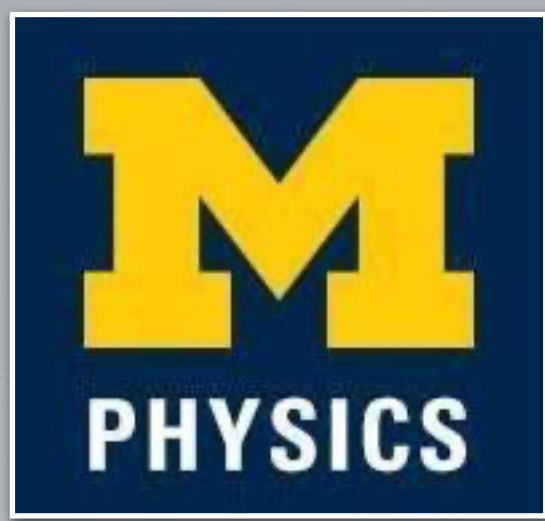




How deep are the cracks in Cosmology?

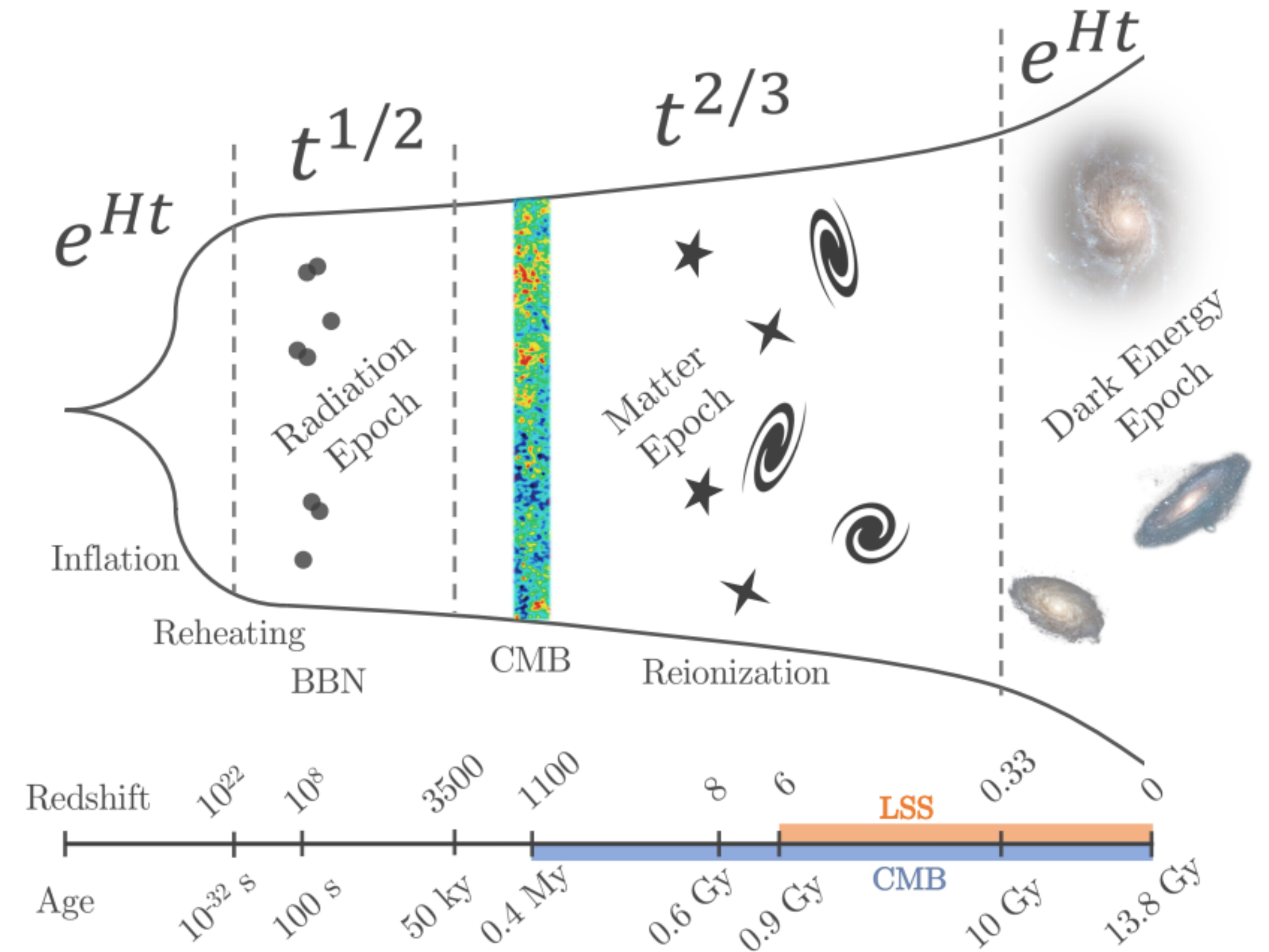
Insights from DESI

Physics Graduate Student
Symposium
18th June 2026

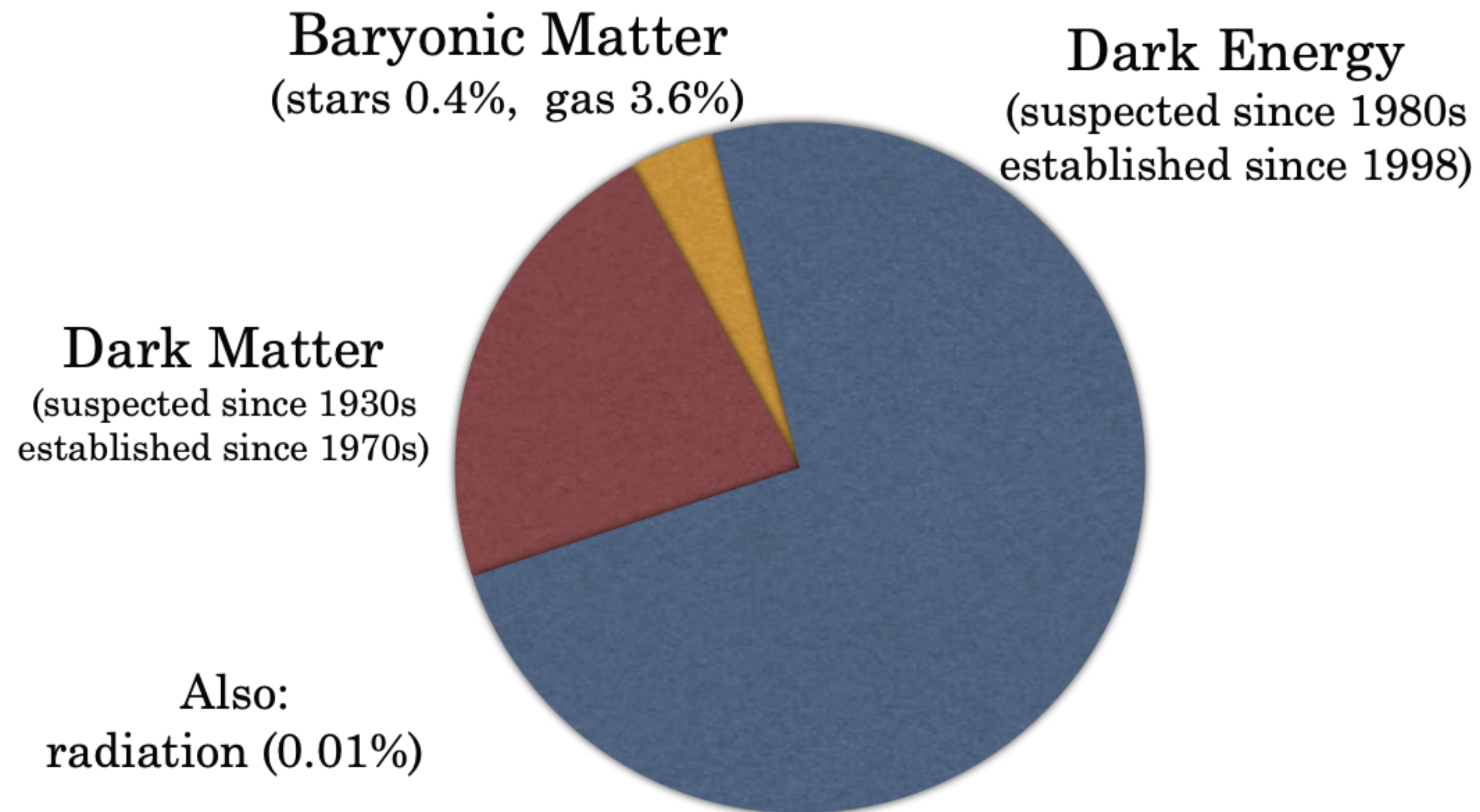
Prakhar Bansal
2nd Year PhD Student
Advisor: Dragan Huterer

The Big Questions

- What is the Universe made up of?
- How did it evolve?
- What is its ultimate fate?



