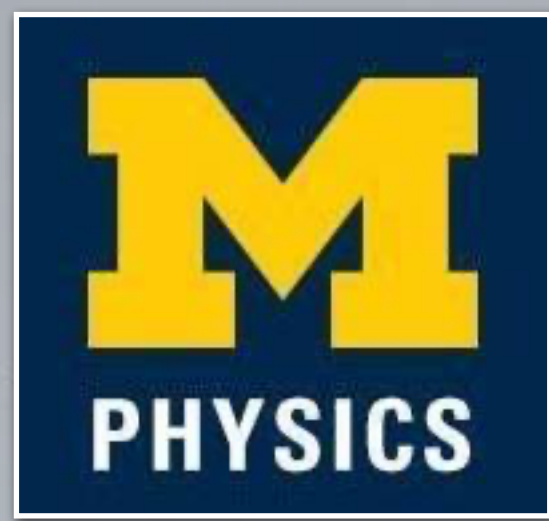




Constraining Late-Time Cosmology with DESI DR2

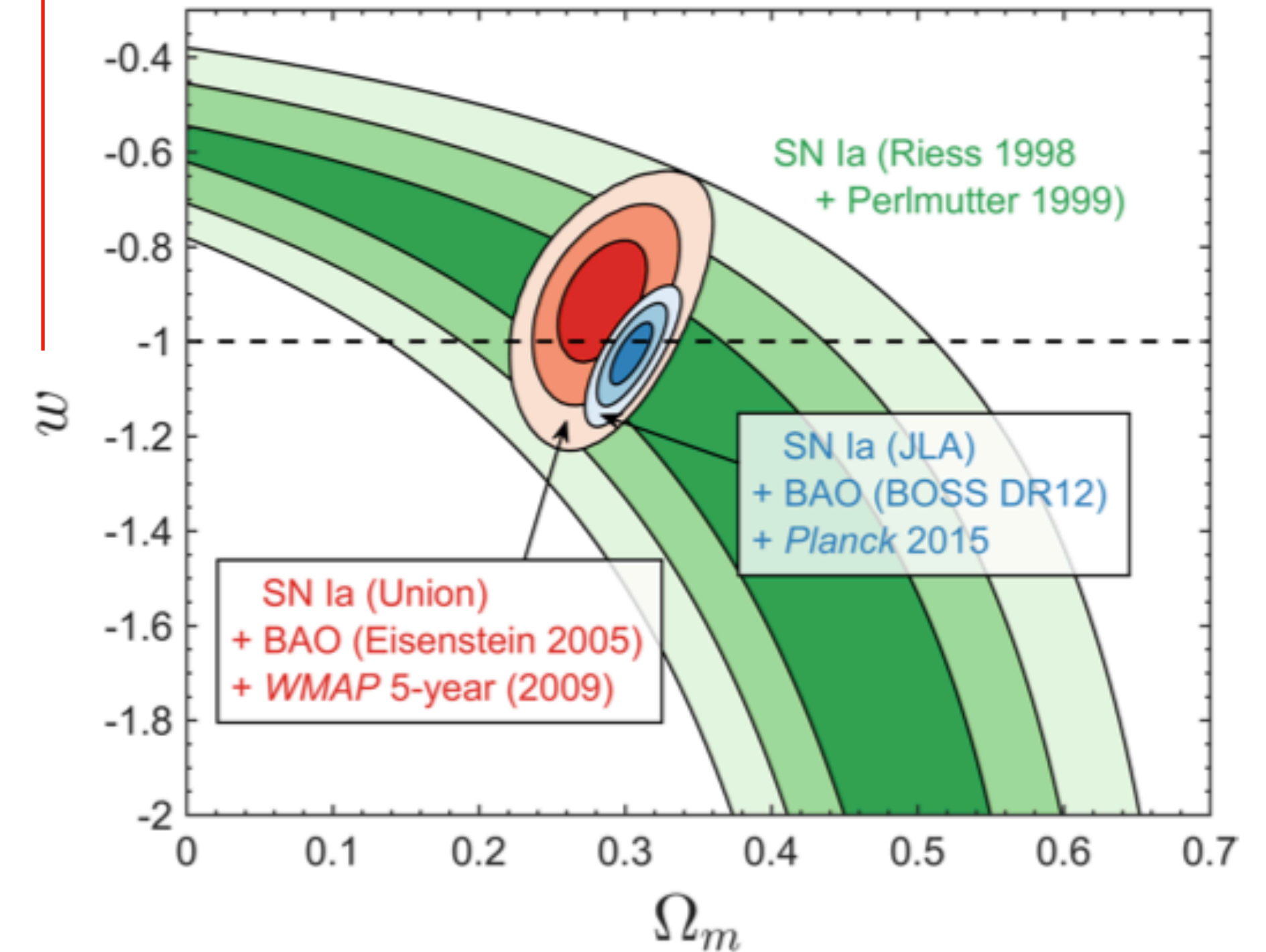
Cosmology Seminar
University of Helsinki
20th May 2026

Prakhar Bansal
2nd Year PhD Student
Advisor: Dragan Huterer

Dark Energy

- The Universe's expansion is accelerating!!
Reason: Dark Energy
- Confirmed in 1998. Nobel Prize in 2011!
- Experiments so far have revealed
 - DE makes up ~70% of the energy budget of the Universe
 - A constant energy density (Λ CDM)
DE model ($w \simeq -1$)

EOS Parameter for DE



$$\dot{\rho} \propto (1 + w)\rho$$

DESI: Dark Energy Spectroscopic Instrument

- 4th Generation Spectroscopic Survey
- 4M Mayall Telescope at Kitt Peak (Tucson, AZ)
- International Collaboration ~900 Scientists, ~70 institutions
- Mapping the distribution of the galaxies in the Universe by precisely measuring their redshifts

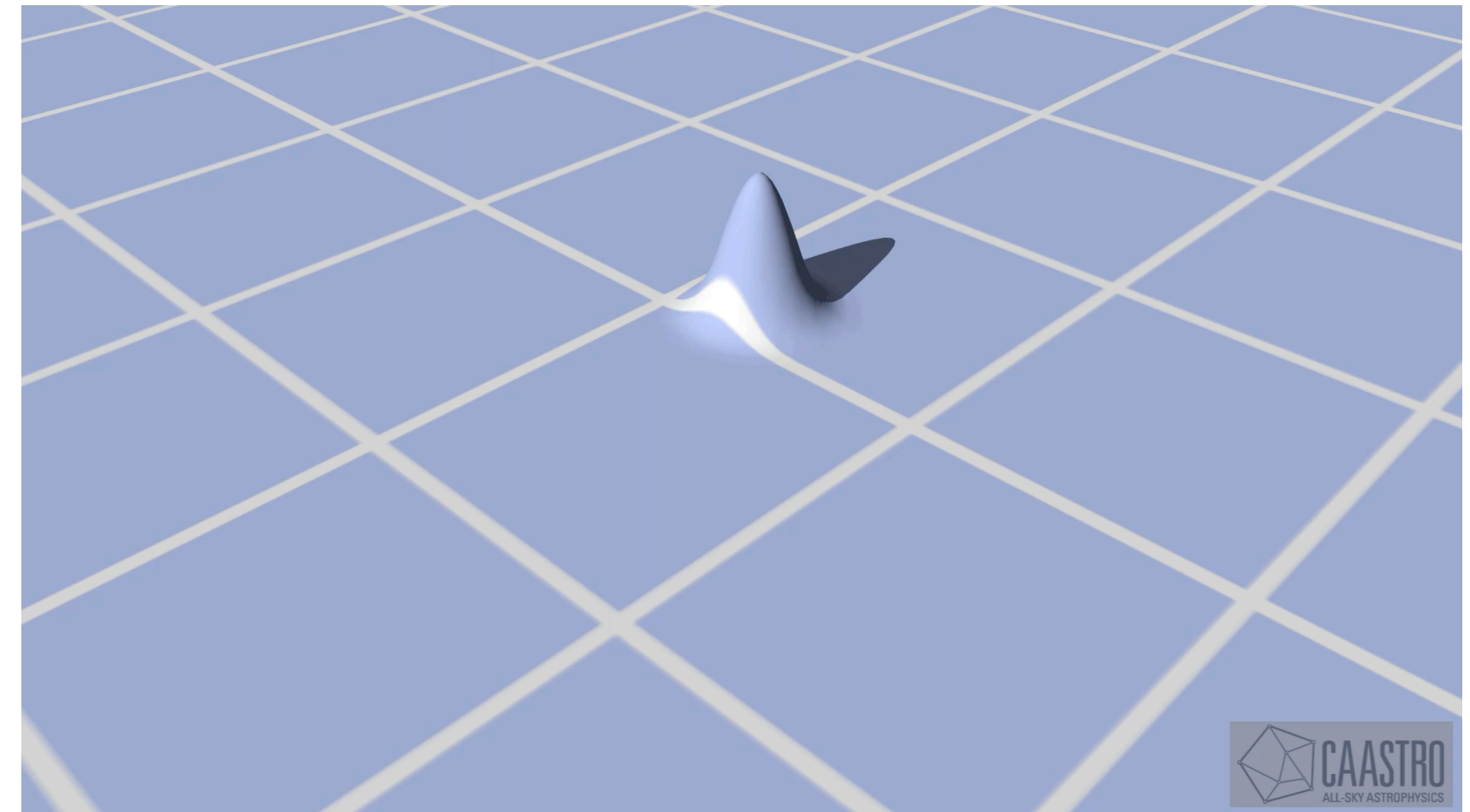


But how does this map of galaxies help??

This map helps us study some patterns in clustering of galaxies governed by the laws of Physics

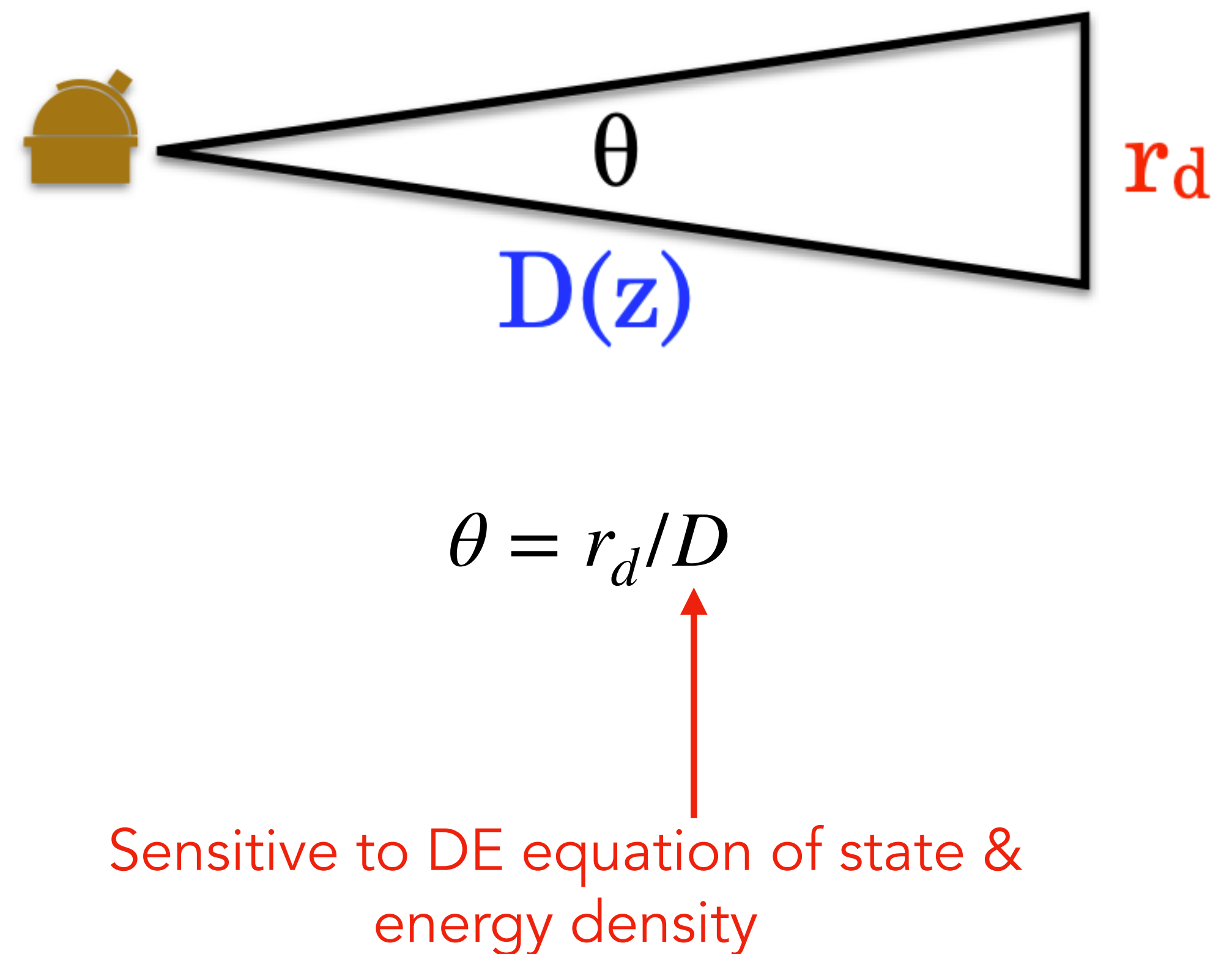
1. Baryon Acoustic Oscillations

- Tightly coupled photons & baryons act as a single fluid plasma
- Overdensity $\longrightarrow$ Collapse
 $\downarrow$
Outwards travelling pressure wave
- At decoupling, $z_d \sim 1060$, the pressure wave stops and the distance this pressure wave travels from big bang ($r_d \sim 150$ Mpc) gets locked in

