Tensions and Problems in Cosmological Data

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CMB@60
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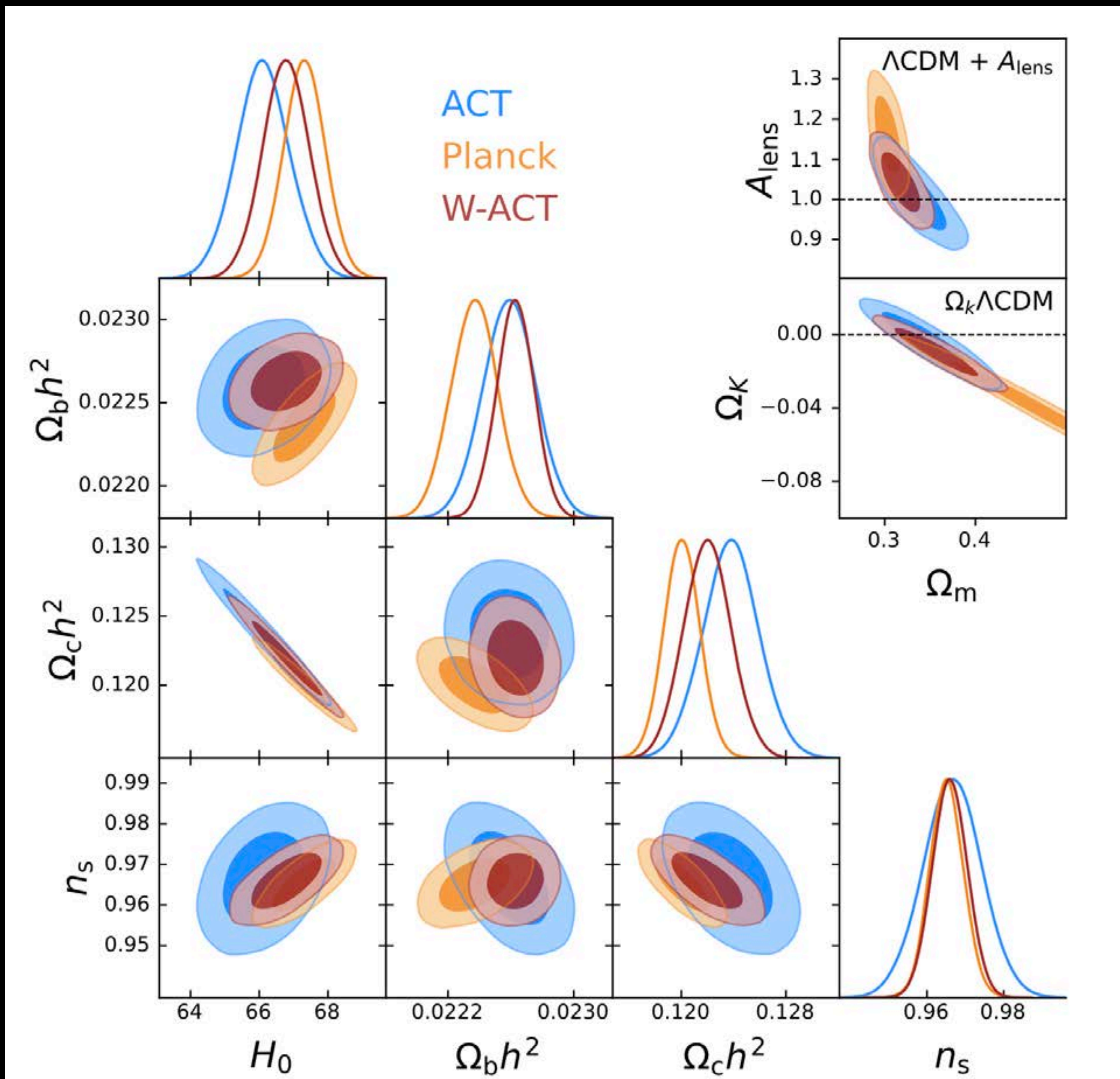
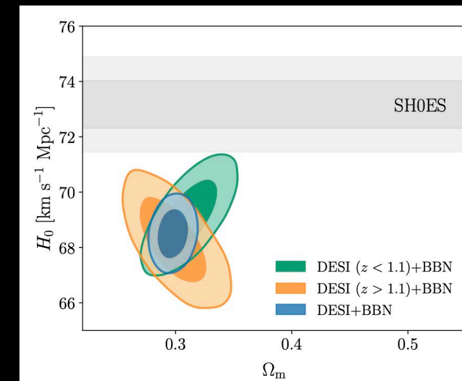
THE ROYAL SOCIETY

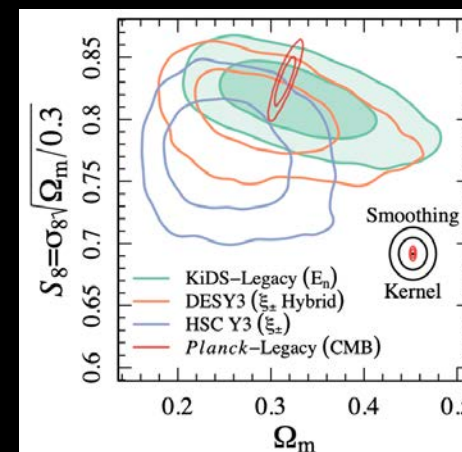
A flat LCDM model is in agreement with most of the data

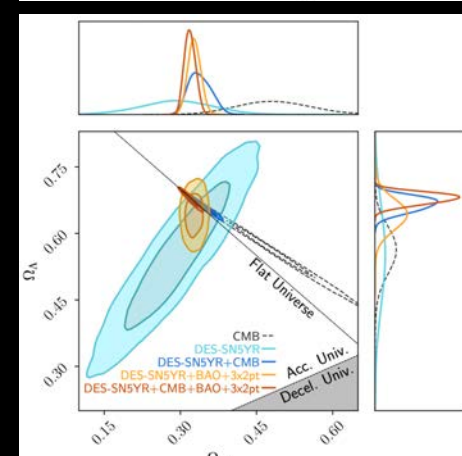
Among the various cosmological models proposed in literature,
the Lambda cold dark matter (LCDM) scenario has been adopted
as the standard model, due to its simplicity and its ability to accurately describe
a wide range of astrophysical and cosmological observations.

A flat LCDM model is in agreement with most of the data









But what does it mean that LCDM agrees well with each probe?

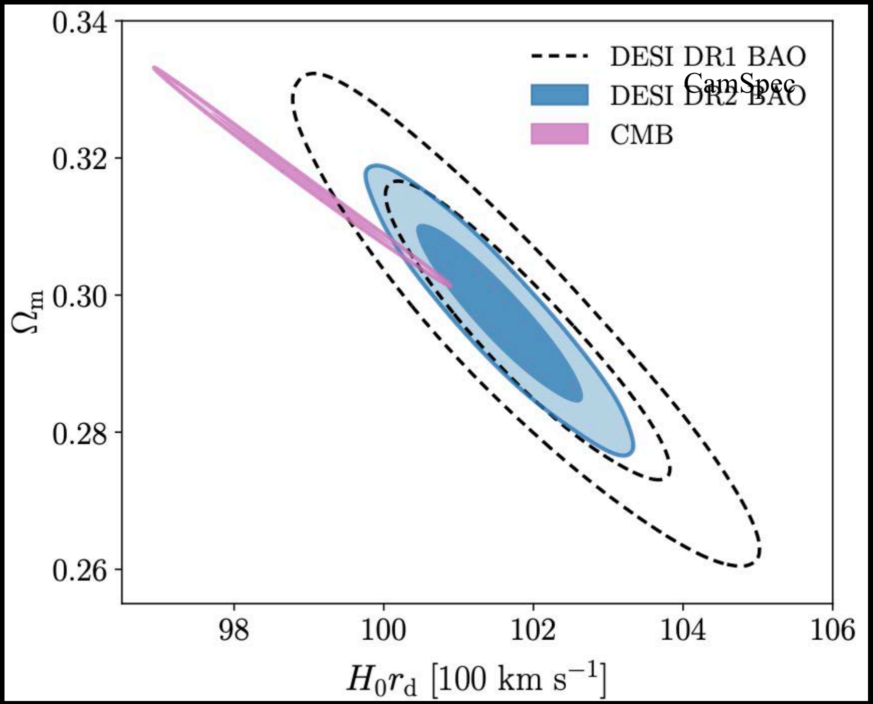
In a Bayesian framework, all models can, in principle, agree with the data.
What matters is whether they are disfavoured due to a poor fit
or because another model is preferred.
Therefore, to me, this means that LCDM provides a good fit to the data
and shows no clear signs of deviation, even when extended.

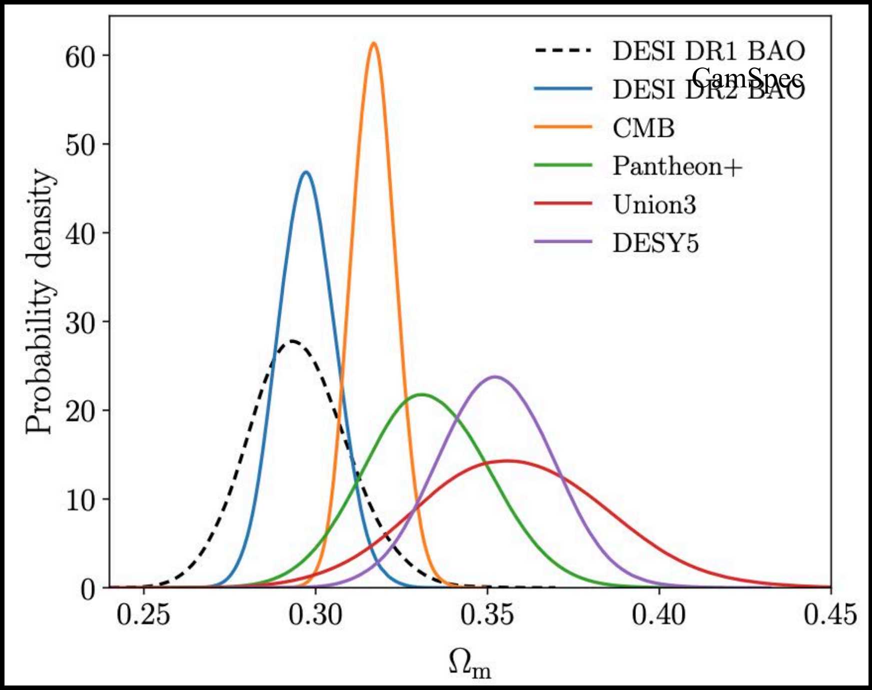
However, currently the cosmological parameters inferred
from different probes are not the same.

So LCDM appears different for the different data!

Tensions and Disagreements in LCDM

DESI collaboration, Abdul Karim et al., arXiv:2503.14738





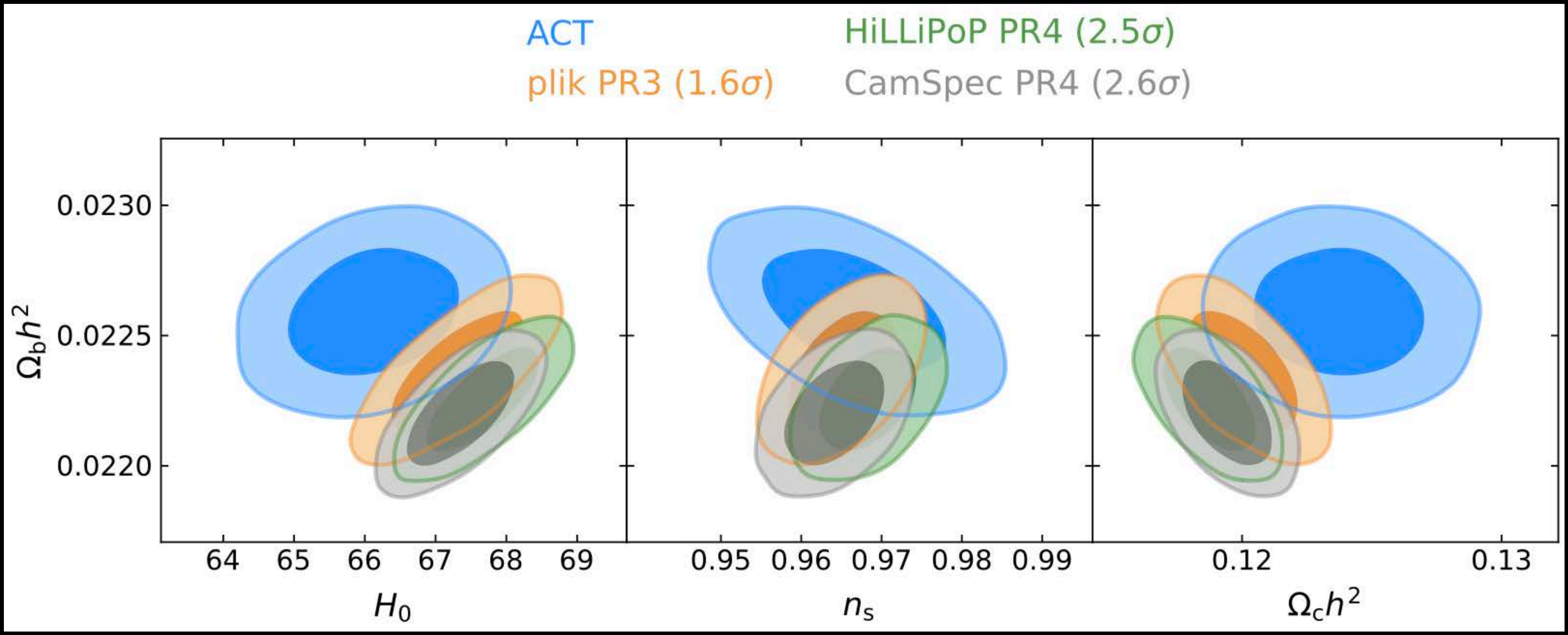
Converting this χ^2 into a probability-to-exceed (PTE) value, we find it is equivalent to a 2.3σ discrepancy between BAO and CMB in ΛCDM, increased from 1.9σ in DR1. However, we note that this reduces to 2.0σ if CMB lensing is excluded. This discrepancy is part of the reason why more models with a more flexible background expansion history than ΛCDM, such as the evolving dark

Finally, as in [38], we note a mild to moderate discrepancy between the recovered values of Ω_m from DESI and SNe in the context of the ΛCDM model. This is shown in the marginalized posteriors in Figure 10: the discrepancy is 1.7σ for Pantheon+, 2.1σ for Union3, and 2.9σ for DESY5, with all SNe samples preferring higher values of Ω_m though with larger uncertainties. For ΛCDM we do not report joint constraints on parameters from any combination of DESI and SNe data. However, as with

See also Ye & Lin, arXiv: 2505.02207

The same LCDM cannot fit 2 datasets together!

CMB tension in LCDM



In Figure 37 we show the comparison of the ACT DR6 results with those from different versions of the *Planck* likelihoods, as discussed in §8. The agreement between ACT and *Planck* is closest for the Plik PR3 at 1.6σ, neglecting correlations between the data and using the four-dimensional parameter distribution that discards the amplitude and optical depth; the PR4 analyses for both Camspec and Hillipop have small shifts to lower baryon and CDM densities compared to PR3, and result in an overall 2.6σ separation in the four-dimensional parameter space.

ACT collaboration, Louis et al., arXiv:2503.14452

Consequences? Indication for DDE

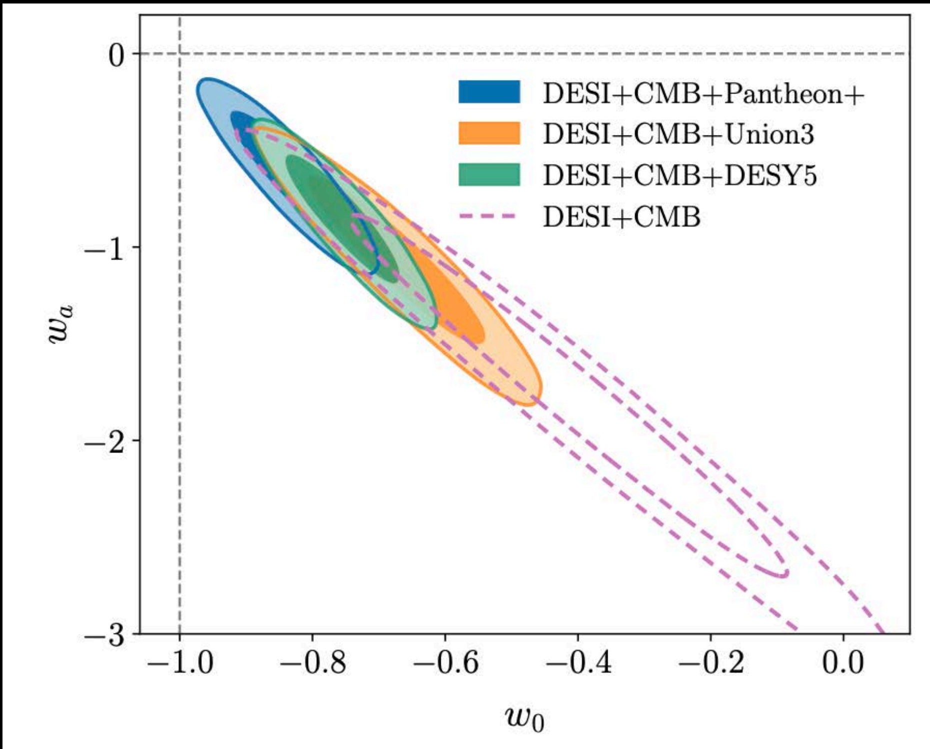


FIG. 11. Results for the posterior distributions of w_0 and w_a, from fits of the w_0w_aCDM model to DESI in combination with CMB and three SNe datasets as labelled. We also show the contour for DESI combined with CMB alone. The contours enclose 68% and 95% of the posterior probability. The gray dashed lines indicate $w_0 = -1$ and $w_a = 0$; the ΛCDM limit ($w_0 = -1$, $w_a = 0$) lies at their intersection. The significance of rejection of ΛCDM is 2.8σ, 3.8σ and 4.2σ for combinations with the Pantheon+, Union3 and DESY5 SNe samples, respectively, and 3.1σ for DESI+CMB without any SNe.

The minimal extension we consider, beyond BAO data alone, is to add a high-redshift constraint from the early universe. This can be achieved by imposing CMB-derived priors on θ_*, ω_b and ω_{bc}, as described in Section IV. These priors are independent of the late-time dark energy, and also marginalize over contributions such as the late ISW effect and CMB lensing. Therefore, they provide us with an early time physics prior that can help us set the sound horizon and is based solely on early-Universe information. The result from this data combination is

$$\left.\begin{aligned} w_0 &= -0.43 \pm 0.22 \\ w_a &= -1.72 \pm 0.64 \end{aligned}\right\} \text{DESI+}(\theta_*, \omega_b, \omega_{bc})_{\text{CMB}}. \quad (24)$$

While this is still bounded by the $w_a > -3$ prior at the lower end, the posterior already clearly disfavors ΛCDM. The $\Delta\chi^2_{\text{MAP}}$ value decreases to -8.0, indicating a preference for an evolving dark energy equation of state at the 2.4σ level.

