BAO miscalibration cannot rescue late-time solutions to the Hubble tension

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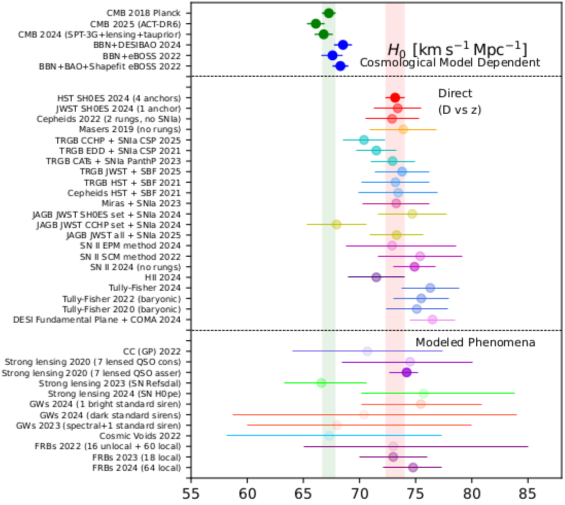
The H_0 tension



Cosmoverse White Paper, E. di Valentino et al.

BAO and the Hubble Tension: the no-go theorem

BAO are sensitive to the angular size of sound horizon at baryon drag

$$\boxed{\theta_d \propto r_d/D \propto r_d H_0 \Longrightarrow H_0 \uparrow \Rightarrow r_d \downarrow}$$

$\Rightarrow$ Calls for **pre-recombination** new physics ($r_d \propto \int_{\mathbf{z*}}^{\infty} ...$).

On the other hand, if r_d is calibrated by BBN inference on ω_b and Ω_m from BAO(+SN), the so-called inverse distance ladder gives $H_0 \sim 68$ km/s/Mps, consistent with Planck result $\Rightarrow$ tension with SH0ES.

The “no-go theorem” precludes a post-recombination solutions to the Hubble tension hinging in a crucial manner on BAO measurements

Objections to the no-go theorem

Possible loophole in no-go theorem due to assumption of fiducial cosmology in BAO pipeline?

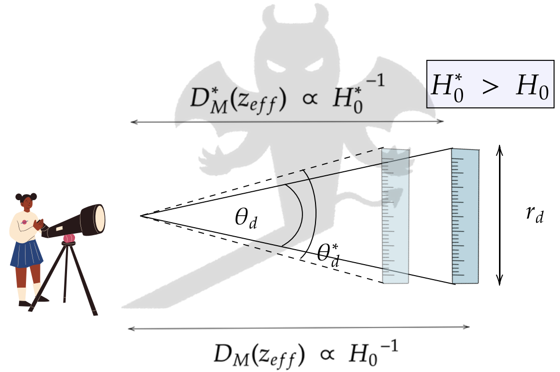
A fiducial cosmology is assumed for

1. transforming redshifts and angles into comoving coordinates
2. constructing BAO template for fitting $\alpha_{\parallel,\perp}$ out of the galaxy (tracer) power spectrum
3. performing reconstruction to sharpen the BAO signal

Should one assume from the start a fiducial cosmology vastly different from LCDM, would the recovered α_s and the associated cosmological inferences be strongly affected or not?

Let's play devil's advocate

We assume that the adoption of a fiducial LCDM cosmology in BAO analyses results in a misdetermination of the αs $\Longrightarrow$ the inferred low-redshift **acoustic angular scale is biased low**



Let's play devil's advocate

In our hypothetical scenario the "true" θ_d^* is larger than the BAO pipeline result:

$$\boxed{\theta_d^* = \epsilon\theta_d \text{ with } \epsilon > 1}$$

Assuming LCDM pre-recombination ($r_d \sim 147$ Mpc), we choose ϵ in the following way:

$$\theta_d^* = \epsilon\theta_d = \epsilon\frac{r_d H_0}{D_M(z)} \sim \frac{73}{\cancel{68}}\frac{r_d \cancel{H_0}}{D_M(z)} \implies \epsilon \sim 1.065$$

Is this enough to rescue late-time solutions to the Hubble tension?

