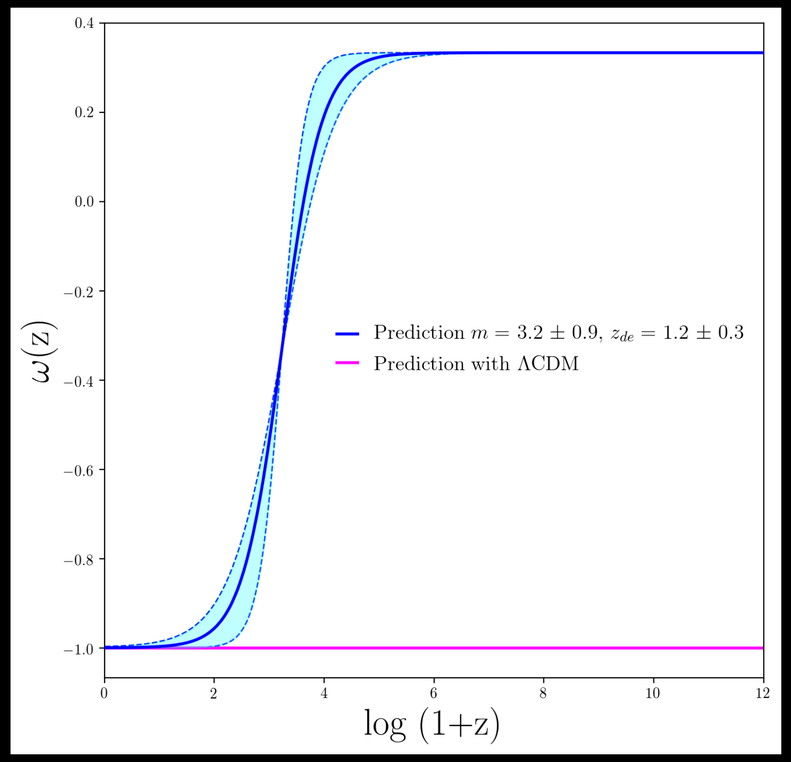
Summary of the best values of the free parameters of the DE model and comparison with the ΛCDM. Column 1: parameter name. Column 2: estimates for our model. Column 3: ΛCDM comparison (Planck Collaboration et al., 2018).

Parameter	Our model	ΛCDM model
Ω_{ϕ_0}	0.631 ± 0.005	0.6889 ± 0.0056
m	3.2 ± 0.9	–
z_{de}	1.2 ± 0.3	–
Ω_{m_0}	0.369 ± 0.005	0.3111 ± 0.0056
ω_0	-0.976 ± 0.358	-1

The equation of state of our early dark energy candidate is given by:

$$\omega_\phi(z) = \frac{4/3}{\left(\frac{1+z_*}{1+z}\right)^m + 1} - 1.$$

$$z_* = \frac{z_{eq} + z_{de}}{2}$$



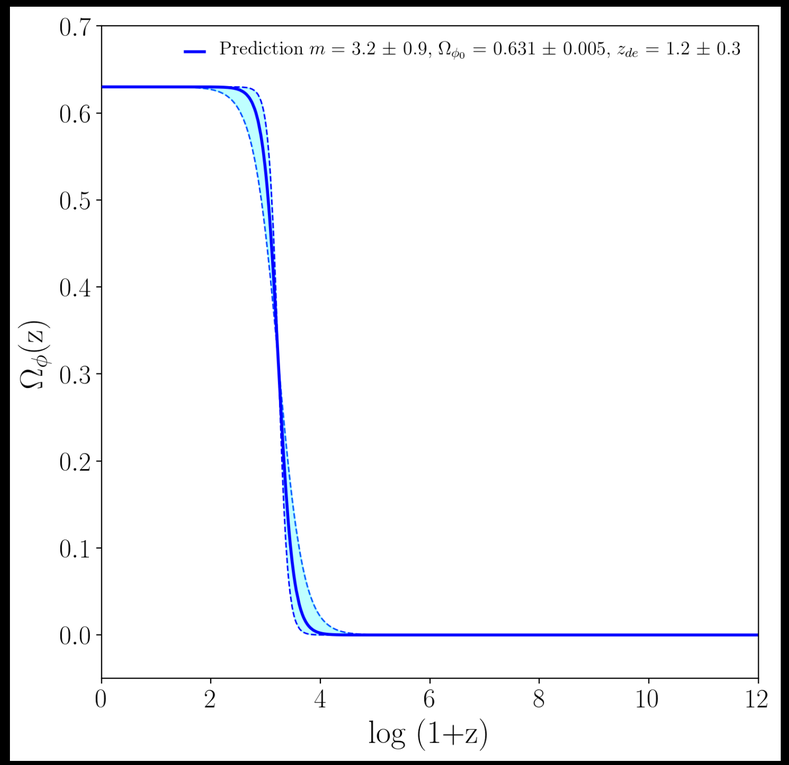
Equation of state w(z) as a function of redshift z.