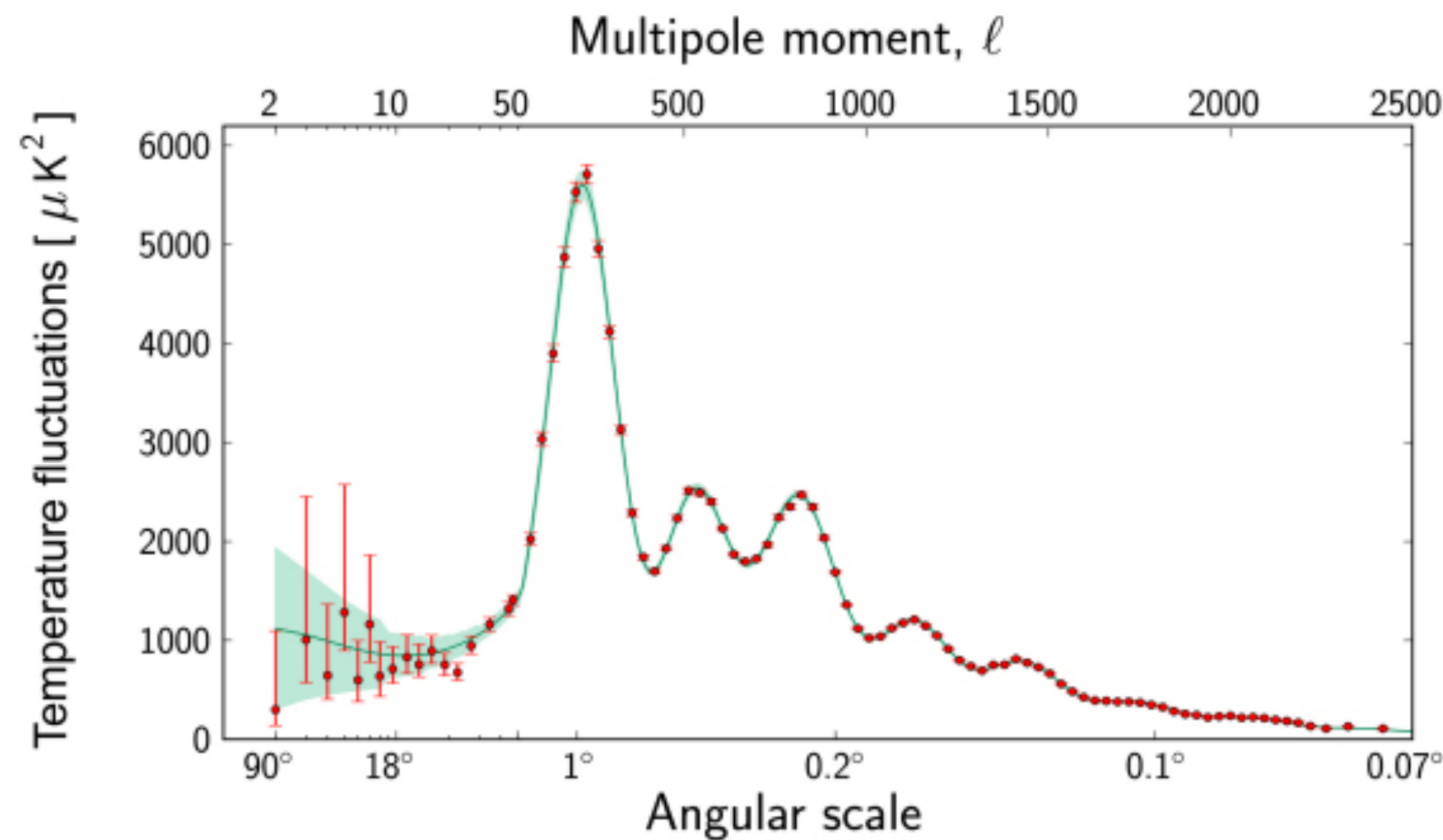
The Standard Model of Cosmology: Λ CDM



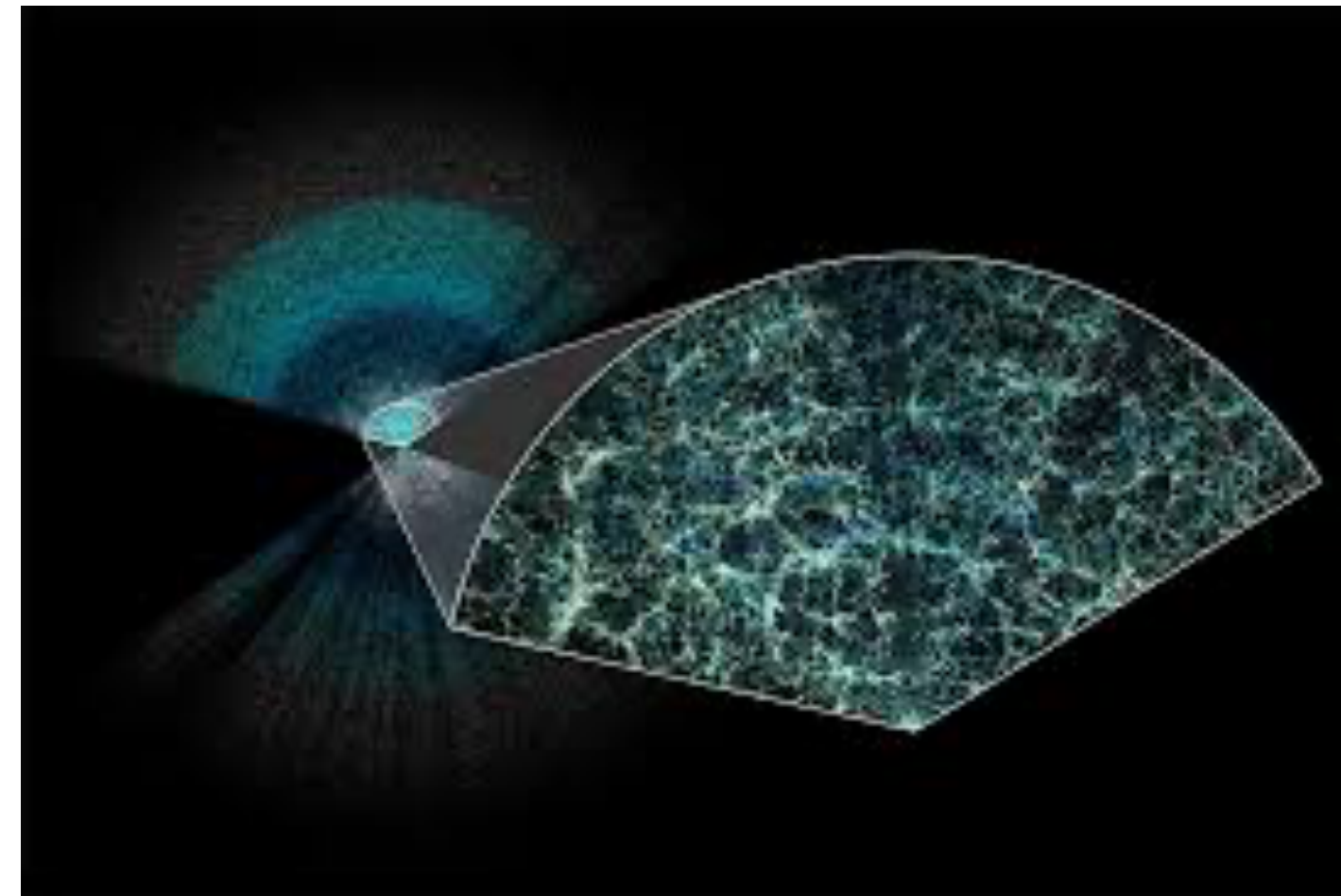
Incredibly simple model
with just 6 parameters

Why should we believe Λ CDM?

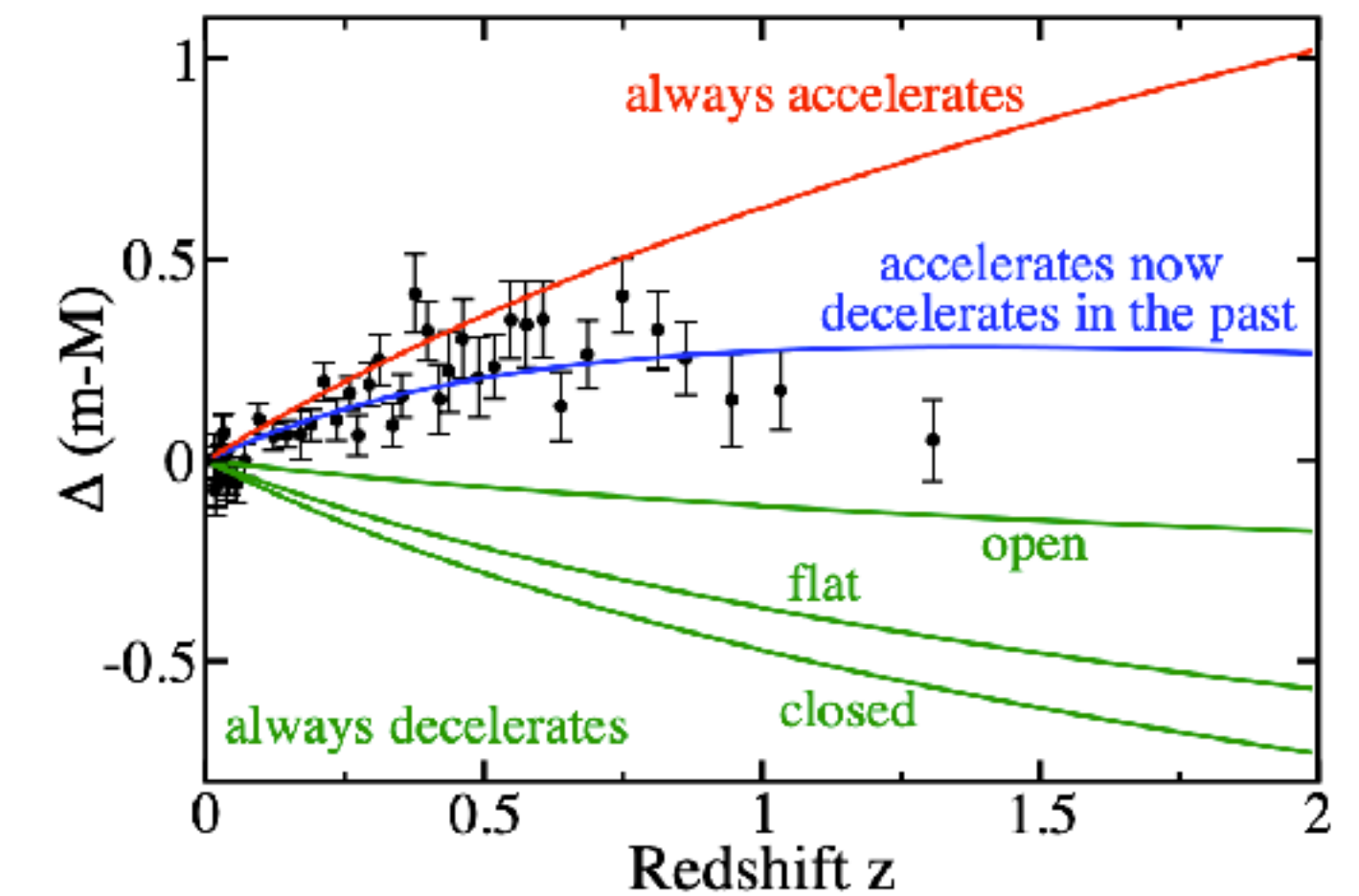
Λ CDM is able to explain a majority of wildly different observations



CMB



Galaxy Clustering

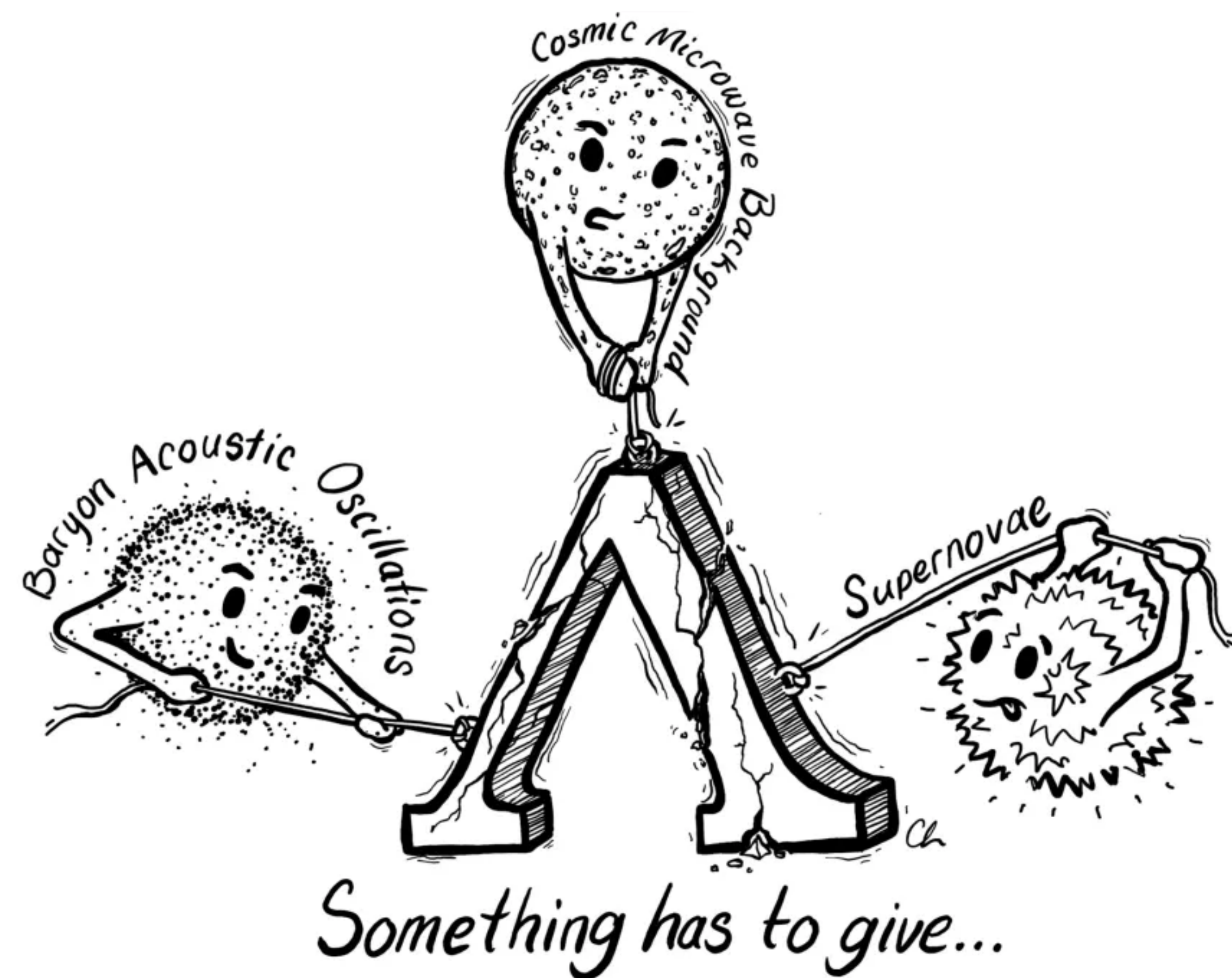


SN Ia

As the observations are getting better, cosmology is increasingly becoming a precision science