Datasets and Methodology

We use the following datasets and priors

- **SDSS** (excluding Ly-α): "conservative" BAO dataset
- **SDSS**$_r$: "rescaled" BAO $\longrightarrow \theta_d^R = \epsilon\theta_d$
- **Pantheon+**: SNeIa catalog $(0.01 < z < 2.26)$
- **Compressed Planck Likelihood**: treated as a BAO at $z \sim 1100$, with a prior on ω_b

$$\mathbf{v} = \begin{pmatrix} 1/\theta_s^\star \\ \omega_b \end{pmatrix}, \quad C_{\mathbf{v}} = \begin{pmatrix} \sigma_{1/\theta_s^* 1/\theta_s^*} & \sigma_{1/\theta_s^* \omega_b} \\ \sigma_{\omega_b 1/\theta_s^*} & \sigma_{\omega_b \omega_b} \end{pmatrix}.$$

- **Late-time inference of** Ω_m: prior on dimensionless matter density $\Omega_m = 0.30 \pm 0.03$

Popular late-time models

IDEA: accelerated late-time expansion achieved via modification of the dark energy (DE) component:

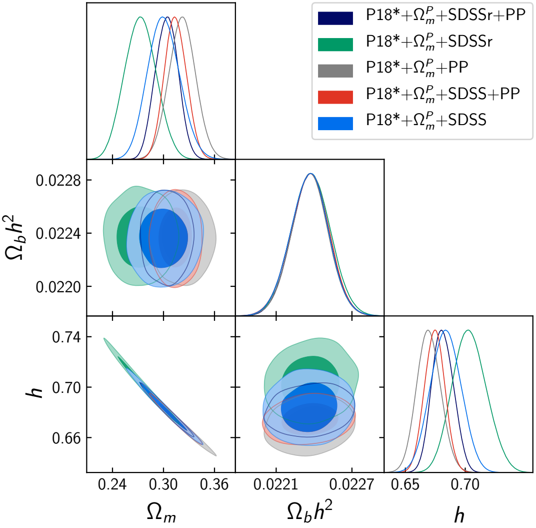
$$\boxed{H^2(z) = H_0^2\left[\Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_{\rm DE} f(z)\right],}$$

where

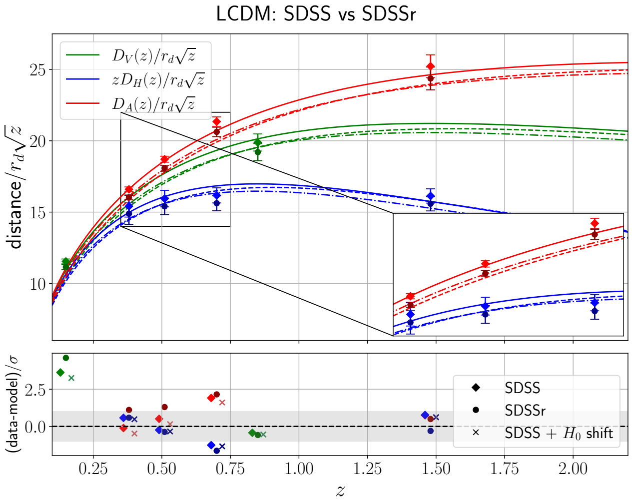
$$f(z) = \exp\left[3\int_0^{\ln(1+z)} {\rm d}\,\ln(1+z')(1+w_{\rm DE}(z'))\right],$$

- wCDM $\longrightarrow f(z) = (1+z)^{3(1+w)}$
- CPL $\longrightarrow f(z) = (1+z)^{3(1+w_0+w_a)}e^{-3w_a\frac{z}{1+z}}$
- L_sCDM $\longrightarrow f(z) = \mathrm{sgn}[z^\dagger - z]$
- PEDE $\longrightarrow f(z) = 1 + \tanh\left[\log_{10}(1+z)\right]$
- ...

