A Negative Cosmological Constant in the Dark Sector?

Invisibles (Online) Workshop
2021

Hunting Invisibles: Dark Sectors, Dark Matter and Neutrinos

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The Concordance Model

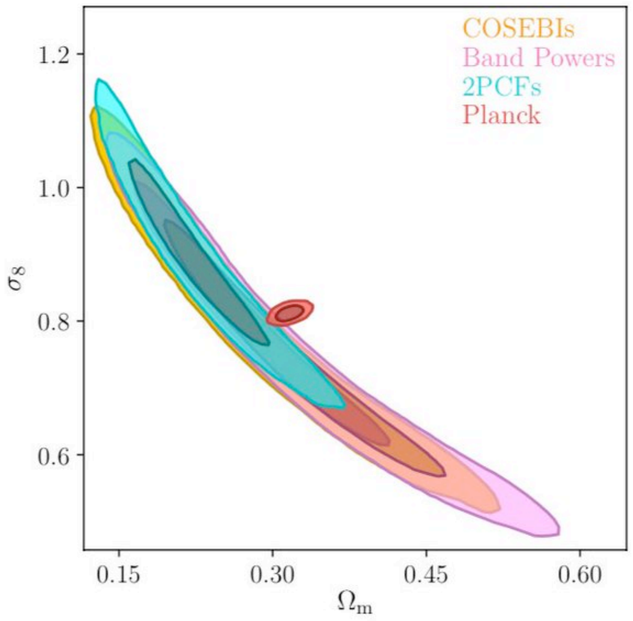
[Adam Riess - Nature 2020]

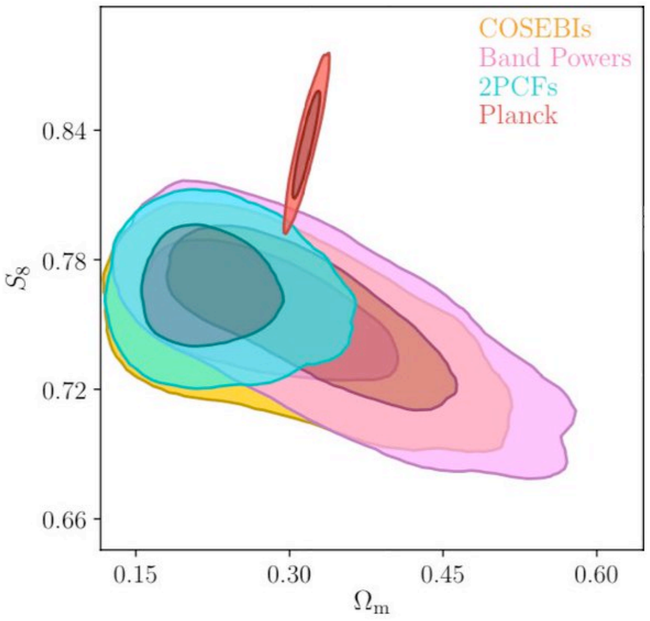
Remarkable agreement with observations across a wide variety of

- Scales
- Epochs

But ...

- A Crisis ($\sim 5\sigma$) in value H_0 Early vs Late
- (Milder $\sim 2\sigma$) but longstanding curiosity in S_8 or σ_8

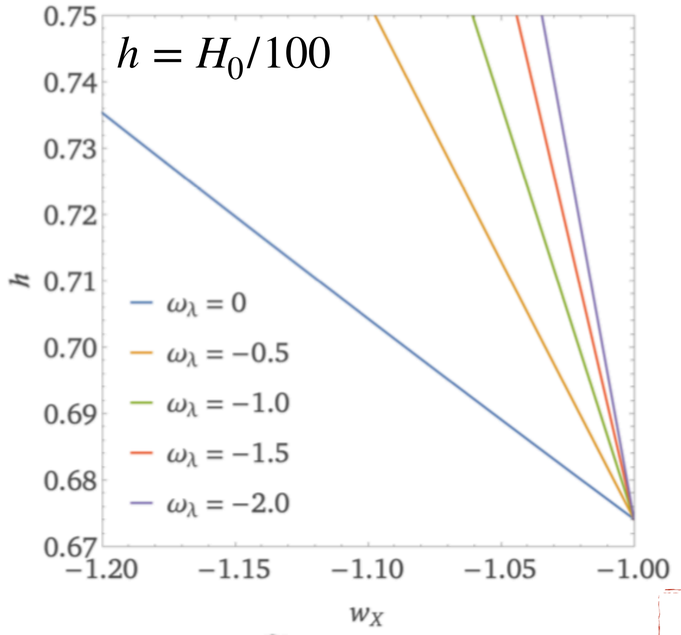




[KiDS-1000 - arXiv: 2007.15633]

How does Ω_λ affect H_0?