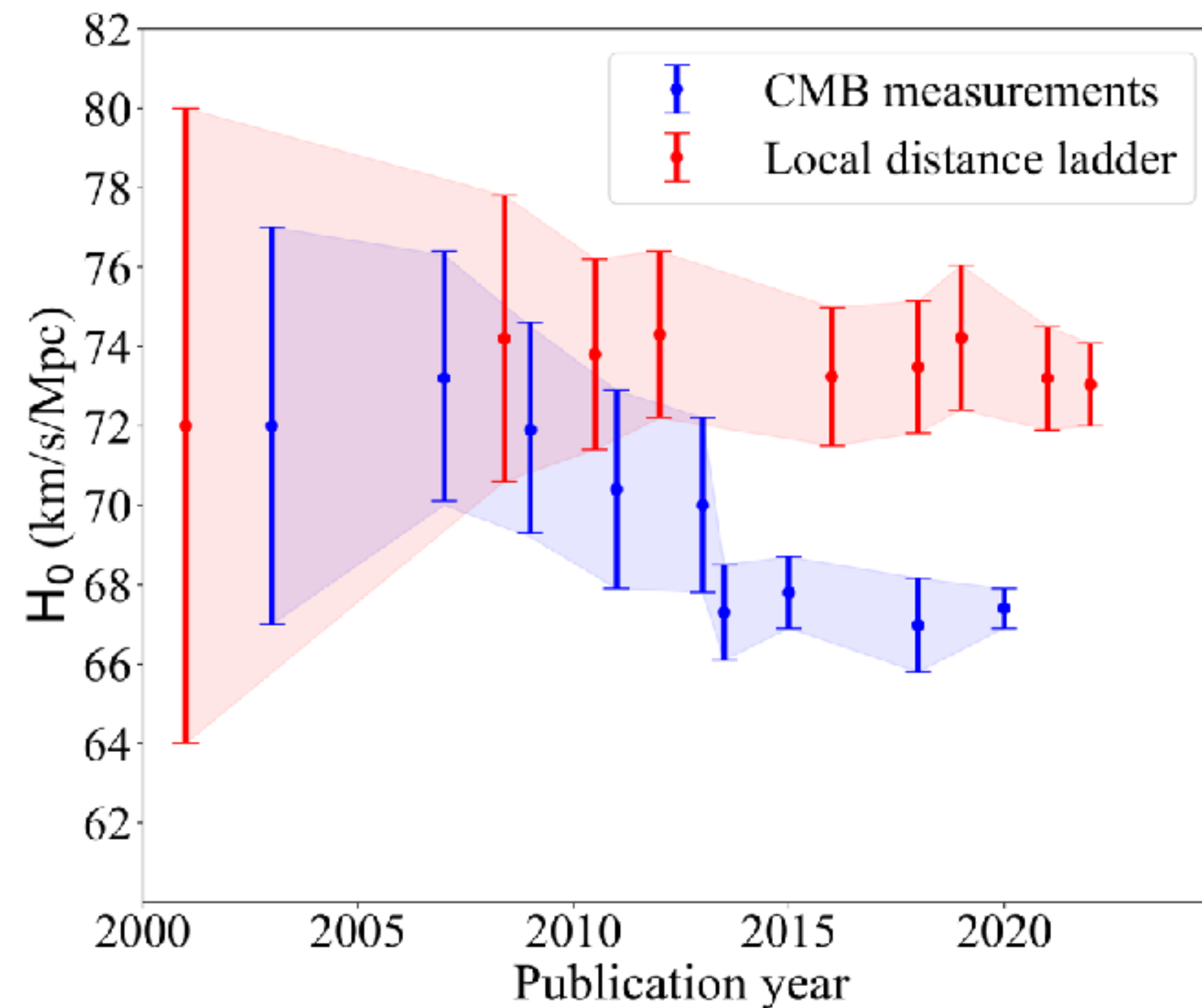
But precision reveals cracks

- Hubble Tension
- Dynamical Dark Energy
- Neutrino Mass
-

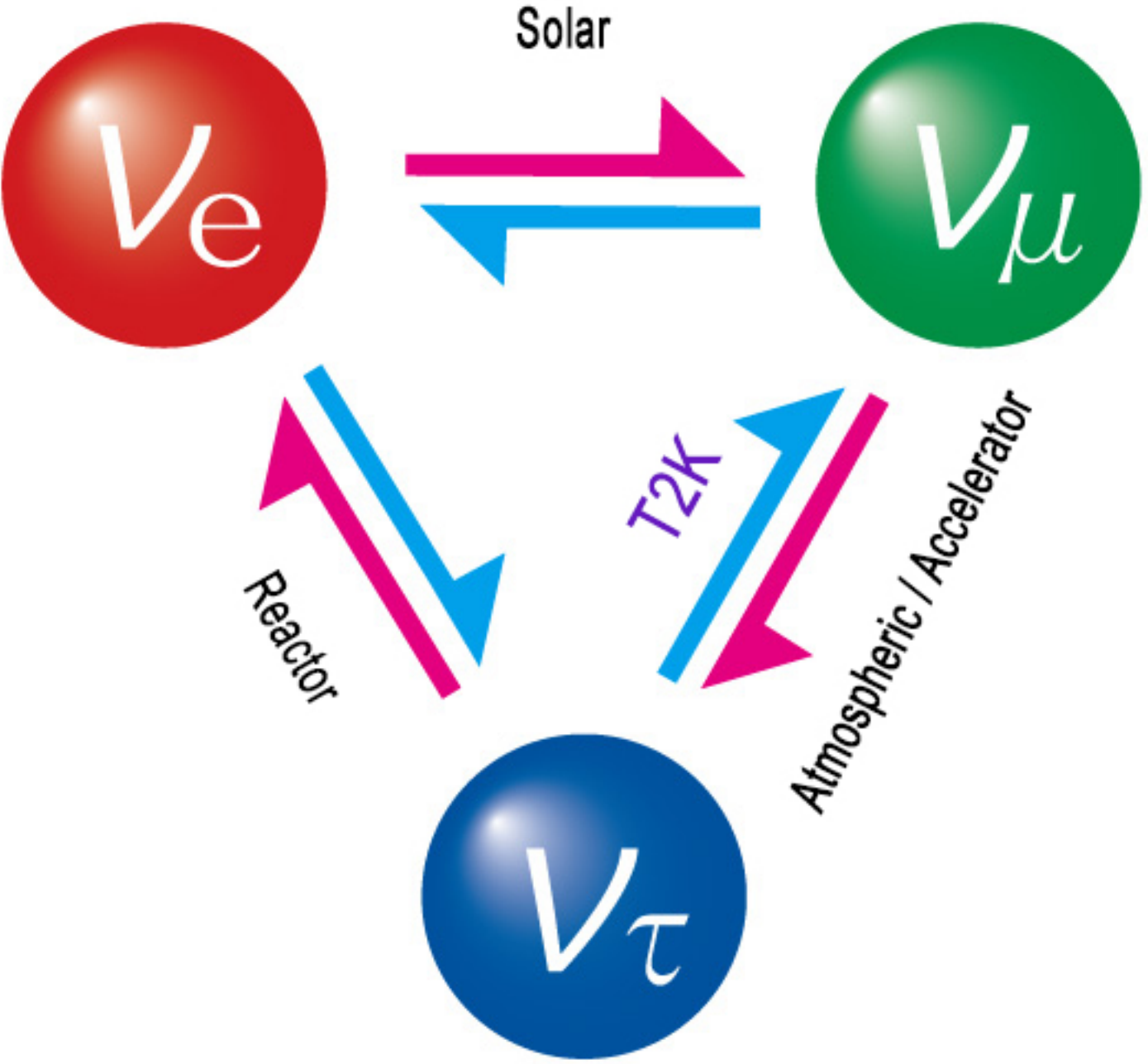


The Hubble Tension

H_0 : The Hubble Constant ($\sim 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$)
(Measure of the expansion rate of the Universe today)



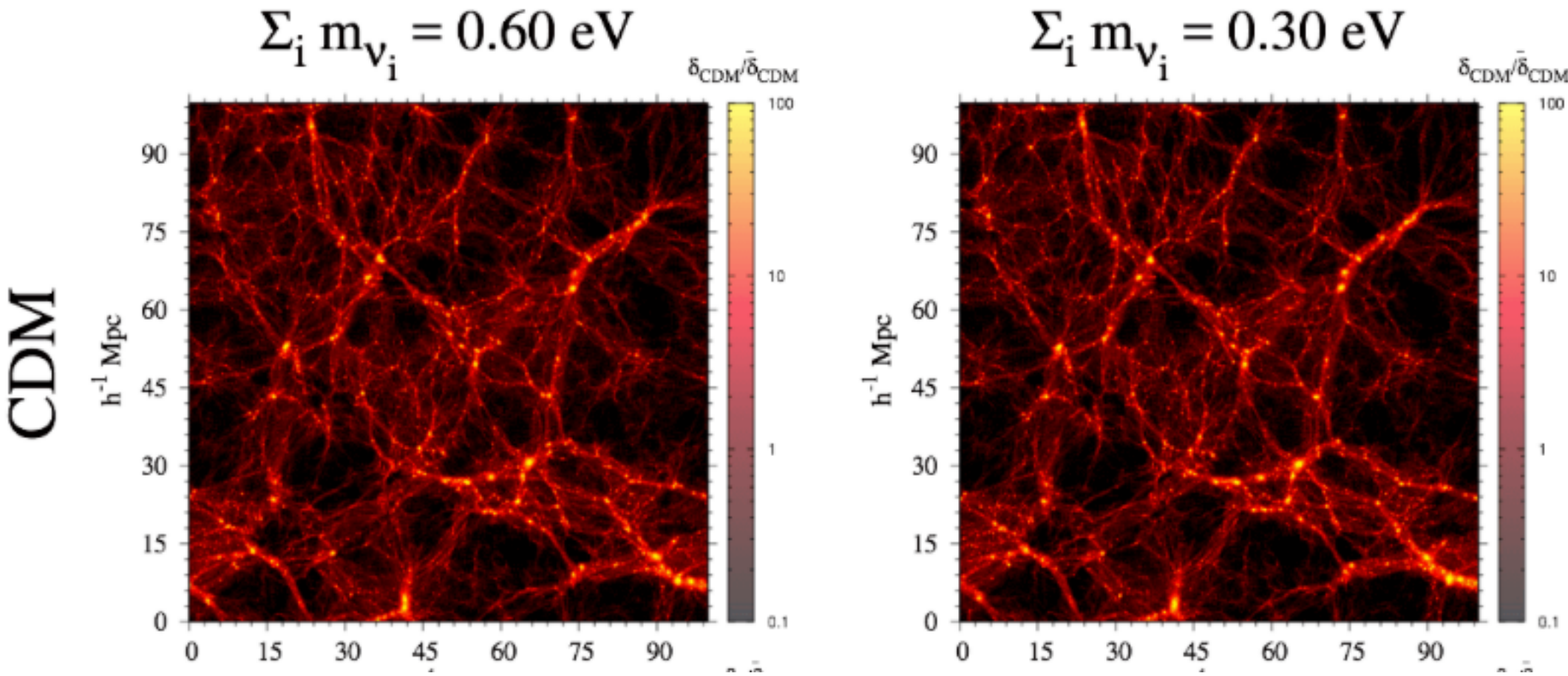
Neutrino Mass



Neutrino oscillation between three generations

$$\Sigma m_\nu \gtrsim 0.06 \text{ eV}$$

Massive neutrinos suppress
the growth of structure

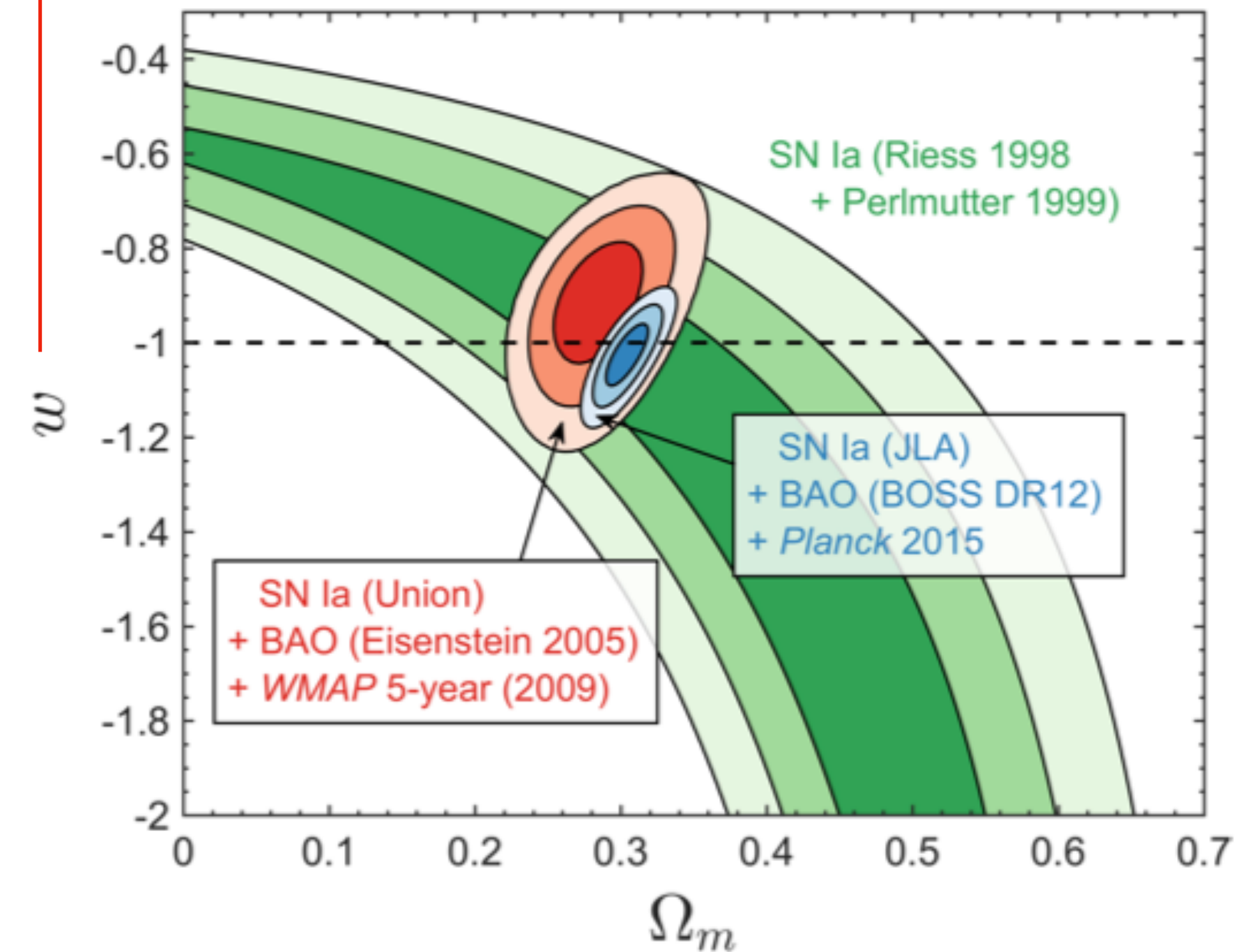


$$\Sigma m_\nu \lesssim 0.06 \text{ eV}$$

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 ($w \simeq -1$)
 - But recent experiments are providing increasing evidence of a time-varying dark energy

EOS Parameter for DE



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

How can we test these cracks?

- Need precise expansion history
 - Need precise structure growth
- } Galaxy Surveys!



