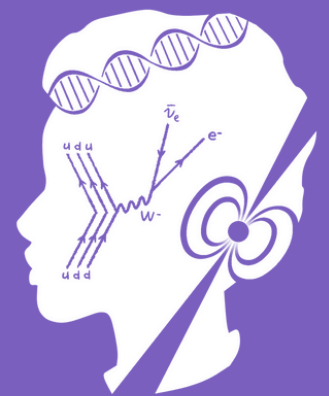


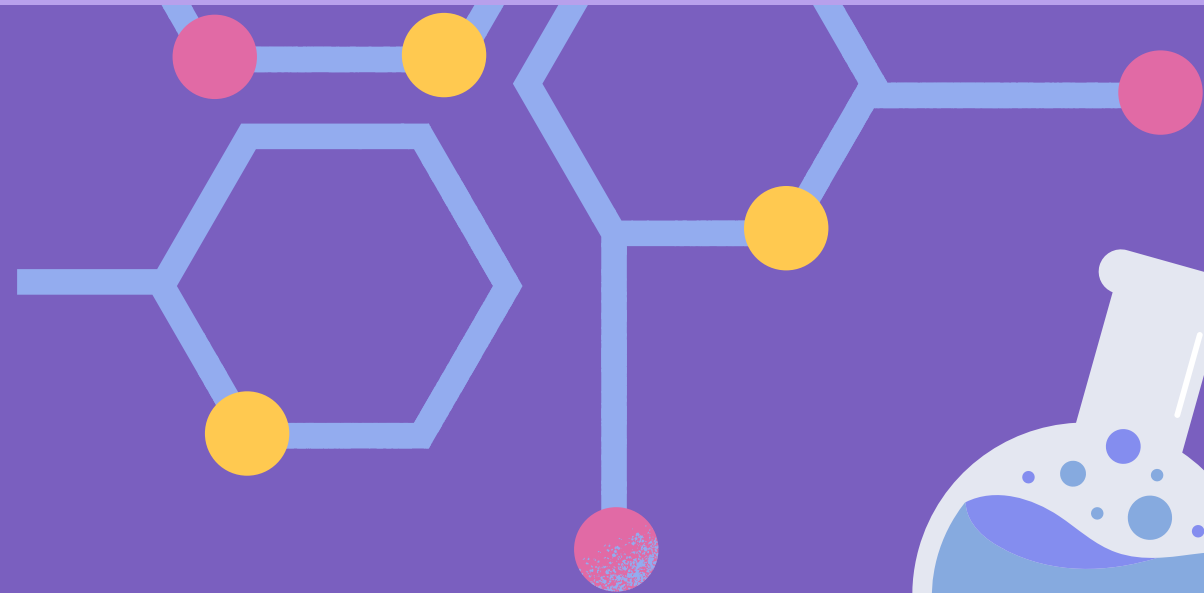
The capacity of Constant Torsion Emergent Gravity (CTEG) to resolve cosmological tensions

Sinah Legner (sl2091@cam.ac.uk)