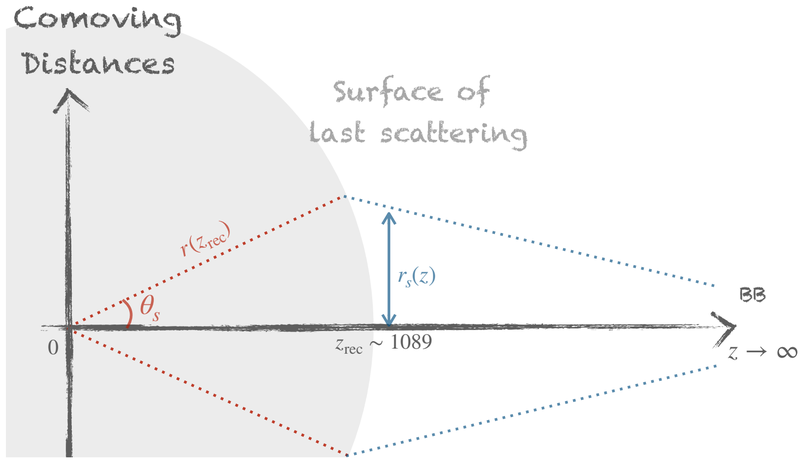
$$\omega_i = \Omega_i h^2$$

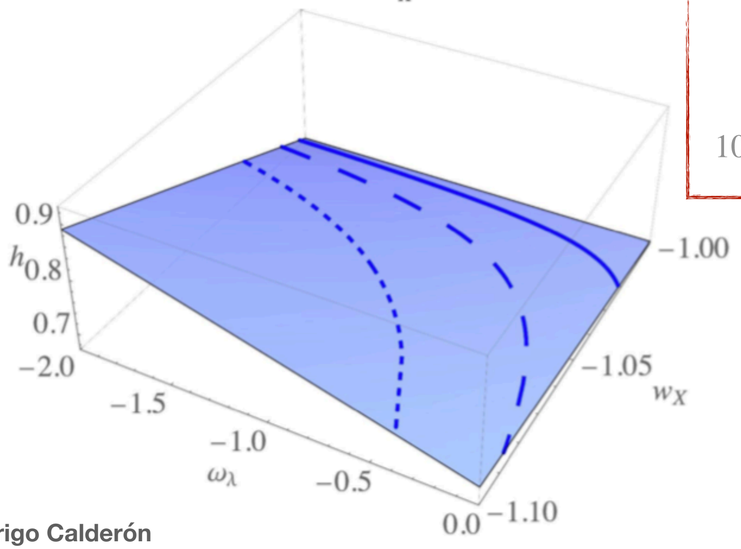


$$\theta_s \simeq \frac{r_s}{r} \rightarrow r = \frac{r_s}{\theta_s}$$

$100\,\omega_b$	$100\,\omega_c$	$N_{\rm eff}$	m_ν (eV)	r_s (Mpc)	r_d (Mpc)	$100\,\theta_s$
2.237	12.00	3.046	(0,0,0.06)	144.43	147.09	1.04110

TABLE I. Parameter values as given by the Planck 2018





θ_s is geometric,
Exquisitely constrained
by Planck '18
$100\,\theta_s(z_{\rm rec}) = 1.04110 \pm 0.00031$

$$r(z_{\rm rec}) \simeq \frac{c}{100h}\int_0^{z_{\rm rec}} \frac{dz'}{\sqrt{\omega_m(z') + \omega_X(z'; w_X) + \omega_\lambda}} = 13872.8\ {\rm Mpc}$$

Find (w_X, ω_λ, h)
satisfying the above equation !

$$h = 0.673 + (w_X + 1)(0.93\omega_\lambda - 0.33)$$

- Needs less "phantomness" to accommodate a higher H_0 $(w_{DE} < -1)$

Results: SNe+BAO+θ_s

TABLE III. 68% credible intervals for SN+BAO+θ_s.