Warm-up: LCDM $\to f(z) = 1$



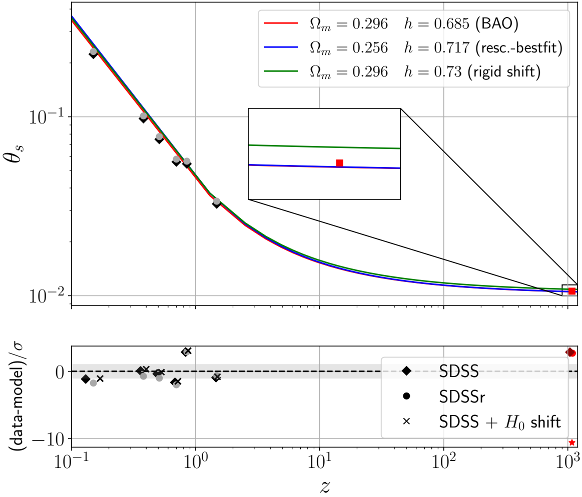
Warm-up: LCDM $\to f(z) = 1$



BAO alone are not really able to discard a "rigid shift" in H_0 ...

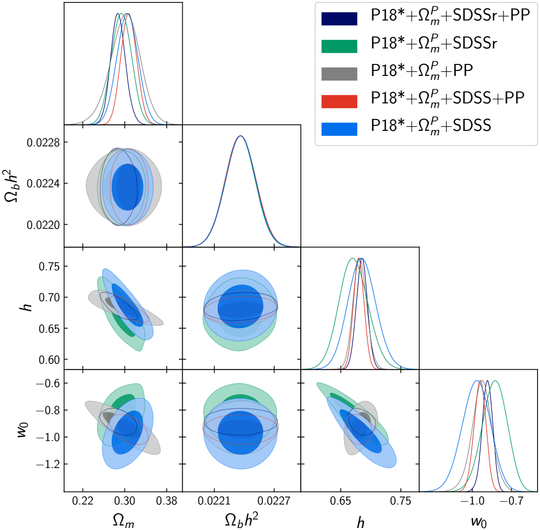
Warm-up: LCDM $\rightarrow f(z) = 1$

The geometric CMB point at $z \sim 1100$ prevents the “rigid shift” in H_0!



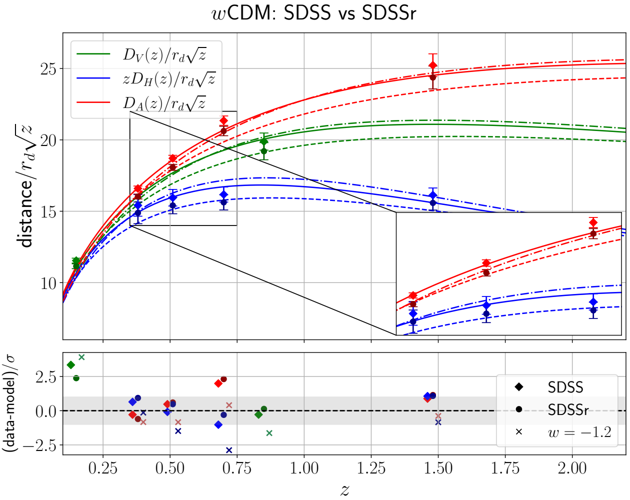
Free to vary EoS: wCDM $\rightarrow f(z) = (1+z)^{3(1+w)}$

Negative shift in H_0...