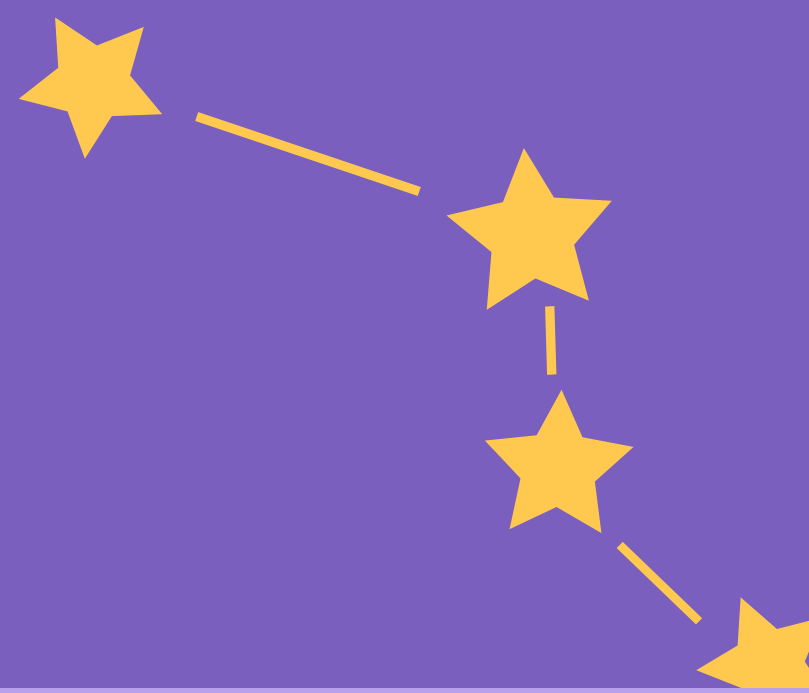
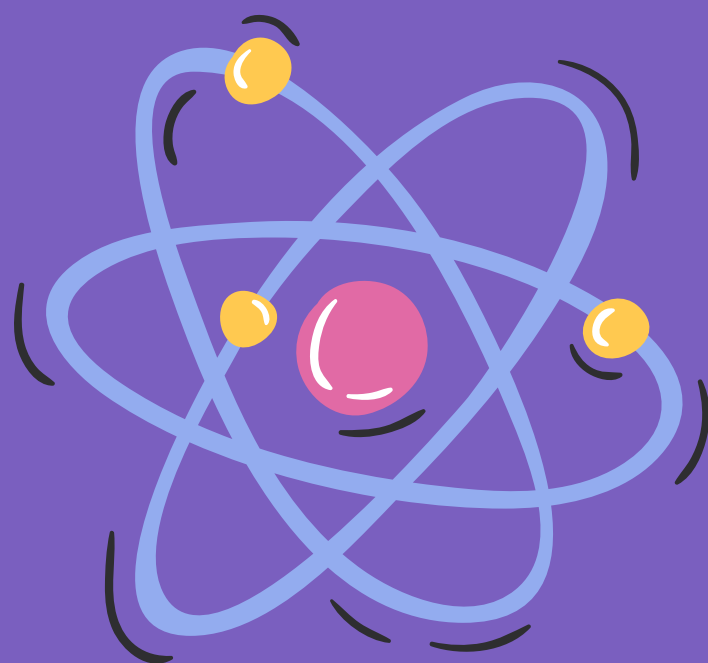
Hill's Coffee Talk - Feb 11th 2025