Replacing these minimal early-Universe priors with the full CMB information leads to only a small shift in the maginalized posteriors

$$\left.\begin{aligned} w_0 &= -0.42 \pm 0.21 \\ w_a &= -1.75 \pm 0.58 \end{aligned}\right\} \text{DESI+CMB}, \quad (25)$$

showing that most of the information that the CMB provides on $w(z)$ comes from its role in anchoring early-Universe values of $(\theta_*, \omega_b, \omega_{bc})$ and thus limiting the freedom for models to fit the low-redshift data without an evolving dark energy component. Nevertheless, when including the full CMB information the $\Delta\chi^2_{\text{MAP}}$ decreases to -12.5, corresponding to a 3.1σ preference for evolving dark energy. This change in the $\Delta\chi^2_{\text{MAP}}$ is driven

DESI collaboration, Abdul Karim et al., arXiv:2503.14738

Consequences? Indication for DDE

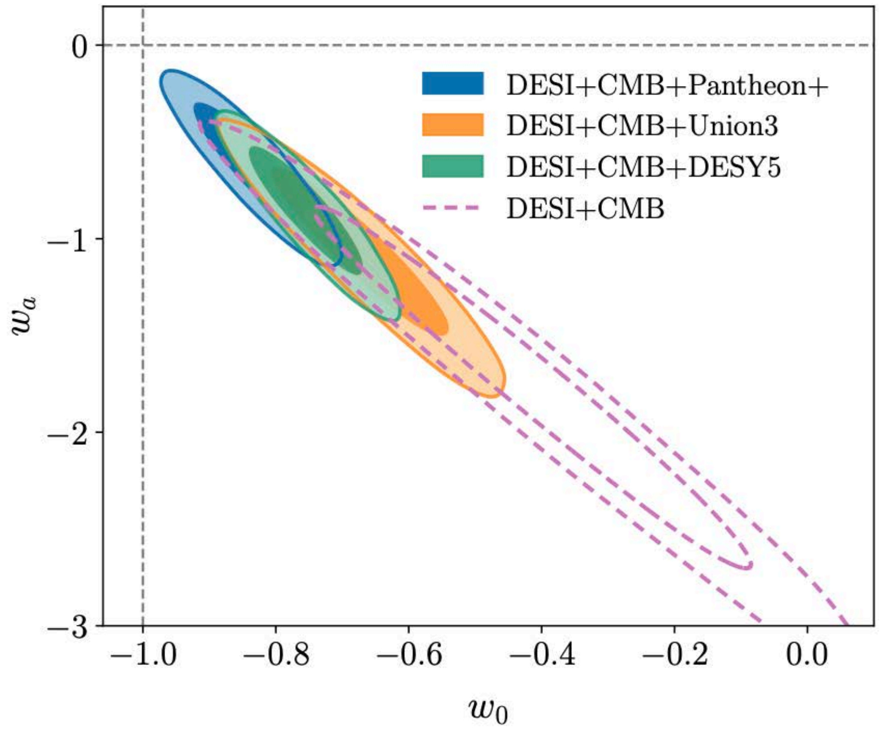
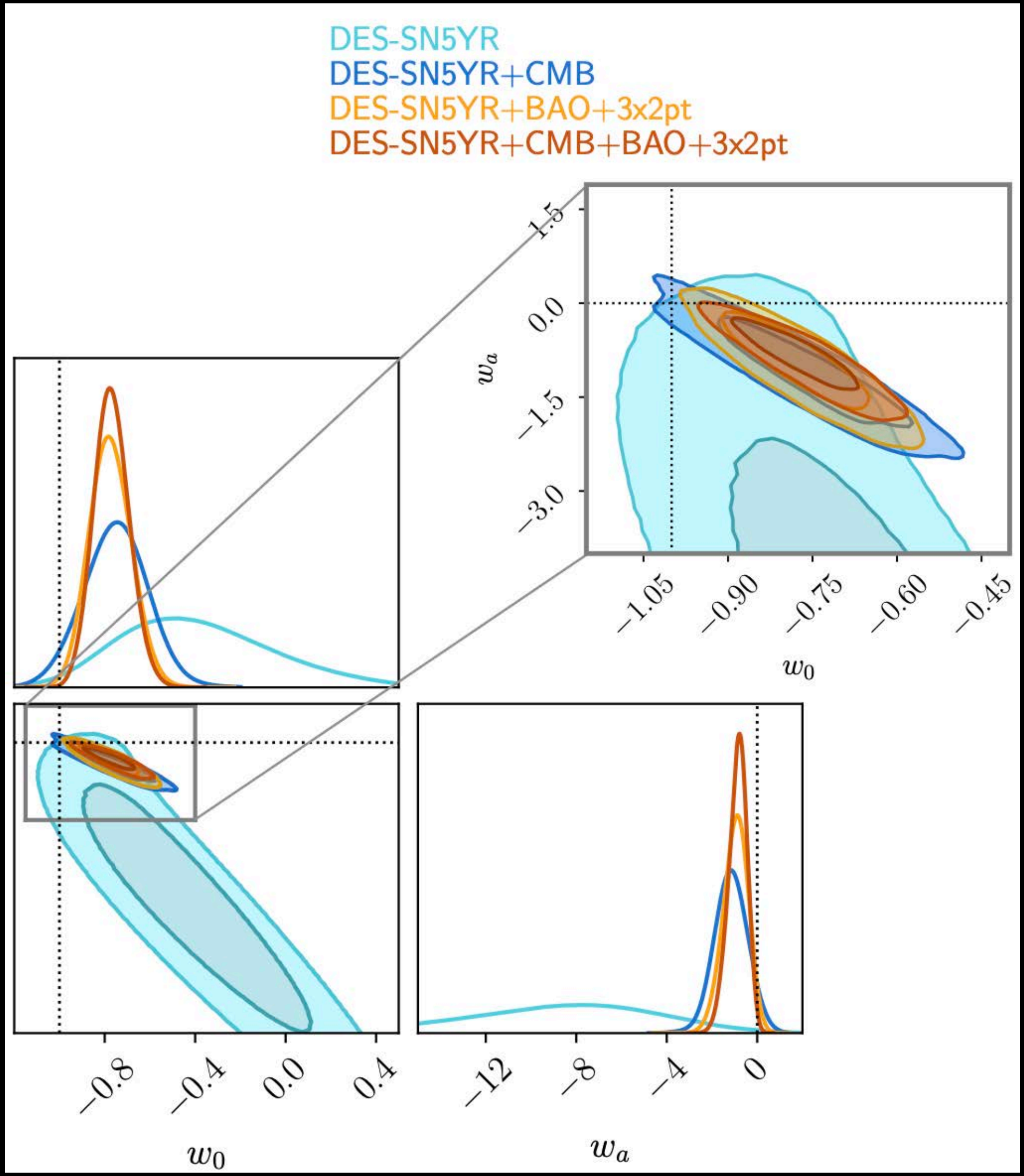


FIG. 11. Results for the posterior distributions of w_0 and w_a, from fits of the w_0w_aCDM model to DESI in combination with CMB and three SNe datasets as labelled. We also show the contour for DESI combined with CMB alone. The contours enclose 68% and 95% of the posterior probability. The gray dashed lines indicate $w_0 = -1$ and $w_a = 0$; the ΛCDM limit ($w_0 = -1$, $w_a = 0$) lies at their intersection. The significance of rejection of ΛCDM is 2.8σ, 3.8σ and 4.2σ for combinations with the Pantheon+, Union3 and DESY5 SNe samples, respectively, and 3.1σ for DESI+CMB without any SNe.

Datasets	$\Delta\chi^2_{\rm MAP}$	Significance	Δ(DIC)
DESI	−4.7	1.7σ	−0.8
DESI+$(\theta_*, \omega_{\rm b}, \omega_{\rm bc})_{\rm CMB}$	−8.0	2.4σ	−4.4
DESI+CMB (no lensing)	−9.7	2.7σ	−5.9
DESI+CMB	−12.5	3.1σ	−8.7
DESI+Pantheon+	−4.9	1.7σ	−0.7
DESI+Union3	−10.1	2.7σ	−6.0
DESI+DESY5	−13.6	3.3σ	−9.3
DESI+DESY3 (3×2pt)	−7.3	2.2σ	−2.8
DESI+DESY3 (3×2pt)+DESY5	−13.8	3.3σ	−9.1
DESI+CMB+Pantheon+	−10.7	2.8σ	−6.8
DESI+CMB+Union3	−17.4	3.8σ	−13.5
DESI+CMB+DESY5	−21.0	4.2σ	−17.2

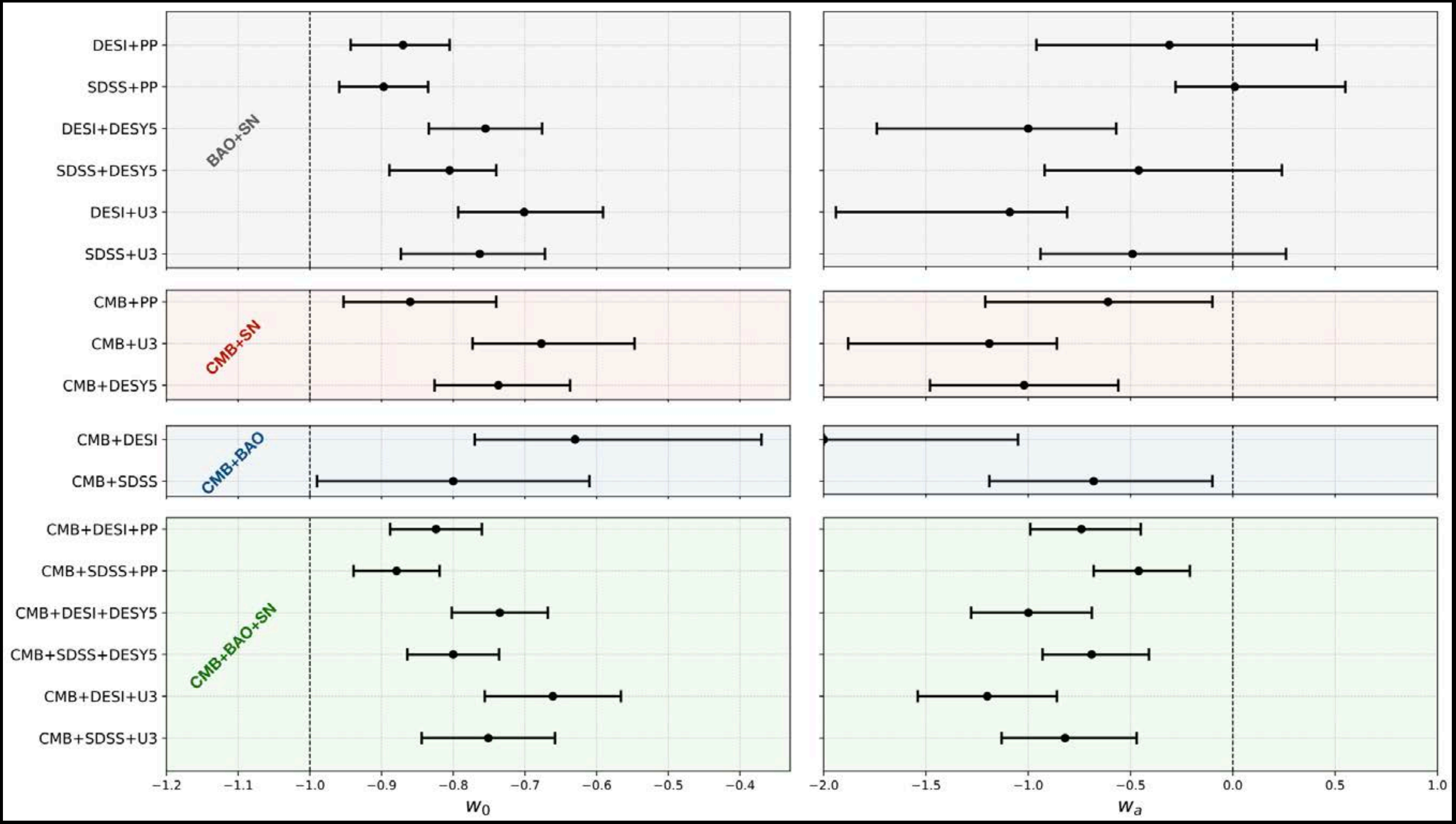
DESI collaboration, Abdul Karim et al., arXiv:2503.14738

Consequences? Indication for DDE



DESY5 collaboration: Abbott et al., arXiv:2401.02929

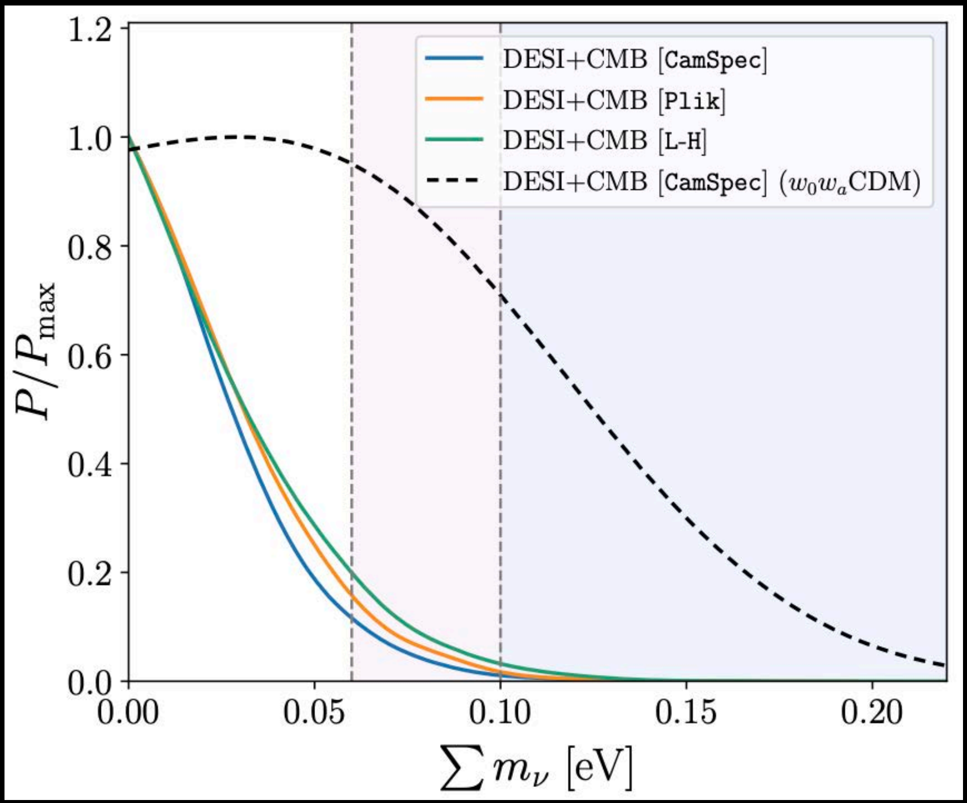
Consequences? Indication for DDE



Overall, our findings highlight that combinations that *simultaneously* include PantheonPlus SN and SDSS BAO significantly weaken the preference for DDE. However, intriguing hints supporting DDE emerge in combinations that do not include DESI-BAO measurements: SDSS-BAO combined with SN from Union3 and DESY5 (with and without CMB) support the preference for DDE.

Giarè et al., *Phys.Dark Univ.* 48 (2025) 101906

Consequences? Neutrino mass tension



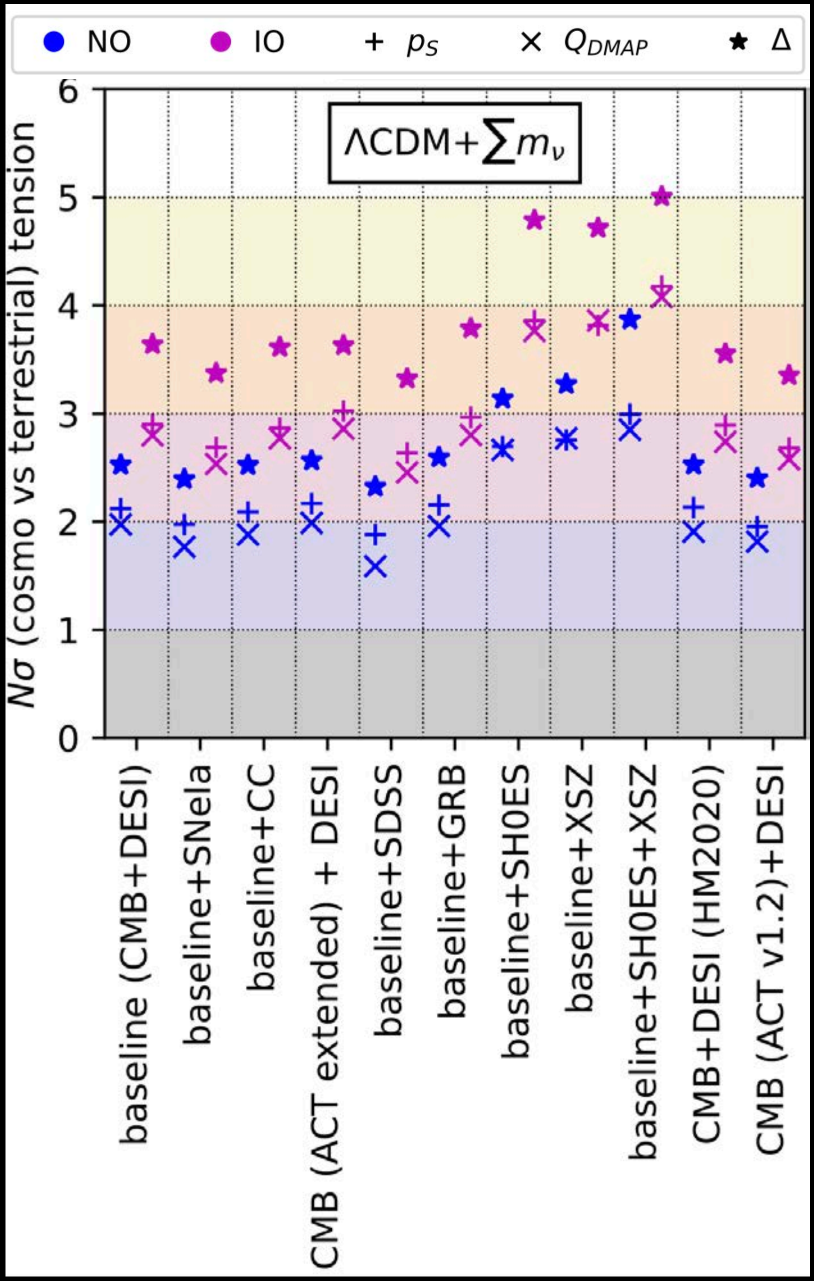
Model/Dataset	Ω_m	H_0 [km s^{-1} Mpc^{-1}]	$H_0 r_\mathrm{d}$ [100 km s^{-1}]	$\sum m_\nu$ [eV]
ΛCDM+$\sum m_\nu$				
DESI BAO+CMB [Camspec]	0.3009 ± 0.0037	68.36 ± 0.29	100.96 ± 0.48	< 0.0642
DESI BAO+CMB [L-H]	0.2995 ± 0.0037	68.48 ± 0.30	101.16 ± 0.49	< 0.0774
DESI BAO+CMB [Plik]	0.2998 ± 0.0038	68.56 ± 0.31	101.09 ± 0.50	< 0.0691

DESI collaboration, Abdul Karim et al., arXiv:2503.14738

Consequences? Neutrino mass tension

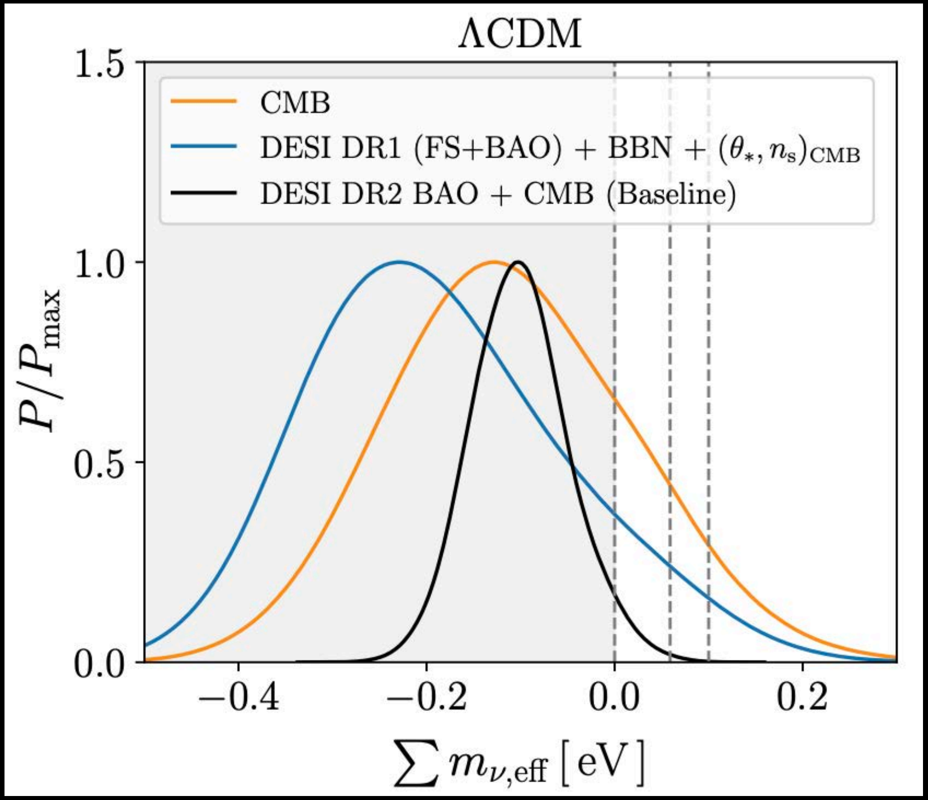
Dataset combination	ΛCDM+$\sum m_\nu$	
	$\sum m_\nu$ (eV)	$B_{\mathrm{NO,IO}}$
baseline (CMB + DESI)	< 0.072	8.1
baseline + SNeIa	< 0.081	7.0
baseline + CC	< 0.073	7.3
baseline + SDSS	< 0.083	6.8
baseline + SH0ES	< 0.048	47.8
baseline + XSZ	< 0.050	46.5
baseline + GRB	< 0.072	8.7
aggressive combination (baseline + SH0ES + XSZ)	< 0.042 eV	72.6
CMB (with ACT "extended" likelihood)+DESI	< 0.072	8.0
CMB+DESI (with 2020 `HMCode`)	< 0.074	7.5
CMB (with `v1.2` ACT likelihood)+DESI	< 0.082	7.4

Jiang et al., *JCAP* 01 (2025) 153



The level of tension between cosmological and terrestrial experiments for NO is around 2.5σ, and increases to approximately 3.5σ for IO, when excluding the most extreme cases involving SH0ES and XSZ.