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

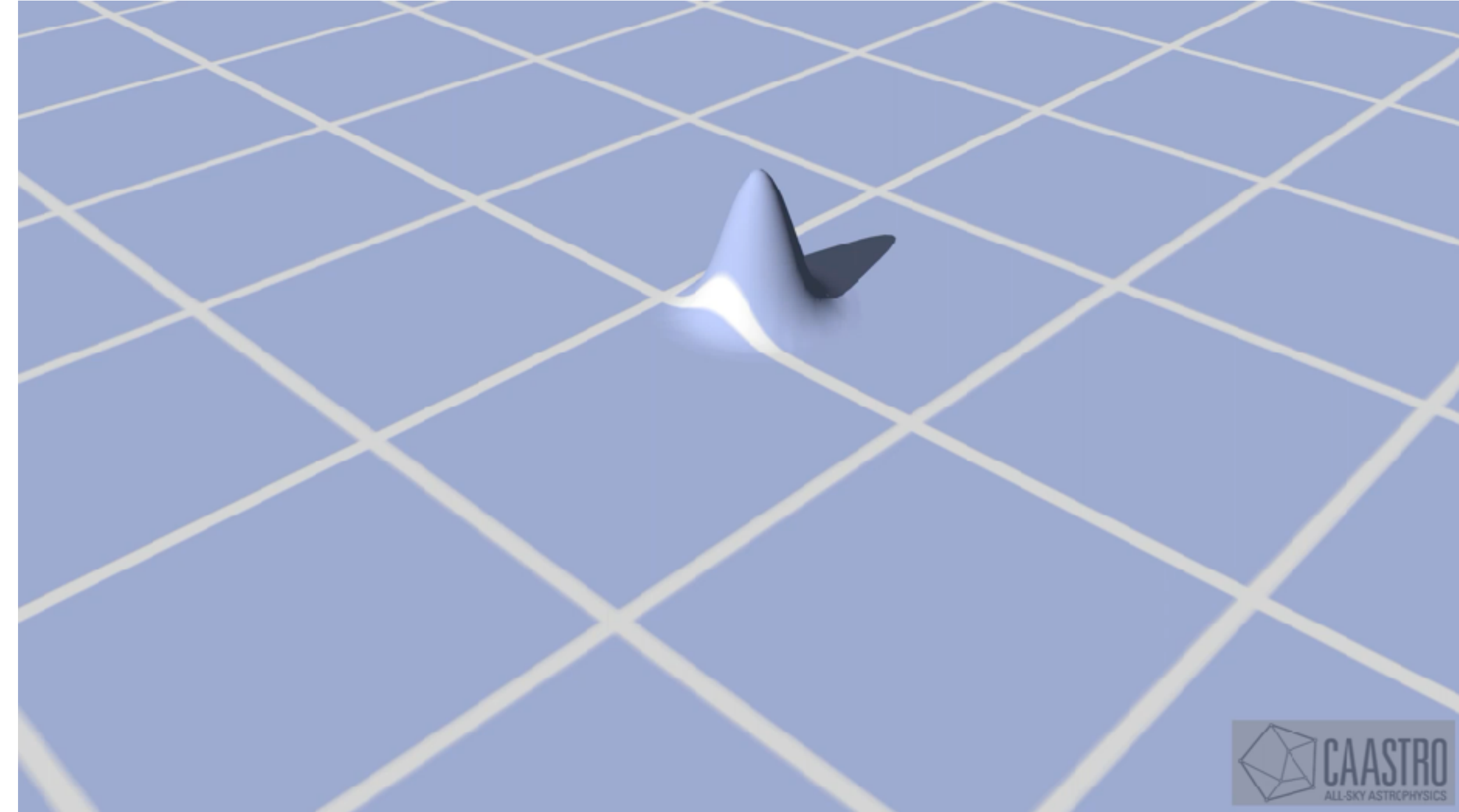


But how does this map of galaxies help??

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

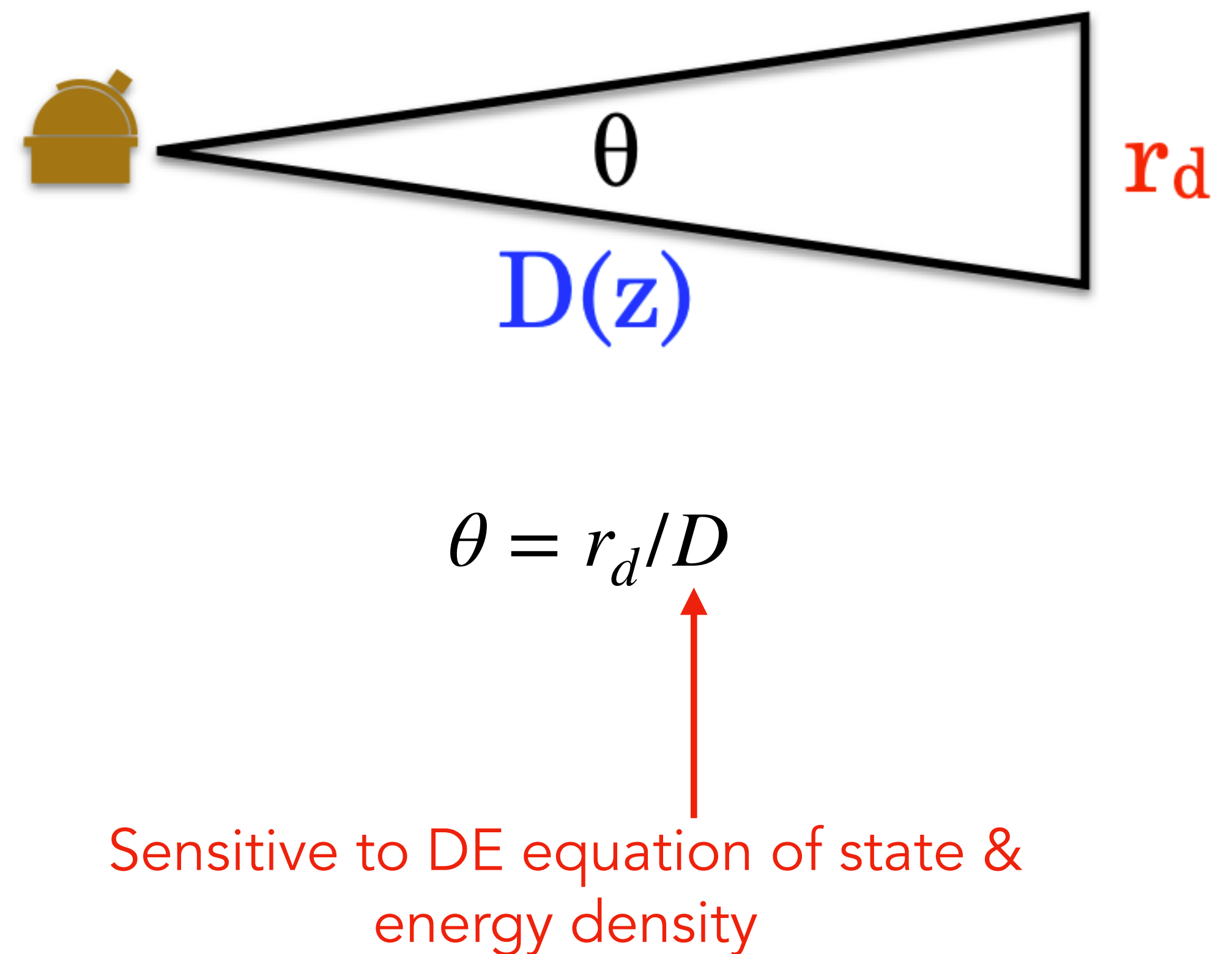
1. Baryon Acoustic Oscillations

- 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

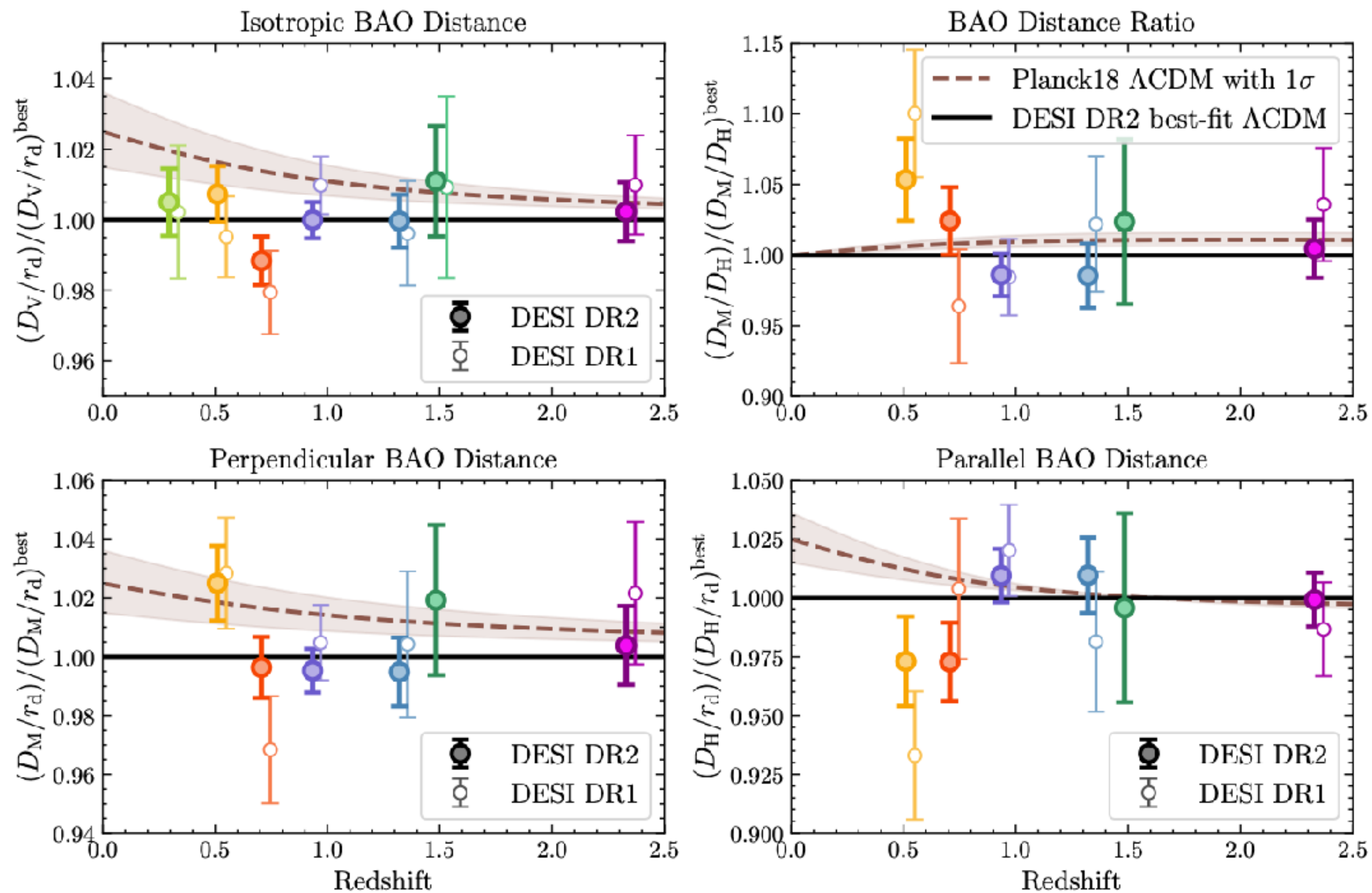


How does the BAO feature help understand DE?

- 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

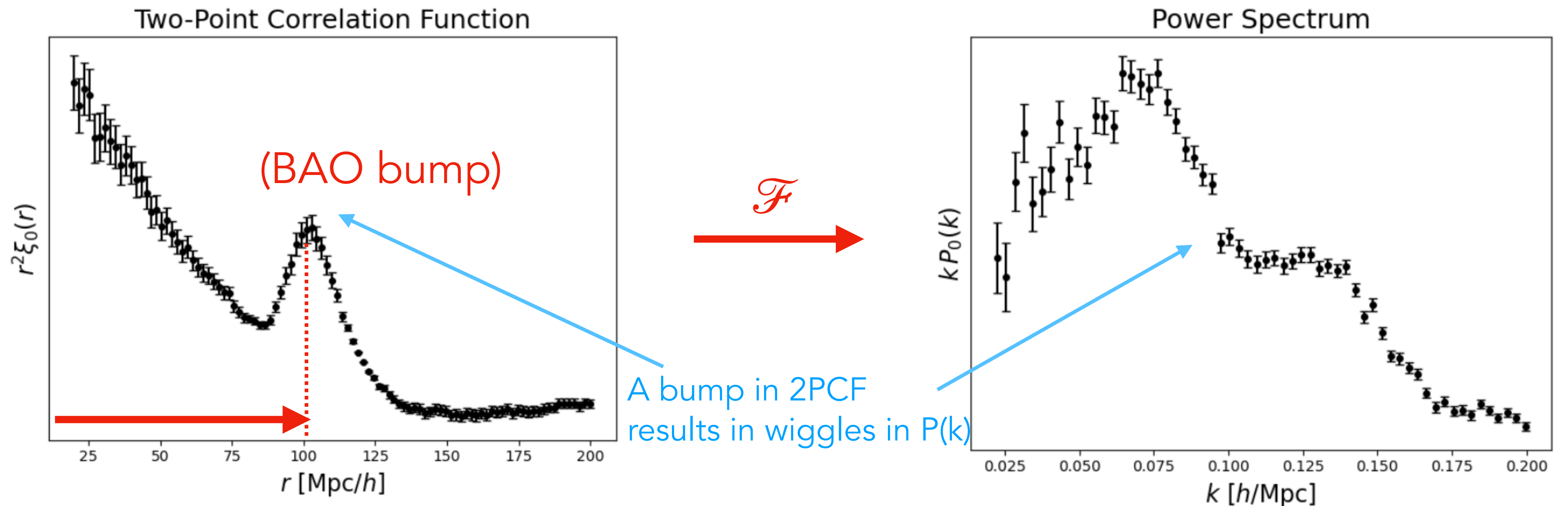


How does the BAO feature help understand DE?