**CAMBRIDGE UNIVERSITY
WOMEN IN PHYSICS SOCIETY**

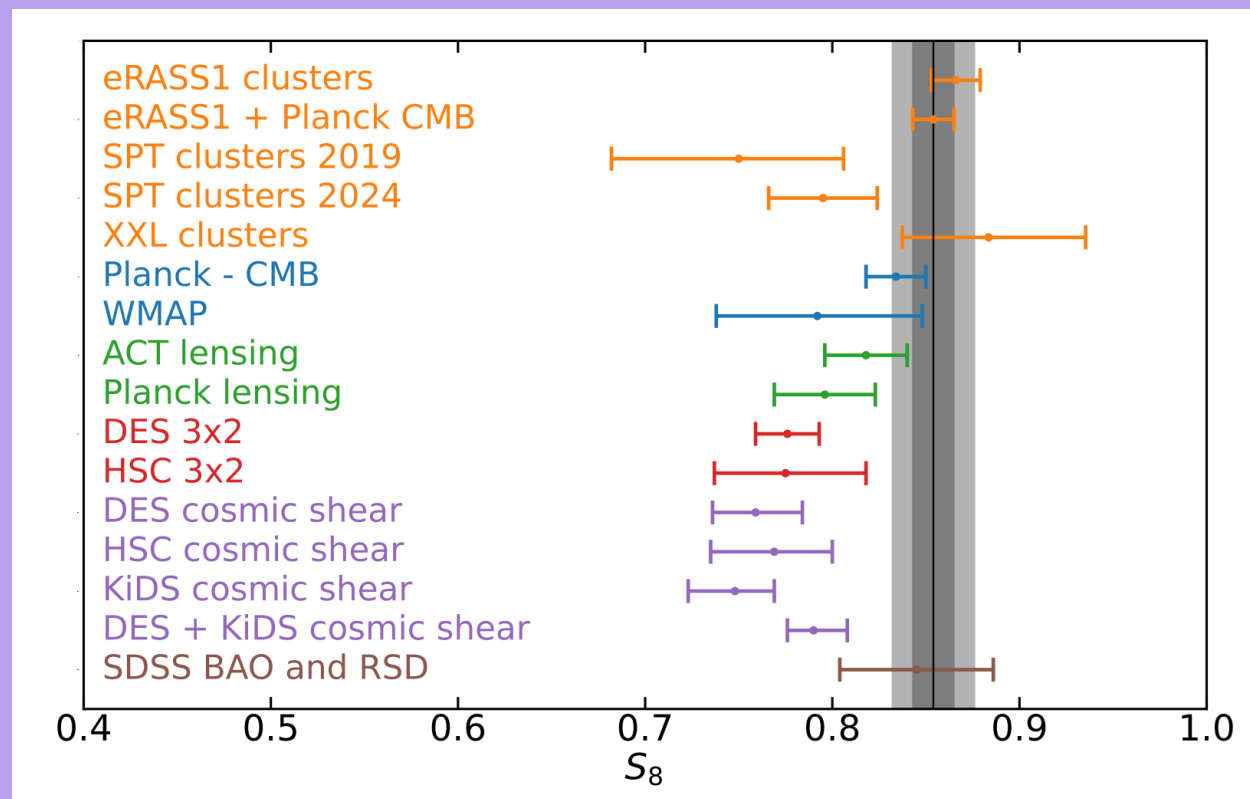
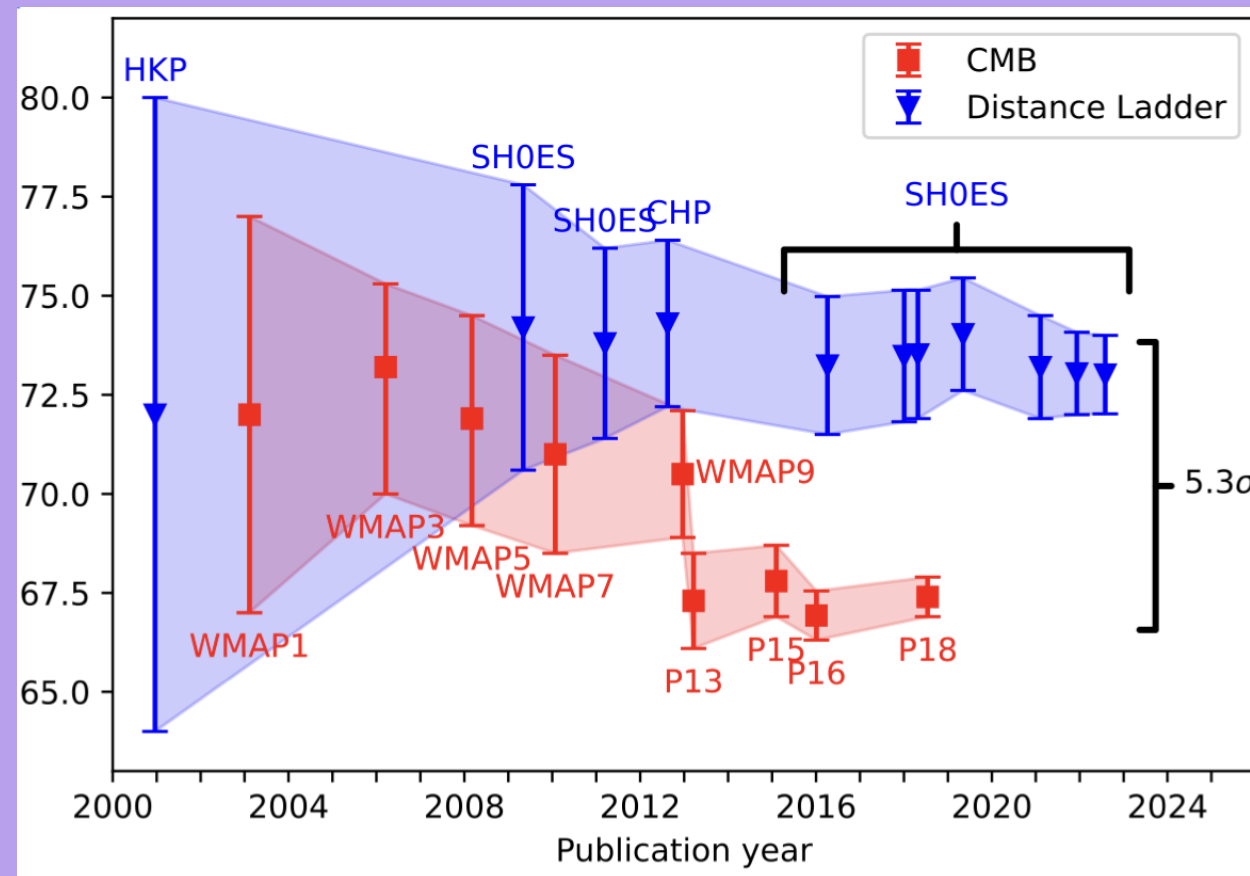