Consequences? Indication for negative neutrino mass



Model/Dataset	Ω_m	H_0 [km s^{-1} Mpc^{-1}]	$\sum m_{\nu,eff}$ [eV]
ΛCDM+$\sum$ m$_{\nu,eff}$			
DESI BAO+CMB (Baseline)	0.2953 ± 0.0043	68.92 ± 0.38	$-0.101^{+0.047}_{-0.056}$
DESI BAO+CMB (`plik`)	0.2948 ± 0.0043	69.06 ± 0.39	$-0.099^{+0.050}_{-0.061}$
DESI BAO+CMB (`L-H`)	0.2953 ± 0.0044	68.89 ± 0.39	$-0.067^{+0.054}_{-0.064}$

DESI collaboration, Elbers et al., arXiv:2503.14744

There is a lot of literature trying to dissect BAO and SN data looking for possible problems.

arXiv > astro-ph > arXiv:2408.07175

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Astrophysics > Cosmology and Nongalactic Astrophysics

[Submitted on 13 Aug 2024 (v1), last revised 3 Feb 2025 (this version, v3)]

Evolving Dark Energy or Supernovae Systematics?

George Efstathiou

Recent results from the Dark Energy Spectroscopic Instrument (DESI) collaboration have been interpreted as evidence for evolving dark energy. However, this interpretation is strongly dependent on which Type Ia supernova (SN) sample is combined with DESI measurements of baryon acoustic oscillations (BAO) and observations of the cosmic microwave background (CMB) radiation. The strength of the evidence for evolving dark energy ranges from ~3.9 sigma for the Dark Energy 5 year (DES5Y) SN sample to ~2.5 sigma for the Pantheon+ sample. The cosmology inferred from Pantheon+ sample alone is consistent with the Planck LCDM model and shows no preference for evolving dark energy. In contrast, the DES5Y SN sample favours evolving dark energy and is discrepant with the Planck LCDM model at about the 3 sigma level. Given these difference, it is important to question whether they are caused by systematics in the SN compilations. A comparison of SN common to both the DES5Y and Pantheon+ compilations shows evidence for an offset of ~0.04 mag. between low and high redshifts. Systematics of this order can bring the DES5Y sample into good agreement with the Planck LCDM cosmology and Pantheon+. I comment on a recent paper by the DES collaboration that rejects this possibility.

arXiv > astro-ph > arXiv:2505.02658

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Astrophysics > Cosmology and Nongalactic Astrophysics

[Submitted on 5 May 2025]

Baryon Acoustic Oscillations from a Different Angle

George Efstathiou

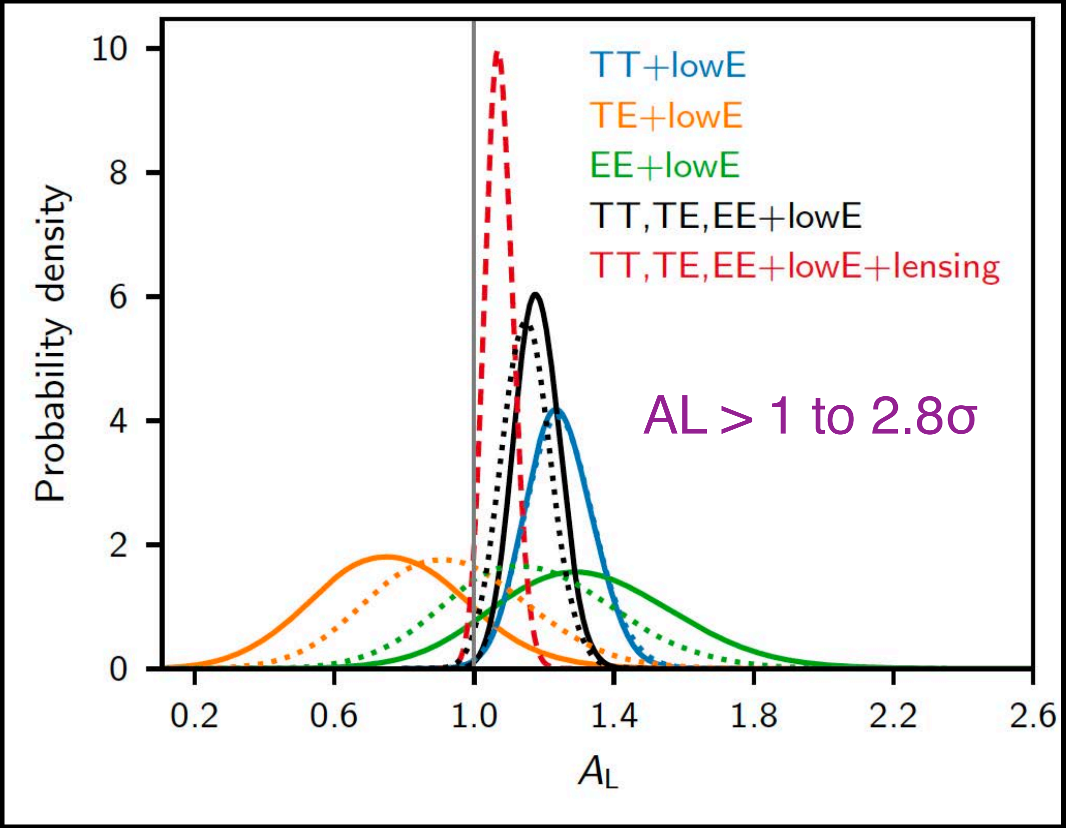
This paper presents an alternative way of analysing Baryon Acoustic Oscillation (BAO) distance measurements via rotations to define new quantities Dperp and Dpar. These quantities allow simple tests of consistency with the Planck LCDM cosmology. The parameter Dperp is determined with negligible uncertainty from Planck under the assumption of LCDM. Comparing with measurements from the Dark Energy Spectroscopic Instrument (DESI), we find that the measurements of Dperp from Data Release 2 (DR2) move into significantly better agreement with the Planck LCDM cosmology compared to DESI Data Release 1 (DR1). The quantity in the orthogonal direction Dpar provides a measure of the physical matter density omega_m in the LCDM cosmology. The DR2 measurements of Dpar\ also come into better agreement with Planck LCDM compared to the earlier DR1 results. From the comparison of Planck and DESI BAO measurements, we find no significant evidence in support of evolving dark energy. We also investigate a rotation in the theory space of the w_0 and w_a parameterization of the dark energy equation-of-state w(z). We show that the combination of DESI BAO measurements and the CMB constrain w(z=0.5) = −0.996 pm 0.046, i.e. very close to the value expected for a cosmological constant. We present a critique of the statistical methodology employed by the DESI collaboration and argue that it gives a misleading impression of the evidence in favour of evolving dark energy. An Appendix shows that the cosmological parameters determined from the Dark Energy Survey 5 Year supernova sample are in tension with those from
DESI DR2 and parameters determined by Planck.

There is a selection bias in our community:
we tend to trust data only when they agree with Planck LCDM.

What about the CMB problems?

Plik PR3 A_L problem

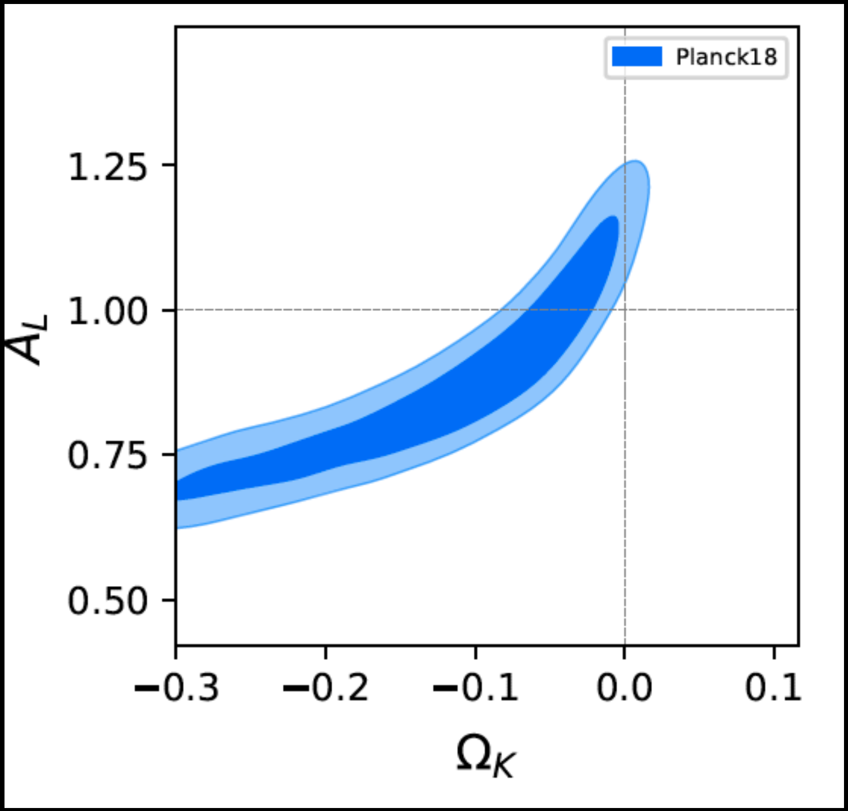
Planck 2018, Astron.Astrophys. 641 (2020) A6

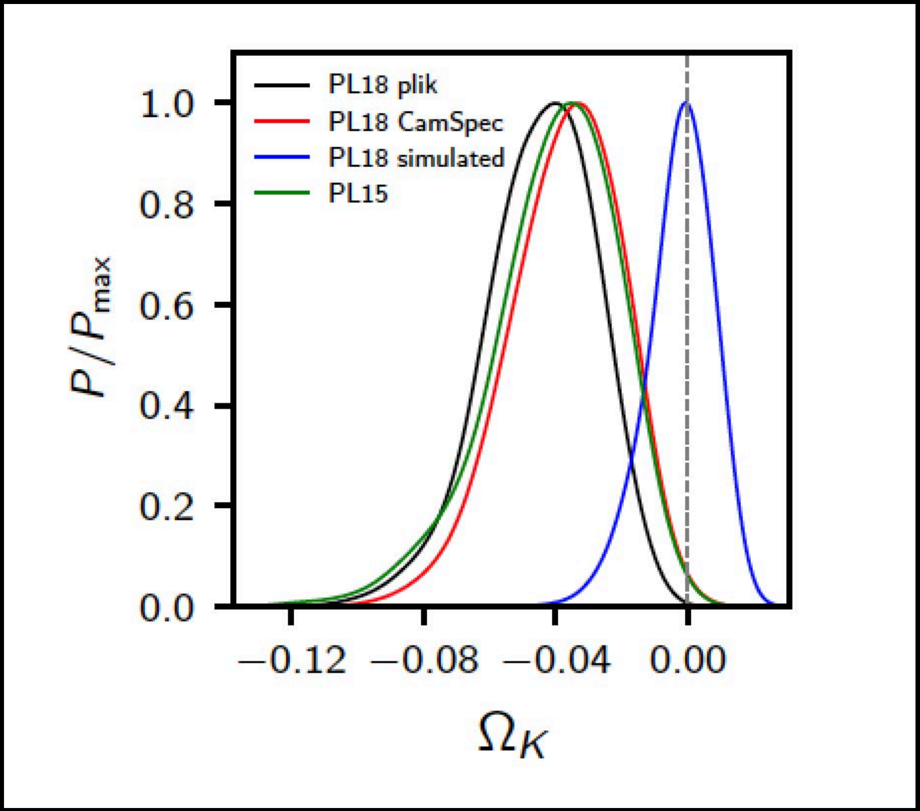


$$A_L = 1.243 \pm 0.096 \quad (68\,\%,\ \textit{Planck}\ \mathrm{TT{+}lowE}),$$
$$A_L = 1.180 \pm 0.065 \quad (68\,\%,\ \textit{Planck}\ \mathrm{TT{,}TE{,}EE{+}lowE}),$$

The preference for a high AL is not merely a volume effect in the full parameter space; the best fit improves by $\Delta\chi^2 \approx 9$ when adding AL for TT+lowE, and by ≈ 10 for TTTEEE+lowE.

Plik PR3 Ω_K problem





Di Valentino, Melchiorri and Silk, *Nature Astron.* 4 (2019) 2, 196-203

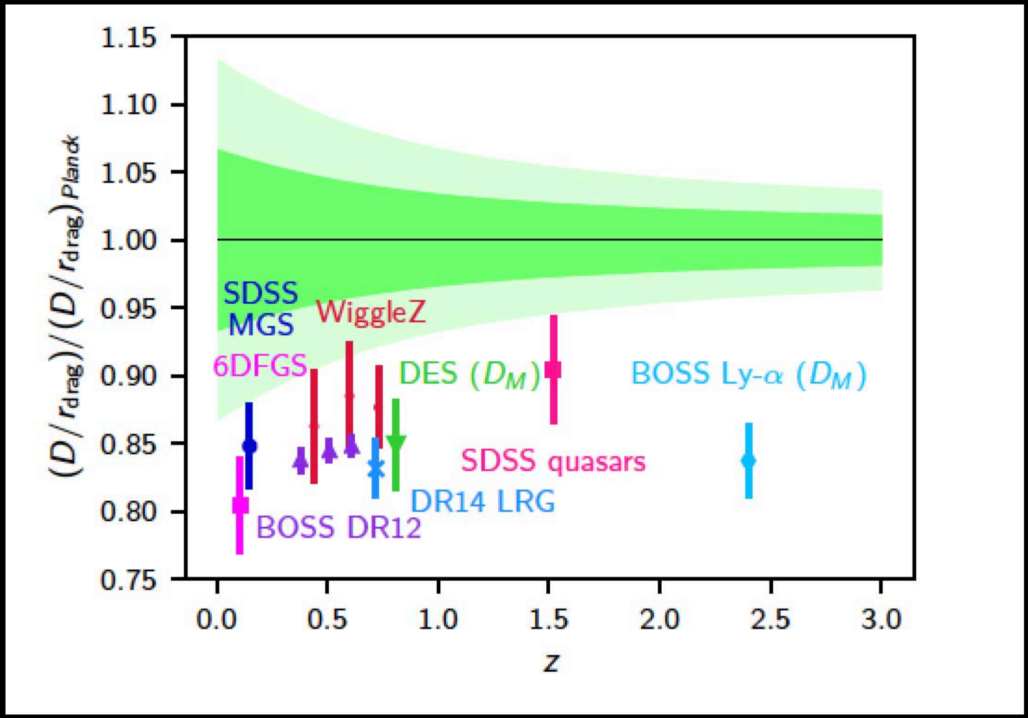
This excess of lensing affects the constraints on the curvature of the universe:

$$\Omega_K = -0.044^{+0.018}_{-0.015} \quad (68\,\%, \textit{Planck}\ \mathrm{TT,TE,EE+lowE}),$$

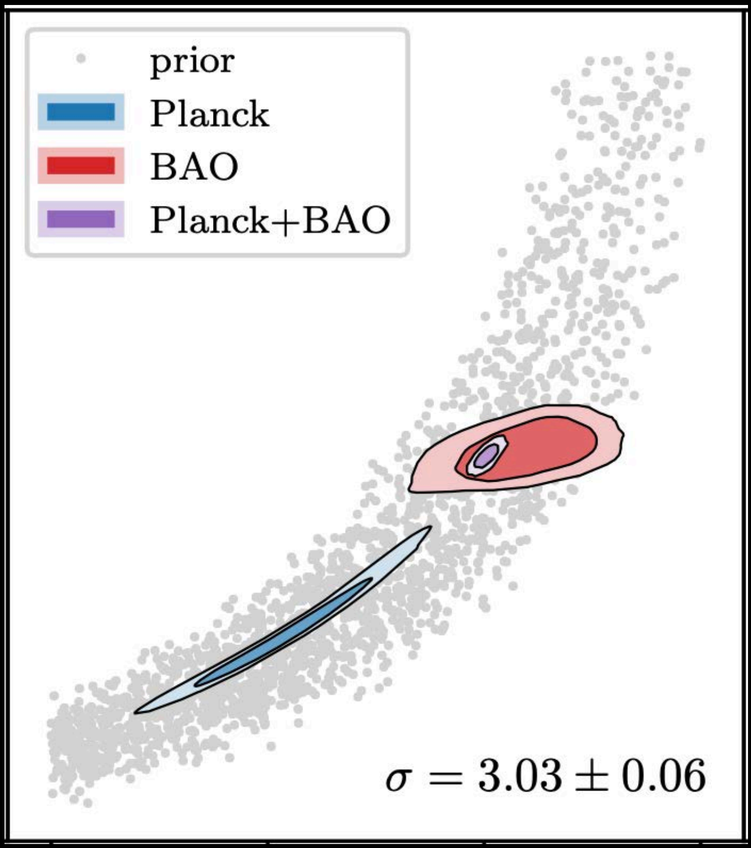
Planck 2018, Astron.Astrophys. 641 (2020) A6

leading to a detection of non-zero curvature,
with a 99% probability region of $-0.095 \leq \Omega_K \leq -0.007$.