The energy density fraction associated with the dark energy field is:

$$\Omega_\phi(z) = \frac{\rho_0}{\rho_{\rm cr}} = \frac{\Omega_{\phi 0} \cdot f(z)}{\Omega_{\phi 0} \cdot f(z) + \Omega_{m0} \cdot (1+z)^3}.$$

The age of the Universe in the framework of a dark energy component is:

$$t_0 = 13.441 \pm 0.004 \ \ \text{Gyr}.$$



Dark energy density fraction evolution with redshift z.

García et al. 2021

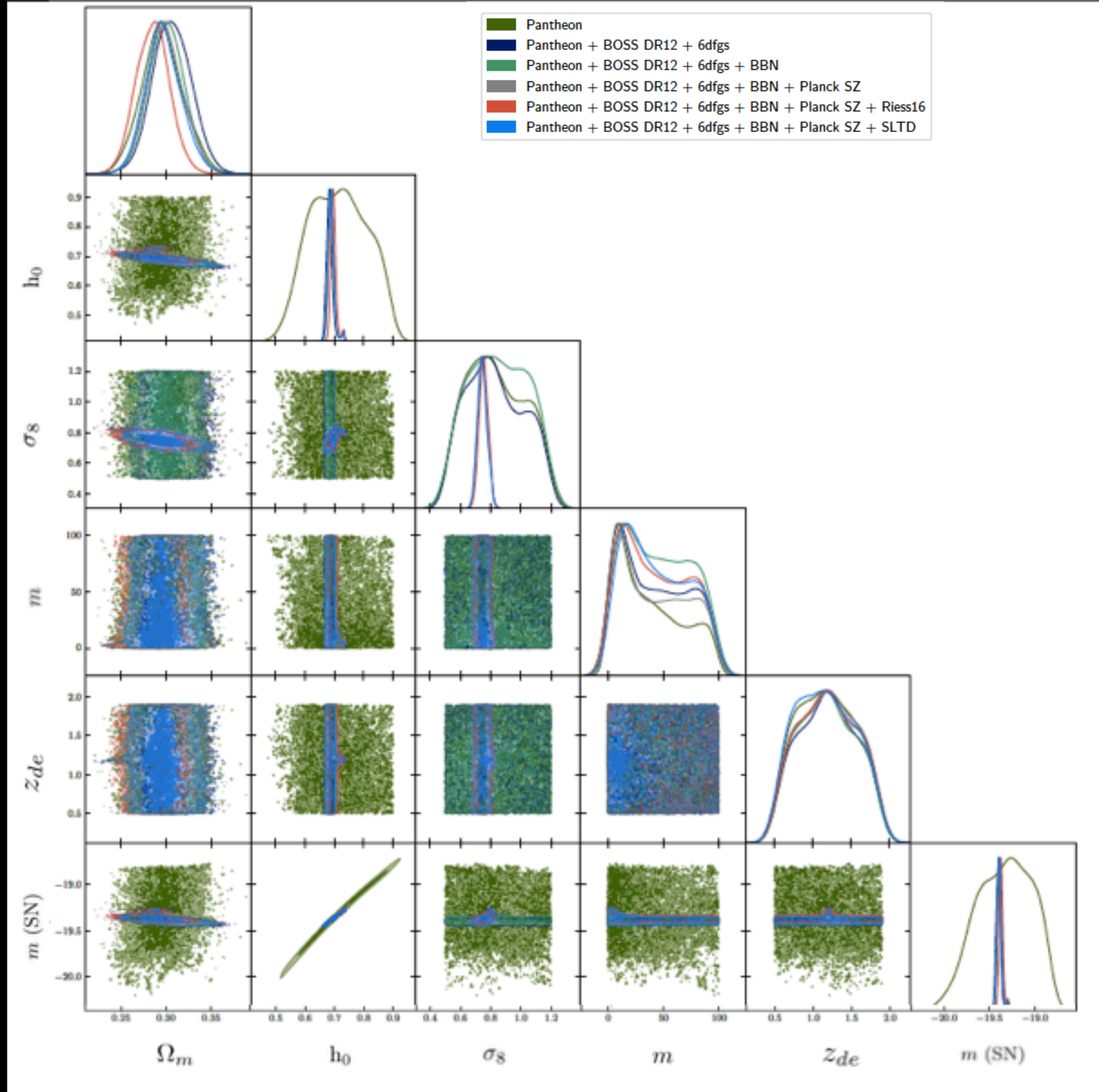
Model 2.