Happy International Day of Women and Girls in Science!



Introduction - Overview

Cosmological Tensions



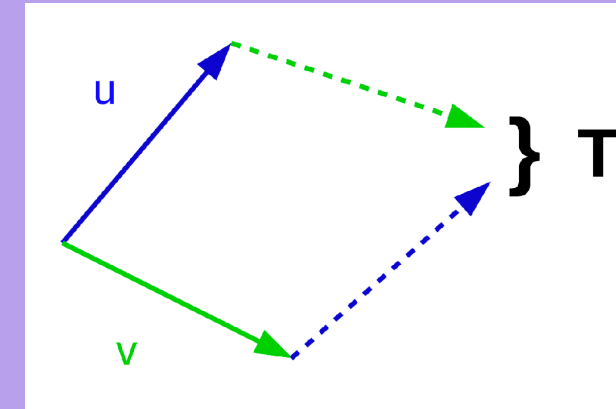
Exploration of different theory of gravity

Constant Torsion Emergent Gravity (CTEG)

Motivates

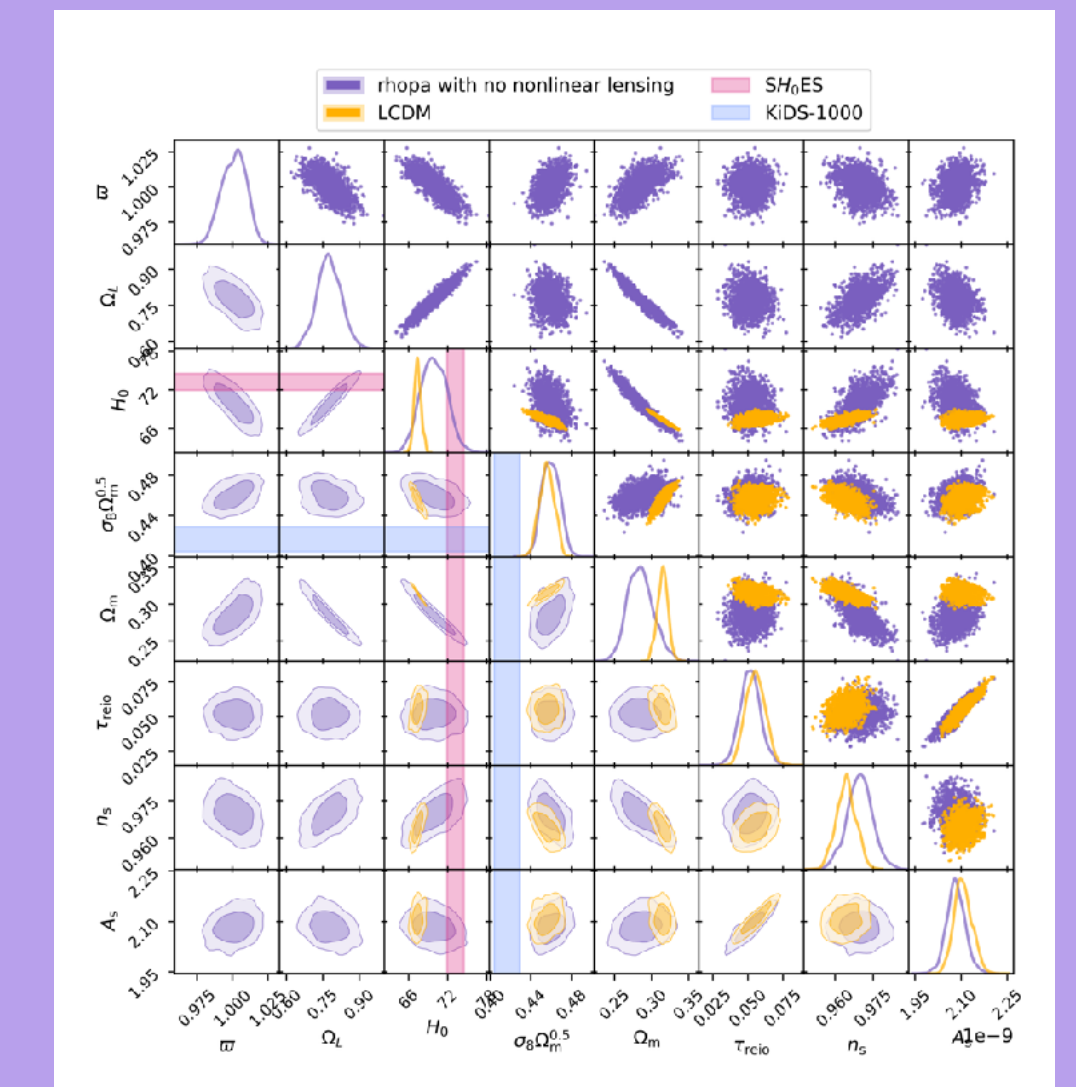
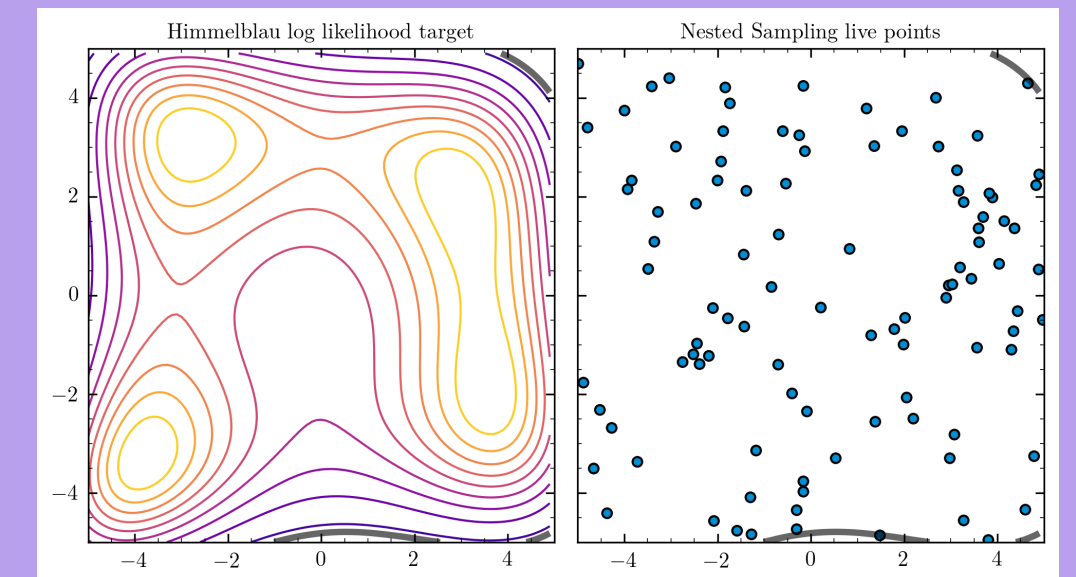
$$\mathcal{L} \propto R^2 + T^2$$

[2003.02690]



Analysis

Constraining CTEG parameters



Comparison with Λ CDM

Alleviate Tension?