Plik PR3 - SDSS tension in kLCDM



Di Valentino, Melchiorri and Silk, *Nature Astron.* 4 (2019) 2, 196-203



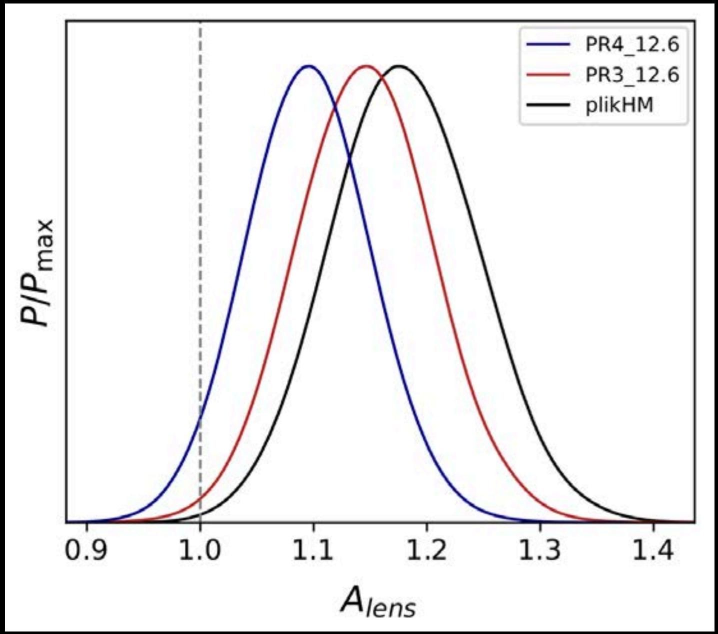
Handley, *Phys.Rev.D* 103 (2021) 4, L041301

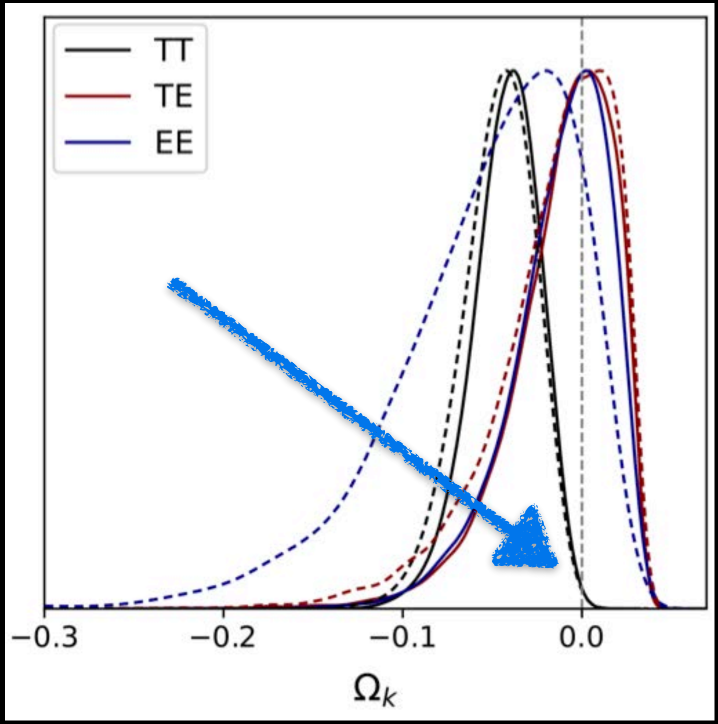
Allowing curvature to vary reveals a significant disagreement between the Planck spectra and BAO data.

CamSpec PR4

PR4_12.6	A_L	Ω_K	$N_{\rm eff}$	m_ν
TTTEEE	1.095 ± 0.056	$-0.025^{+0.013}_{-0.010}$	3.00 ± 0.21	< 0.161
TT	1.198 ± 0.084	$-0.042^{+0.022}_{-0.016}$	$2.98^{+0.28}_{-0.35}$	< 0.278
TE	0.96 ± 0.15	$-0.010^{+0.035}_{-0.015}$	$3.11^{+0.38}_{-0.42}$	< 0.400
EE	0.995 ± 0.15	$-0.012^{+0.034}_{-0.017}$	4.6 ± 1.3	< 2.37
PR3_12.6	A_L	Ω_K	$N_{\rm eff}$	m_ν
TTTEEE	1.146 ± 0.061	$-0.035^{+0.016}_{-0.012}$	$2.94^{+0.20}_{-0.23}$	< 0.143
TT	1.215 ± 0.089	$-0.047^{+0.024}_{-0.017}$	$2.89^{+0.28}_{-0.32}$	< 0.248
TE	0.96 ± 0.17	$-0.015^{+0.043}_{-0.015}$	$2.96^{+0.42}_{-0.49}$	< 0.504
EE	1.15 ± 0.20	$-0.053^{+0.063}_{-0.029}$	$2.46^{+0.94}_{-1.7}$	-

Rosenberg et al., arXiv:2205.10869





This new likelihood does not truly resolve
the problem of AL/ΩK,
which originates primarily from the TT power spectrum.
Moreover, the constraints from TT remain essentially
unchanged between the two releases.

CamSpec PR4

PR4_12.6	A_L	Ω_K	$N_{\rm eff}$	m_ν
TTTEEE	1.095 ± 0.056	$-0.025^{+0.013}_{-0.010}$	3.00 ± 0.21	< 0.161
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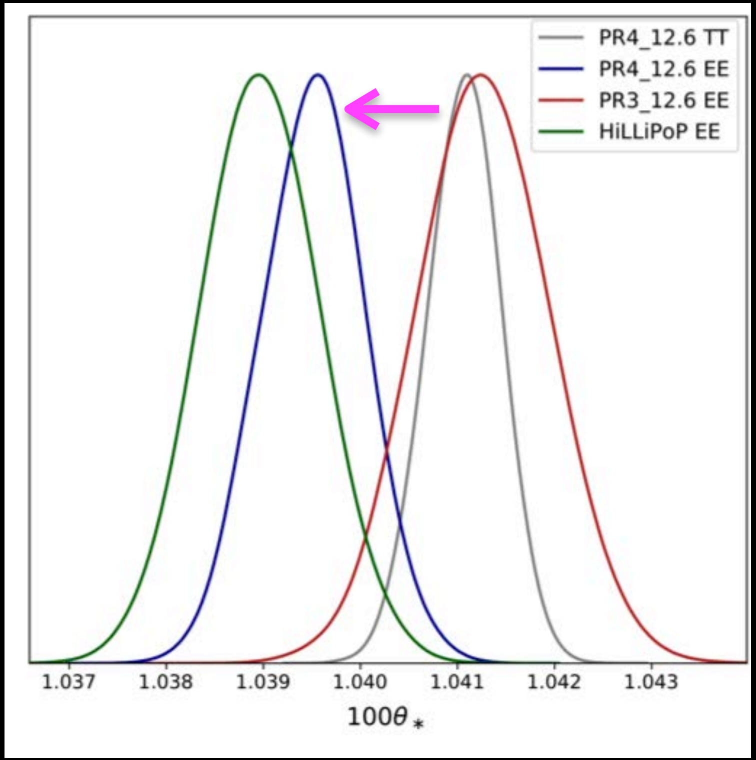


Rosenberg et al., arXiv:2205.10869

The constraints derived from the EE power spectrum are the ones pulling all parameters toward ΛCDM, thereby alleviating the tensions.

However, this change in EE induces a significant shift in the acoustic scale parameter θ, leading to an internal tension of 2.8σ between TT and EE, which increases to over 3.2-3.3σ when AL/ΩK are allowed to vary.

CamSpec PR4

	ℓ range	N_D	$\hat{\chi}^2$	$(\hat{\chi}^2 - 1)/\sqrt{2/N_D}$
TT 143x143	30 – 2000	1971	1.021	0.67
TT 143x217	500 – 2500	2001	0.985	-0.47
TT 217x217	500 – 2500	2001	1.002	0.05
TT All	30 – 2500	5973	1.074	4.07
TE	30 – 2000	1971	1.055	1.73
EE	30 – 2000	1971	1.026	0.82
TEEE	20 – 2000	3942	1.046	2.02
TTTEEE	30 – 2500	9915	1.063	4.46

Table 1. χ^2 of the different components of the PR4_12.6 likelihood with respect to the TTTEEE best-fit model. N_D is the size of the data vector. $\hat{\chi}^2 = \chi^2/N_D$ is the reduced χ^2. The last column gives the number of standard deviations of $\hat{\chi}^2$ from unity.

Visually the ΛCDM best-fit shown in Figs. 6-8 appears to match the spectra well; to more quantitatively check the agreement of the data and the model for PR4_12.6 we calculate χ^2 values with respect to the TTTEEE best-fit model, shown in Table 1. For each of the individual TT spectra as well as co-added TT, TE and EE we find acceptable values for χ^2. However, the χ^2 values for total TT and TTTEEE are somewhat large, being over 4σ high. The source of these high χ^2 is primarily at $500 \lesssim \ell \lesssim 1000$, and to a lesser extent $\ell < 500$. We

Moreover, the reduced χ2 values reveal a >4σ tension between the data and the ΛCDM best-fit from TTTEEE.

Rosenberg et al., arXiv:2205.10869

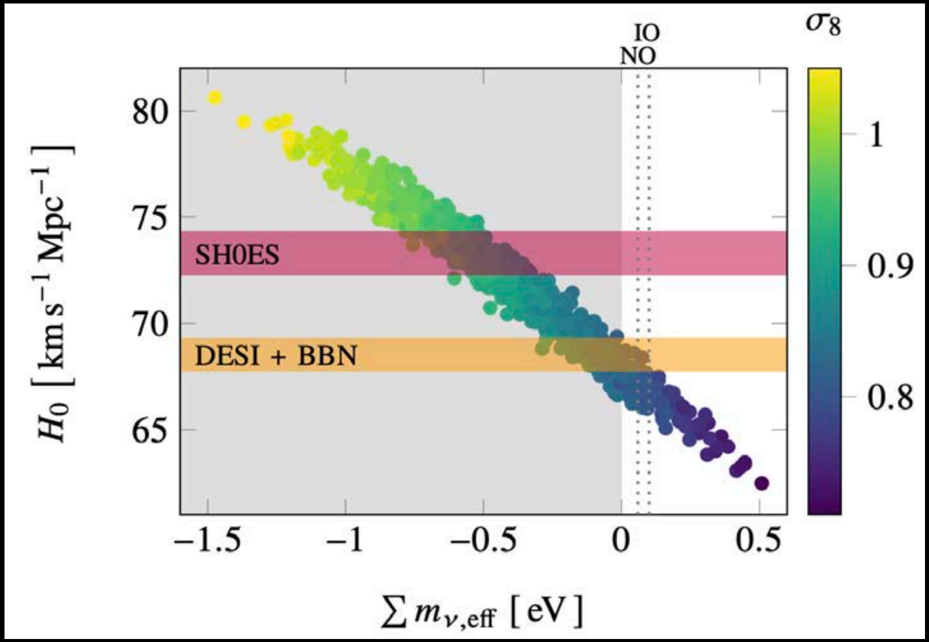
A_L for different data releases

Table 1. Posterior A_L Constraints from Analyses of Planck Temperature and Polarization Data since 2018 Release

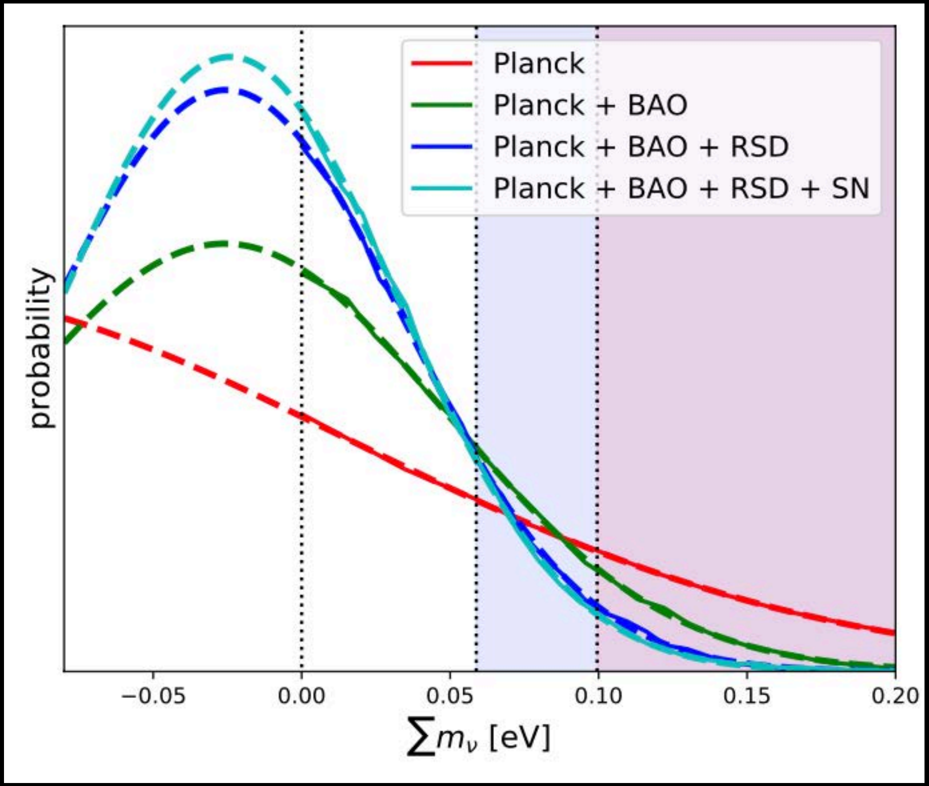
Reference	Data Version	Likelihood	Data Combination	A_L	'$N\sigma$' Preference for $A_L > 1$
Planck Collaboration VI (2020)	PR3/2018	`plik`	TTTEEE+`lowl`/`lowE`	1.180 ± 0.065	2.8σ
	PR3/2018	`plik`	TT+`lowl`/`lowE`	1.243 ± 0.096	2.5σ
Rosenberg et al. (2022)	PR3/2018	`CamSpec`	TTTEEE+`lowl`/`lowE`	1.146 ± 0.061	2.4σ
	PR3/2018	`CamSpec`	TT+`lowl`/`lowE`	1.215 ± 0.089	2.4σ
	PR4/NPIPE	`CamSpec`	TTTEEE+`lowl`/`lowE`	1.095 ± 0.056	1.7σ
	PR4/NPIPE	`CamSpec`	TT+`lowl`/`lowE`	1.198 ± 0.084	2.4σ
Tristram et al. (2023)	PR4/NPIPE	`HiLLiPoP`	TTTEEE+`lowl`/`LoLLiPoP`[a]	1.036 ± 0.051	0.7σ
	PR4/NPIPE	`HiLLiPoP`	TT+`lowl`/`LoLLiPoP`	1.068 ± 0.081	0.8σ

Addison et al, arXiv:2310.03127

Negative total neutrino mass



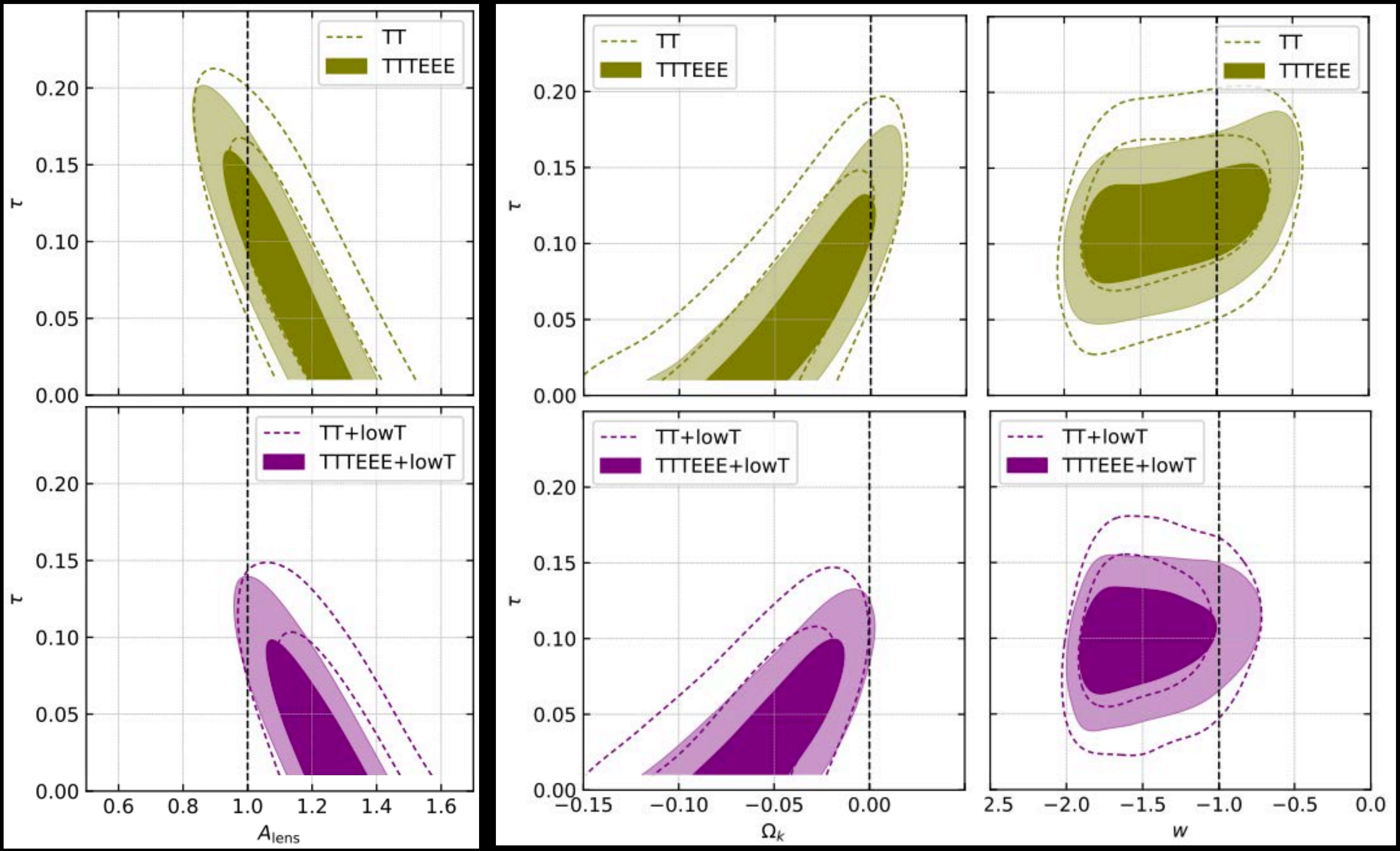
Elbers et al., arXiv: 2407.10965



eBOSS collaboration, Alam et al., *Phys.Rev.D* 103 (2021) 8, 083533

The excess of lensing observed in the CMB affects the inferred total neutrino mass: Planck alone (CamSpec PR4) prefers a negative neutrino mass, a trend already seen in Plik PR3 combined with SDSS.

The role of the optical depth



When the lowE data are excluded, the results become consistent with ΛCDM, and the Planck anomalies disappear.

Giarè, Di Valentino, Melchiorri, Phys.Rev.D 109 (2024) 10, 103519

We should stop fitting the data to our beliefs.

We shouldn't interpret observations through personal, theoretical, or historical priors.
If data agree with our beliefs, we call them "robust."
If they don't, we dismiss them or question their reliability.

I'm not saying we need new physics:
but we've become too precise and not accurate enough.

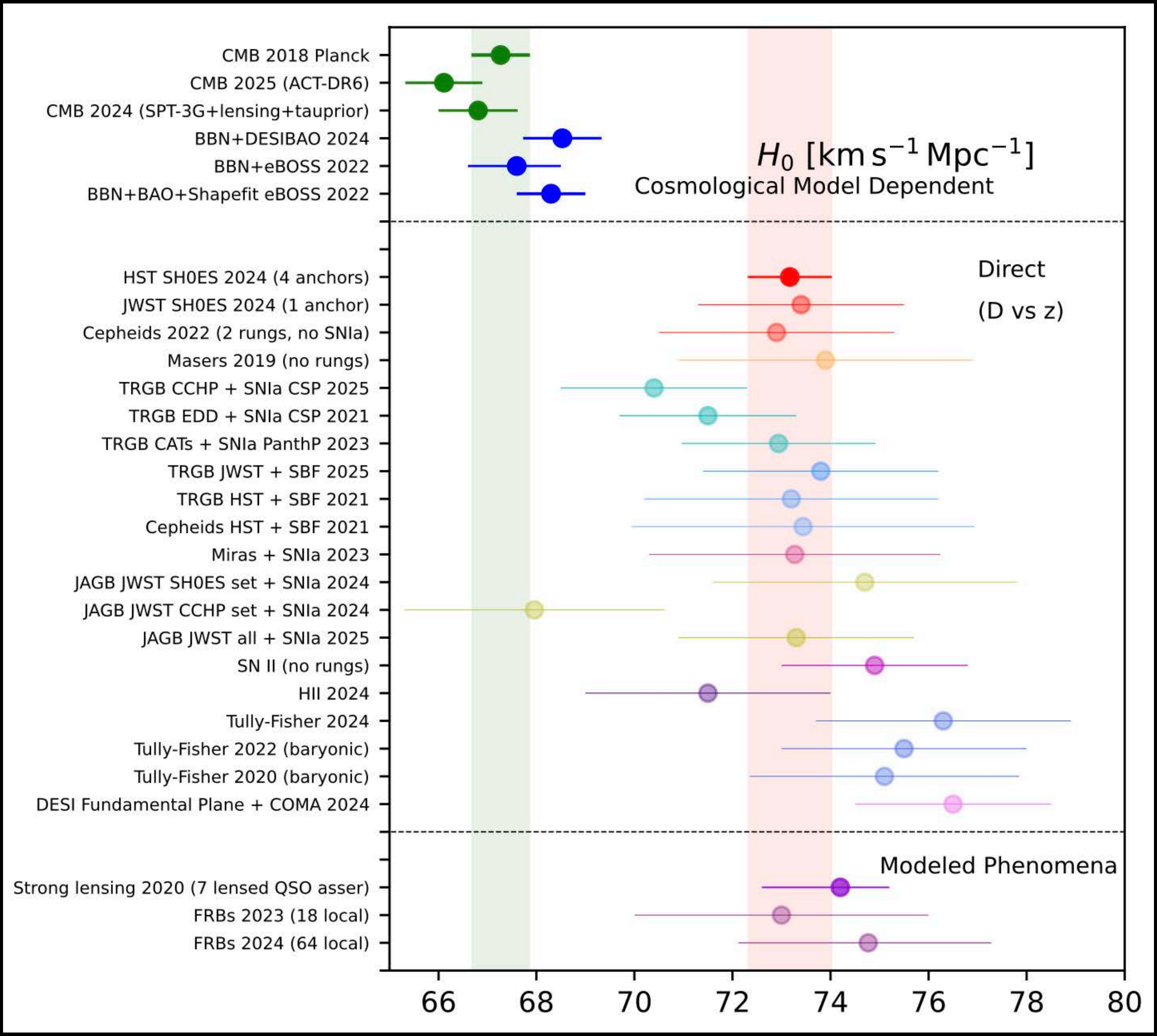
We're cherry-picking datasets based on convenience:
Plik PR3 or CamSpec PR4? Pantheon+ or DESY5? DESI or SDSS?
Depends on which agrees better with "our" preferred results.