Constraining the model with CosmoSIS

Using the concordance cosmology, we skip computing the value of Ω_ϕ. Instead, we explore the parameter space for Ω_m, and set $\Omega_k = 0$.

$$\omega(z) = \frac{4/3}{\left(\frac{1+z_*}{1+z}\right)^m + 1} - 1$$

$$z_* = \frac{z_{eq} + z_{DE}}{2}$$



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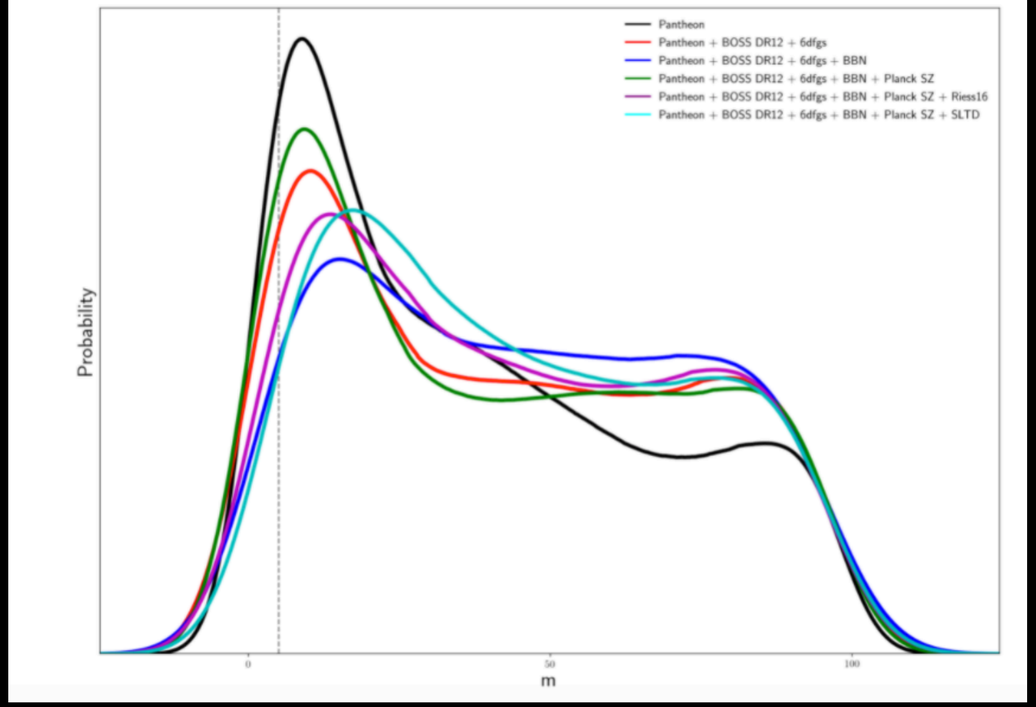