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)

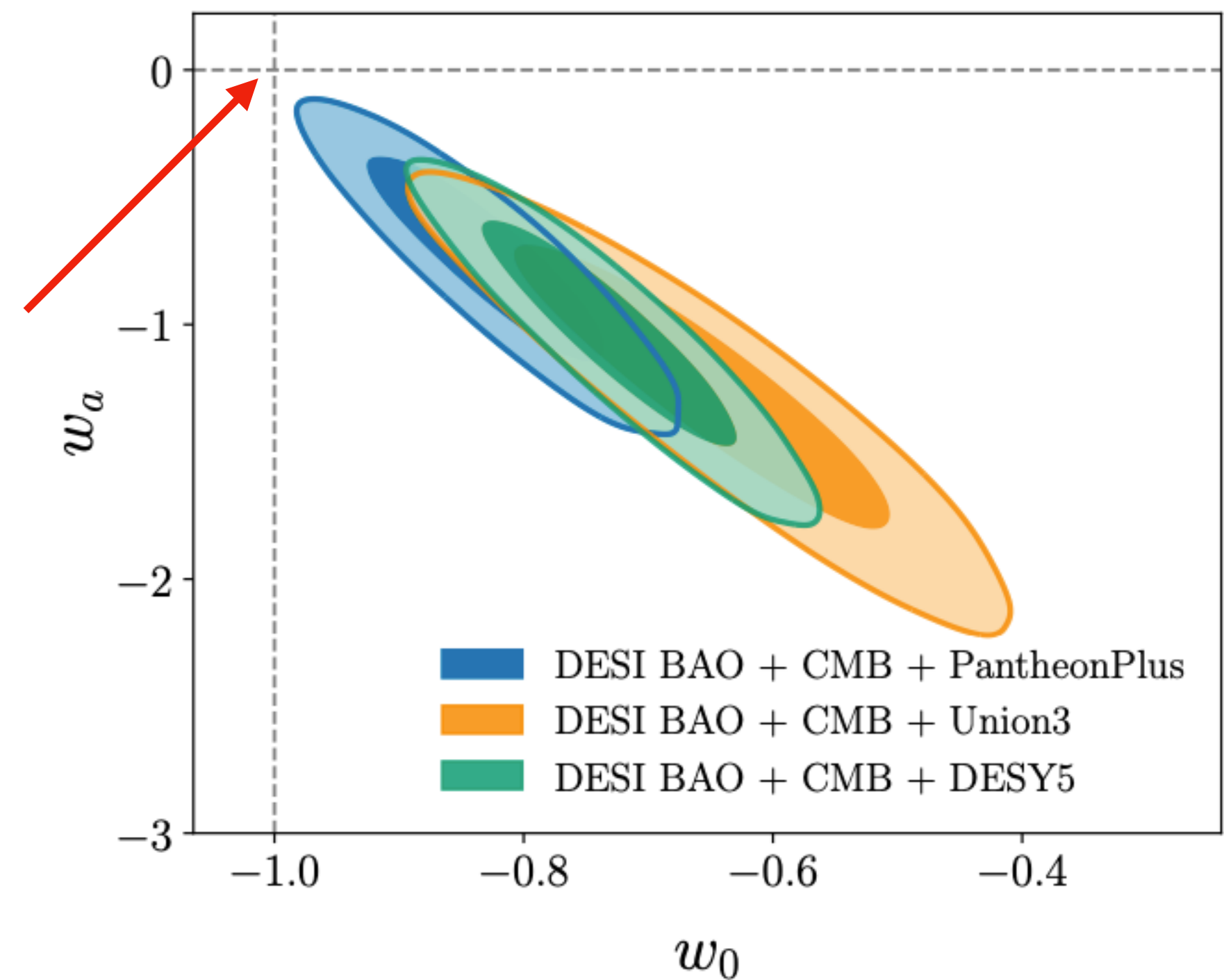
$w_0 w_a$ Parametrization

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

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

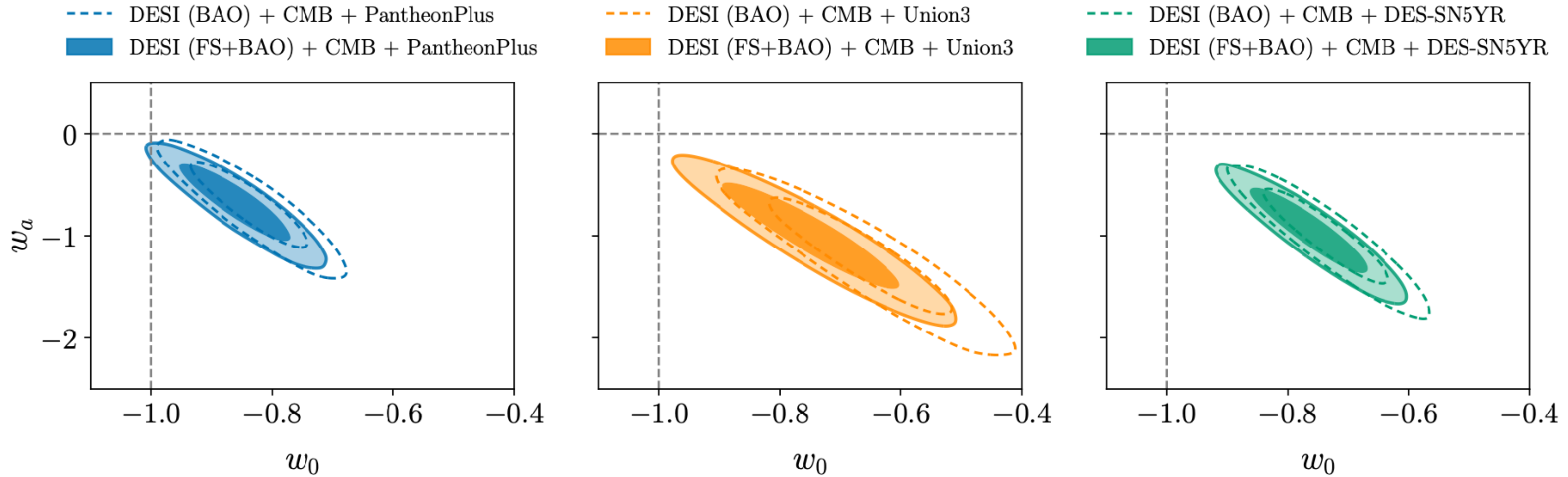
Λ CDM is recovered

Λ CDM
Point



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

DESI DE Results (DR1 Full Shape)

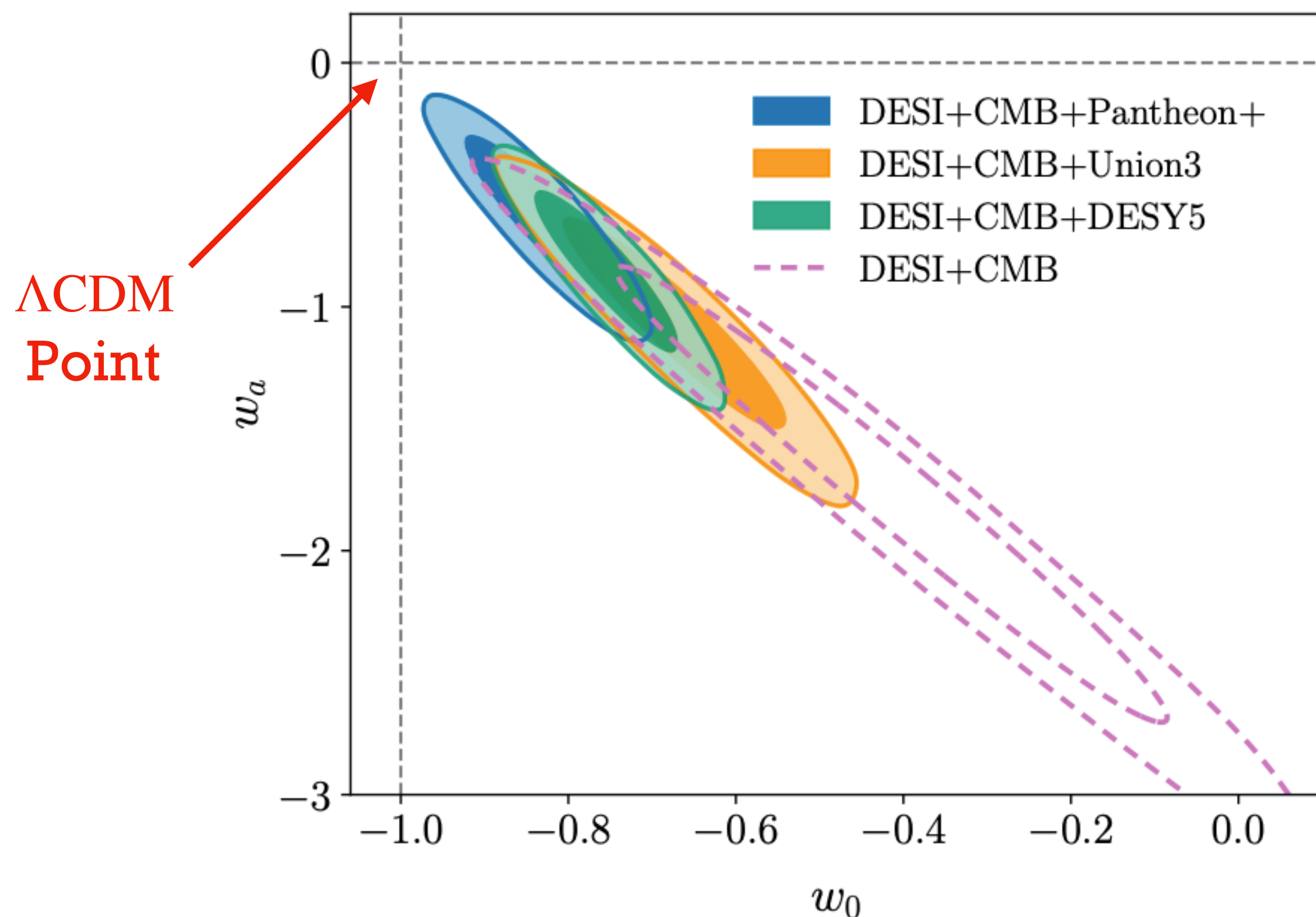


Contours shrink by $\sim 20\%$ on adding FS information

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

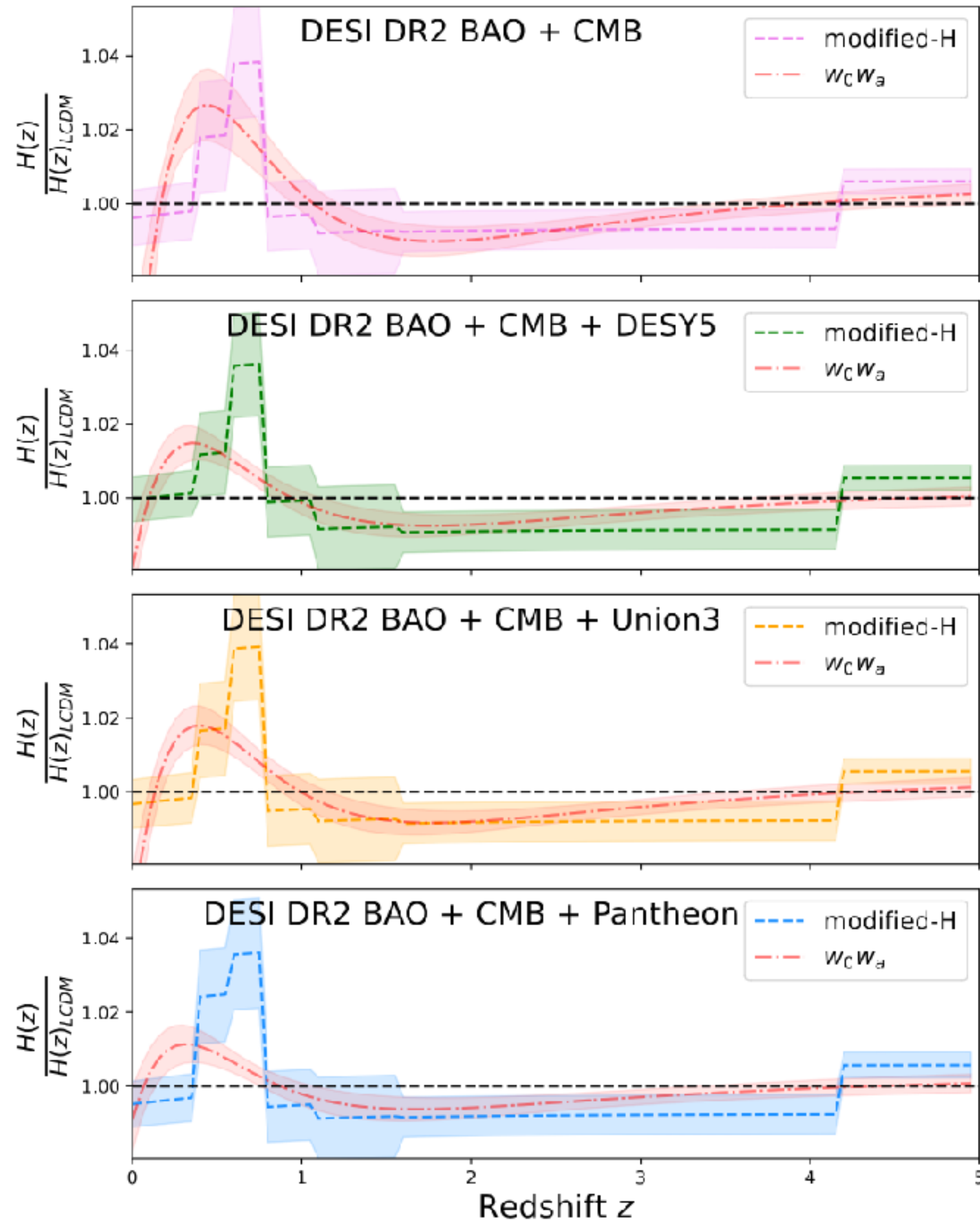
3.1σ , 2.8σ , 3.8σ , 4.2σ deviation from Λ CDM

Upcoming: DR2 Full Shape!