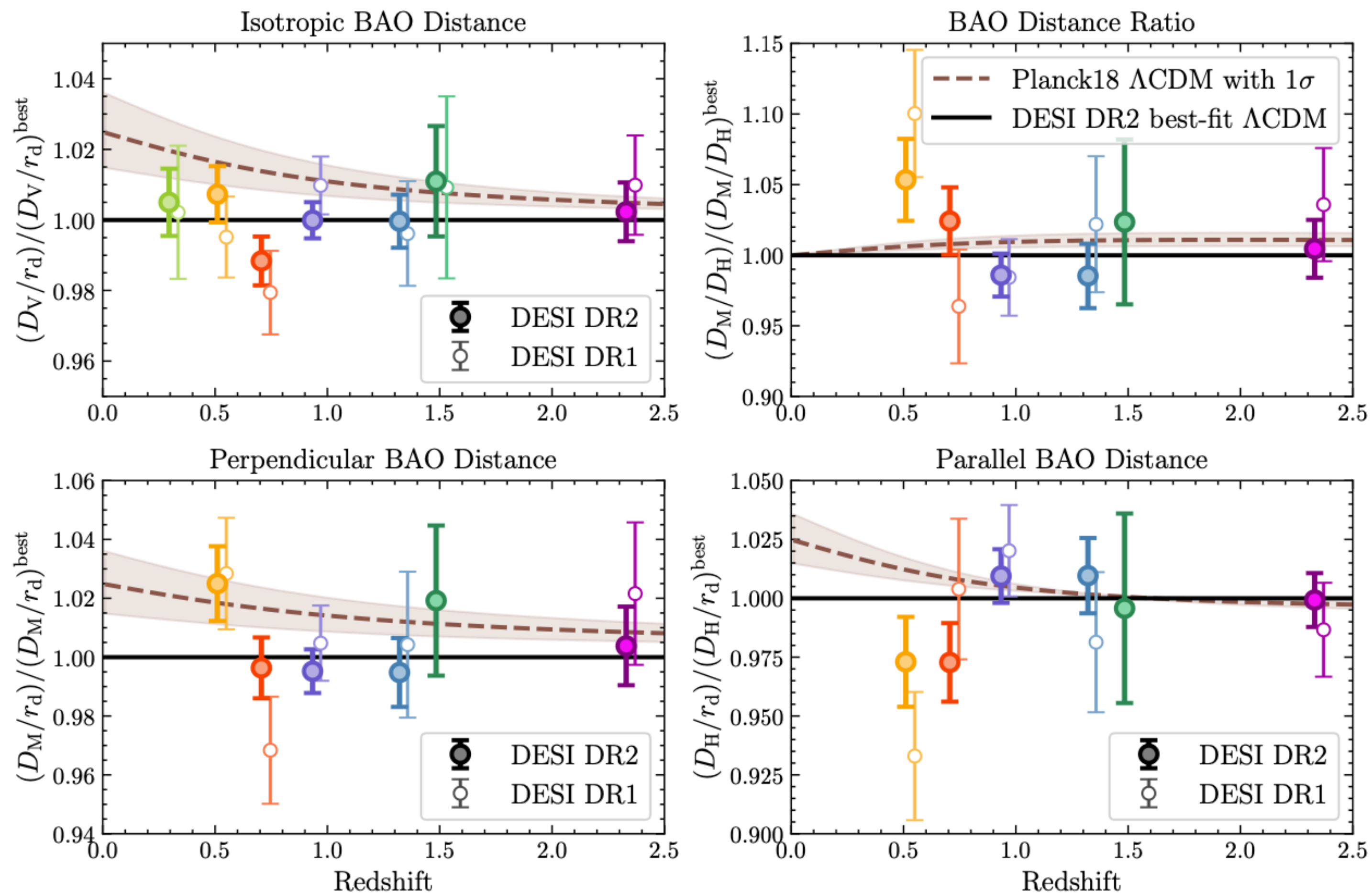


How does the BAO feature help understand DE?

- Due to this feature, two galaxies have a preferential probability of being separated by a distance r_d
- Excessive clustering at a preferred scale
- "Standard Ruler"
- What we actually observe is the angle to the Standard Ruler

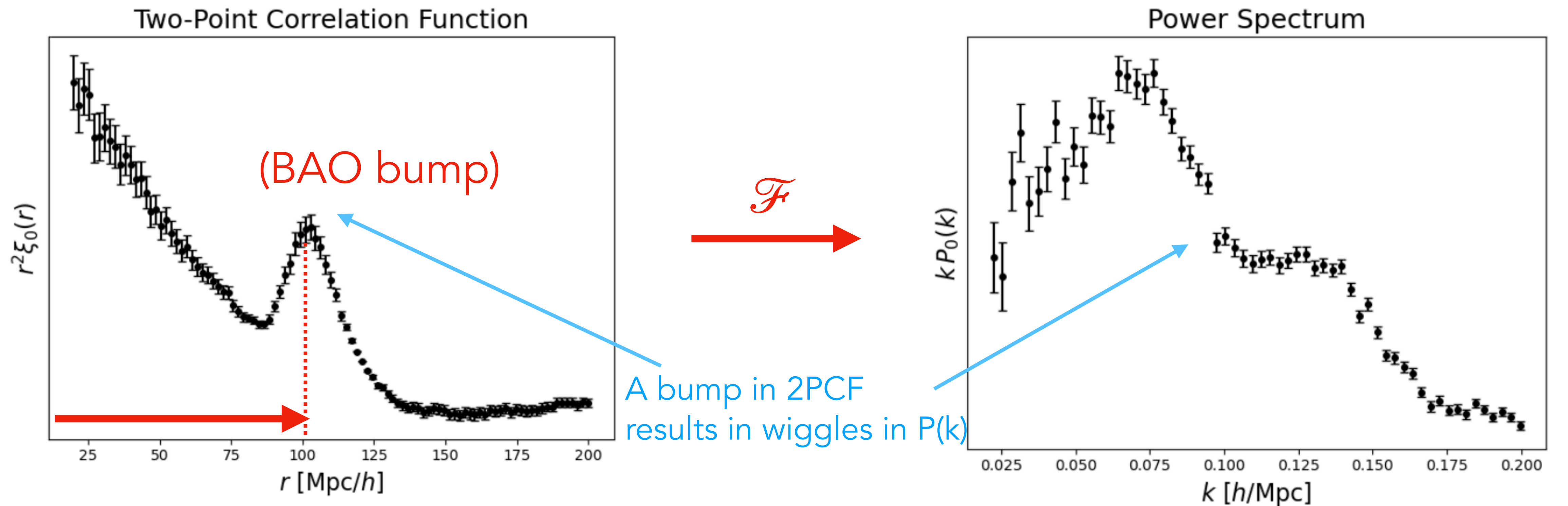


How does the BAO feature help understand DE?



2. Full Shape Analysis

- BAO measurement is the most important measurement of DESI for cosmology
- But it's not the only measurement!



DESI DE Results (DR1 BAO)

DESI 2024 VI: Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations

- Came out in April 2024
- > 400 unique articles!!

A Tantalizing 'Hint'
That Astronomers
Got Dark Energy
All Wrong

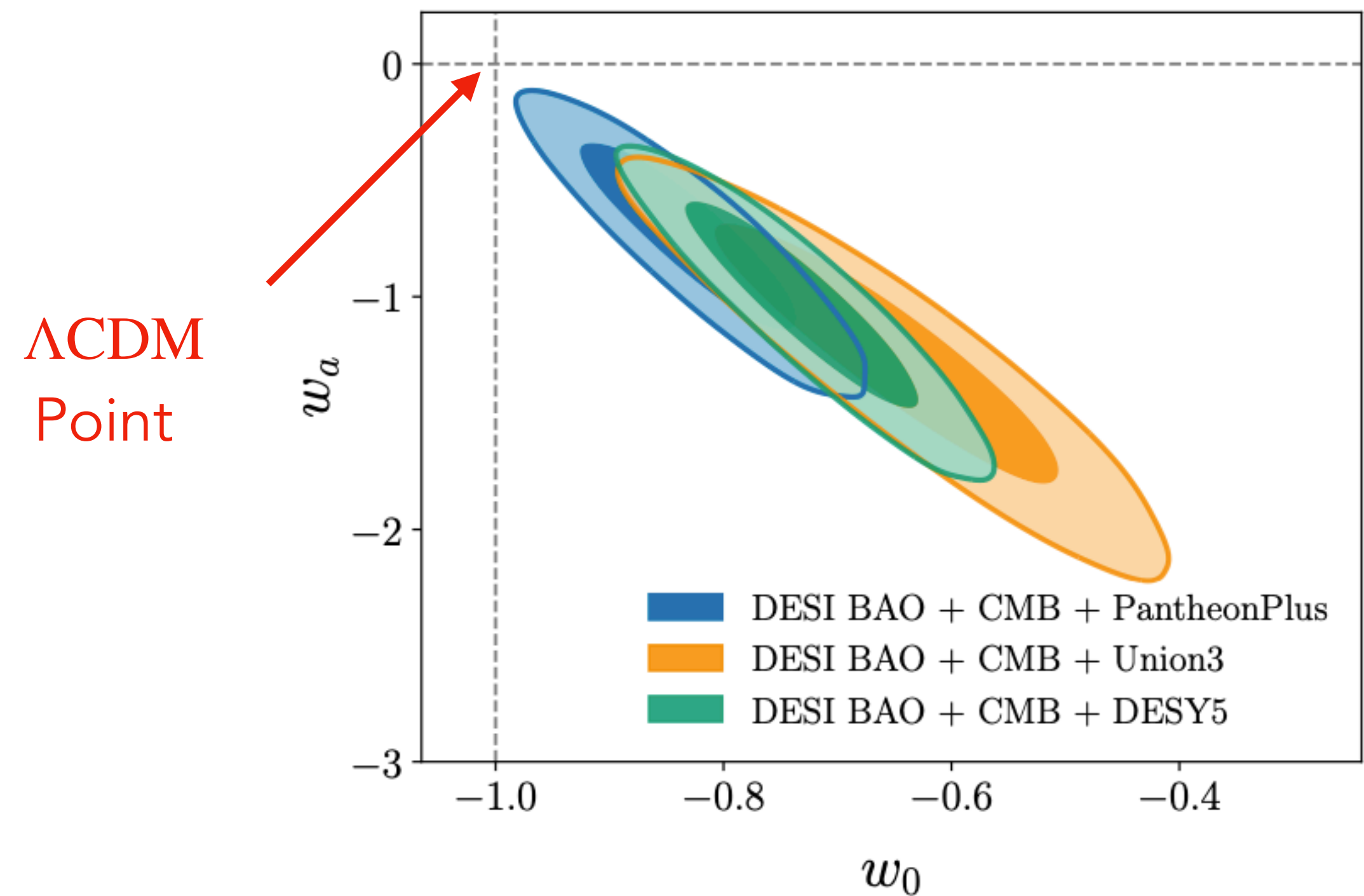
DESI DE Results (DR1 BAO)

$w_0 w_a$ Parametrization

$$w = \frac{p_{\text{DE}}}{\rho_{\text{DE}}} = w_0 + (1 - a)w_a$$

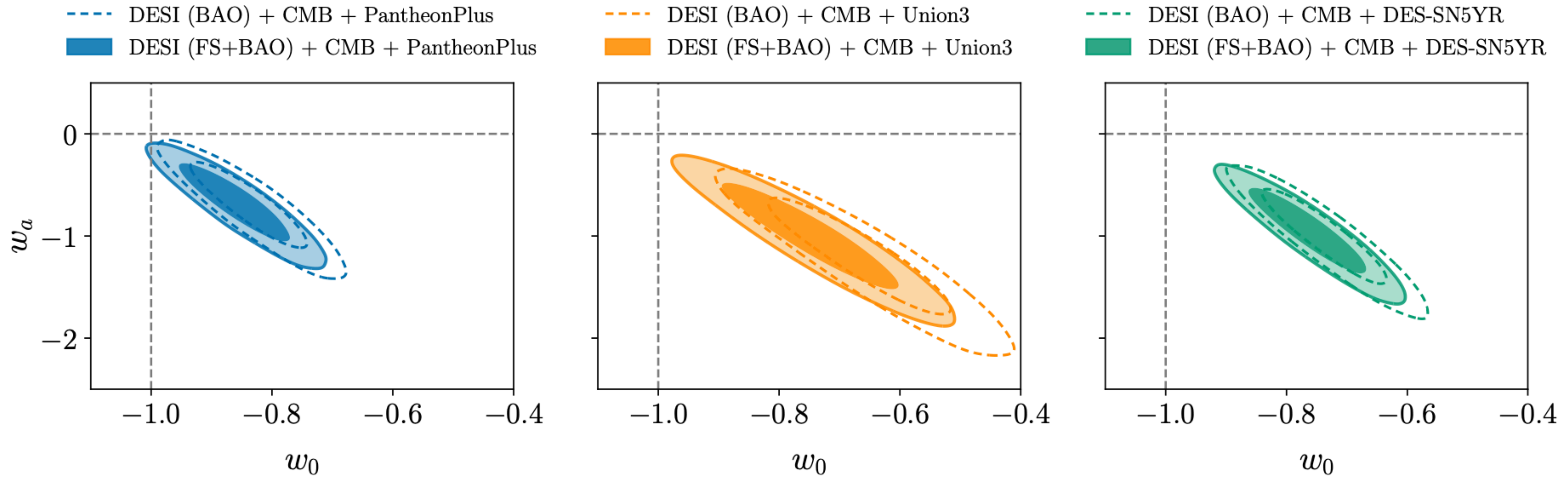
As $w_0 \rightarrow -1, w_a \rightarrow 0$

Λ CDM is recovered



$2.5\sigma, 3.5\sigma, 3.9\sigma$ deviation from Λ CDM!!

DESI DE Results (DR1 Full Shape)

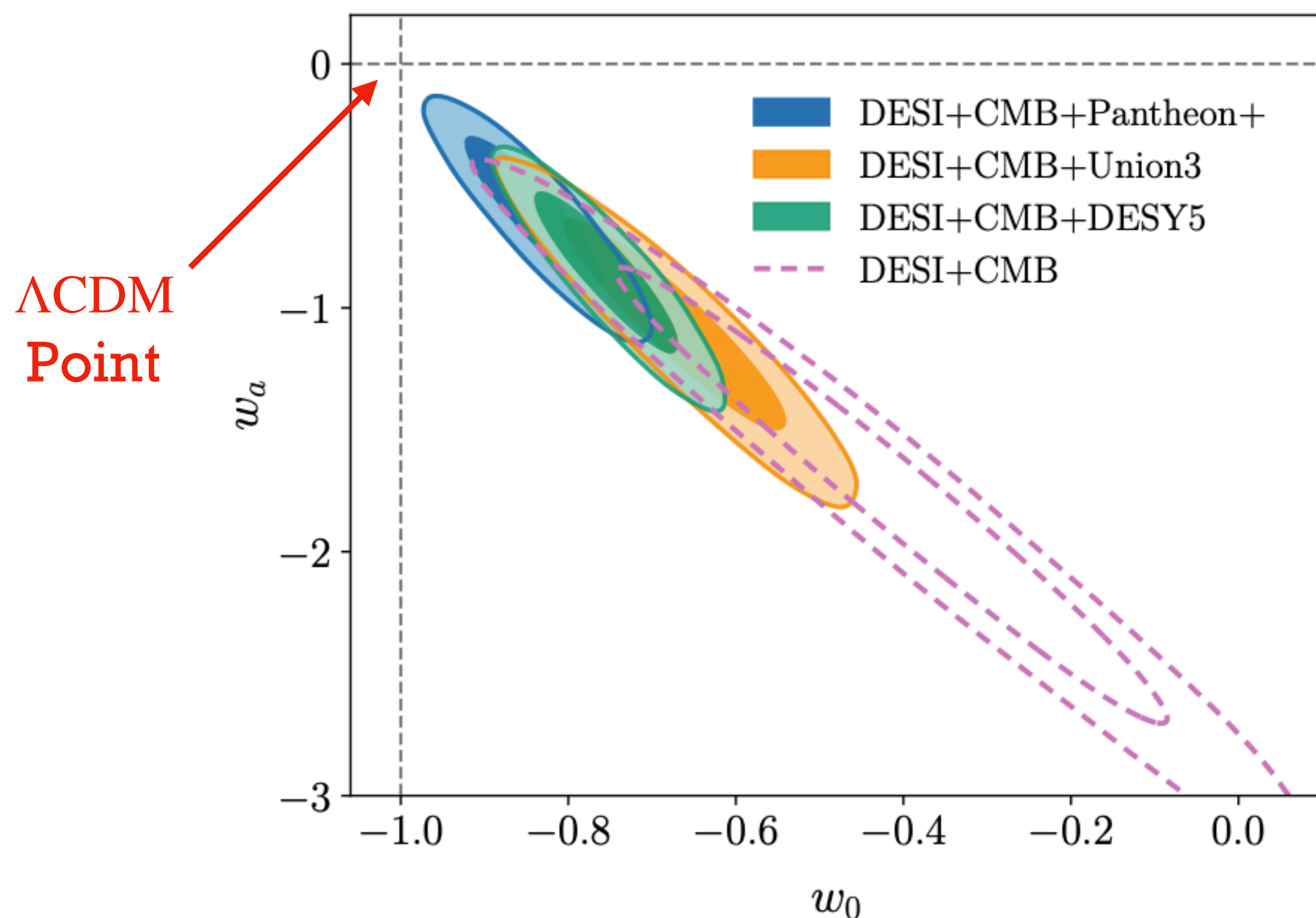


Contours shrink by $\sim 20\%$ on adding FS information

In total 42 Nuisance Parameters!