The same is happening with BAO: once considered a gold standard, is now questioned.
And we cannot just go back to using older data like SDSS only when it supports our narrative.

That's arbitrary and it's undermining scientific objectivity.

We should let the data breathe.

Latest H0 measurements



And finally we're ignoring the elephant in the room.

All the discussions so far focus on possible signs of new physics in the data, yet none of them can account for the high value of H0.

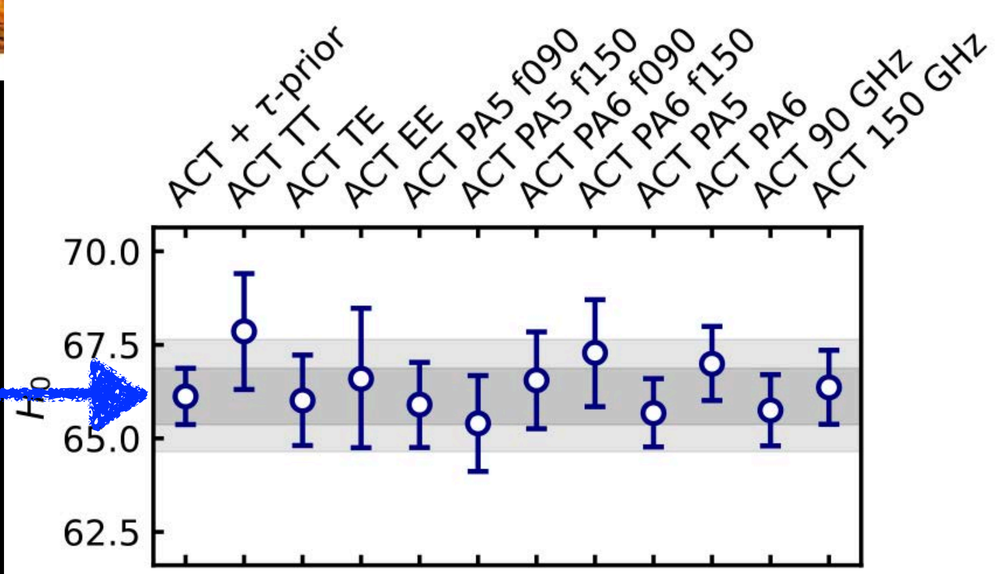
CosmoVerse, Di Valentino et al., arXiv:2504.01669

On the same side of Planck, i.e. preferring smaller values of H_0 we have:

Ground based CMB telescope

ACT-DR6:
H0 = 66.11 ± 0.79 km/s/Mpc in ΛCDM

ACT-DR6 + WMAP:
H0 = 66.78 ± 0.68 km/s/Mpc in ΛCDM

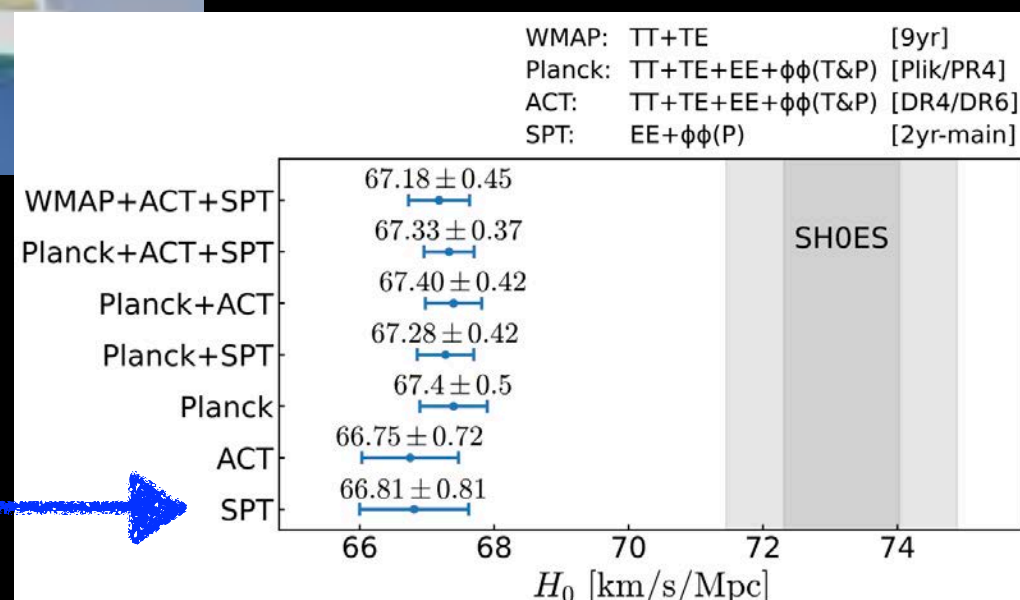


ACT-DR6 2025

ΛCDM - dependent

On the same side of Planck, i.e. preferring smaller values of H_0 we have:

Ground based CMB telescope



SPT-3G:
H0 = 66.81 ± 0.81 km/s/Mpc in ΛCDM

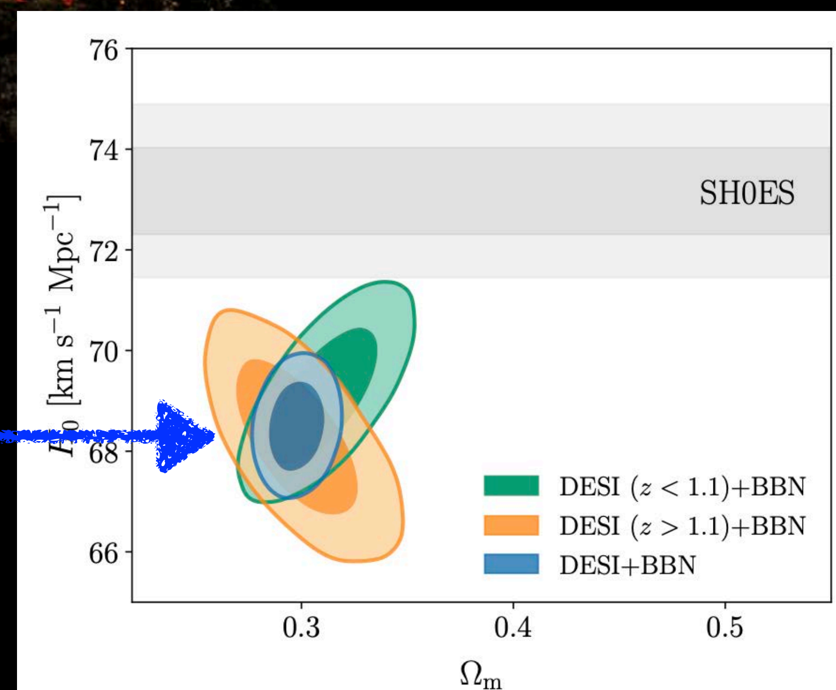
SPT-3G collaboration, arXiv:2411.06000

ΛCDM - dependent

On the same side of Planck, i.e. preferring smaller values of H_0 we have:

In ΛCDM the tension between the DESI+BBN and SH0ES H0 results now stands at 4.5σ independent of the CMB

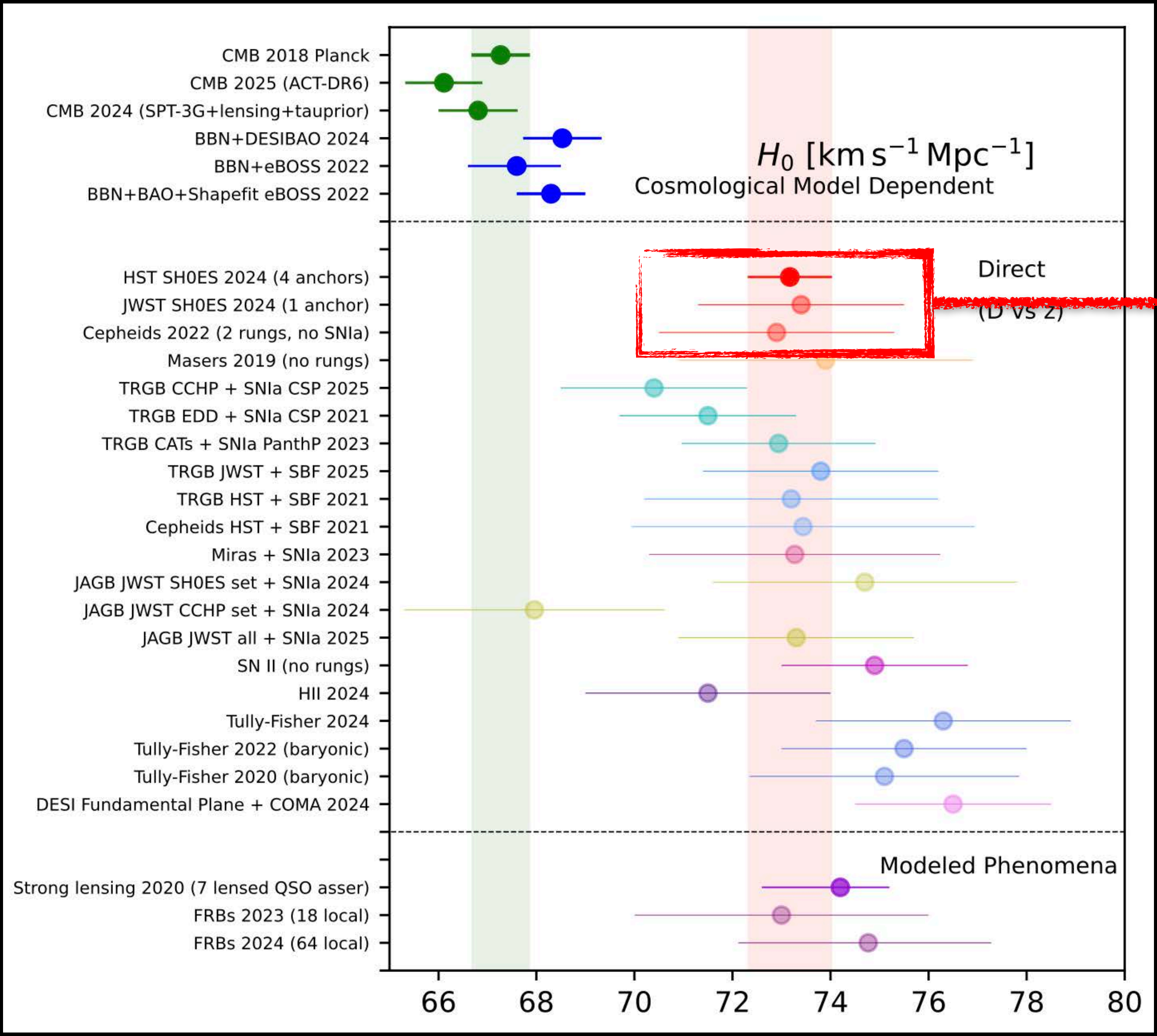
DESI+BBN:
H0 = 68.51 ± 0.58 km/s/Mpc in ΛCDM



ΛCDM - dependent

DESI collaboration, Abdul Karim et al., arXiv:2503.14738

Latest H0 measurements



Cepheids-SN Ia:

H0 = 73.4 ± 2.1 km/s/Mpc

Riess et al., arXiv: *2408.11770*

H0 = 73.17 ± 0.86 km/s/Mpc

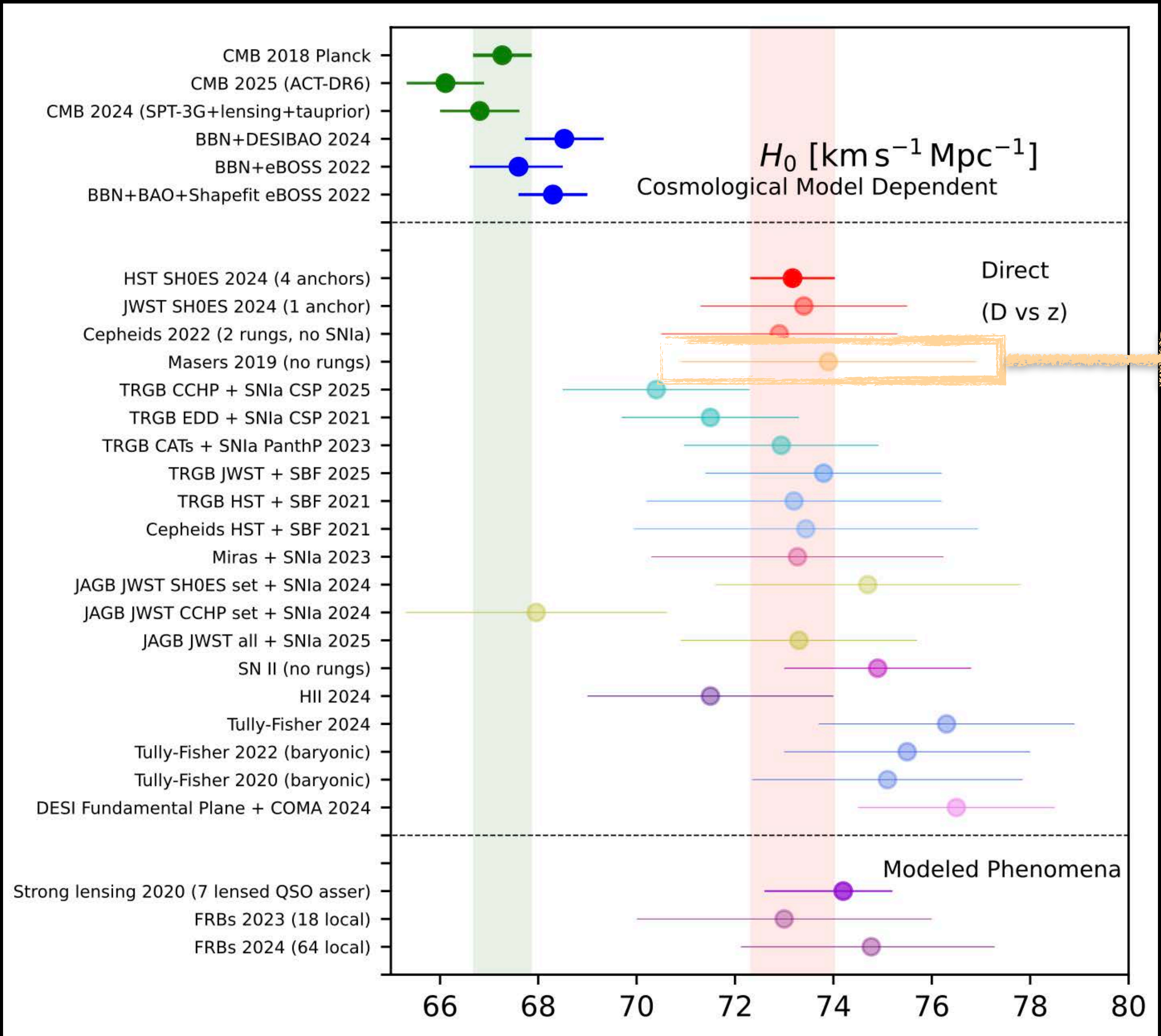
Breuval et al., arXiv:*2404.08038*

H0 = 72.9 ± 2.4 km/s/Mpc

Kenworthy et al., arXiv:2204.10866

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



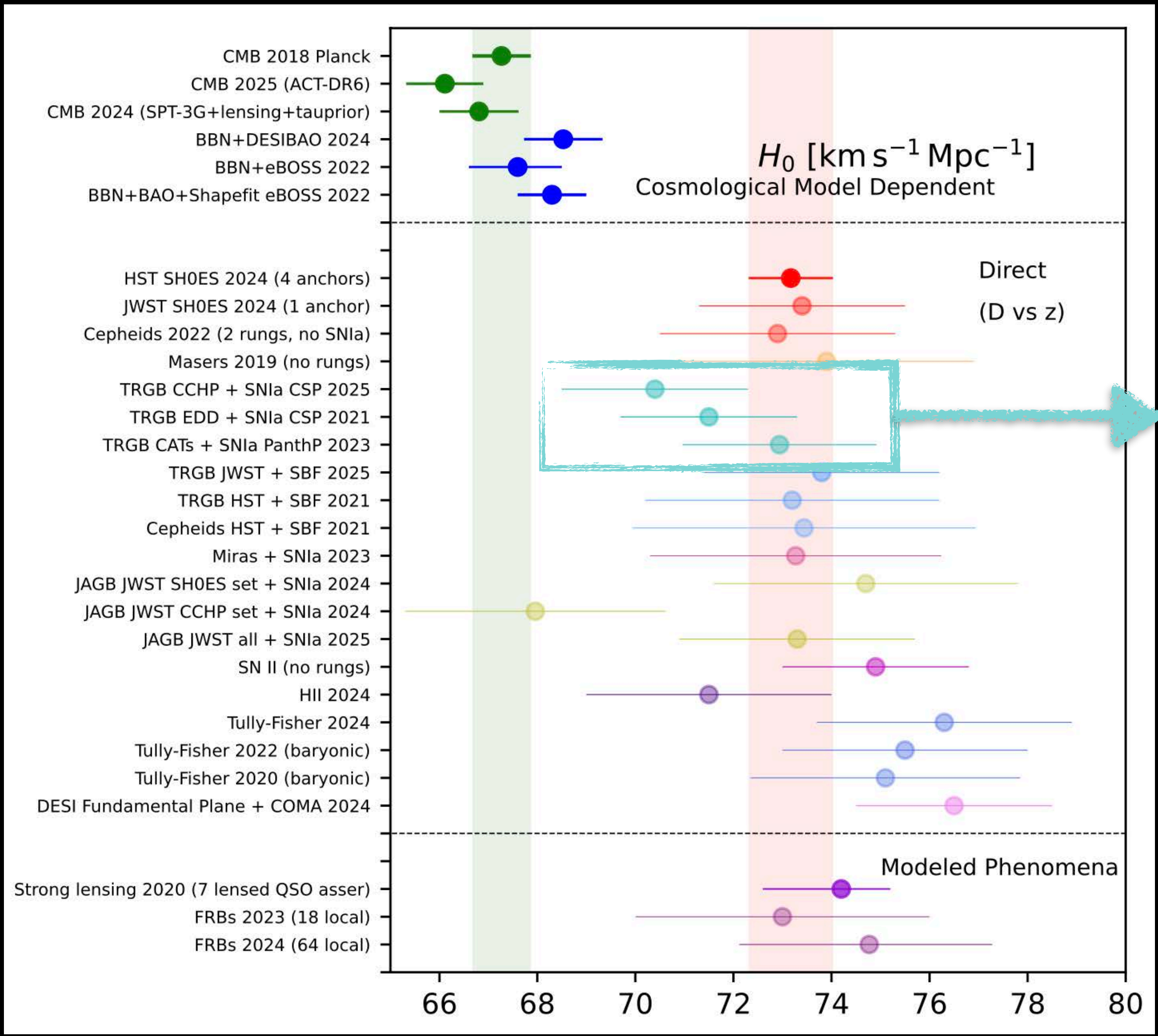
The Megamaser Cosmology Project measures H0 using geometric distance measurements to six Megamaser - hosting galaxies. This approach avoids any distance ladder by providing geometric distance directly into the Hubble flow.