Model	$100h$	w_0	w_∞ or w_a	ω_λ	$\ln \mathcal{Z}$	K
Λ	$67.382^{+0.107}_{-0.096}$				-532.4	1
w	$68.62^{+0.85}_{-0.83}$	$-1.042^{+0.028}_{-0.029}$		[0]	-533.1	0.54
λw	$68.66^{+0.79}_{-0.75}$	$-1.0102^{+0.0076}_{-0.0203}$		$-0.91^{+0.73}_{-1.88}$	-534.7	0.11
CPL	$68.60^{+0.78}_{-0.84}$	$-1.038^{+0.032}_{-0.029}$	$-0.020^{+0.074}_{-0.055}$	[0]	-532.6	0.83
λCPL	$68.72^{+0.77}_{-0.87}$	$-1.007^{+0.016}_{-0.028}$	$-0.58^{+0.43}_{-1.11}$	$-0.032^{+0.058}_{-0.044}$	-534.1	0.18
CPLw_0	$68.52^{+0.83}_{-0.85}$	$-1.052^{+0.039}_{-0.038}$	$[-(1+w_0)]$	[0]	-533.0	0.60
λCPLw_0	$68.51^{+0.72}_{-0.74}$	$-1.014^{+0.011}_{-0.021}$	$[-(1+w_0)]$	$-0.84^{+0.65}_{-1.57}$	-534.6	0.12
CPLw_a	$68.34^{+0.39}_{-0.63}$	$[-1]$	$-0.124^{+0.083}_{-0.050}$	[0]	-532.1	1.48
λCPLw_a	$68.63^{+0.78}_{-0.75}$	$[-1]$	$-0.034^{+0.024}_{-0.057}$	$-1.03^{+0.78}_{-1.81}$	-533.1	0.52
I	$68.46^{+0.82}_{-0.83}$	$-1.042^{+0.033}_{-0.032}$	$[-1]$	[0]	-533.2	0.48
λI	$68.41^{+0.82}_{-0.75}$	$-1.0092^{+0.0081}_{-0.0242}$	$[-1]$	$-0.92^{+0.76}_{-1.92}$	-534.8	0.093
II	$67.86^{+0.21}_{-0.34}$	$[-1]$	$-1.127^{+0.090}_{-0.053}$	[0]	-532.2	1.33
λII	$68.58^{+0.66}_{-0.59}$	$[-1]$	$-1.059^{+0.035}_{-0.070}$	$-1.15^{+0.75}_{-1.76}$	-532.1	1.36
III	$67.93^{+0.47}_{-0.50}$	$-1.04^{+0.14}_{-0.11}$	$-1.128^{+0.092}_{-0.049}$	[0]	-532.3	1.20
λIII	$68.93^{+1.03}_{-0.89}$	$-1.046^{+0.070}_{-0.083}$	$-1.090^{+0.054}_{-0.068}$	$-0.65^{+0.43}_{-0.95}$	-531.4	2.96

[Calderon+20 - arXiv:2008.10237]

Bayes Theorem

$$\mathscr{P}(\theta\,|\,\mathscr{D}) = \frac{\mathscr{L}(\mathscr{D}\,|\,\theta) \times \pi(\theta)}{\mathscr{Z}(\mathscr{D})}$$

"Likelihood" "Prior" "Evidence"

Compute Bayes Factor

$$K \equiv \frac{\mathscr{Z}_1}{\mathscr{Z}_0}$$

$K < 1$ Disfavoured

$K > 1$ Favoured

Use as indicator!