2.5σ , 3.4σ , 3.8σ deviation from Λ CDM!!

DESI DE Results (DR2 BAO)



- Came out in March 2025
- 2.4x more galaxies than DR1
- ~20 - 40% improvement in the BAO distances

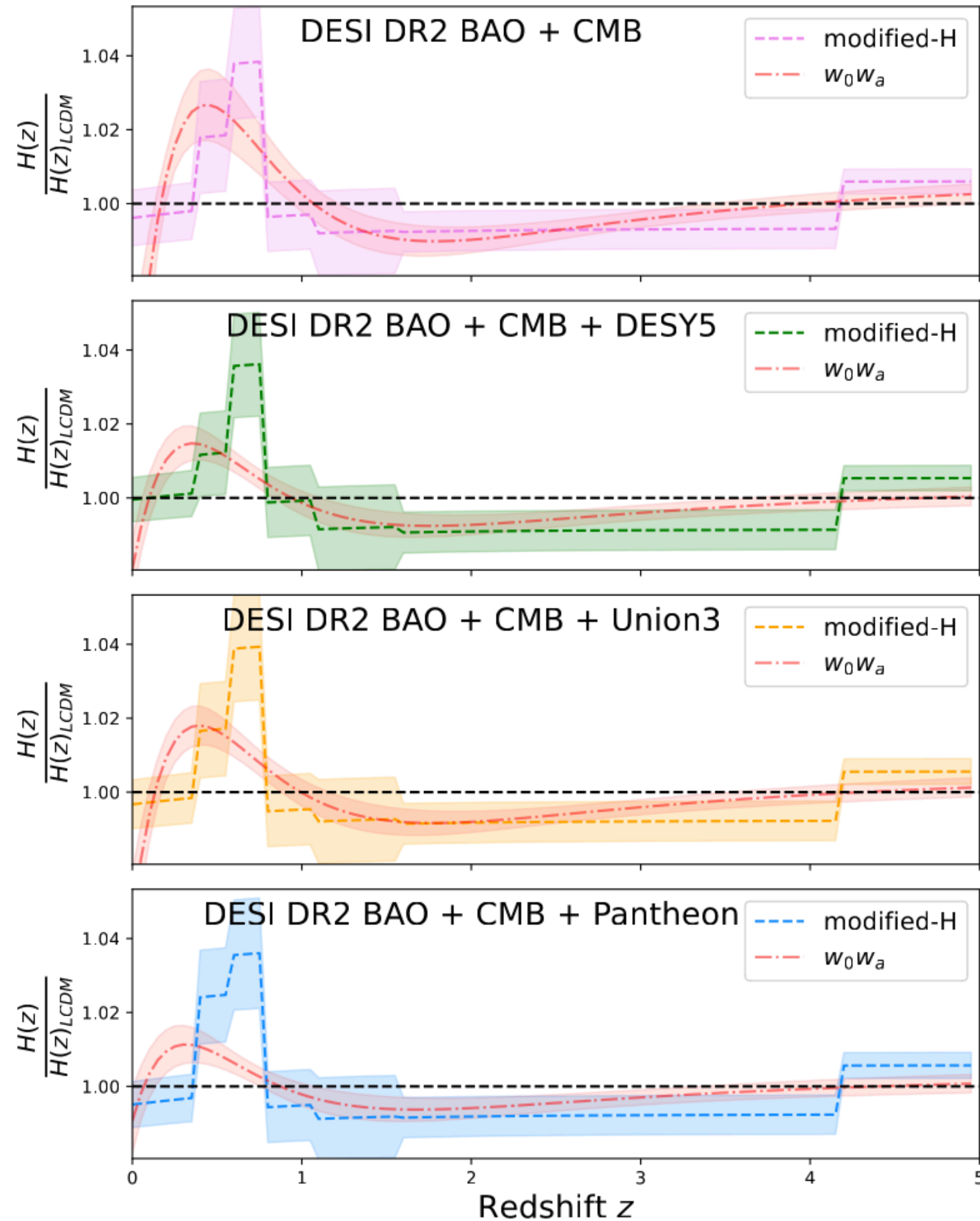
3.1σ , 2.8σ , 3.8σ , 4.2σ deviation from Λ CDM

Upcoming: DR2 Full Shape!

1. Expansion History Preferences of DESI DR2 and external data

[Phys. Rev. D 112, 023528](#)

Results



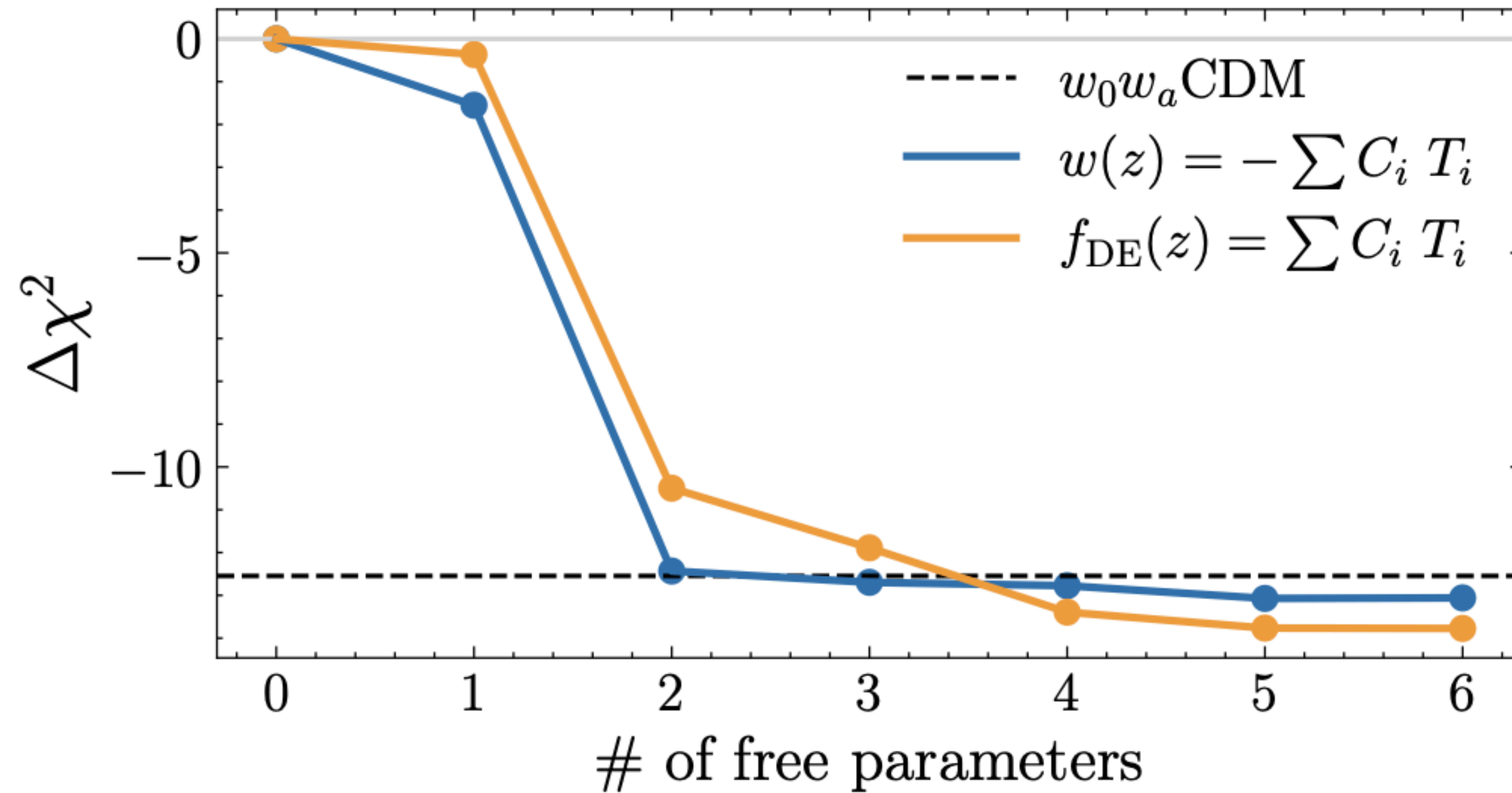
Modified-H Model

$$H(z) = H(z)^{LCDM}(1 + \alpha_i)$$

6 free parameters
(as opposed to 2 in w_0w_A)

w_0w_a parametrization is flexible enough
to model the DESI data favoured
expansion history!!

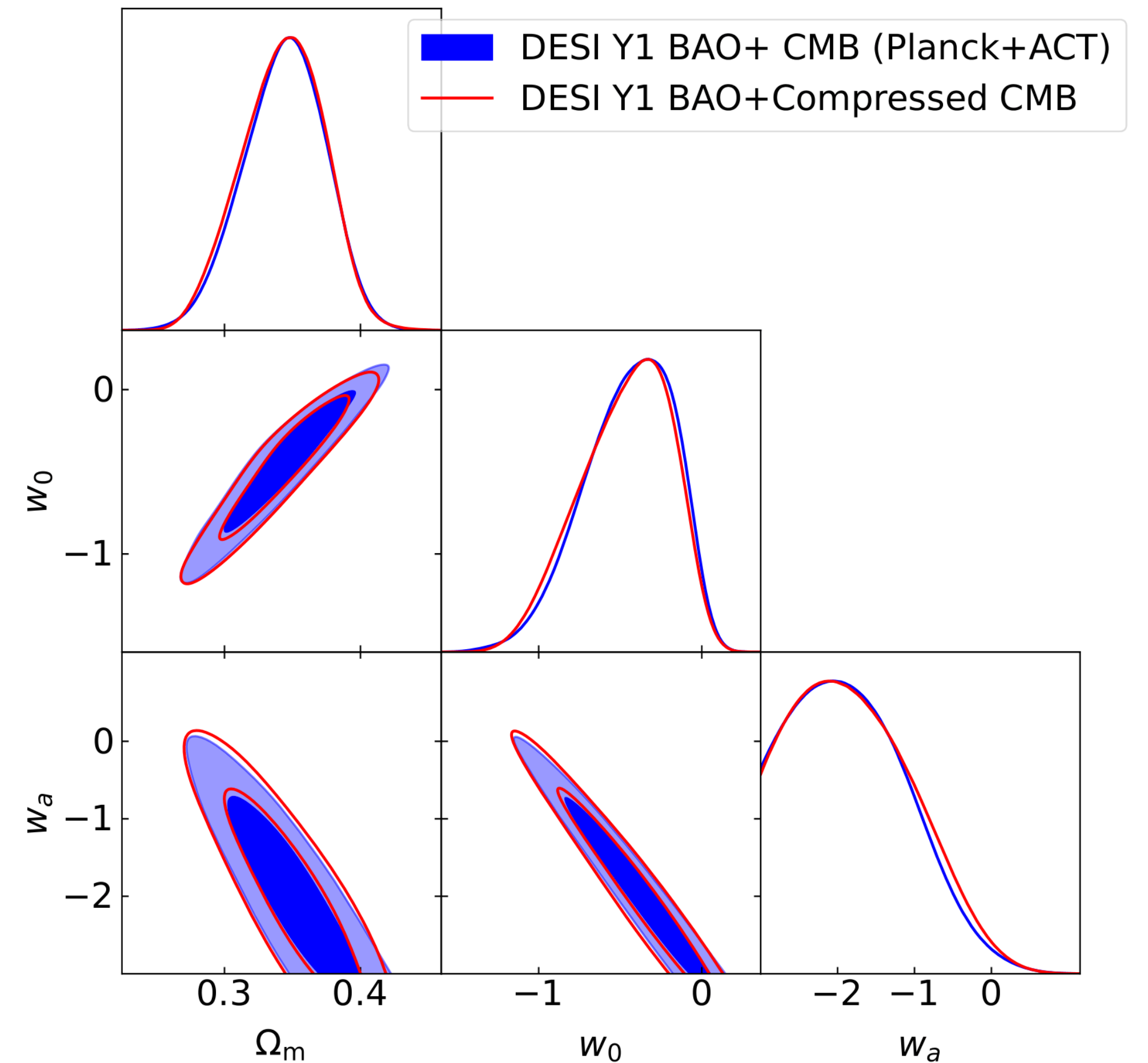
...Later confirmed by independent studies