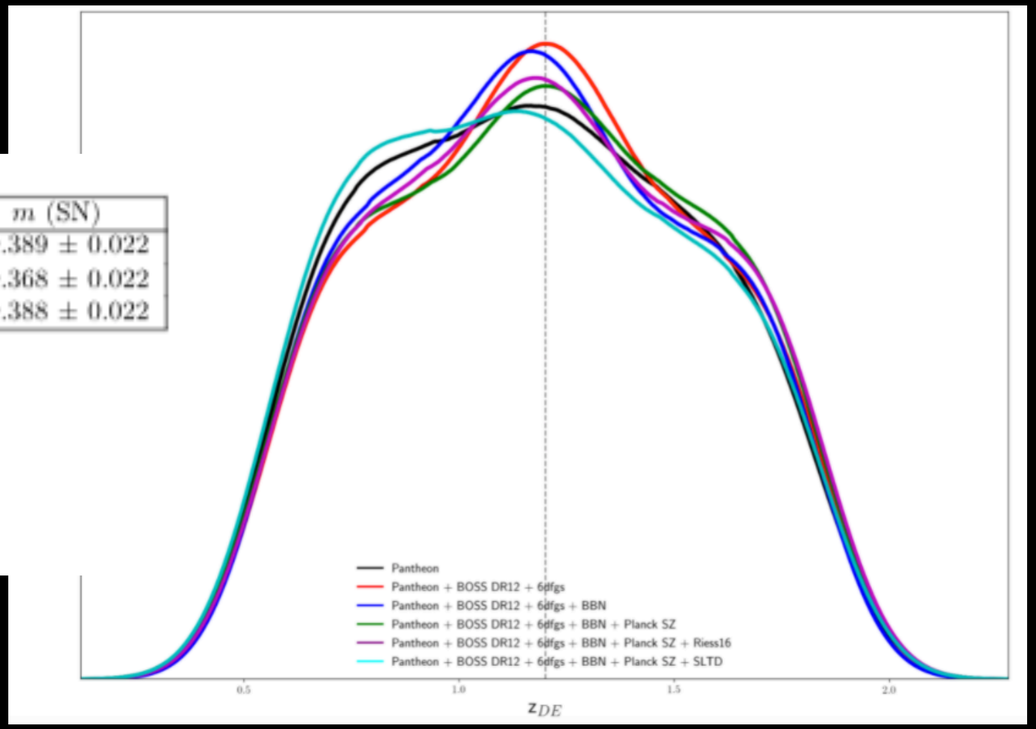

	Ω_m	h_0	σ_8	Ω_ϕ	m	z_{dc}	m (SN)
Test 4	0.298 ± 0.020	0.687 ± 0.001	0.742 ± 0.031	0.702 ± 0.020	53.809 ± 40.805	0.609 ± 0.149	-19.389 ± 0.022
Test 5	0.283 ± 0.016	0.697 ± 0.01	0.723 ± 0.001	0.713 ± 0.016	66.312 ± 35.453	1.073 ± 0.478	-19.368 ± 0.022
Test 6	0.299 ± 0.024	0.688 ± 0.009	0.744 ± 0.031	0.701 ± 0.024	27.382 ± 23.816	0.858 ± 0.305	-19.388 ± 0.022