H0 = 73.9 ± 3.0 km/s/Mpc

Pesce et al. arXiv:2001.09213

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



The Tip of the Red Giant Branch (TRGB) is the peak brightness reached by red giant stars after they stop using hydrogen and begin fusing helium in their core.

H0 = 70.39 ± 1.94 km/s/Mpc

Freedman et al., arXiv:*2408.06153*

H0 = 71.5 ± 1.8 km/s/Mpc

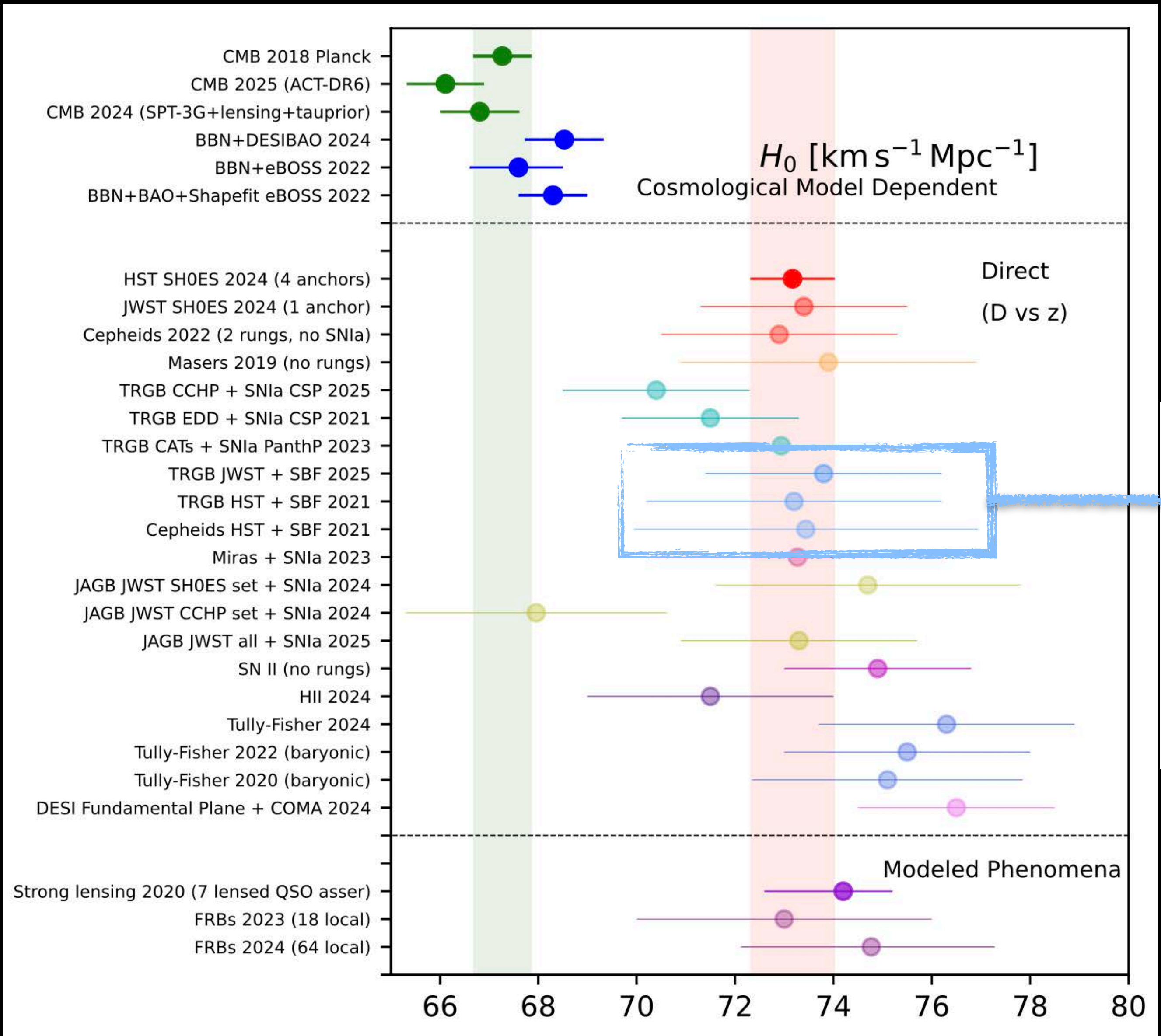
Anand et al., arXiv: *2108.00007*

H0 = 73.22 ± 2.06 km/s/Mpc

Scolnic et al., arXiv:2304.06693

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



H0 = 73.8 ± 2.4 km/s/Mpc

Jensen et al., arXiv:2502.15935

H0 = 73.2 ± 3.5 km/s/Mpc

Blakeslee et al., arXiv:2101.02221

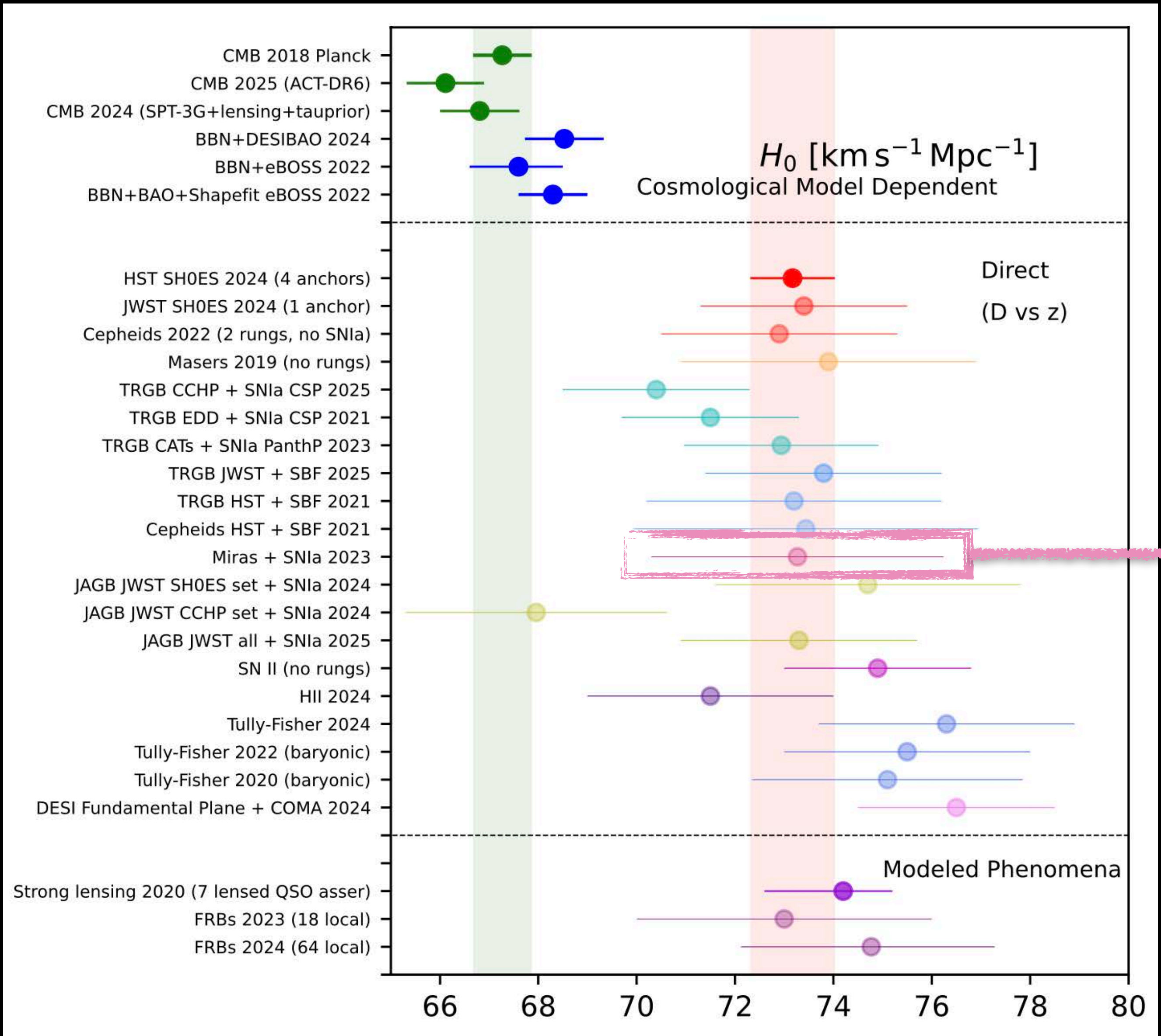
H0 = 73.44 ± 3.0 km/s/Mpc

Blakeslee et al., arXiv:2101.02221

Surface Brightness Fluctuations (substitutive distance ladder for long range indicator, calibrated by both Cepheids and TRGB)

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



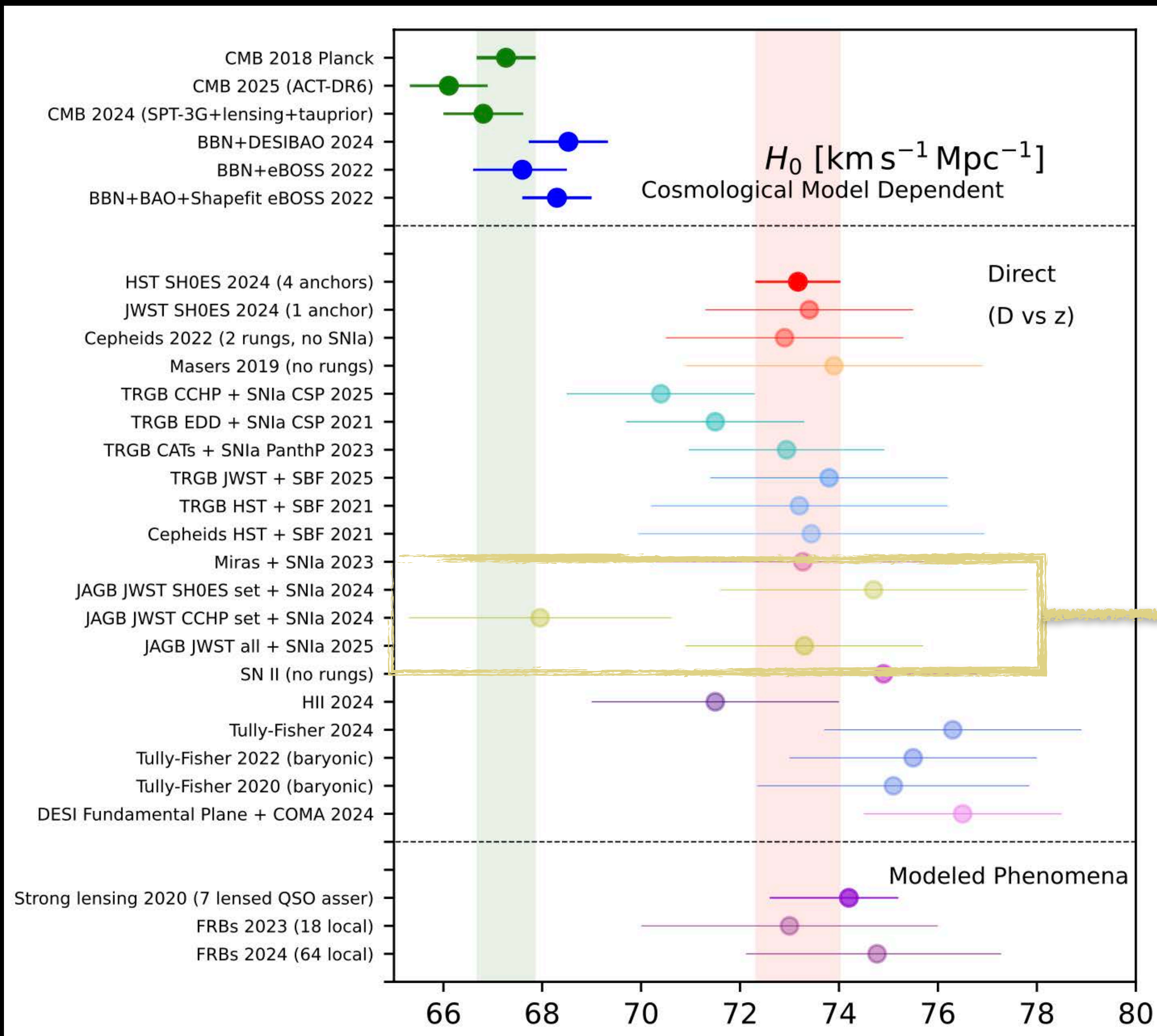
MIRAS
variable red giant stars from older stellar populations

H0 = 72.37 ± 2.97 km/s/Mpc

Huang et al., arXiv:2312.08423]

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



H0 = 74.7 ± 3.1 km/s/Mpc

Li et al., arXiv: *2401.04777*

H0 = 67.96 ± 2.65 km/s/Mpc

Lee et al., arXiv:2408.03474

H0 = 73.3 ± 2.4 km/s/Mpc

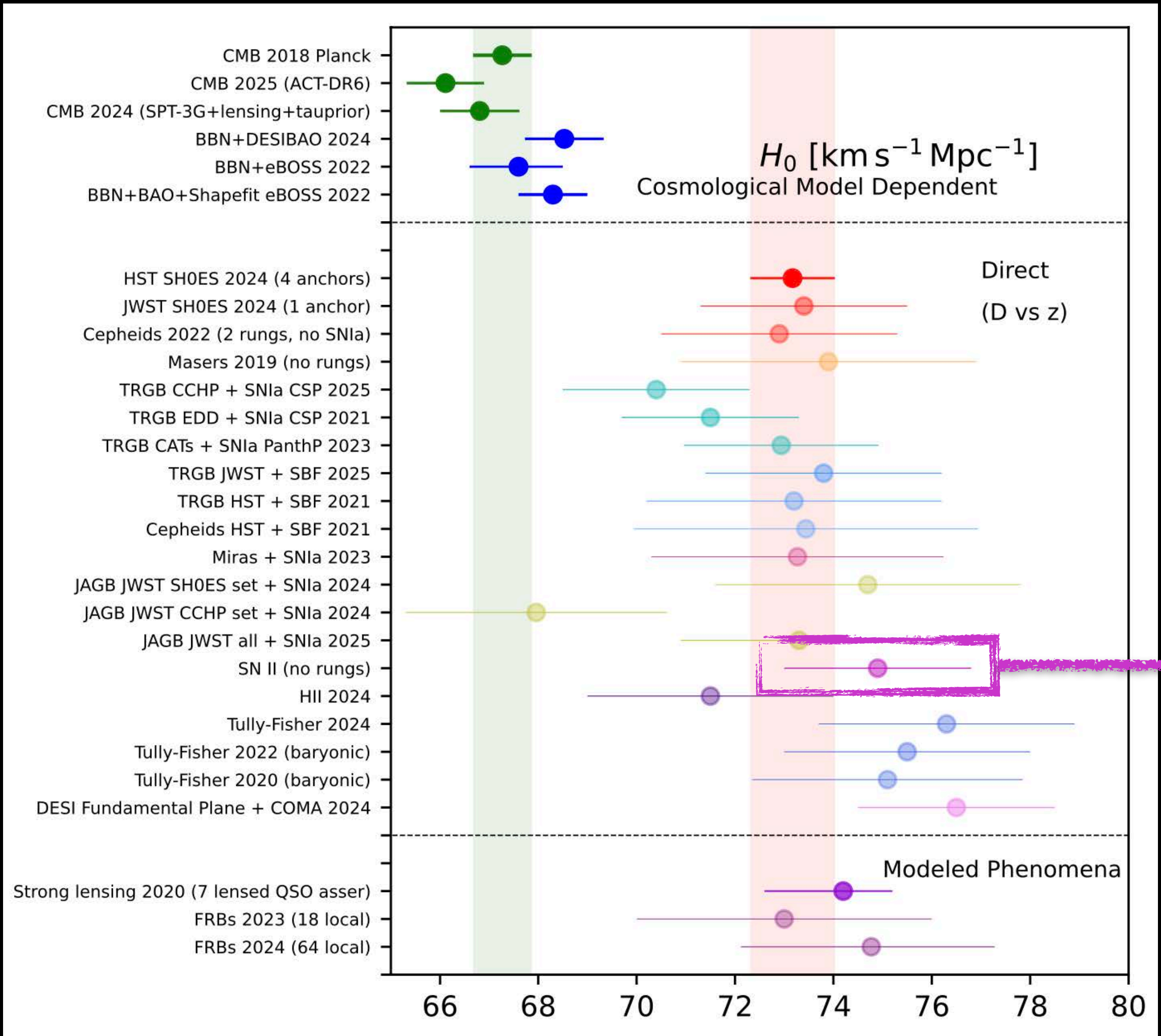
Li et al., arXiv: *2502.05259*

JAGB

The J-regions of the Asymptotic Giant Branch is expected from stellar theory to be populated by thermally-pulsing carbon-rich dust-producing asymptotic giant branch stars.

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



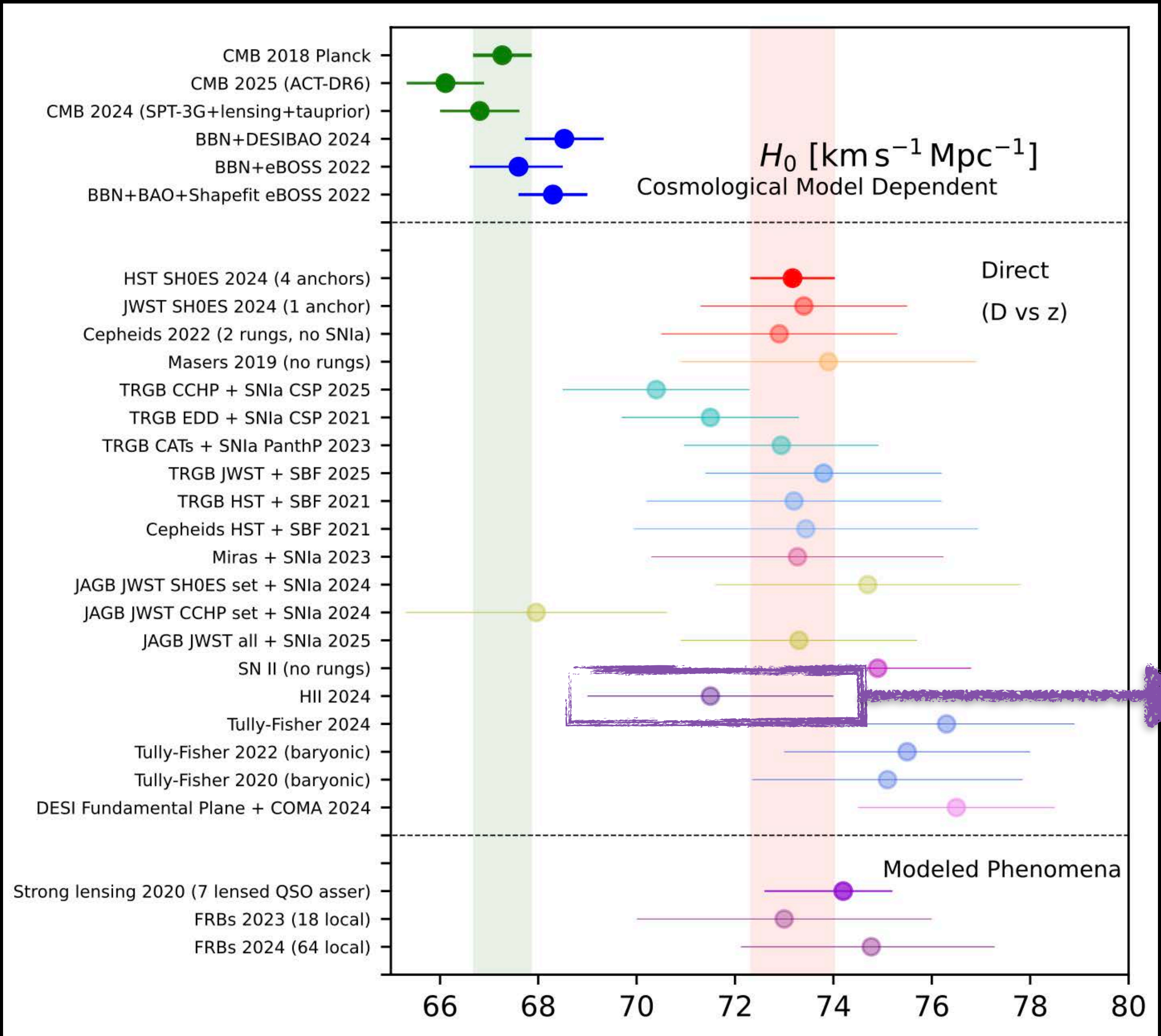
CosmoVerse, Di Valentino et al., arXiv:2504.01669

H0 = 74.9 ± 1.9 km/s/Mpc

Vogl et al., arXiv:2411.04968

Spectral modeling-based Type II supernova distances: for each of these supernovae distances were measured through a recent variant of the tailored Expanding Photosphere Method using radiative transfer models.