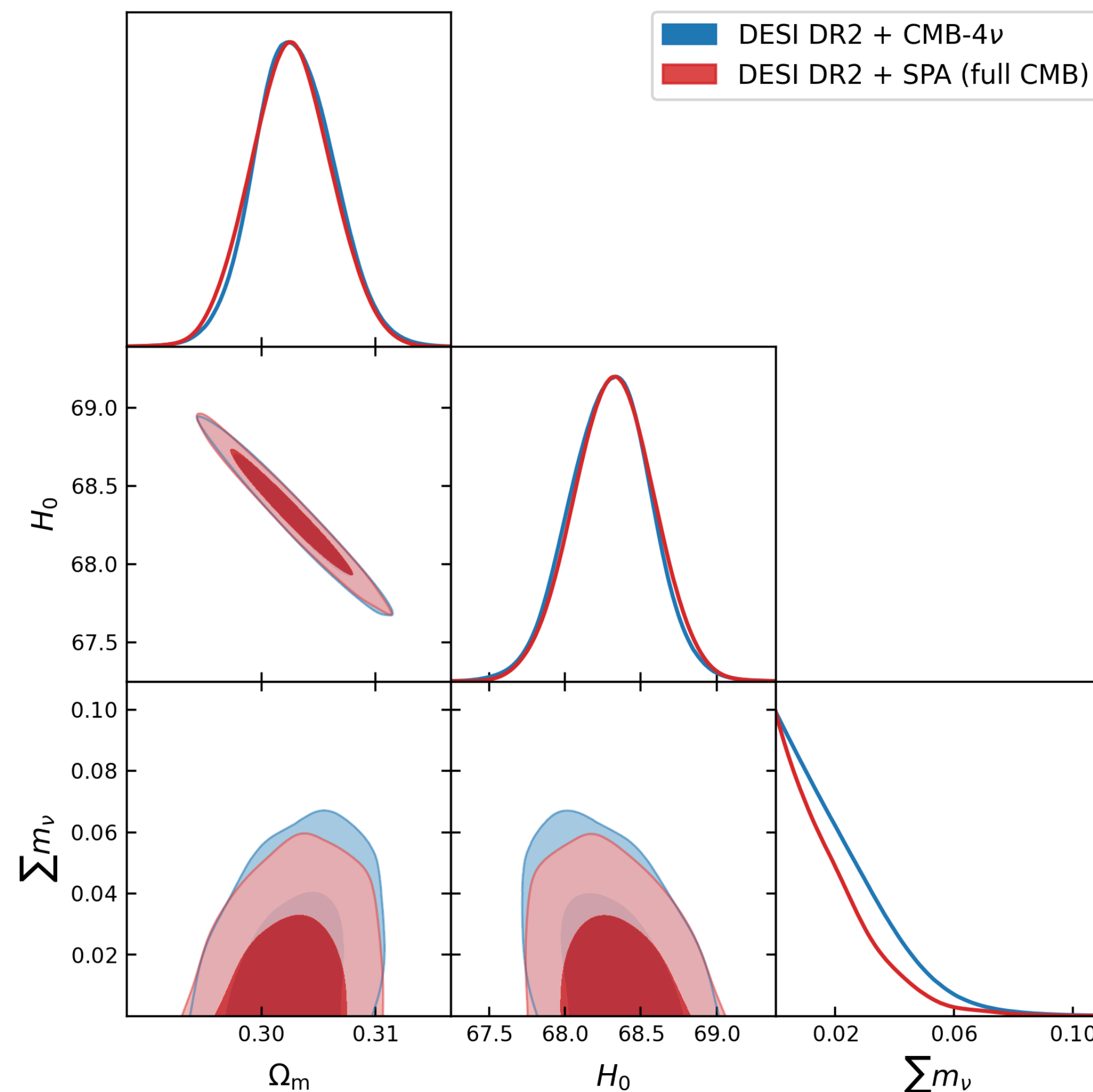
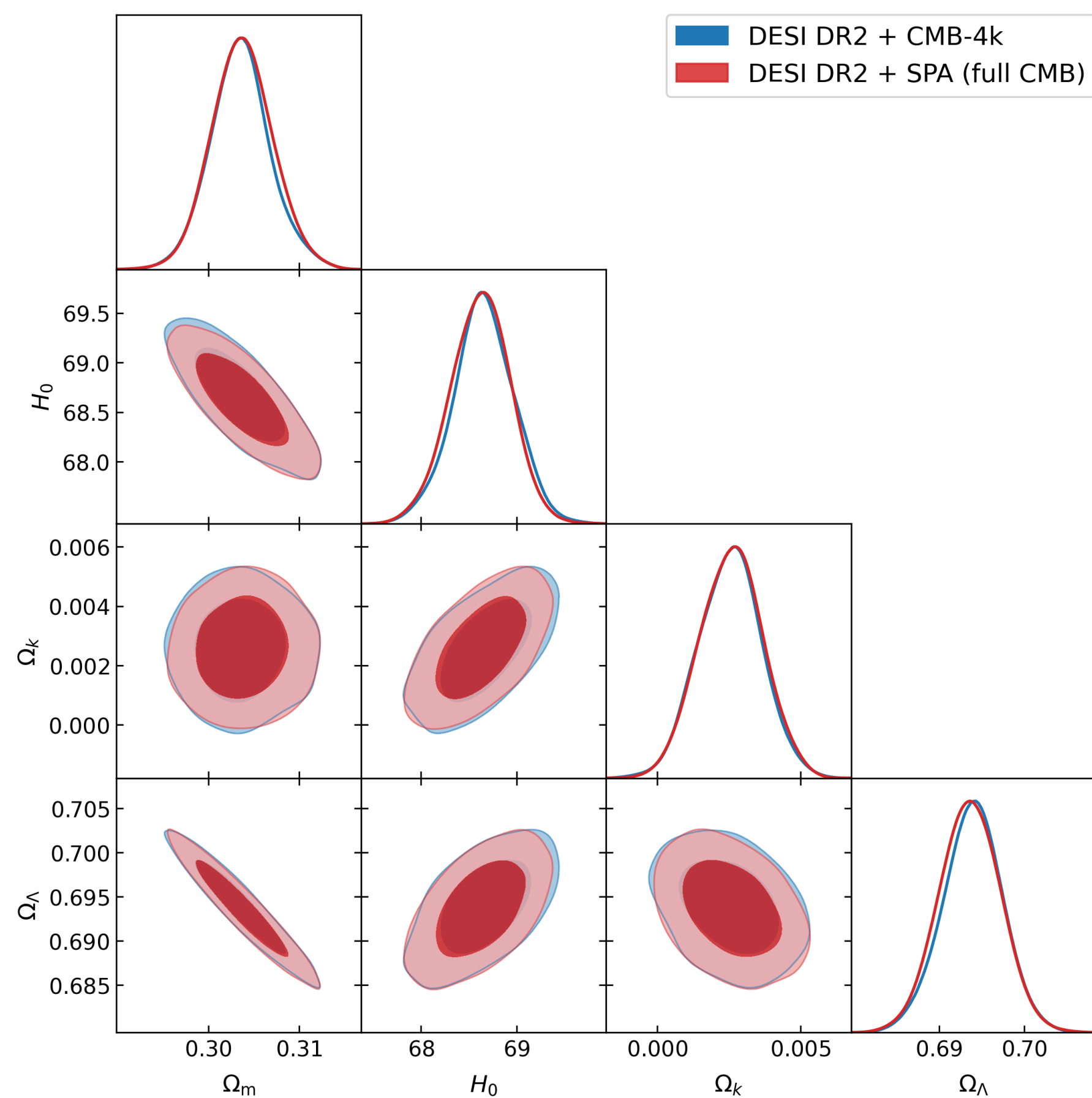
Corollary: CMB Compression

$$\mathbf{v}_{\text{CMB}} \equiv (R, \ell_a, \Omega_b h^2)$$

- Useful for non-physical models for which the CMB power spectrum cannot be evaluated
- Means and Covariances calculated from Planck+ACT6 lensing LCDM chains
- Validated against LCDM and $w_0 w_a$ CDM full CMB constraints



Followup: CMB Compressions for Ω_K and m_ν



A simple user-friendly suite of fast CMB likelihoods!



2. On the Difficulties with Late-Time Solutions for the Hubble Tension

[arXiv: 2602.0629](#)

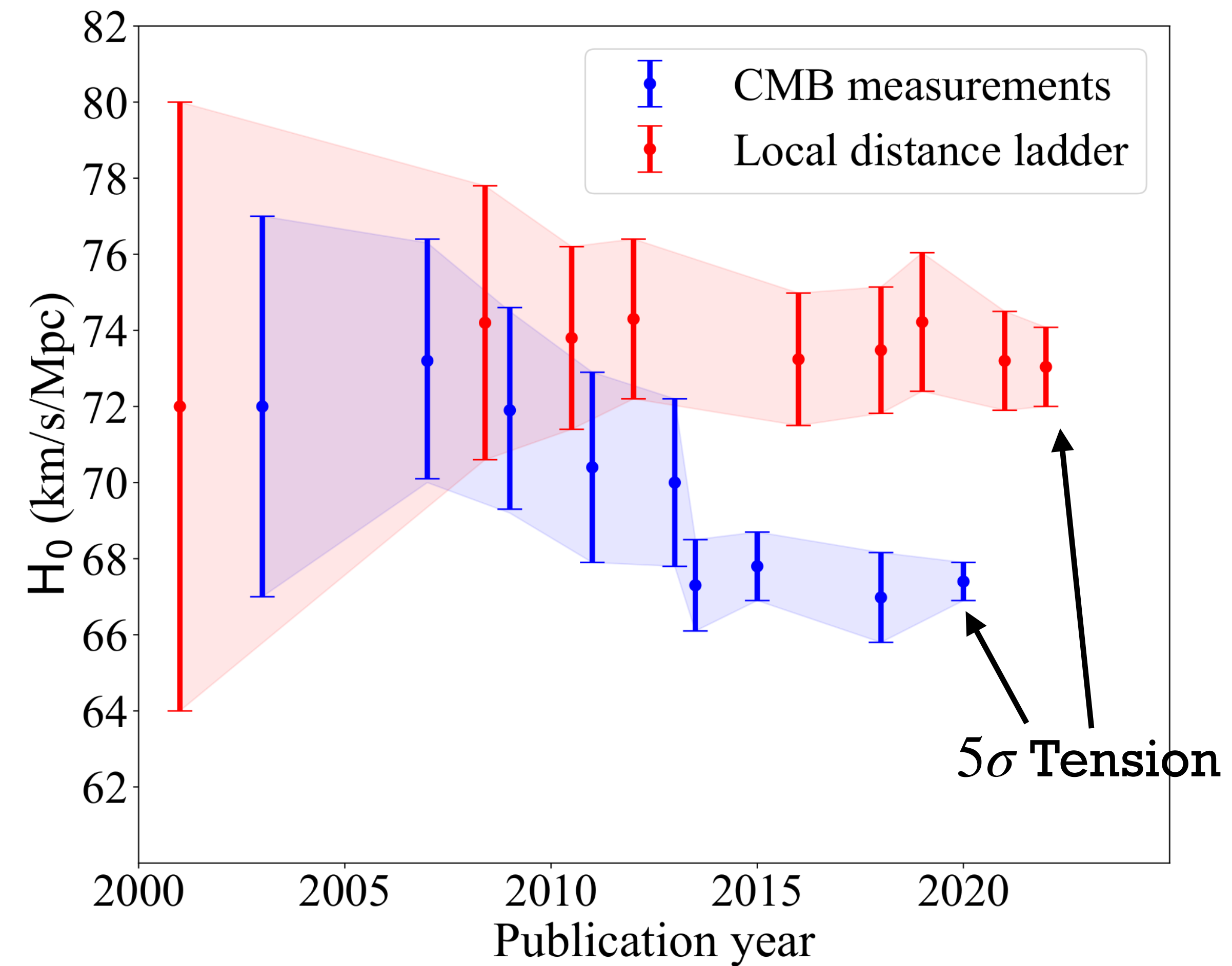
The Hubble Tension

H_0

Hubble Constant: Measure of the expansion rate today

Two ways to measure H_0

- CMB: Early Time Probe ($z \sim 1100$)
- SNIa Distance Ladder: Late Time Probe ($z \sim 0.001-0.15$)



How does a typical SNIa likelihood work?

$$\mu = 5 \log_{10}(d_L) + 25$$

$$m_{app} = \mu + M_{abs}$$

$$m_{app} = 5 \log_{10}(d_L) + 25 + M_{abs}$$

$$m_{app} = 5 \log_{10}(H_0 d_L) - 5 \log_{10} H_0 + 25 + M_{abs}$$

$$m_{app} = 5 \log H_0 d_L + \mathcal{M}$$



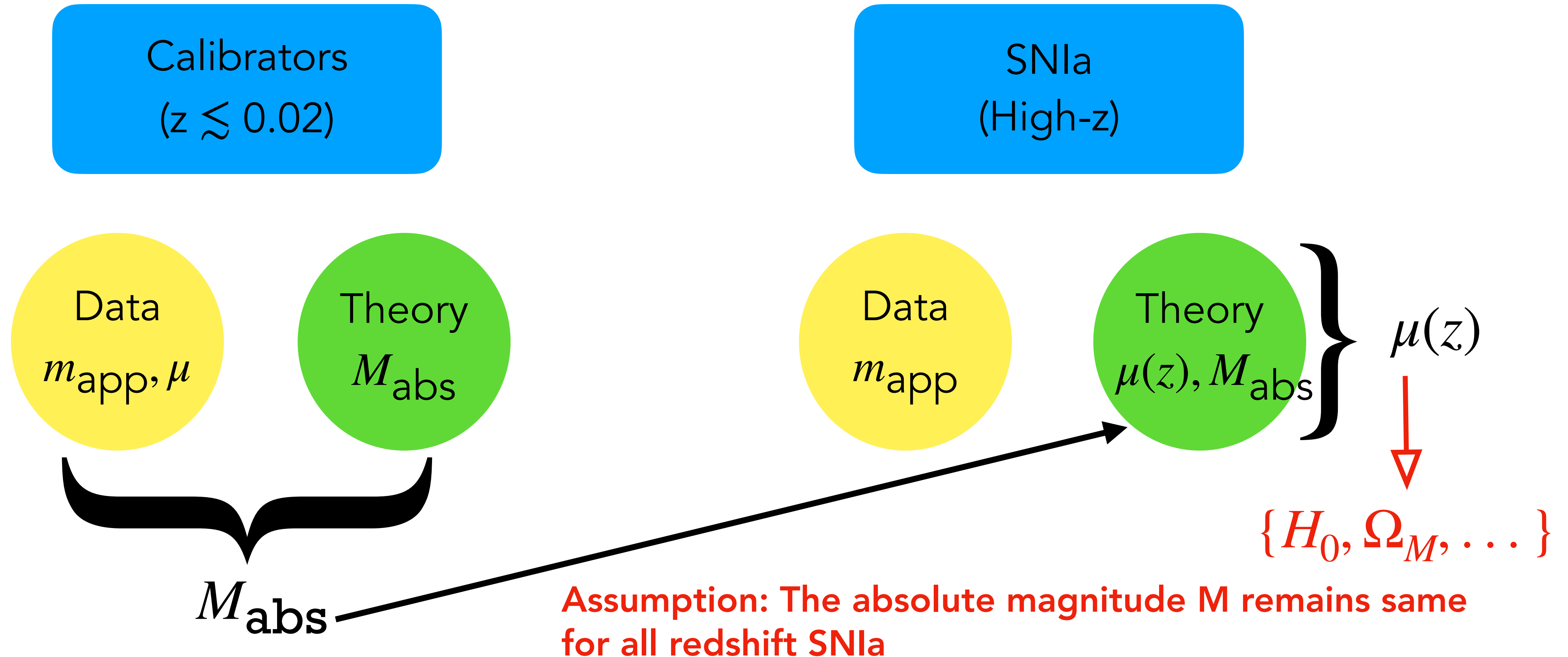
$\{\Omega_M, \Omega_K, w_0, w_a \dots\}$