1. Expansion History Preferences of DESI DR2 and external data

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

Results



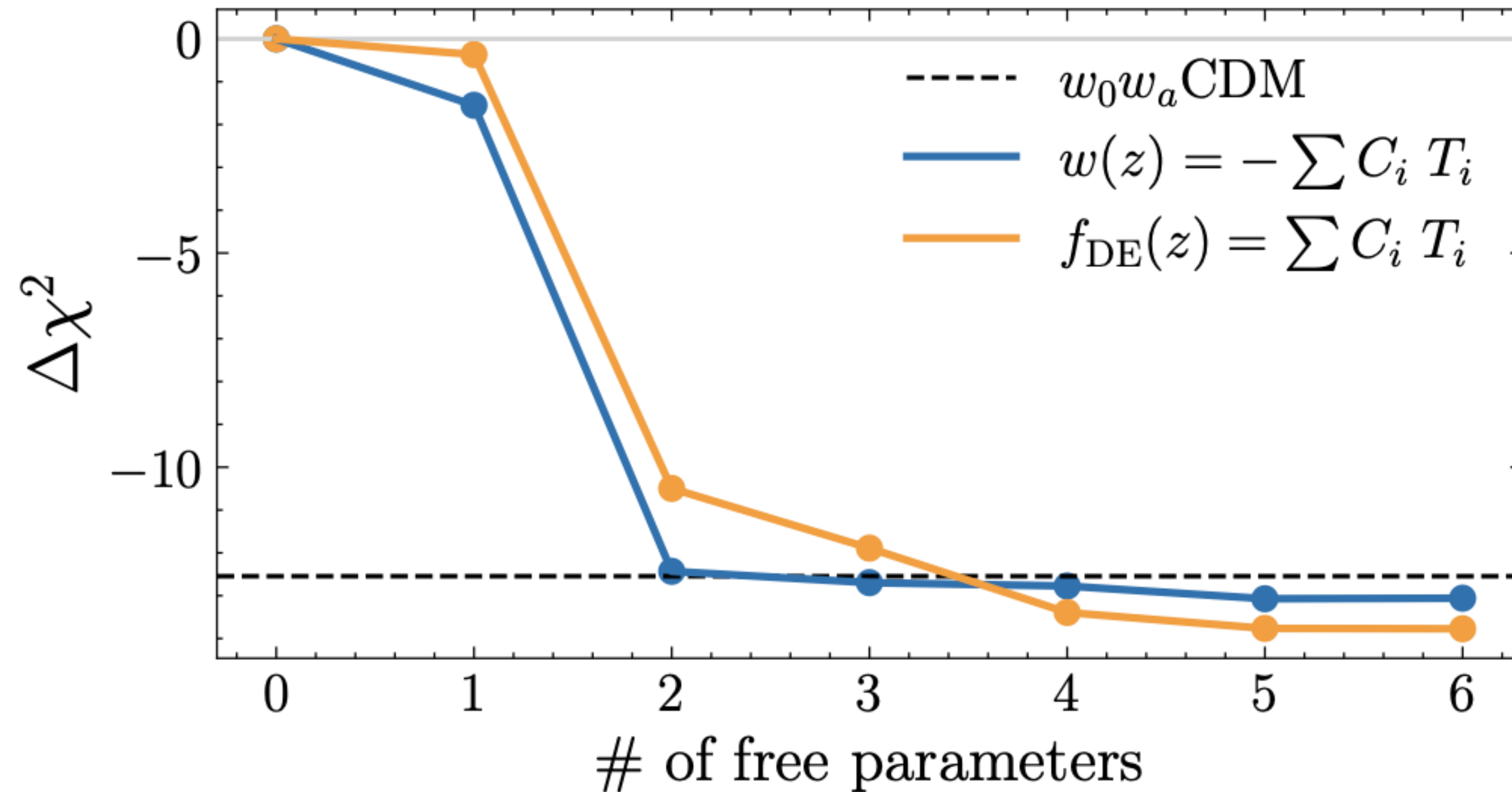
Modified-H Model

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

6 free parameters
(as opposed to 2 in $w_0 w_A$)

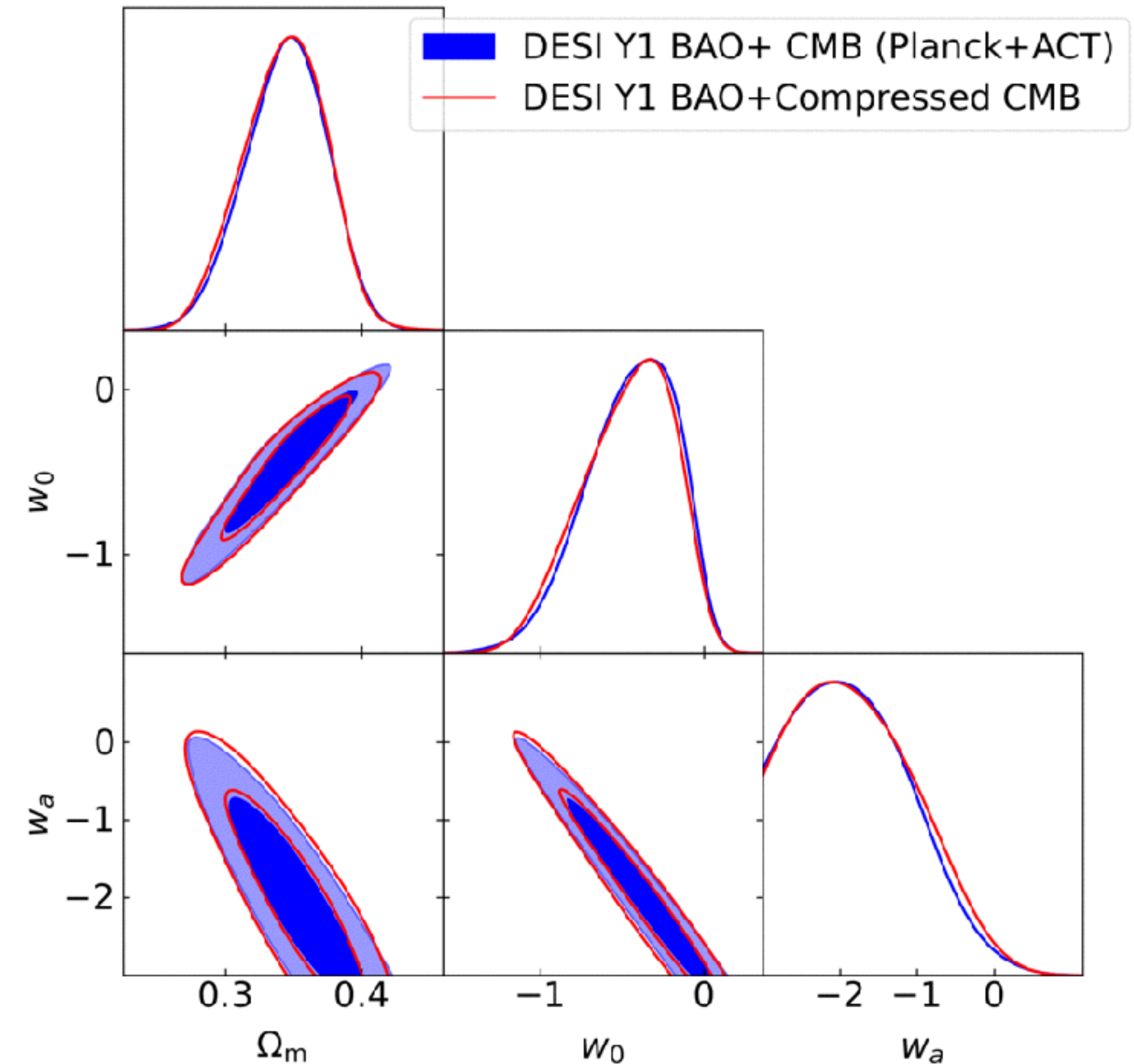
$w_0 w_a$ parametrization is flexible enough
to model the DESI data favoured
expansion history!!

...Later confirmed by independent studies



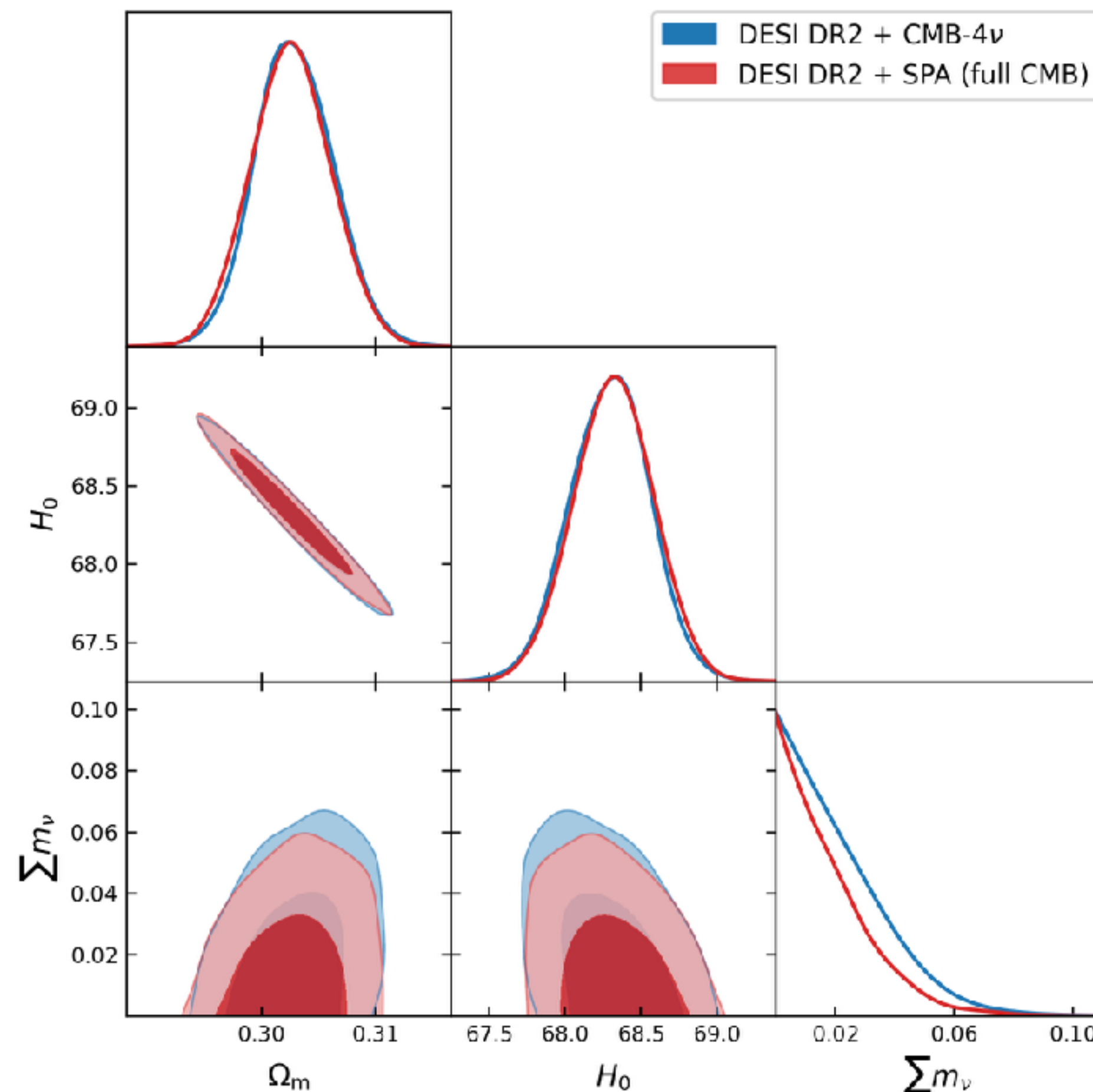
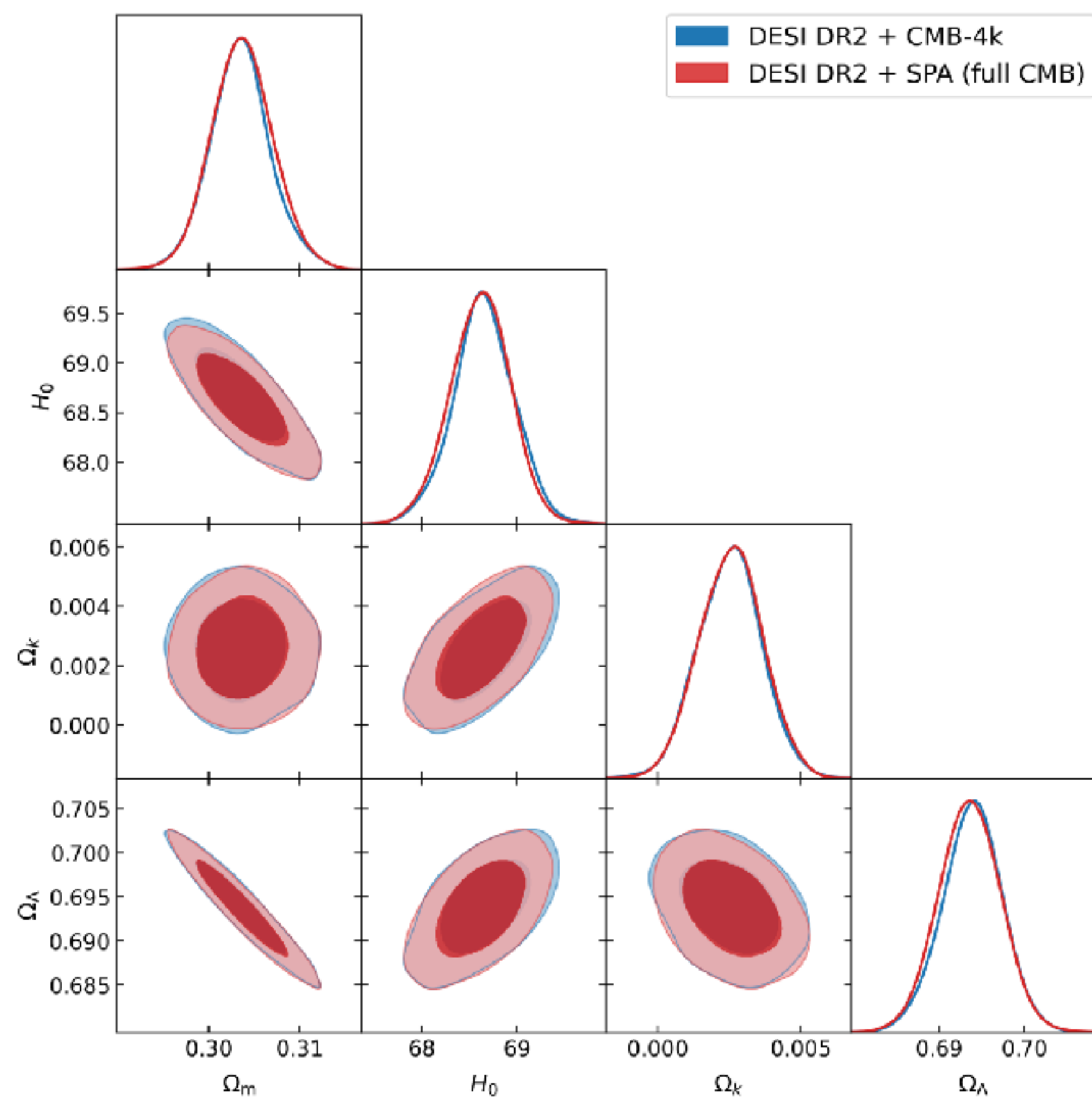
Corollary: CMB Compression