Latest H0 measurements



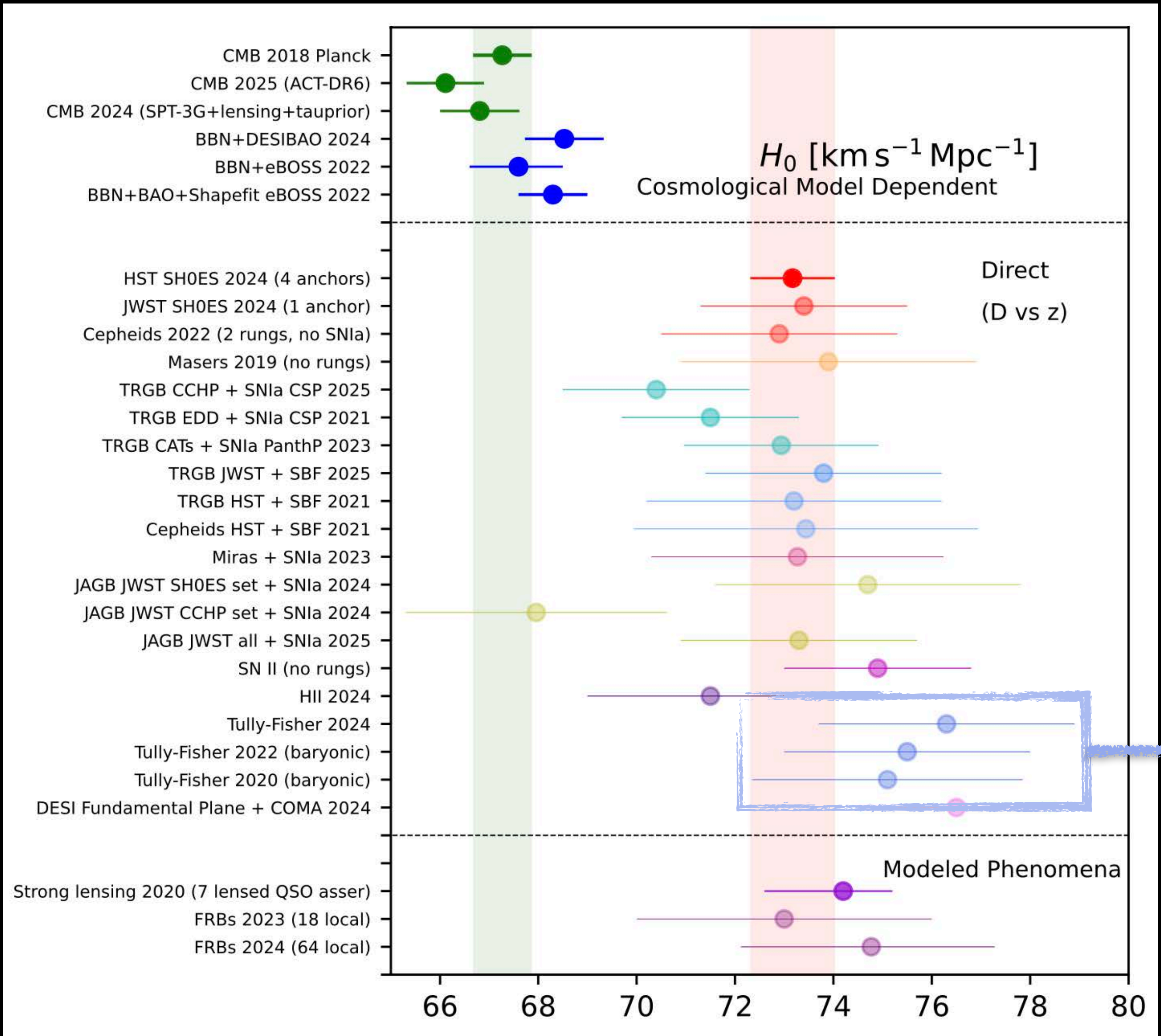
H0 = 71.5 ± 2.5 km/s/Mpc

Chávez et al., arXiv:2404.16261

HII galaxies calibrated using Giant Extragalactic HII Regions (GEHRs) in local galaxies with Cepheid-based distances.

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



H0 = 76.3 ± 2.6 km/s/Mpc

Scolnic et al. arXiv:2412.08449

H0 = 75.5 ± 2.5 km/s/Mpc

Kourkchi et al. arXiv:2201.13023

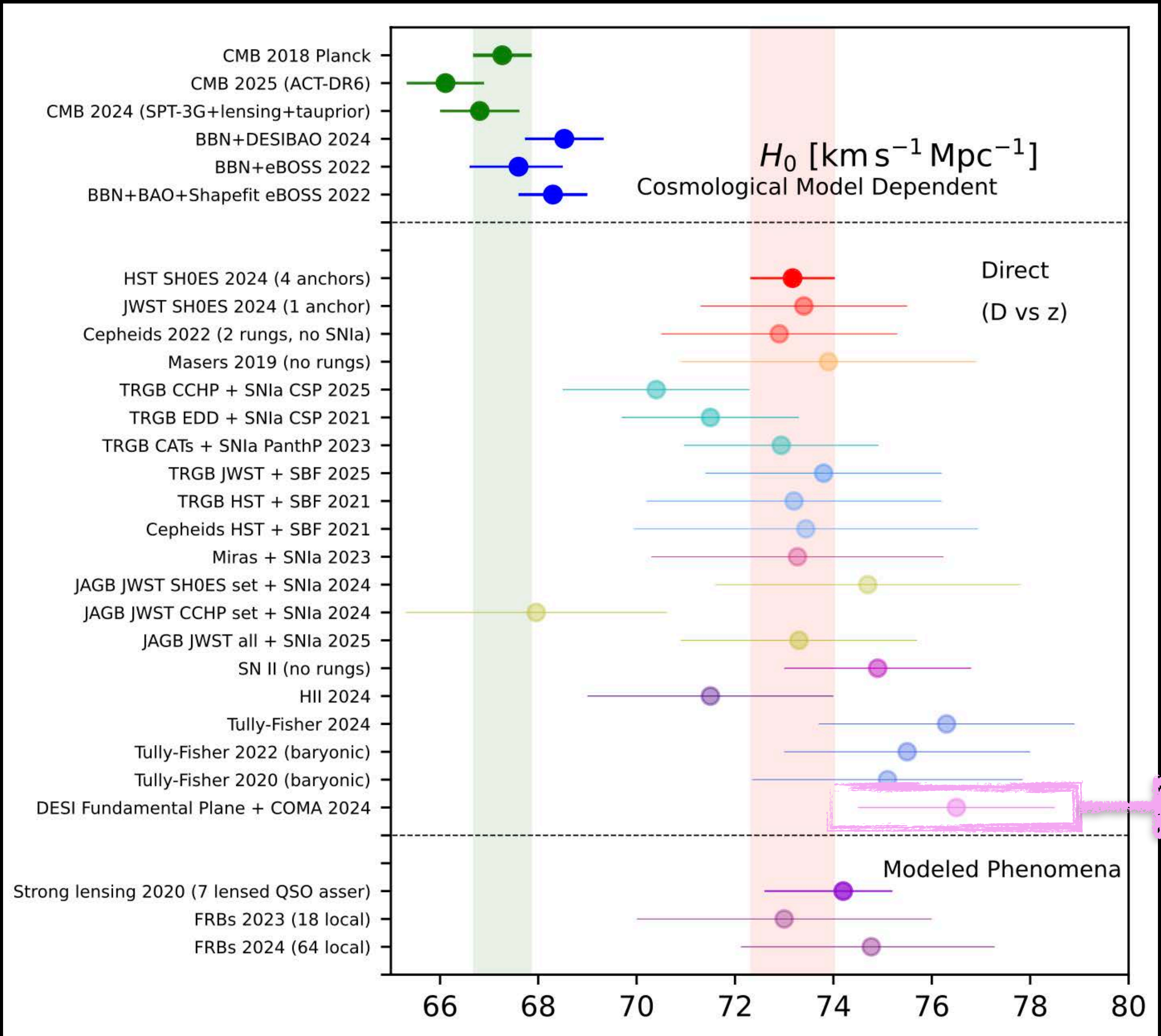
H0 = 75.10 ± 2.75 km/s/Mpc

Schombert et al. arXiv:2006.08615

Tully-Fisher Relation (based on the correlation between the rotation rate of spiral galaxies and their absolute luminosity or total baryonic mass, and using as calibrators Cepheids and TRGB)

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Latest H0 measurements



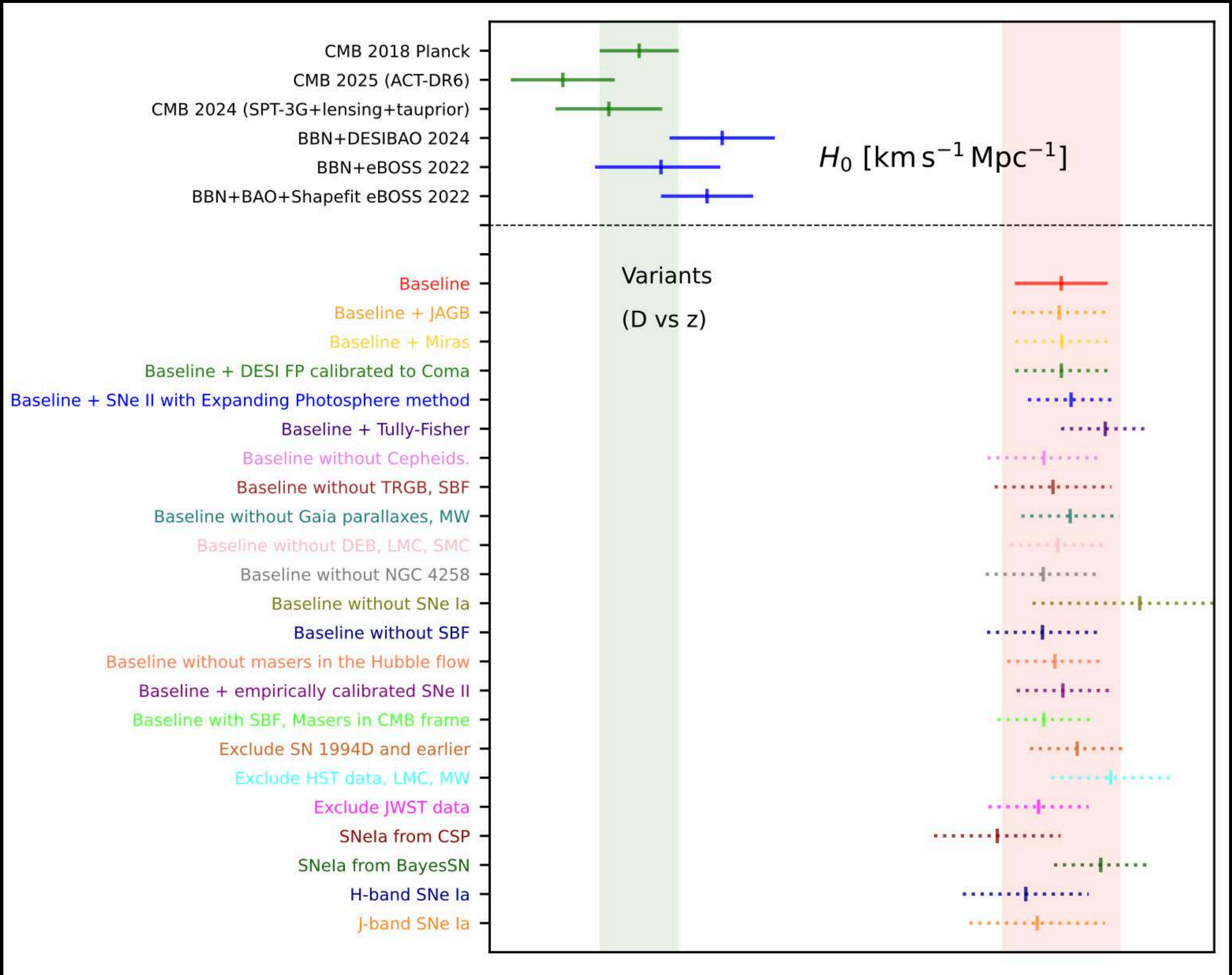
DESI measured relation between H0 and the distance to the Coma cluster using the fundamental plane relation of early-type galaxies.

H0 = 76.5 ± 2.2 km/s/Mpc

Scolnic et al., arXiv: *2409.14546*

CosmoVerse, Di Valentino et al., arXiv:2504.01669

Towards a consensus value on the local expansion rate of the Universe



Casertano et al., in preparation

- We obtained a decorrelated, optimized, multi-method mean.
- The final uncertainty on H0 decreases by 25% compared to SH0ES, reaching 1% precision.
- Excluding Cepheids or some of the distance anchors does not lead to significant changes in the result.
- Replacing Pantheon+ with CSP removes 40% of the SN, causing H0 to decrease by ~0.7 km/s/Mpc.

The Hubble tension doesn't depend on any one source!

Concluding

If all data must agree with Planck LCDM to be trusted,
then we’re no longer testing models, we’re protecting them.

ΛCDM is a remarkably successful fitting model,
but it was never meant to be untouchable.
It’s built on ingredients (dark matter, a cosmological constant, and inflation)
none of which have a fundamental theoretical explanation or direct detection.
We use them because they work phenomenologically,
not because we understand what they are.

Clinging to ΛCDM as the final word in cosmology
risks mistaking convenience for truth,
and turning precision cosmology into confirmation bias dressed as science.

We must stay open to what the data are really telling us,
let’s not always dismiss deviations and anomalies as systematics and statistical flukes,
and be ready for a reassessment of both our methods and assumptions.

Thank you!

e.divalentino@sheffield.ac.uk

COSMOVERSE • COST ACTION CA21136

Addressing observational tensions in cosmology with systematics and fundamental physics

https://cosmoversetensions.eu/

WG1 – Observational Cosmology and systematics

Unveiling the nature of the existing cosmological tensions and other possible anomalies discovered in the future will require a multi-path approach involving a wide range of cosmological probes, various multiwavelength observations and diverse strategies for data analysis.

READ MORE

WG2 – Data Analysis in Cosmology

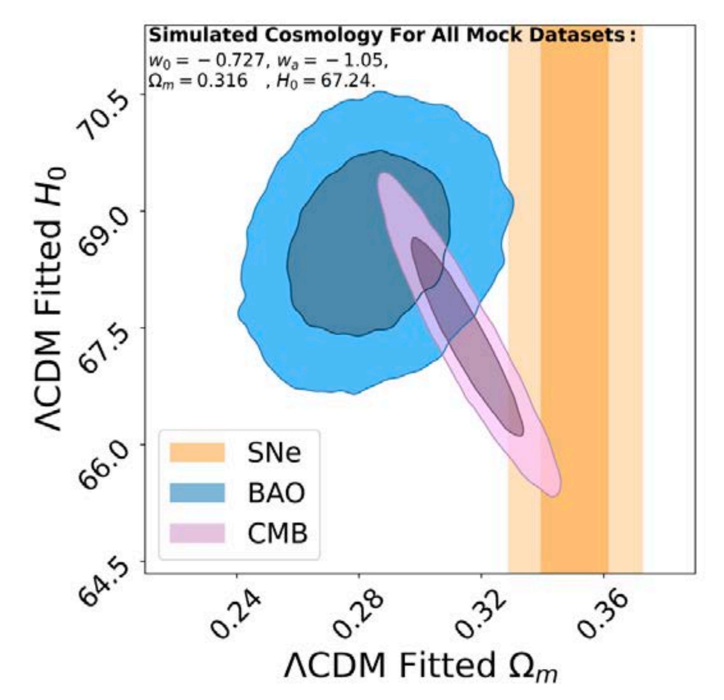
Presently, cosmological models are largely tested by using well-established methods, such as Bayesian approaches, that are usually combined with Monte Carlo Markov Chain (MCMC) methods as a standard tool to provide parameter constraints.

READ MORE

WG3 – Fundamental Physics

Given the observational tensions among different data sets, and the unknown quantities on which the model is based, alternative scenarios should be considered.

READ MORE



Tang et al., arXiv:2412.04430

Data/Mock	ΛCDM Fit	Ω_m Agreement Between Probes (See Section III.1)
Real Data (DESI Y1 VI BAO, DES-SN5YR, Planck18 CMB)	BAO: $\Omega_m = 0.295 \pm 0.015$, $H_0 = 68.5 \pm 0.8$ SNe : $\Omega_m = 0.353 \pm 0.017$ CMB: $\Omega_m = 0.315 \pm 0.007$, $H_0 = 67.3 \pm 0.6$	p-value $= 0.035$
Mock simulated in DESI+CMB Best-Fit ΛCDM $\Omega_m = 0.31$, $H_0 = 68$	BAO: $\Omega_m = 0.311 \pm 0.019$, $H_0 = 68.0 \pm 0.8$ SNe : $\Omega_m = 0.310 \pm 0.011$ CMB: $\Omega_m = 0.310 \pm 0.012$, $H_0 = 68.0 \pm 0.8$	p-value $= 0.999$
Mock simulated in DESI+CMB+DESY5SN Best-Fit w_0w_aCDM $\Omega_m = 0.316$, $w_0 = -0.727$, $w_a = -1.05$, $H_0 = 67.24$	BAO: $\Omega_m = 0.281^{+0.019}_{-0.016}$, $H_0 = 68.6 \pm 0.8$ SNe : $\Omega_m = 0.350 \pm 0.011$ CMB: $\Omega_m = 0.315 \pm 0.012$, $H_0 = 67.4 \pm 0.8$	p-value $= 0.003$

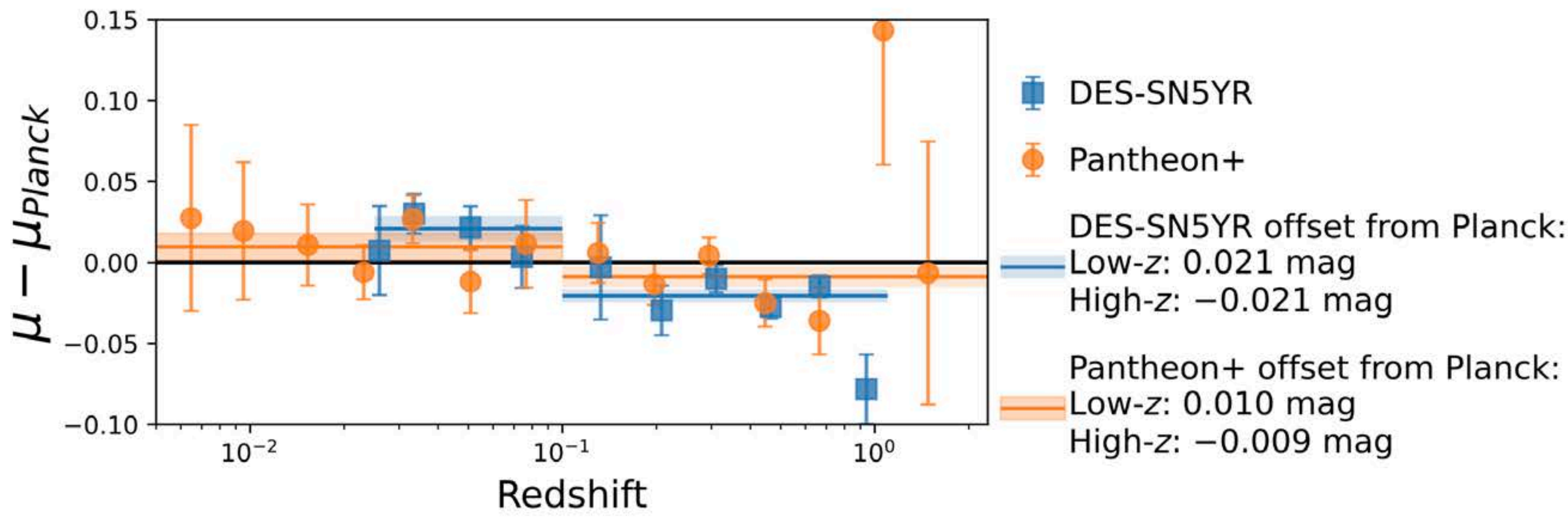


Figure 1. Pantheon+ and DES-SN5YR binned Hubble residuals calculated w.r.t. a FlatΛCDM cosmology assuming $\Omega_M = 0.315$ from *Planck*. In each redshift bin we show the weighted mean of the Hubble residual and statistical-only uncertainties. The horizontal bands show the weighted mean of the Hubble residuals (and associated uncertainties) above and below redshift 0.1 for both Pantheon+ and DES-SN5YR.