$\{\text{SN Properties}, H_0\}$

Marginalized over in std analyses

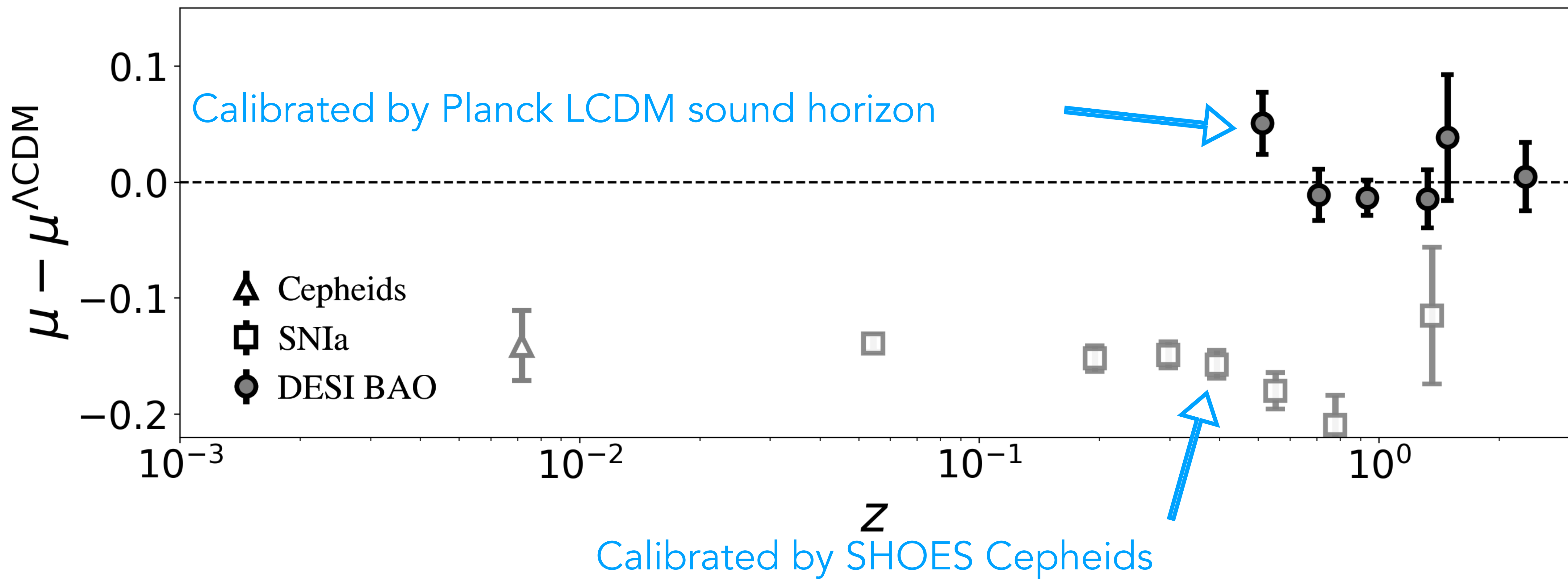
How does a typical (Calib.) SNIa likelihood work?

$$m_{app} = \mu + M_{abs}$$



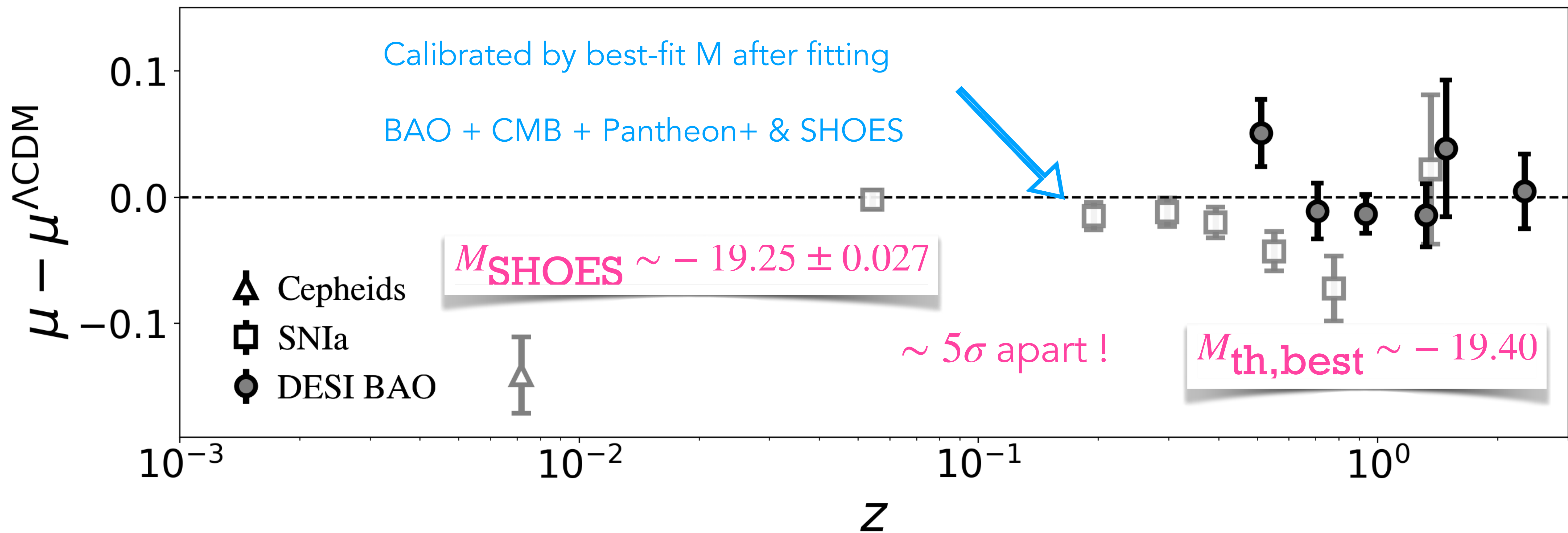
Hubble Tension as “M” tension

Fixing M to SHOES Best-fit value



Hubble Tension as "M" tension

Allowing M to be a free parameter

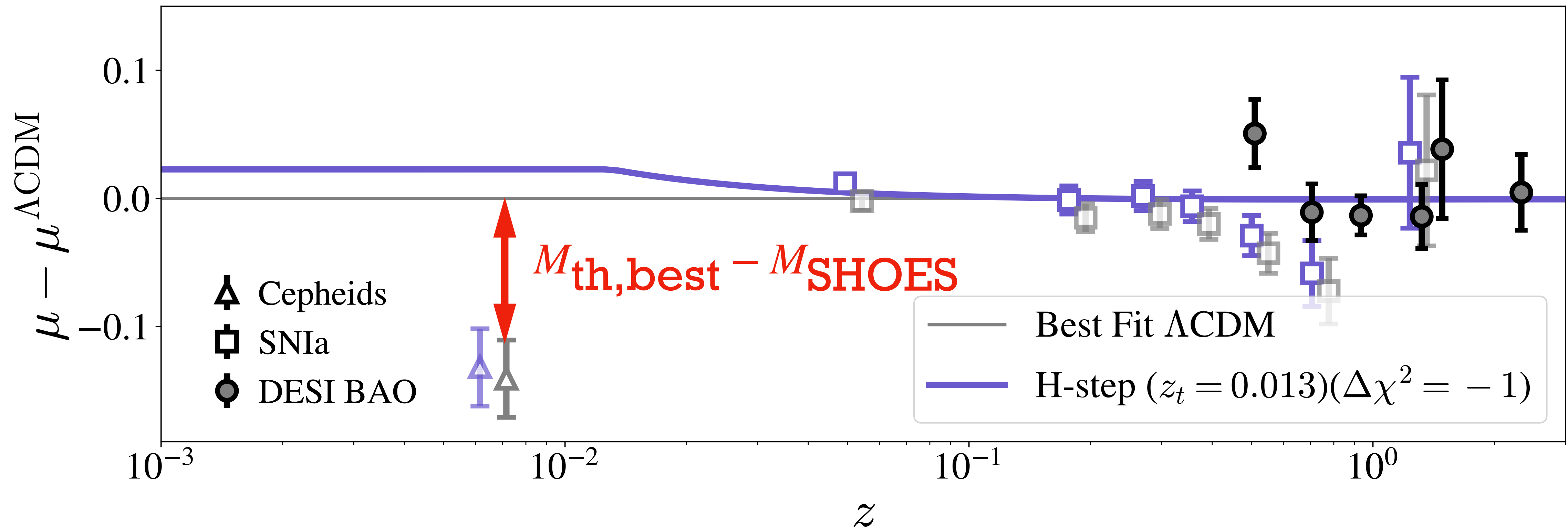


Hubble Tension as “M” tension

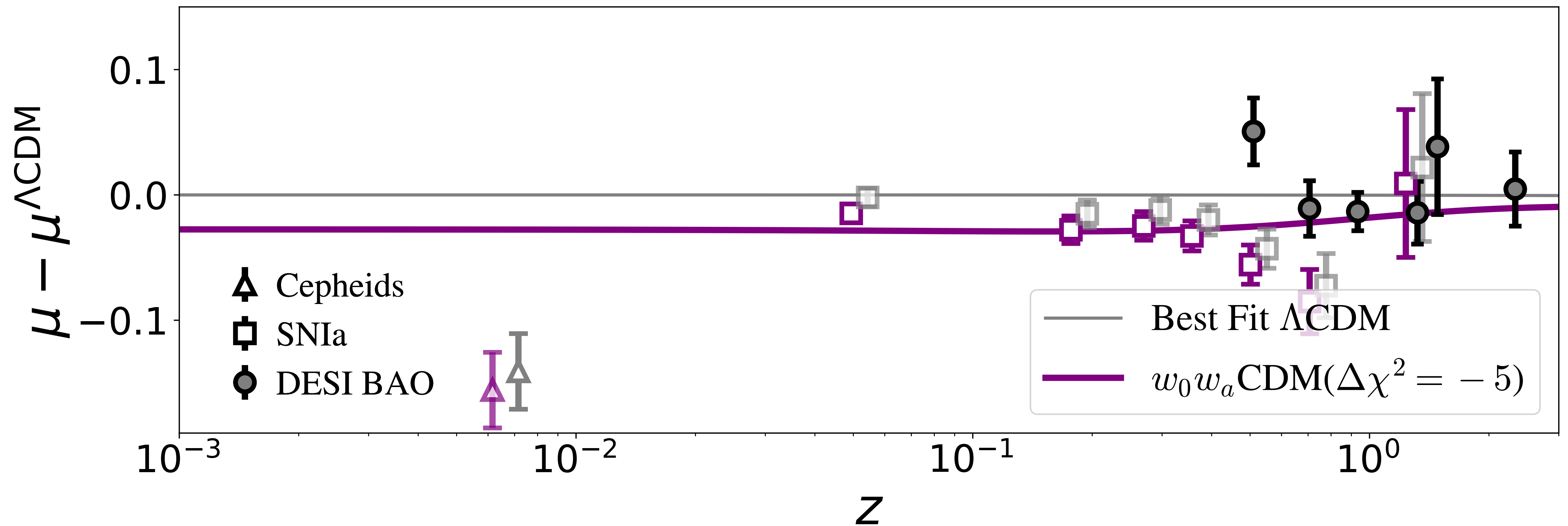
Thus, a model which **solves** Hubble Tension would give a best-fit absolute magnitude M (in the combined fit to BAO+CMB+SNIa data) which is consistent with the best-fit value preferred by SHOES Cepheids (-19.25 ± 0.027)

A simple expansion history modification cannot resolve this tension!

$$H(z) = \begin{cases} H_0 E(z), & \text{if } z \leq z_t \\ H_0^E E(z), & \text{if } z > z_t \end{cases}$$



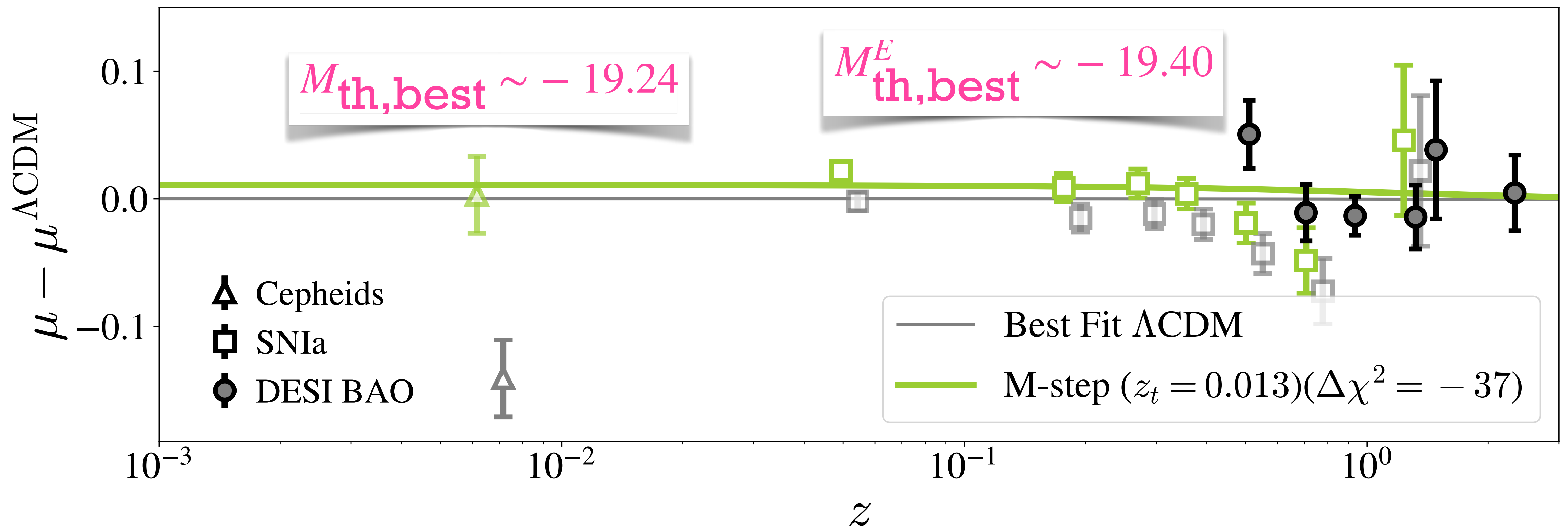
A simple expansion history modification cannot resolve this tension!