- Full CMB likelihood: $\sim 7\text{K}$ data points
- Compressed CMB: 3 data points
- Run time goes from $\sim 6\text{-}7$ hours to 3-4 minutes



One of the most accurate compressions as of now!!
Also adopted in DESI DR2 BAO Key Paper*

Follow-up: 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

[Phys. Rev. D 113, 103539](#)

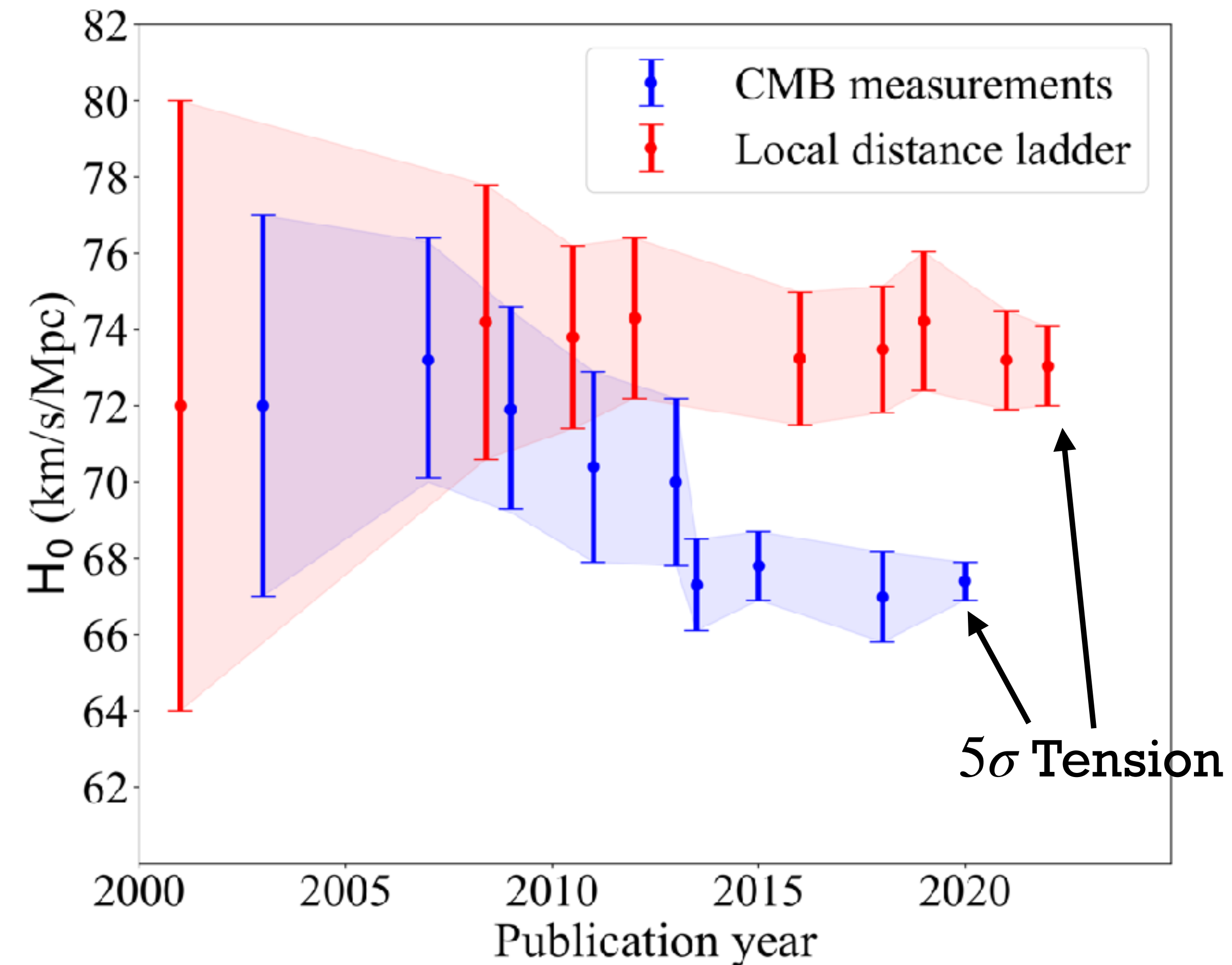
The Hubble Tension

H_0

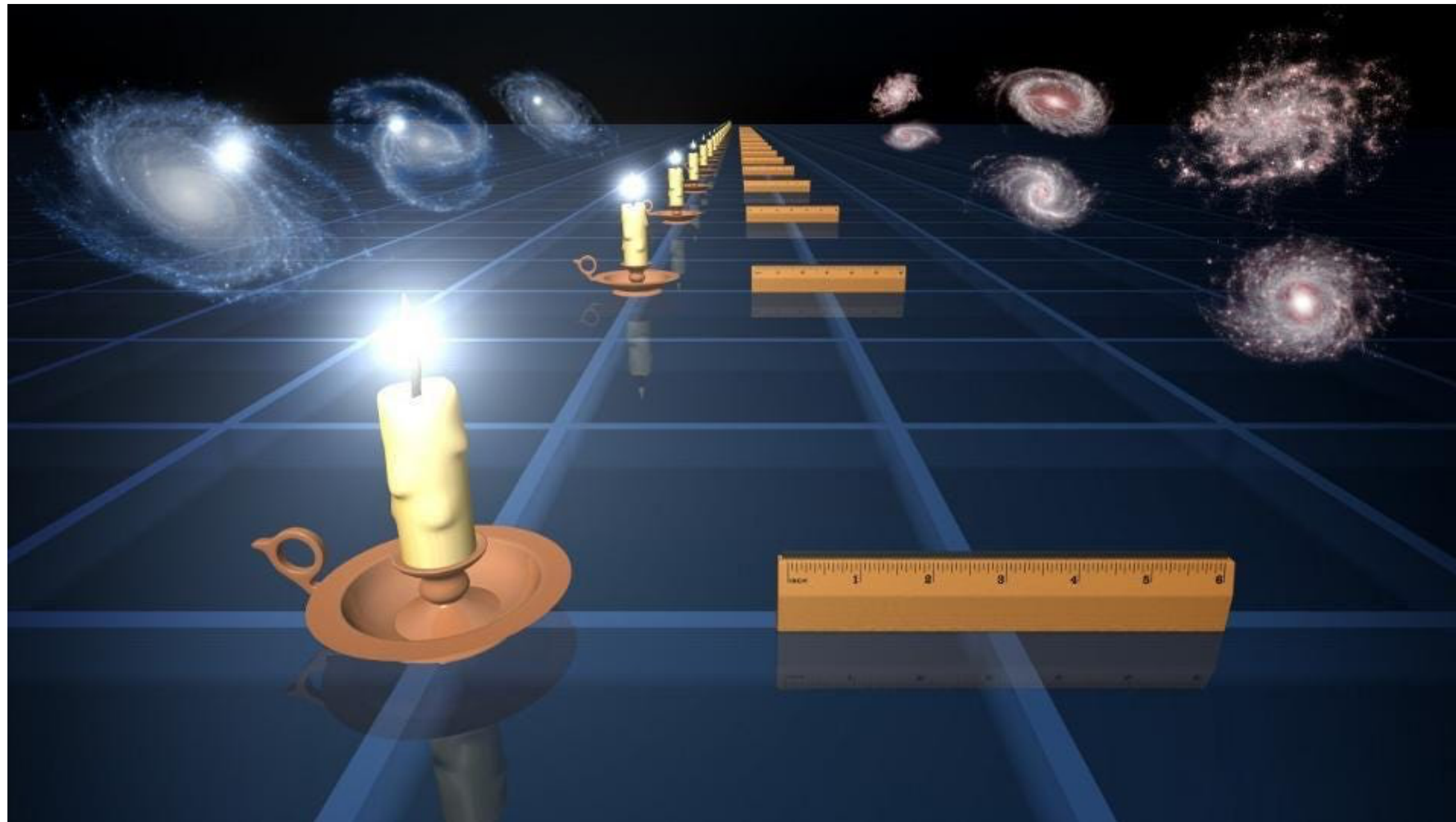
Hubble Constant: Measure of the expansion rate today

Two ways to measure H_0

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



SN Ia distance ladder



SN Ia: Standard Candles
(All SN Ia are *believed* to have same Luminosity (absolute magnitude))

$$f = \frac{L}{4\pi d^2}$$
$$m_{app} = \mu + M_{abs}$$

What we measure

Cosmological Information
(What we want to determine)

Unknown
(Can be determined
for nearby SN Ia)

H_0

This work

- We first show that simple late time modifications of the expansion history cannot resolve Hubble Tension
- What works instead is letting go of the standard candle assumption and allowing for an evolution in the SNIa absolute magnitude
- We also show a particular (somewhat fine tuned) modified gravity model can achieve such a transition

$$S = \int d^4x \sqrt{-g} \left[\frac{M_{\text{Pl}}^2}{2} F(\varphi) R \dots \dots \dots \right]$$

↑
Ricci Scalar

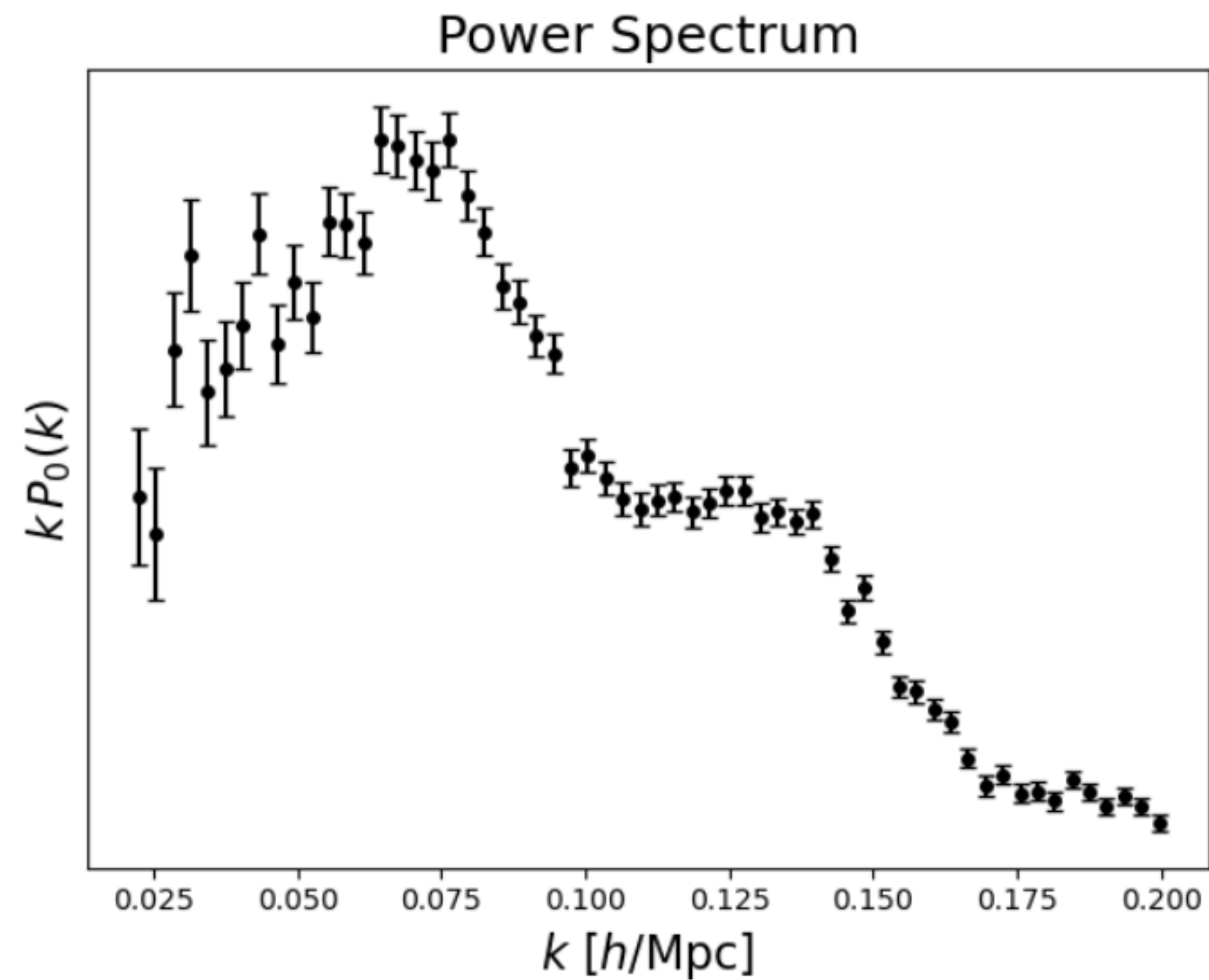
3. FolpsD: combining EFT and phenomenological approaches for joint power spectrum and bispectrum analyses

[arXiv: 2604.08895](#)

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

(With Alejandro Aviles, Hernan Noriega, Isaac Garzon.....)