6 CONCLUSION

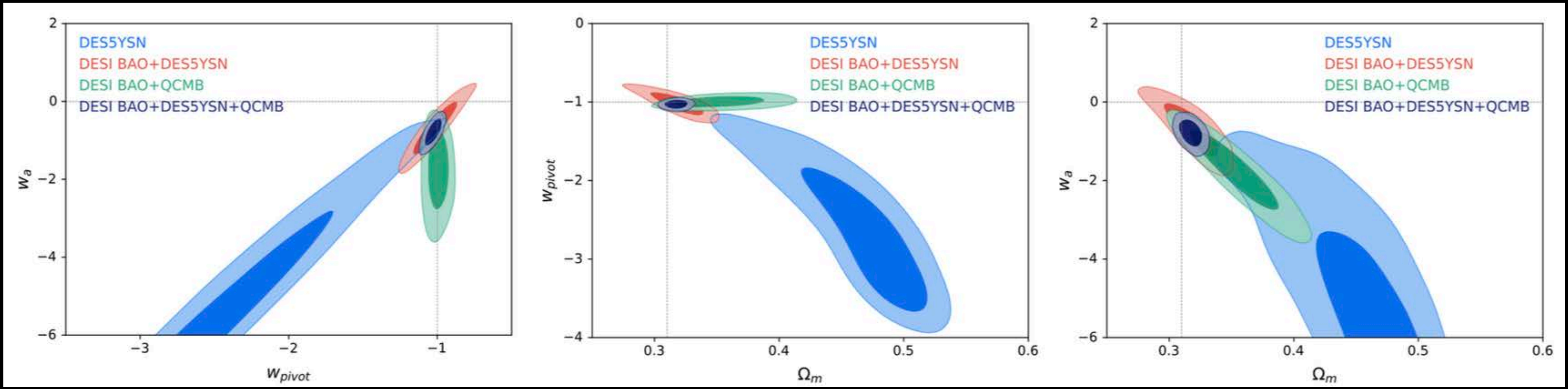
Efstathiou (2024) noted a 0.04 mag low-vs-high redshift distance offset (Eq. 1) between overlapping Pantheon+ and DES-SN5YR events. We have investigated this offset and find that it is explained as follow.

- **Two analysis improvements since Pantheon+**: These improvements are related to the intrinsic scatter model and host stellar mass estimates, and account for 0.018 mag discrepancy between Pantheon+ and DES-SN5YR (from −0.042 to −0.024, see Table 1);
- **Selection differences between Pantheon+ and DES-SN5YR:** Larger distance bias corrections are required for the more heavily biased Pantheon+ sample of spectroscopically identified events, compared to smaller bias corrections for the more complete sample of photometrically classified events in DES-SN5YR (Fig. 4). This difference in selection functions does not affect cosmology results, but leads to misleading conclusions in an object-to-object comparison like the one presented by Efstathiou (2024), where only 20% of the brightest SNe are selected from both analyses. This effect account for an additional 0.016 mag discrepancy between Pantheon+ and DES-SN5YR (from −0.024 to −0.008, see Table 1). This biased comparison can be avoided by comparing the binned Pantheon+ and DES-SN5YR Hubble diagrams as shown in Fig. 1.

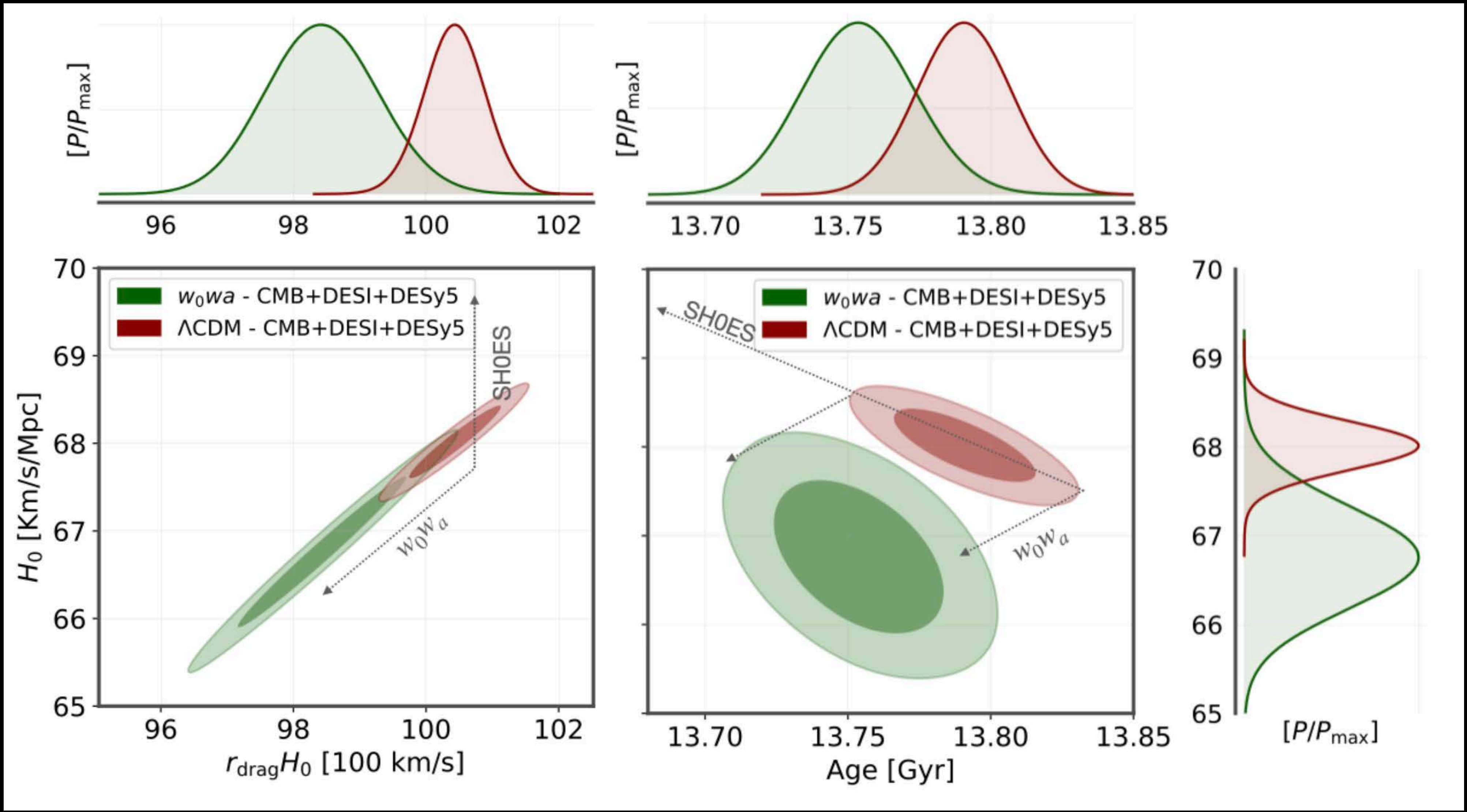
Vincenzi et al., arXiv:2501.06664

Analysis changes applied to DES-SN5YR	Contribution to $\Delta\mu_{\rm offset}$ [mag]	Remaining $\Delta\mu_{\rm offset}$ [mag]
None		**−0.042**
Revert to Pantheon+ intrinsic scatter model ($*$)	**0.008**	**−0.034**
Revert to Pantheon+ host stellar mass estimations	**0.010**	**−0.024**
Remove offset due to different selection functions (‡)	**0.016**	**−0.008**

Approach used to build the Hubble diagram ↓	**Spectroscopic SN Ia sample (~same data)**	**Photometric SN Ia sample**
Simulation-based method	**Pantheon+**	**DES-5YR**
Bayesian Hierarchical method ("UNITY")	**Union3**	



Efstathiou, arXiv:2505.02658



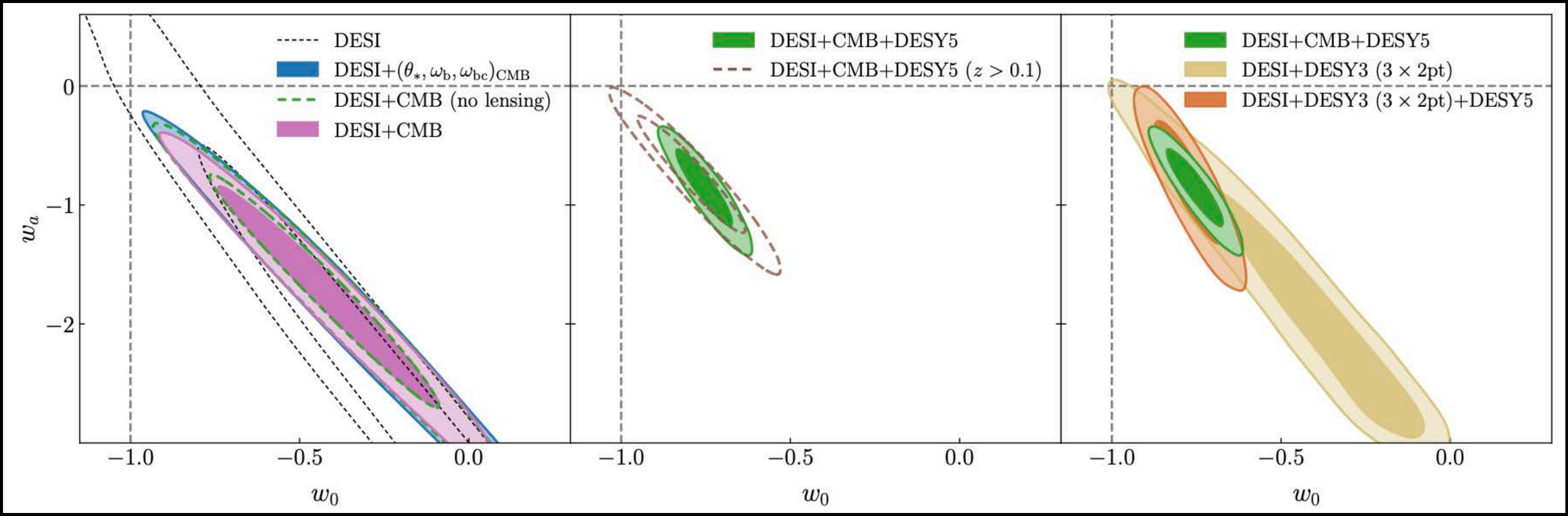
Giarè & Di Valentino, in preparation

Model	Q_{DMAP}	$\sigma_{Q_{\mathrm{DMAP}}}$	logR	d	logS	$\sigma_{\log S}$
ΛCDM	6.21	2.00	0.9 ± 0.4	2.4 ± 0.8	-2.7 ± 0.2	2.2 ± 0.2
$w_0 w_a$CDM	3.57	1.35	3.6 ± 0.4	4.0 ± 0.8	-0.2 ± 0.2	0.9 ± 0.1

TABLE I. Statistical Quantities for ΛCDM and $w_0 w_a$CDM.

Table I summaries the quantified (in)consistency between CMB and BAO in ΛCDM and $w_0 w_a$CDM. The tension is confirmed by both metrics with significance 2.2σ and 2.0σ for *Suspiciousness* and *goodness-of-fit* respectively. This estimation is consistent with the

Ye & Lin, arXiv: 2505.02207



DESI collaboration, Abdul Karim et al., arXiv:2503.14738

THE ASTROPHYSICAL JOURNAL, 530:593–617, 2000 February 20

TYPE Ia SUPERNOVAE, EVOLUTION, AND THE COSMOLOGICAL CONSTANT

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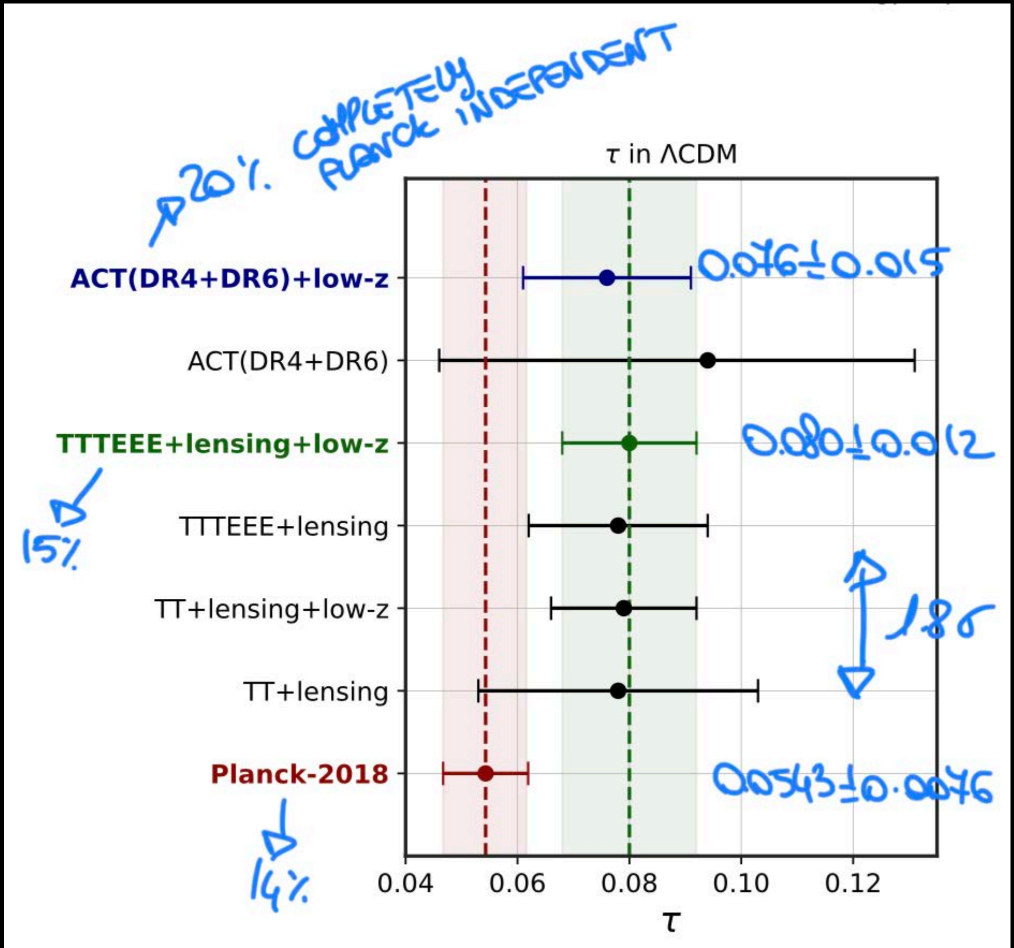
Received 1999 May 4; accepted 1999 September 30

We conclude our discussion of this model by summarizing the evidence in the data for a nonzero cosmological constant, presuming the δ model to be true. In R98 and P99, the marginal posterior probability that $\Omega_\Lambda > 0$ was presented as such a summary; this probability was found to equal 99.6% (2.9 σ), 99.99% (3.9 σ), and 99.8% (3.1 σ) in the MLCS, TF, and SF analyses, respectively, apparently indicating strong evidence that Ω_Λ is nonzero. But this quantity is not a correct measure of the strength of the evidence that $\Omega_\Lambda \neq 0$. This probability would equal unity if negative values of Ω_Λ were considered unreasonable a priori, yet presumably even in this case one would not consider the data to demand a nonzero cosmological constant with absolute certainty. The correct quantity to calculate is the odds in favor of a model with $\Omega_\Lambda \neq 0$ versus a model with $\Omega_\Lambda = 0$. Considering such models to be equally probable a priori, this is given by the Bayes factor comparing these models.[12] We find $B = 5.4$ using the MLCS data and $B = 6.8$ using the SF data, each indicating positive but not strong evidence for a nonzero cosmological constant

[12] These Bayes factor calculations can also be viewed as providing the posterior probability that $\Omega_\Lambda = 0$ by putting a prior probability of 0.5 on the $\Omega_\Lambda = 0$ line; in the calculations reported in R98 and P99, this line has zero prior probability [only finite intervals in $(\Omega_M, \Omega_\Lambda)$ have nonzero prior probability in their analyses].

lowE independent optical depth



By using different combinations of Planck temperature and polarization data at l > 30, ACT and Planck reconstructions of the lensing potential, BAO measurements from BOSS and eBOSS surveys, and Type-Ia supernova data from the Pantheon-Plus sample, we can constrain τ independently.

The most constraining limit $\tau = 0.080 \pm 0.012$ comes from TTTEEE+lensing+low-z.

Using only ACT- based temperature, polarization, and lensing data, from ACT(DR4+DR6)+low-z we got $\tau = 0.076 \pm 0.015$ which is entirely independent of Planck.

Giarè, Di Valentino, Melchiorri, Phys.Rev.D 109 (2024) 10, 103519

BAO measurements

To simplify let's consider an ensemble of galaxy pairs at a specific redshift z.

When the pairs are oriented across the line-of-sight,
a preferred angular separation of galaxies Δθ can be observed.
This allows us to measure the comoving distance DM(z) = rd/Δθ to this redshift,
which is an integrated quantity of the expansion rate of the universe.

$$D_{\mathrm{M}}(z) = \frac{c}{H_0} \int_0^z \mathrm{d}z' \frac{H_0}{H(z')}$$

The angular diameter distance will be DA(z) = DM(z)/(1 + z).

Conversely, when the pairs are aligned along the line-of-sight, a preferred redshift separation Δz can be observed. This measures a comoving distance interval that, for small values, provides a redshift dependent measurement of the Hubble parameter, represented by the equivalent distance variable DH(z) = c/H(z) = rd/Δz.

Hence BAO measurements constrain the quantities DM(z)/rd and DH(z)/rd.
This interpretation holds under standard assumptions and models similar to ΛCDM.
For measurements in redshift bins with low signal-to-noise ratios,
the angle-averaged quantity DV(z)/rd can be constrained,
where DV(z) is the angle-average distance that represents the average of the distances
measured along and perpendicular to the line-of-sight.

$$D_{\mathrm{V}}(z) = \left(z D_{\mathrm{M}}(z)^2 D_H(z)\right)^{1/3}$$

DESI collaboration, arXiv:2404.03002