**So what type of solutions
can work?**

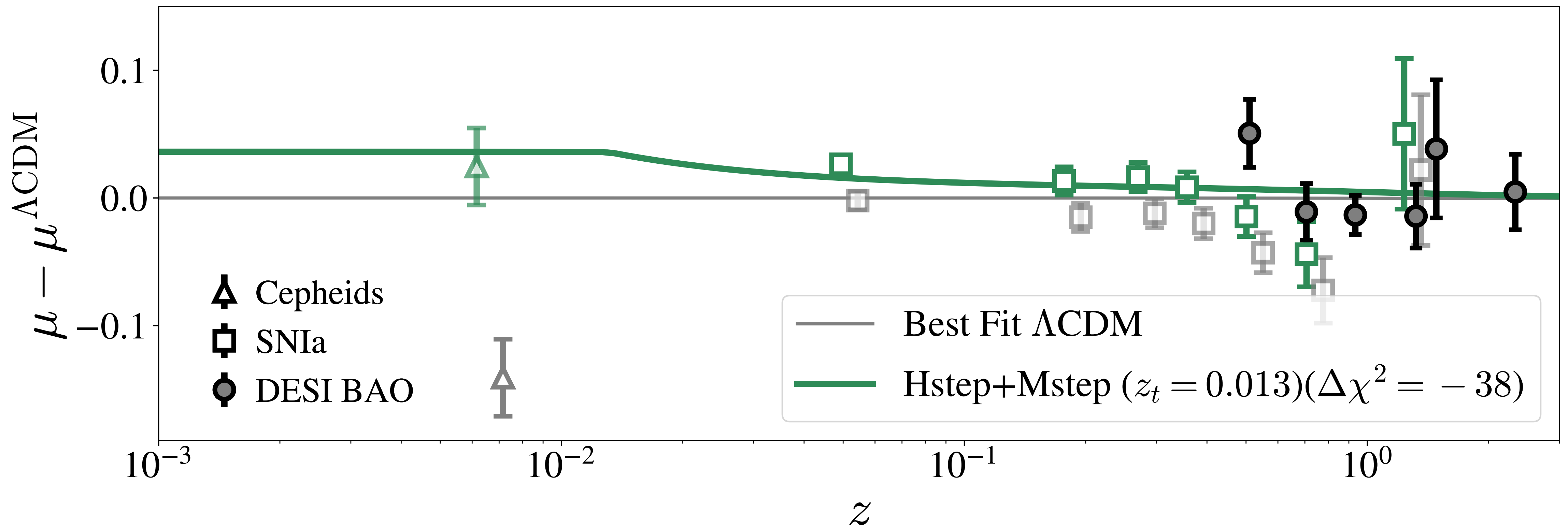
1. Allowing for a break in SNIa absolute magnitude significantly improves the $\Delta\chi^2$

$$m(z) = \begin{cases} \mu(z) + M, & \text{if } z \leq z_t \\ \mu(z) + M^E, & \text{if } z > z_t \end{cases}$$



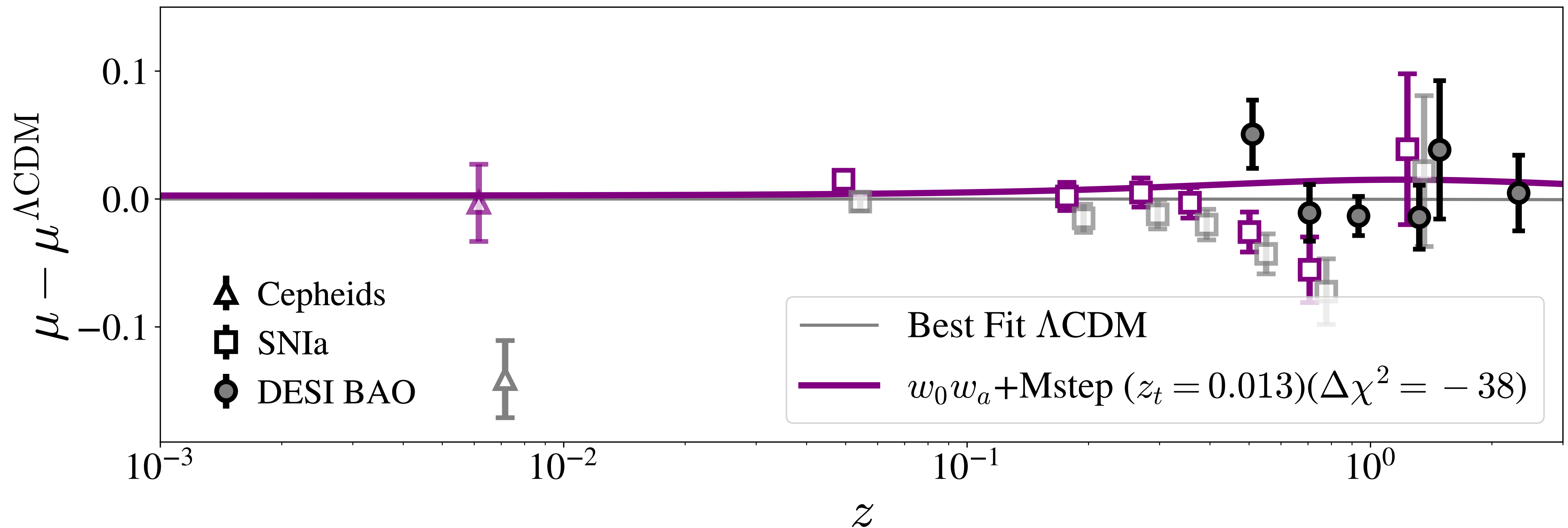
2. A break in absolute magnitude along with a modified expansion history also works

$$m(z) = \begin{cases} \mu(z) + M, & \text{if } z \leq z_t \\ \mu(z) + M^E, & \text{if } z > z_t \end{cases} \quad H(z) = \begin{cases} H_0 E(z), & \text{if } z \leq z_t \\ H_0^E E(z), & \text{if } z > z_t \end{cases}$$

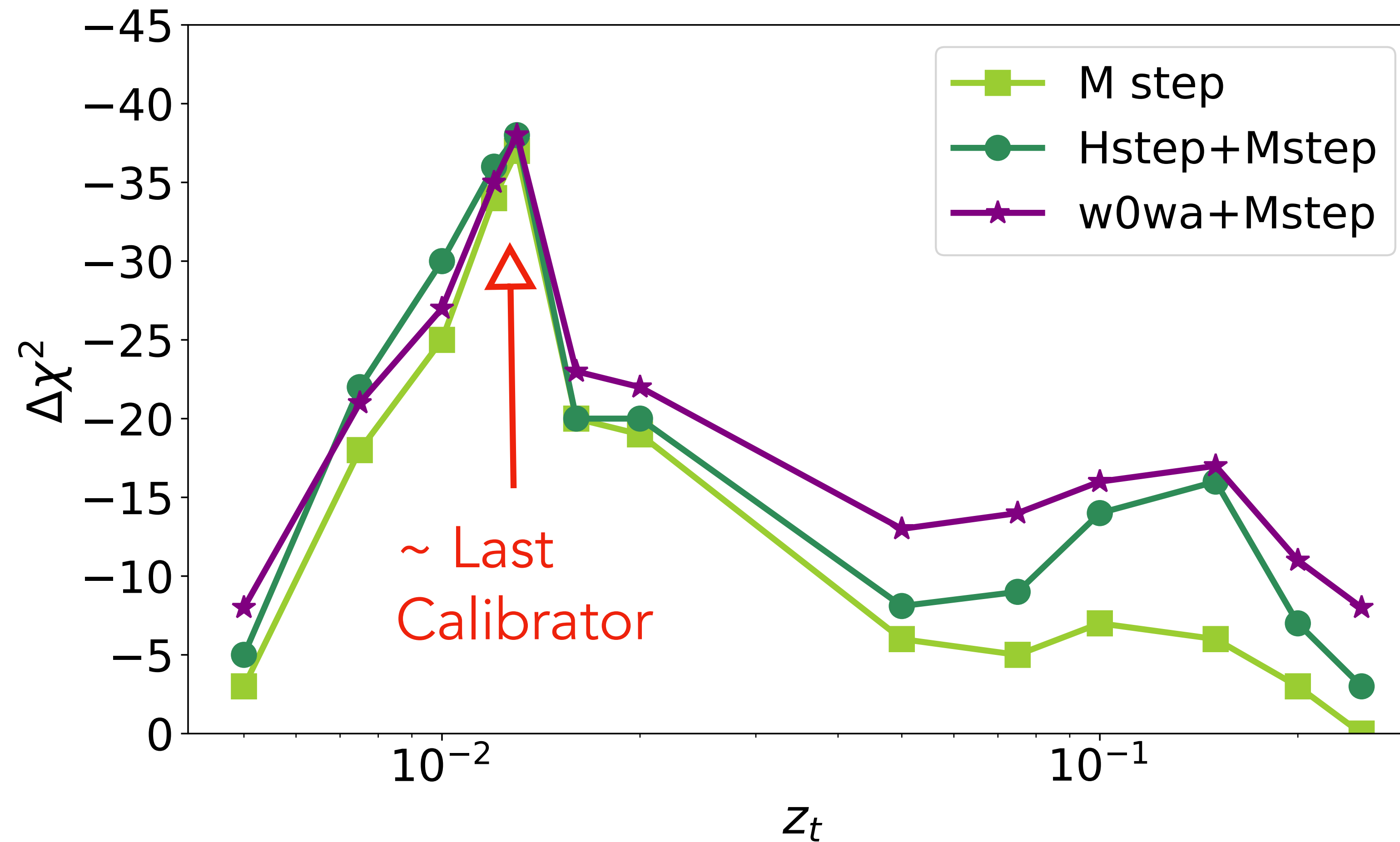


2. A break in absolute magnitude along with a modified expansion history also works

$$m(z) = \begin{cases} \mu(z) + M, & \text{if } z \leq z_t \\ \mu(z) + M^E, & \text{if } z > z_t \end{cases}$$

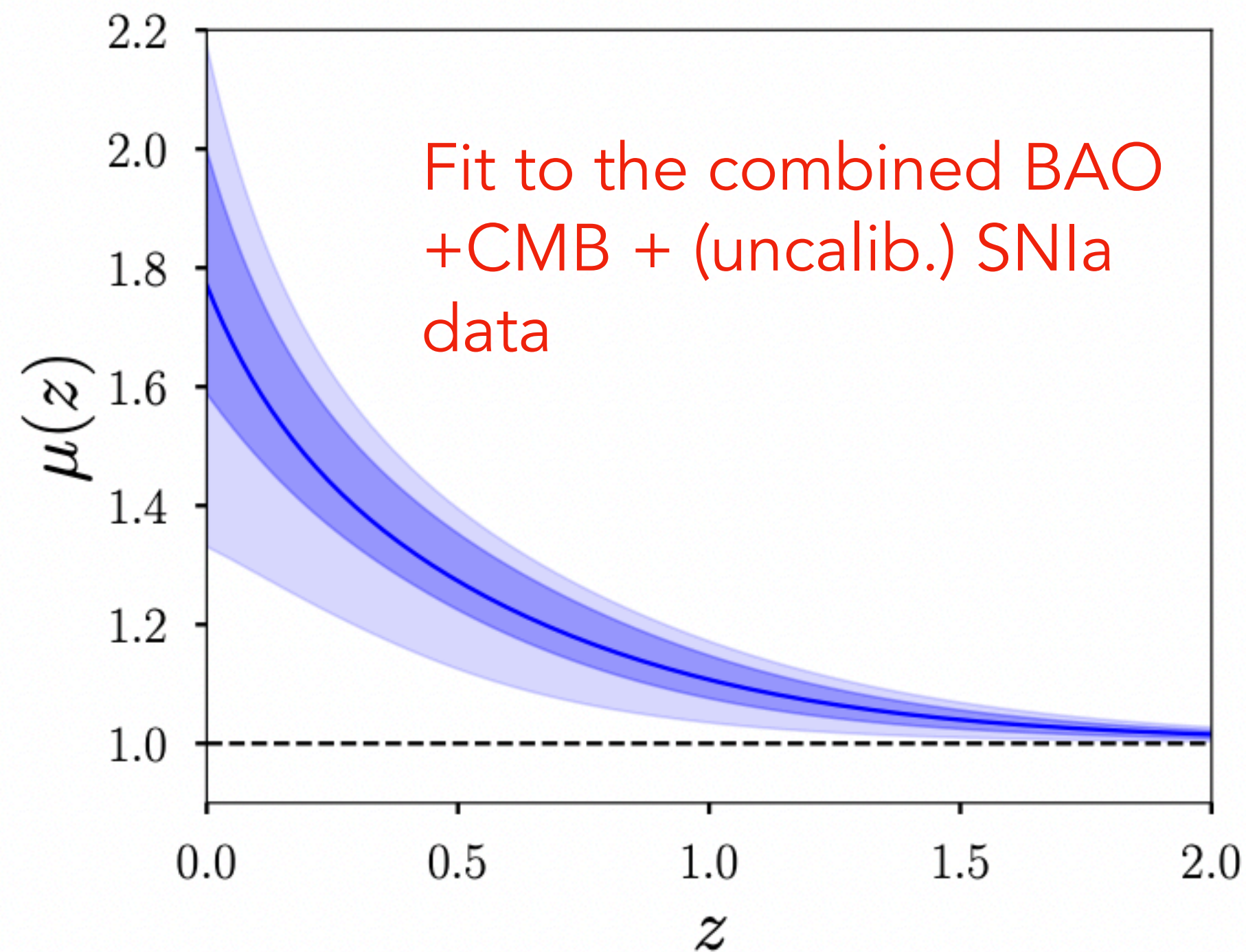


Does the redshift of this step in magnitude also matter?



Is there any “physical” way to achieve this magnitude transition?

A “tweaked” non-minimally coupled scalar field

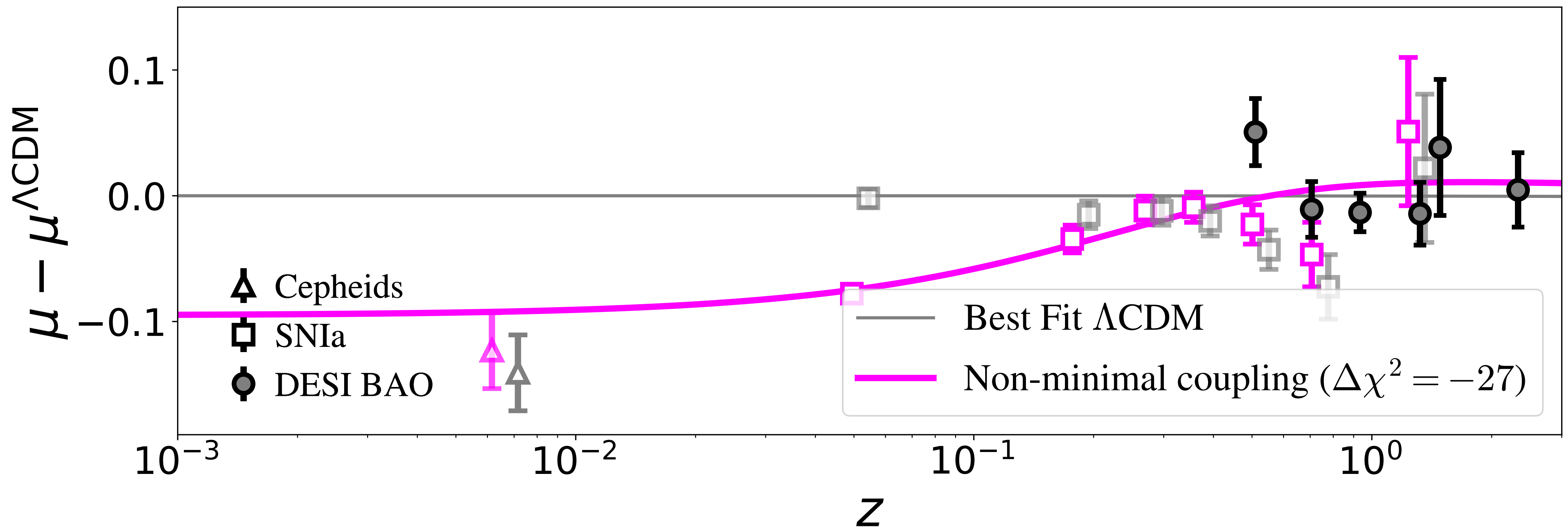


$$\nabla^2 \Phi = 4\pi G \mu_{MG} \rho$$

Assuming, a power law variation of Chandrasekhar mass, and hence peak SNIa luminosity,

$$M(z) = M^E + n \log[\mu_{MG}(z)]$$

Is there any “physical” way to achieve this magnitude transition?