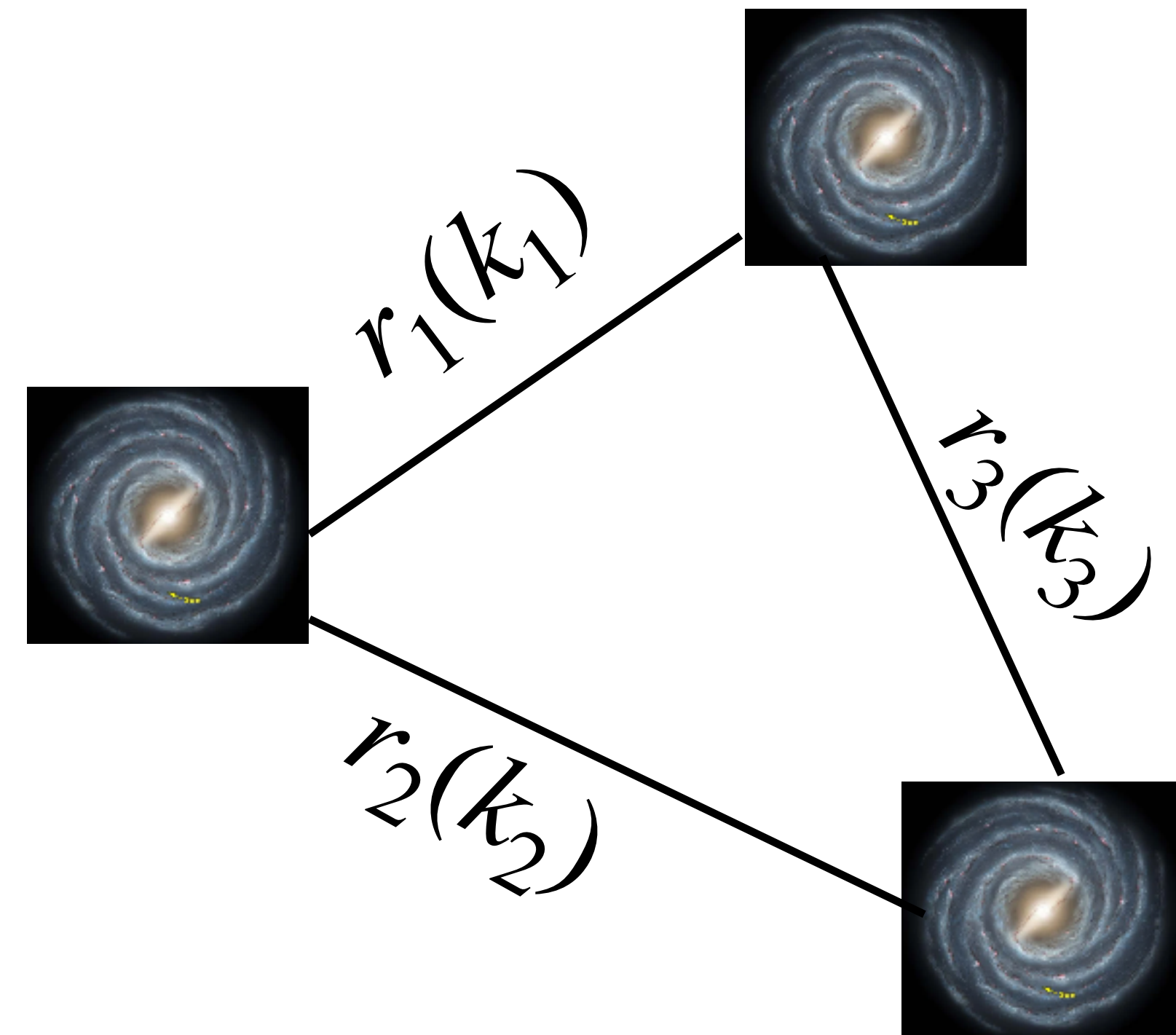
Power Spectrum



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 ($\sim 0.2\text{s/ PS}$)

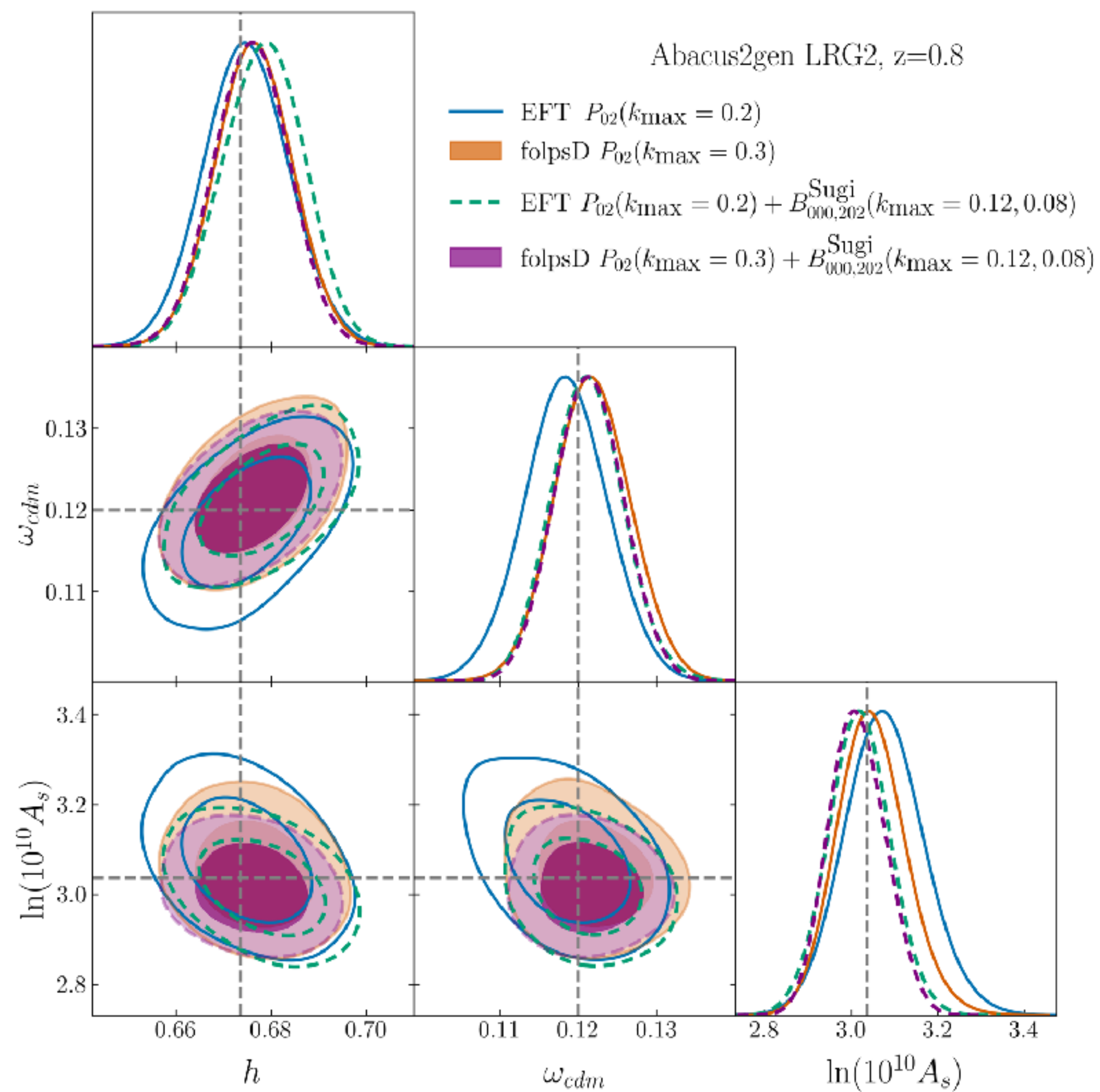
FOLPSD

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

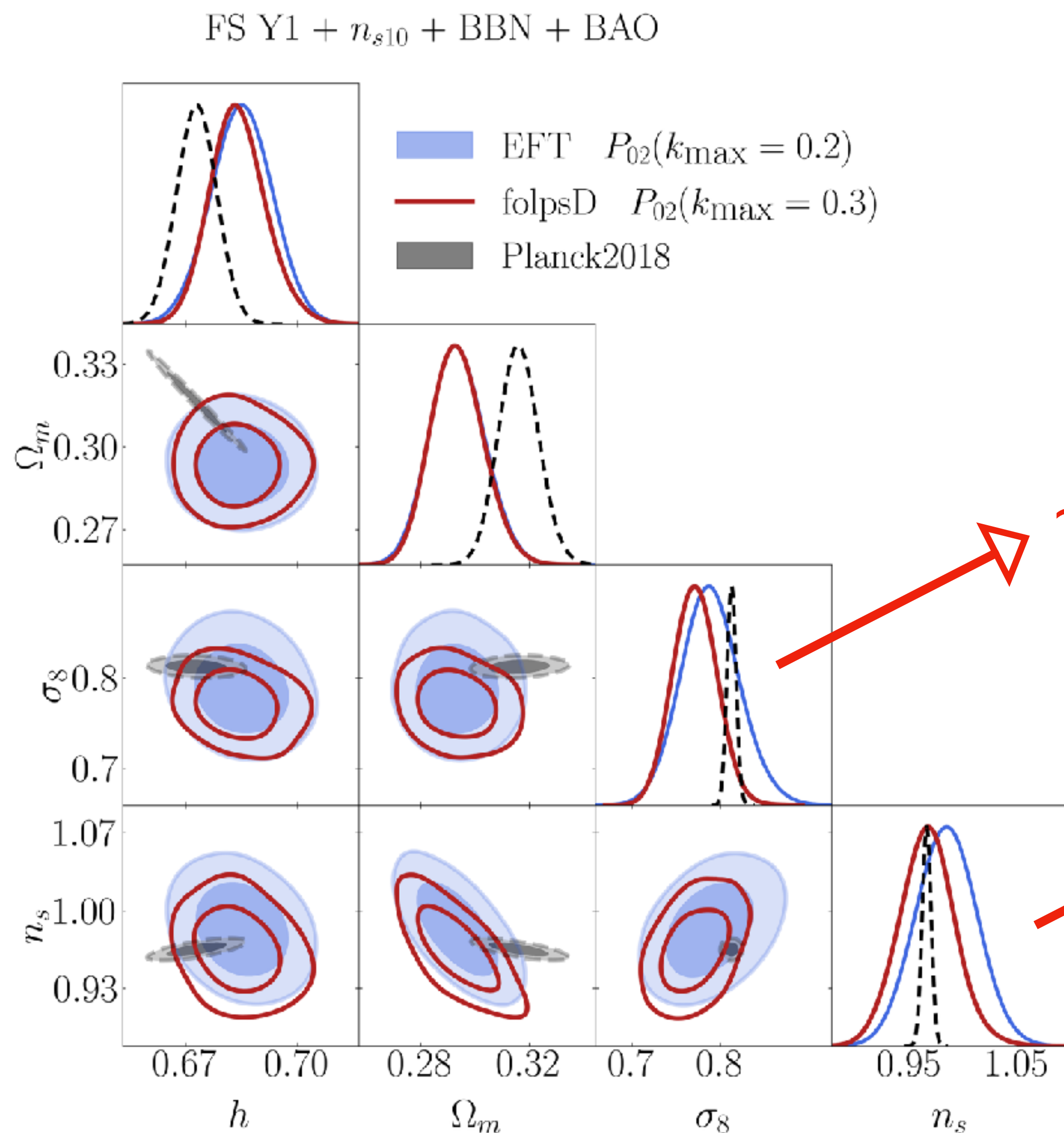
P. Bansal^{1,2}, A. Aviles^{3,4}, H. E. Noriega³, C. Guandalin,⁵
I. Garzon,³ G. Niz^{6,4}, M. S. Wang⁵, U. Andrade^{1,2},
F. Beutler⁵, A. de Mattia⁷, D. Gonzalez^{6,3}, J. Hou^{8,9,10},
D. Huterer^{11,2}, E. Paillas^{12,13}, M. Pellejero Ibanez⁵

- Bispectrum included
- EFT + a phenomenological damping term
- Even faster ($\sim 0.1\text{s/ PS}$, 0.02s/ BS)

FolpsD vs EFT (Abacus2gen Mocks LRG2 z0.800)



FolpsD vs EFT (DESI Y1 Full Shape + BAO)



This improved modelling can help us derive more stringent constraints for quantities of interest ($w_0, w_a, \Sigma m_\nu \dots$) without waiting years for additional data

$\sim 25\%$ improvement in σ_8

$\sim 8\%$ improvement in n_s

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!