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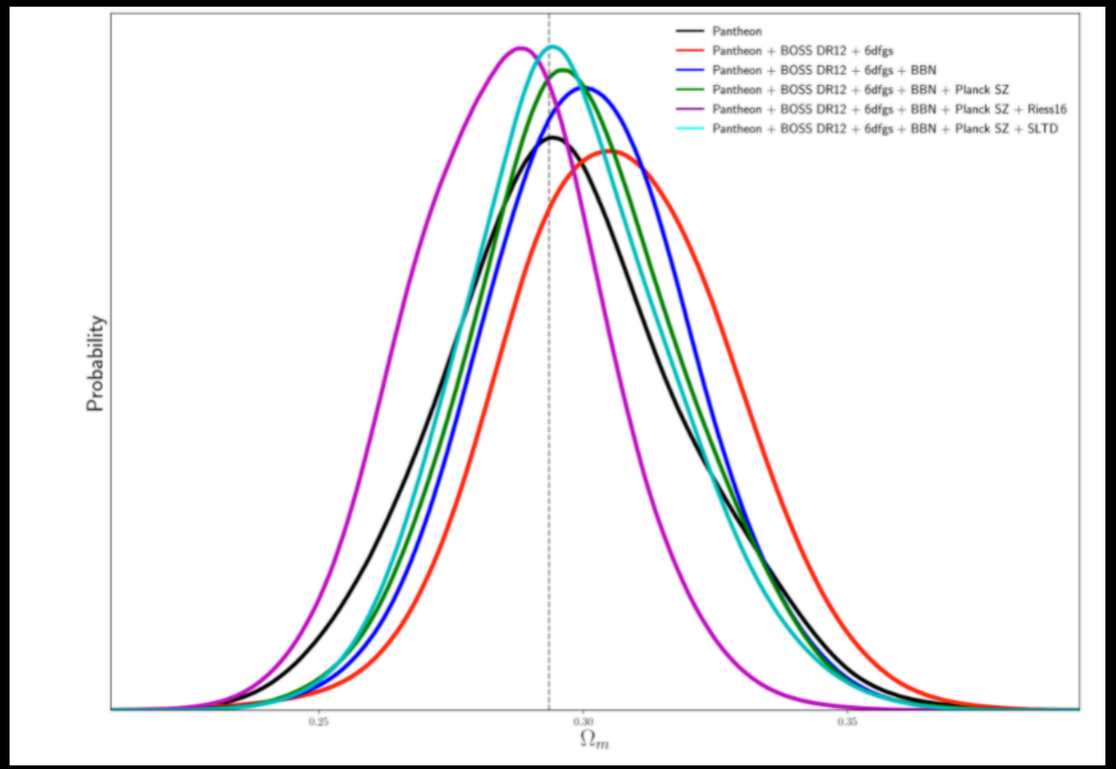