Summary

The only type of late-time solutions that work for Hubble Tension, must do one of the following

1. A late time transition in SNIa absolute magnitude M
2. A late time transition in SNIa absolute magnitude M along with a modification in expansion history
3. Violating Distance Duality Relation ($d_L = (1 + z)^n d_A$; $n \neq 2$)

See eg. Teixeira et.al. Phys. Rev. D 112, 023515

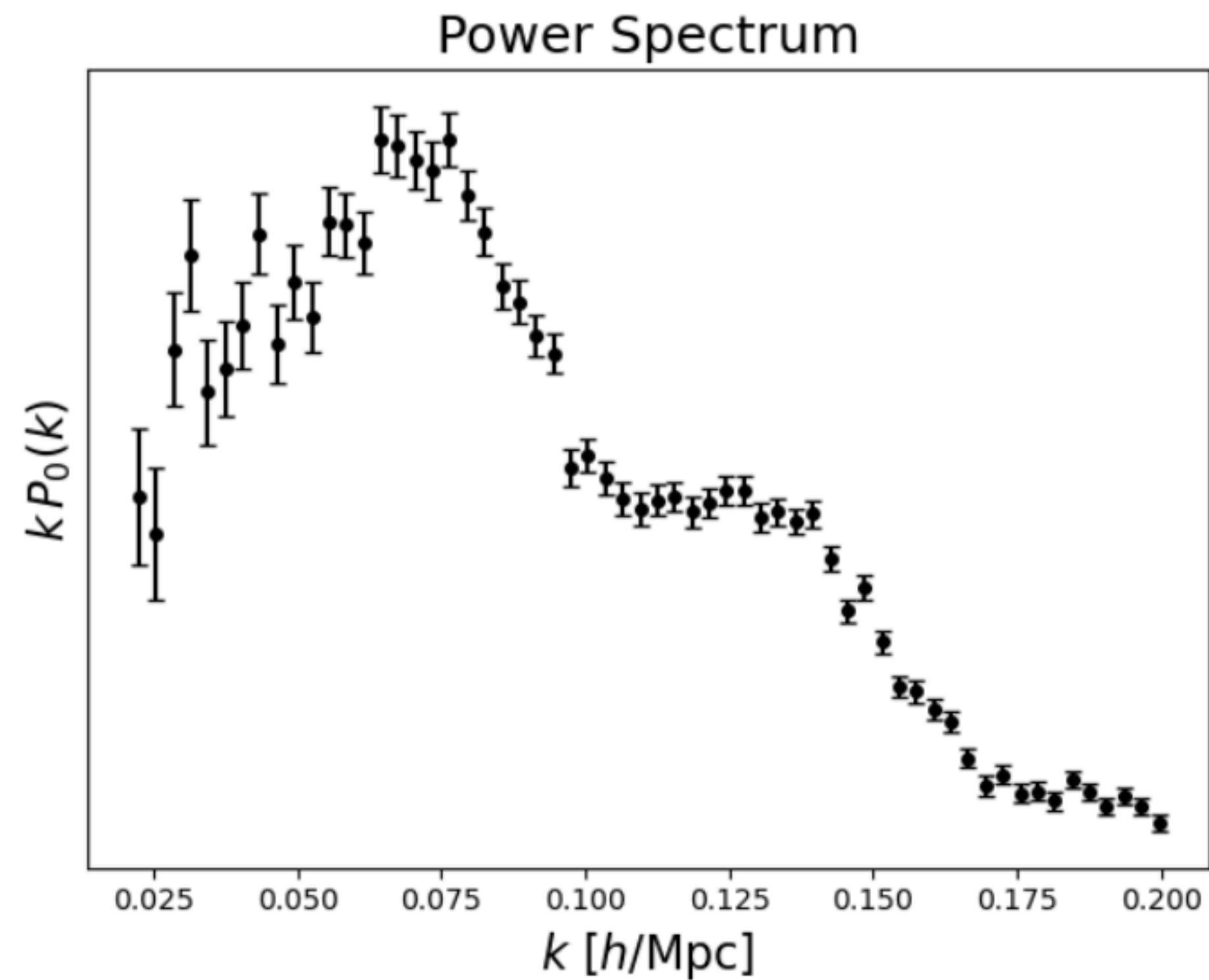
3. FolpsD: combining EFT and phenomenological approaches for joint power spectrum and bispectrum analyses

[arXiv: 2604.08895](#)

<https://github.com/cosmodesi/FolpsD/tree/main>

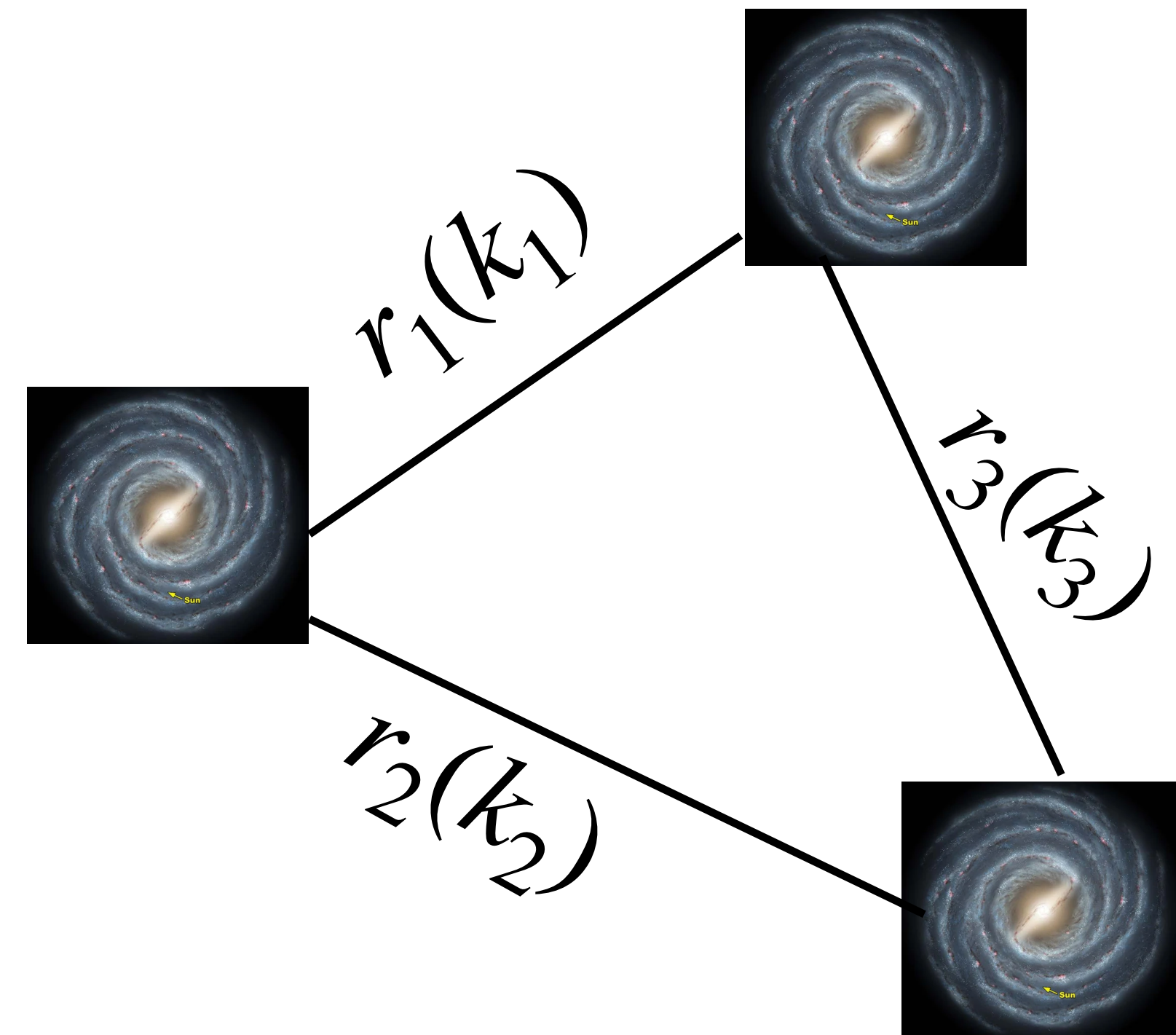
(With Alejandro Aviles, Hernan Noriega, Isaac Garzon)

Power Spectrum



Fourier analogue of 2PCF
 $P(k)$

Bispectrum



Fourier analogue of 3PCF
 $B(k_1, k_2, k_3)$

EFT vs FOLPS-D

$$\text{FolpsD} = \text{Damping}(k_{\parallel}) \times \text{Folps}$$

$$P(k, \mu) = \mathcal{D}(k^2 \mu^2) \left[P_K(k, \mu) + P_{1\text{-loop}}(k, \mu) \right] + P_{\text{ctr}}^{\text{LO}}(k, \mu) + P_{\text{shot}}(k, \mu).$$

$$\mathcal{D}(x^2) = \frac{1}{1 + x^2},$$

$$x^2 = (X_{\text{FoG,p}} f \sigma_v k \mu)^2,$$

This damping term allows us to model the small scale non-linear modes ($k > 0.20 \, h \, \text{Mpc}^{-1}$) and thus derive extra information from the PS

FOLPS

Fast computation of non-linear power spectrum in cosmologies with massive neutrinos

Hernán E. Noriega,^{a,b} Alejandro Aviles,^{b,c,1} Sebastien Fromenteau,^d Mariana Vargas-Magaña^a

- EFT based code
- Massive ν and Modified gravity models
- Computationally very fast (~ 0.2 s/ PS)

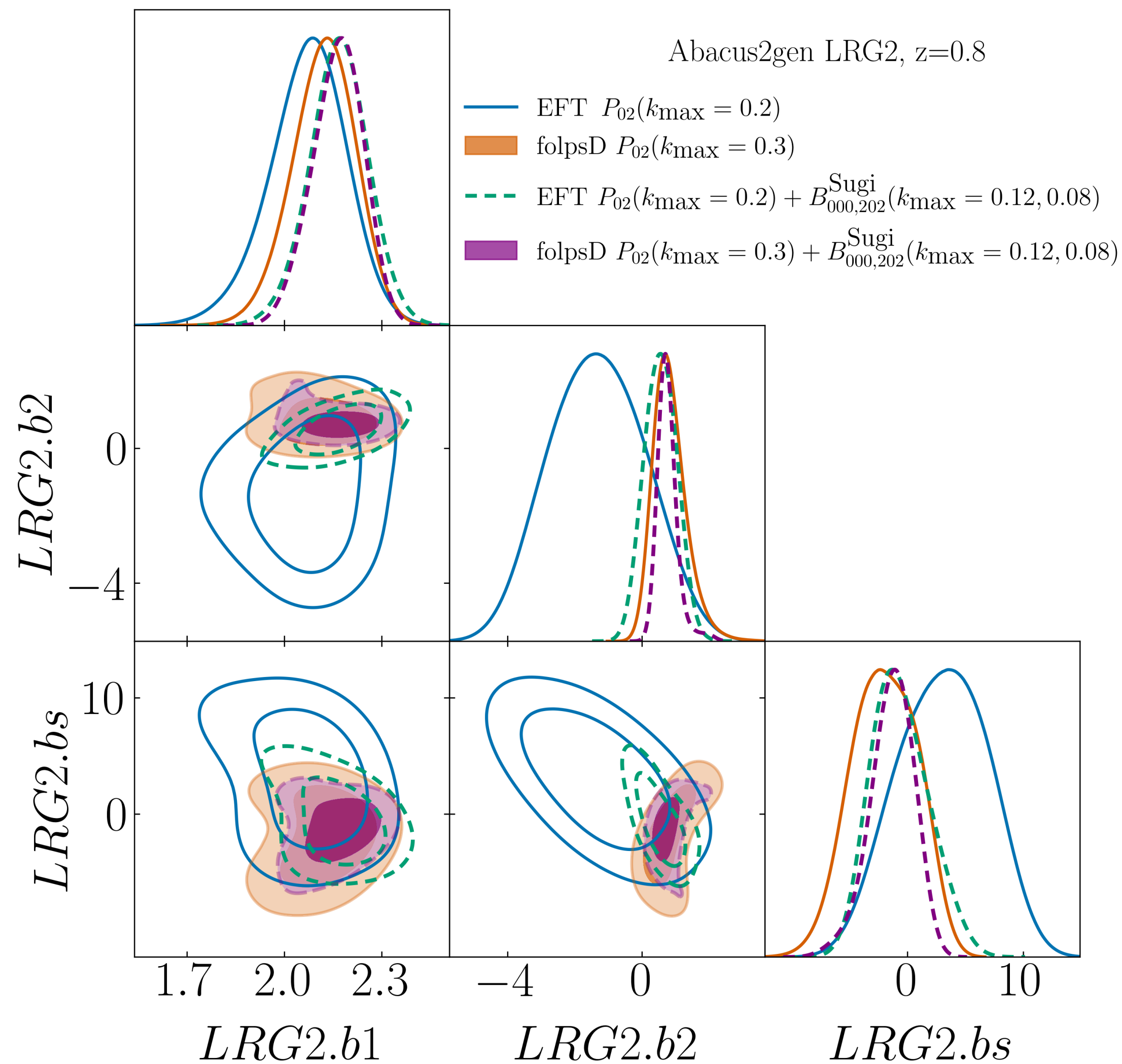
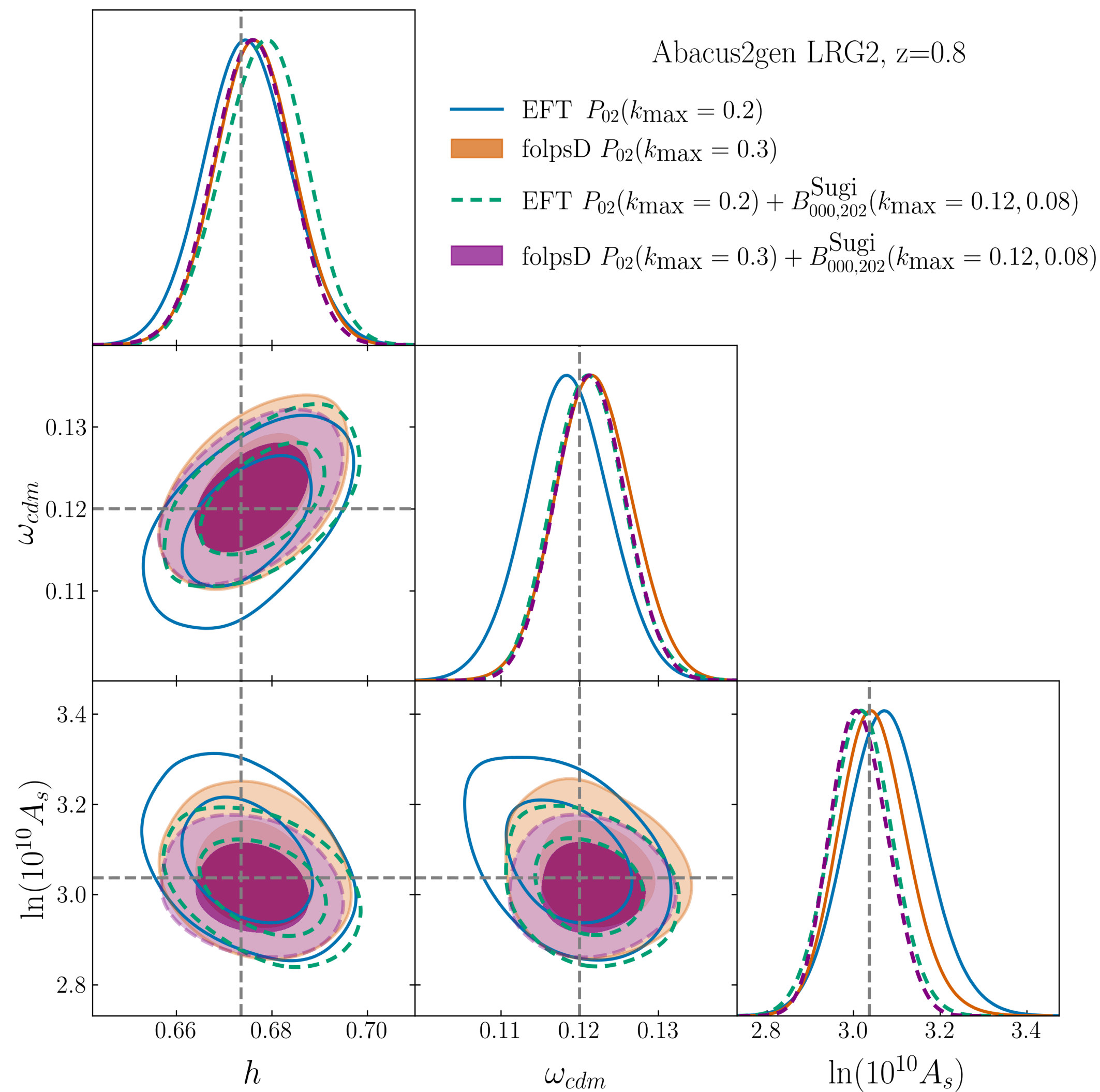
FOLPSD