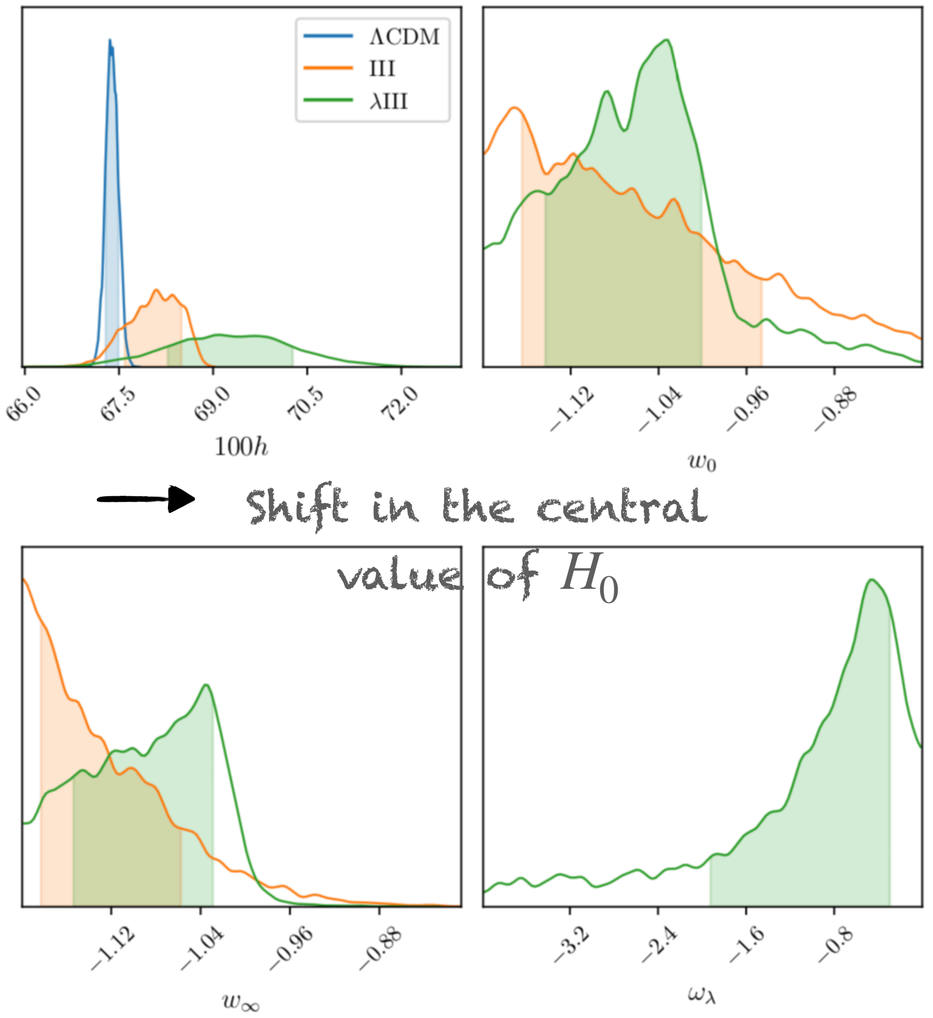
Results: SNe+BAO+θ_s+H_0

TABLE IV. 68% credible intervals for SN+BAO+θ_s +H_0 (HST Mira).

Model	$100h$	w_0	w_∞ or w_a	ω_λ	$\ln Z$	K
Λ	$67.386^{+0.105}_{-0.099}$				-533.5	1
w	$68.83^{+0.82}_{-0.83}$	$-1.049^{+0.028}_{-0.027}$		[0]	-533.7	0.82
λw	$68.81^{+0.86}_{-0.77}$	$-1.0122^{+0.0086}_{-0.0251}$		$-0.81^{+0.66}_{-1.75}$	-535.4	0.16
CPL	$68.77^{+0.75}_{-0.80}$	$-1.044^{+0.031}_{-0.028}$	$-0.020^{+0.072}_{-0.057}$	[0]	-533.3	1.26
λCPL	$68.75^{+0.84}_{-0.78}$	$-1.005^{+0.015}_{-0.022}$	$-0.035^{+0.053}_{-0.042}$	$-0.71^{+0.52}_{-1.26}$	-534.8	0.30
CPLw_0	$68.71^{+0.82}_{-0.83}$	$-1.061^{+0.038}_{-0.037}$	$[-(1+w_0)]$	[0]	-533.7	0.87
λCPLw_0	$68.72^{+0.83}_{-0.93}$	$-1.016^{+0.012}_{-0.033}$	$[-(1+w_0)]$	$-0.72^{+0.58}_{-1.64}$	-535.3	0.18
CPLw_a	$68.42^{+0.35}_{-0.48}$	$[-1]$	$-0.134^{+0.063}_{-0.044}$	[0]	-532.8	1.99
λCPLw_a	$68.76^{+0.70}_{-0.73}$	$[-1]$	$-0.035^{+0.022}_{-0.054}$	$-1.12^{+0.83}_{-1.69}$	-533.7	0.81
I	$68.67^{+0.80}_{-0.82}$	$-1.050^{+0.032}_{-0.031}$	$[-1]$	[0]	-533.9	0.69
λI	$68.51^{+1.09}_{-0.77}$	$-1.0096^{+0.0076}_{-0.0272}$	$[-1]$	$-0.96^{+0.80}_{-1.92}$	-535.6	0.13
II	$67.89^{+0.18}_{-0.30}$	$[-1]$	$-1.137^{+0.083}_{-0.044}$	[0]	-533.1	1.53
λII	$68.73^{+0.70}_{-0.60}$	$[-1]$	$-1.074^{+0.040}_{-0.073}$	$-1.09^{+0.67}_{-1.24}$	-532.6	2.54
III	$68.09^{+0.41}_{-0.50}$	$-1.077^{+0.131}_{-0.087}$	$-1.137^{+0.080}_{-0.045}$	[0]	-533.1	1.52
λIII	$69.28^{+0.99}_{-1.00}$	$-1.063^{+0.062}_{-0.080}$	$-1.083^{+0.054}_{-0.071}$	$-0.74^{+0.45}_{-1.18}$	-533.3	1.31

[Calderon+20 - arXiv:2008.10237]

73.30 ± 4 (HST-Mira)



Conclusions & Perspectives

- SN+BAO constrain the **late-time** expansion history to be close to that of ΛCDM ($w_X \sim -1$)
- Higher "**Evidence**" for models with new physics appearing at large-z !
- Although not enough to solve the tension, Introducing λ does allow for higher values of $H_0 \sim 69$
- If **True** value of $H_0 \sim 73\ \mathrm{km\,.\,s^{-1}\,.\,Mpc^{-1}}$
  - ↳ Potentially rule out such models. (& any other ΛCDM competitor!)
  - ↳ Gravitational Wave determination of H_0

- Check out poster for more !

Click here to visit interactive poster

- Other interesting phenomenological features

Thank you!