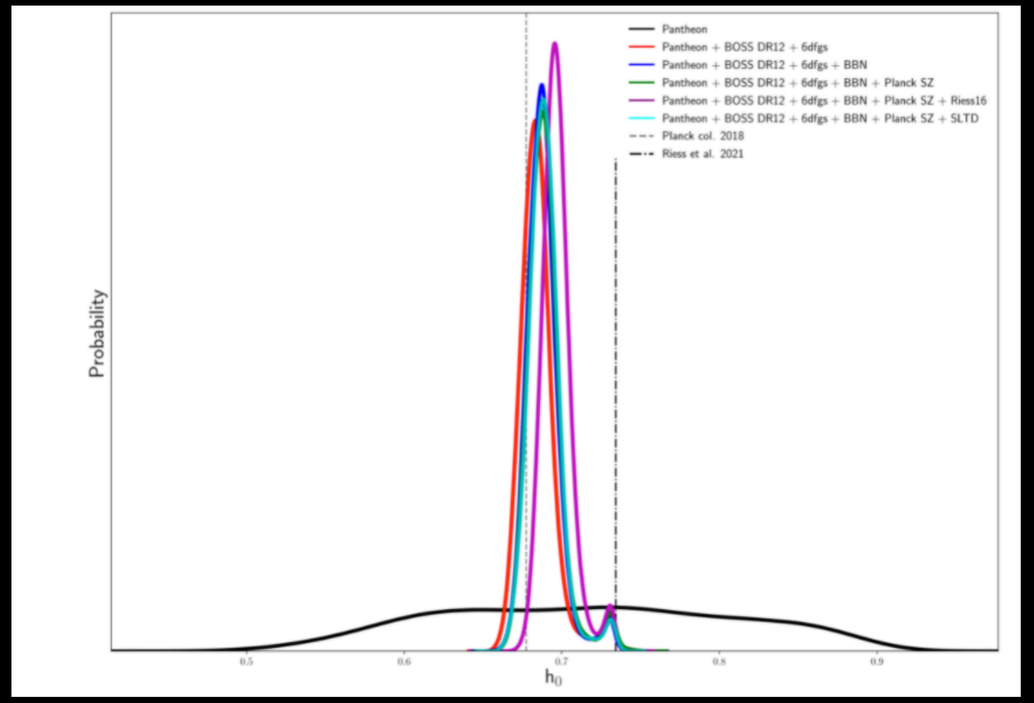

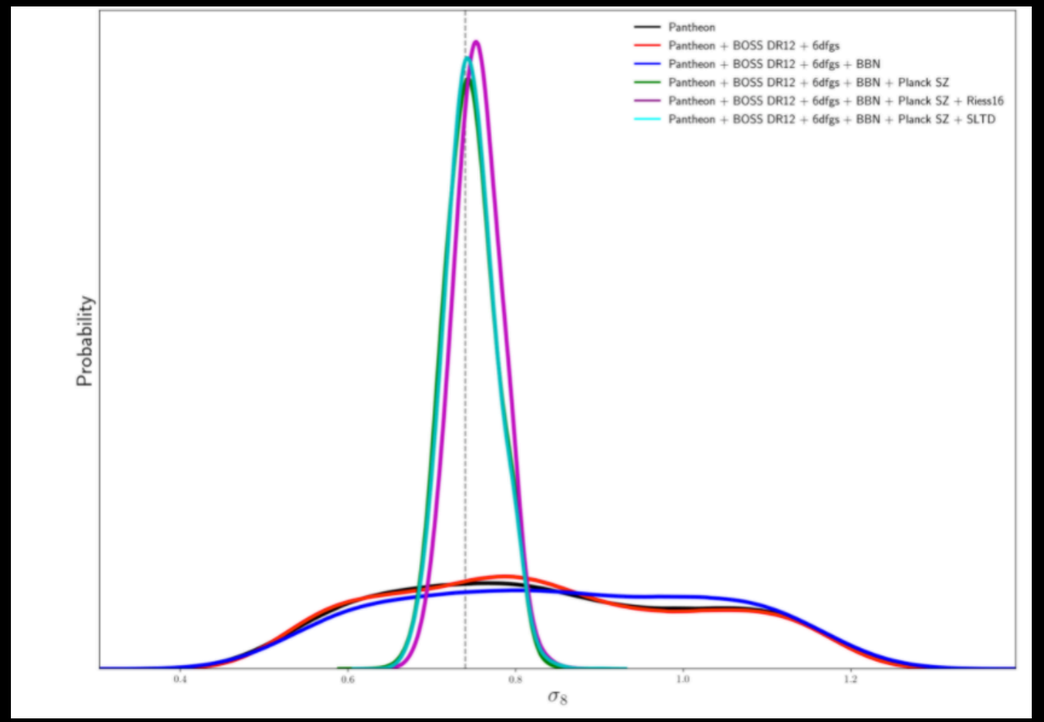

Conclusions & Perspectives

- The current Hubble tension (and in at some degree, the sigma-8 tension) could be addressed by introducing dynamical dark energy models that have non-negligible contributions to the Hubble parameter in the early Universe.

- These models produce a faster evolution of the structure, since they departure from the radiation domination epoch earlier than the ΛCDM model. Further analysis is needed to understand in depth the impact of these early dark energy models.

- Next steps for this investigation aim to:

  * Include other cosmological likelihoods in cosmoSIS,

  * Test these models in scenarios during the radiation domination epoch,

  * Explore other cosmological estimators & observational constraints that allow us to validate / exclude the present parametrizations of the equation of state.

Thanks for your attention!

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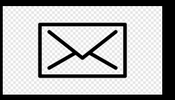

@PenLua