FolpsD: combining EFT and phenomenological approaches for joint power spectrum and bispectrum analyses

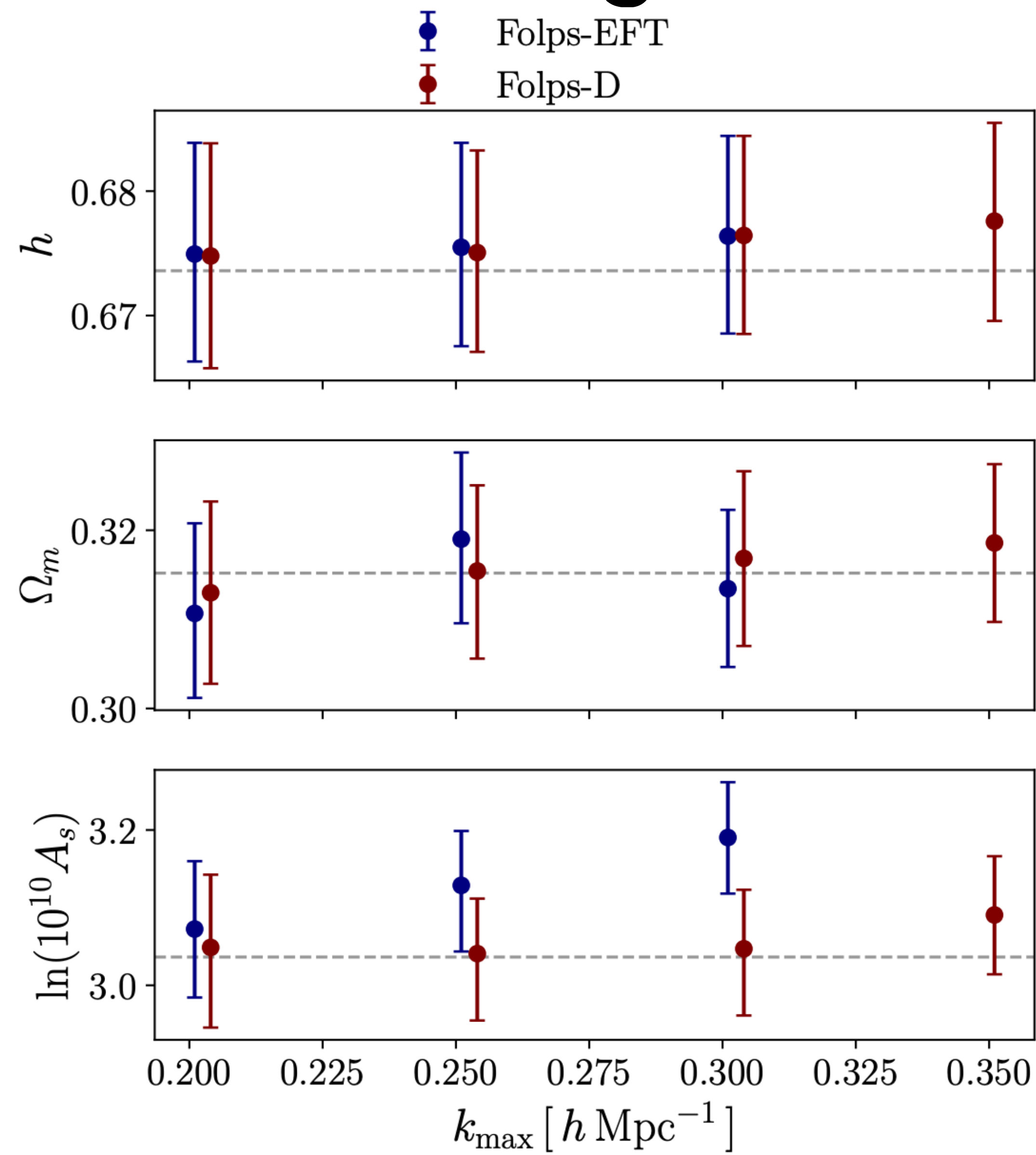
P. Bansal^{1,2}, A. Aviles^{3,4}, H. E. Noriega³, C. Guandalin,⁵
I. Garzon,³ G. Niz^{6,4}, M. S. Wang⁵, U. Andrade^{1,2},
F. Beutler⁵, A. de Mattia⁷, D. Gonzalez^{6,3}, J. Hou^{8,9,10},
D. Huterer^{11,2}, E. Paillas^{12,13}, M. Pellejero Ibanez⁵

- Bispectrum included
- EFT + a phenomenological damping term
- Even faster (~ 0.1 s/ PS, 0.02 s/ BS)

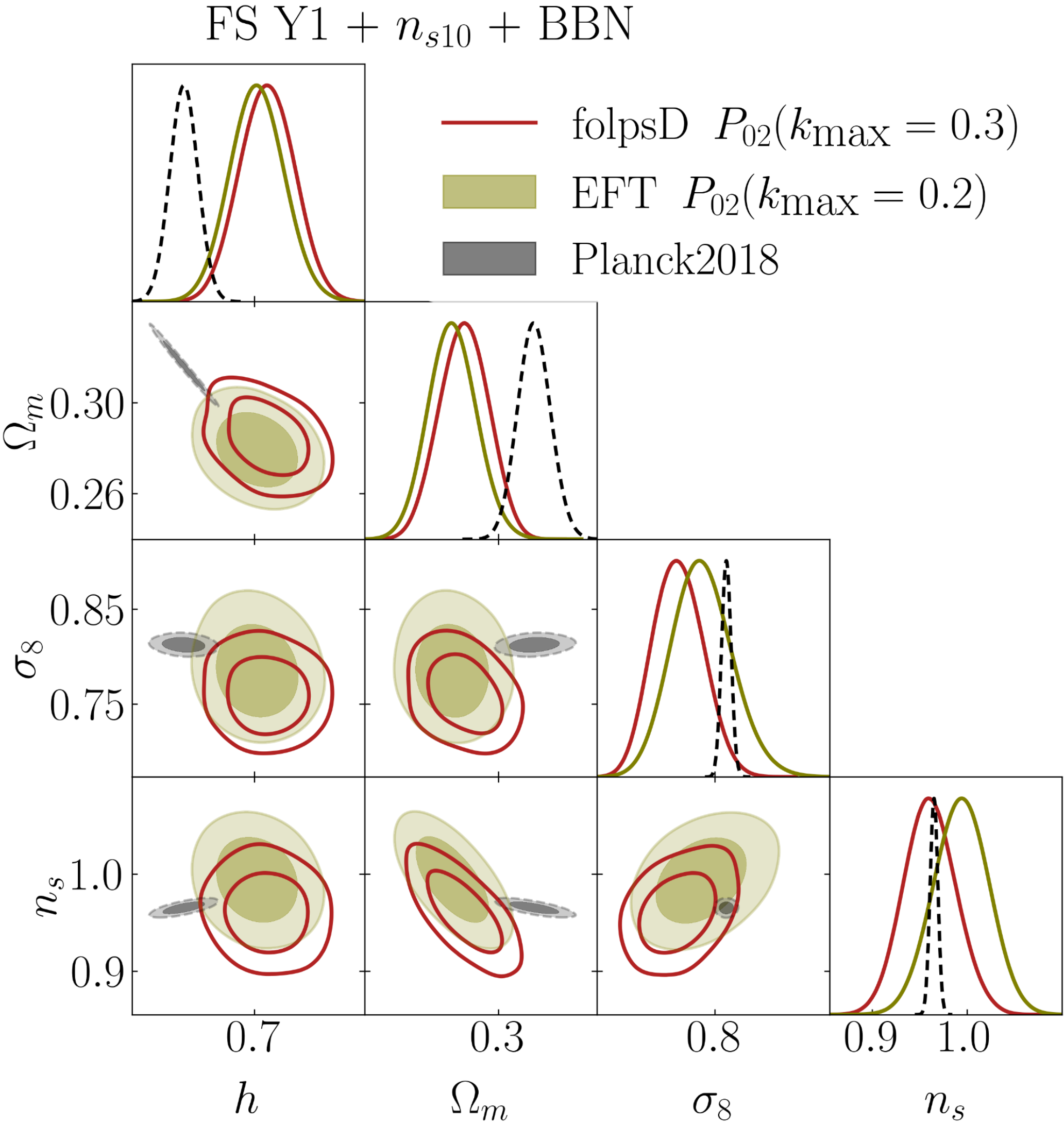
FolpsD vs EFT (Abacus2gen Mocks LRG2 z0.800)



FolpsD vs EFT (Abacus2gen Mocks LRG2 z0.800)

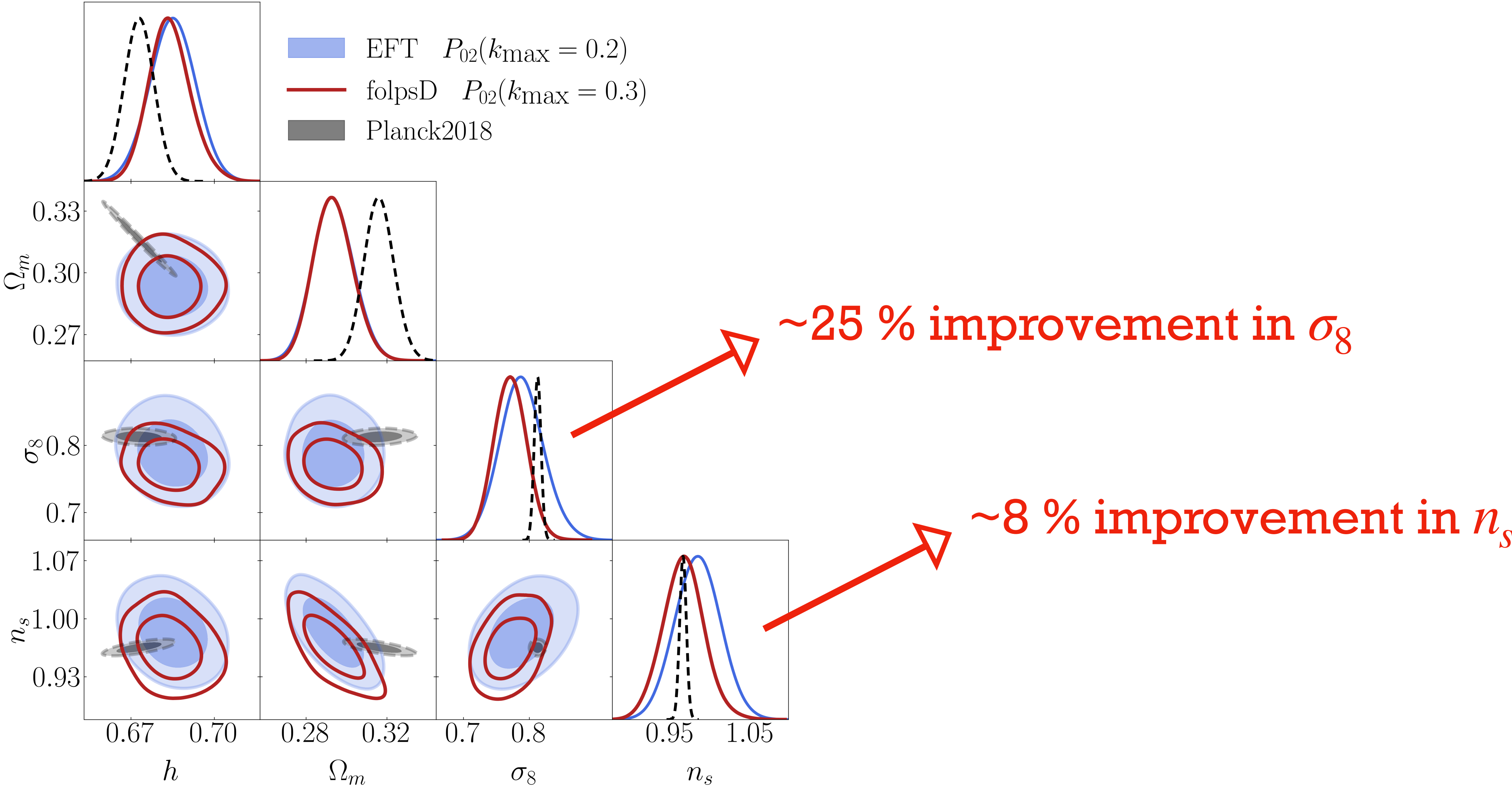


FolpsD vs EFT (DESI Y1 Full Shape)



FolpsD vs EFT (DESI Y1 Full Shape + BAO)

FS Y1 + n_{s10} + BBN + BAO



Summary

1. Upcoming & ongoing high-precision surveys like DESI will provide increasingly stringent tests of our cosmological model
2. Late-time expansion history modifications alone cannot resolve the Hubble Tension unless accompanied by a transition in the SNIa absolute magnitude
3. More sophisticated theoretical and modelling tools, including joint power spectrum + bispectrum analyses, can extract significantly more information from the same data

Looking Ahead: DESI DR2 Full Shape Analysis!