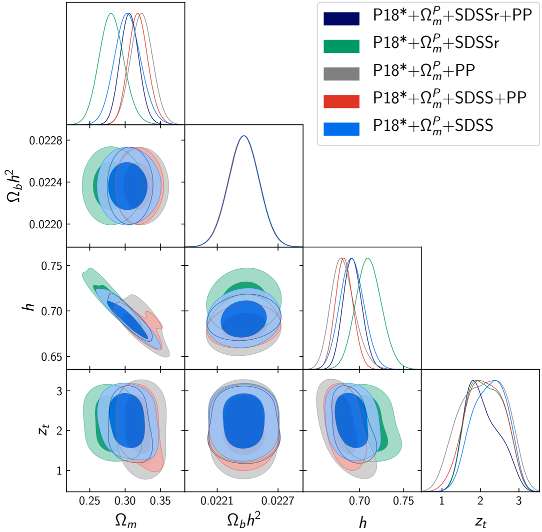


Free to vary EoS: wCDM $\rightarrow f(z) = (1+z)^{3(1+w)}$

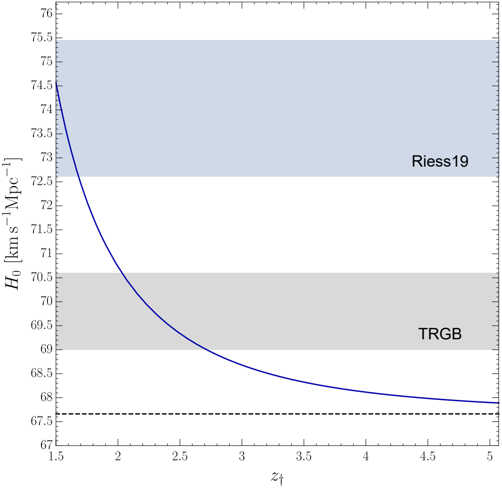
Negative shift in $H_0 \implies$ quintessence DE ($w > -1$) is preferred by fit to SDSS_r



Interesting results: L_sCDM



Interesting results: L_sCDM



O. Akarsu, S. Kumar, E. Ozulker, J.A. Vazquez Phys.Rev.D 104 (2021) 123512

Conclusions

We asked ourselves whether a bias in BAO measurements would be sufficient to rescue a number of popular post-recombination proposals on the market. In short, even under our extreme and rather generous assumptions, the answer is **NO**, because of two important effects:

1. Unanchored SNe tightly constrain the shape of the late-time expansion history, preventing it from deviating significantly from LCDM;
2. A severe tension would be introduced between BAO measurements and geometrical CMB information, unless Ω_m is significantly different from 0.3.

Backup slides: Compressed CMB likelihood

Typical compression scheme includes also a prior on ω_m, which we discarded since:

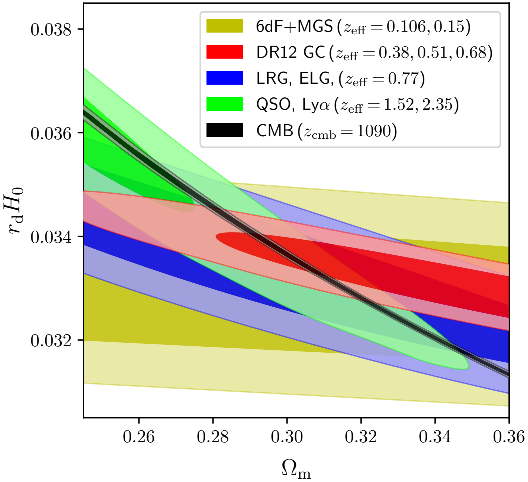
$$\Omega_m = \frac{\omega_b + \omega_c}{(H_0/100)^2} \implies H_0 \uparrow \text{ then } \omega_c \uparrow$$

Ω_m and ω_c are fixed/calibrated by BAO and/or uncalibrated Supernovae and Big Bang Nucleosynthesis $\implies$ an increase in H_0 requires an increase in ω_c

$$\frac{\delta\omega_c}{\omega_c} \sim 2\frac{\delta h}{h}$$

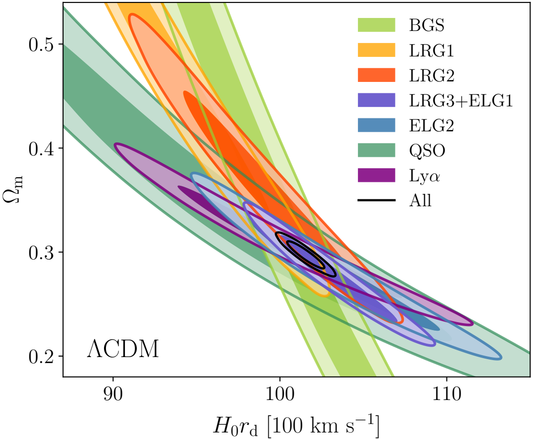
DP, J. Jiang, L. Escamilla, S. da Costa, S. Vagnozzi, Phys.Rev.D 111 (2025), 023506

Backup slides



W. Lin, X. Cheng, K. Mack, Astrophys.J. 920 (2021) 2, 159

Backup slides



DESI Collaboration, M. Abdul-Karim et al., arXiv 2503.14738