Tension in Cosmology - Hubble Tension

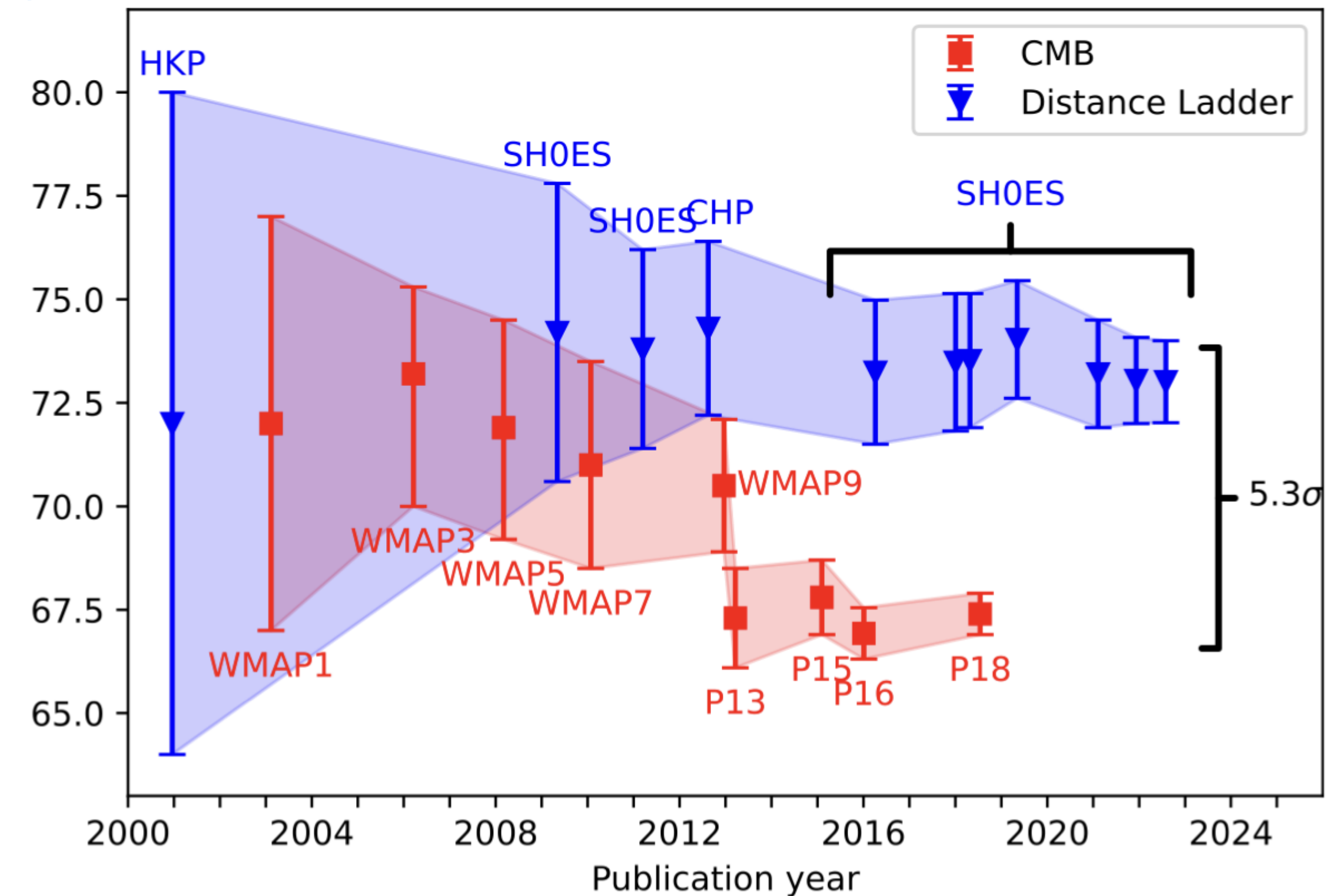
H_0 : Characterises Universe's expansion today.

Cosmic Microwave Background (CMB):

- $H_0 = 67.4 \pm 0.5$ km/s/Mpc. [[1807.06209](#)]
- CMB fluctuation data, fitted with Λ CDM model
- Measurement trusted, but Λ CDM assumptions are debated

SH0ES(Cosmic Distance Ladder):

- $H_0 = 73.2 \pm 1.3$ km/s/Mpc. [[2112.04510](#)]
- Determined using Supernovae observations
- Challenges: Crowding, dust, metallicity, and calibration issues
- Tension at 5σ



Tension in Cosmology - S8 Tension

S8: Quantifies clustering of matter on large scale

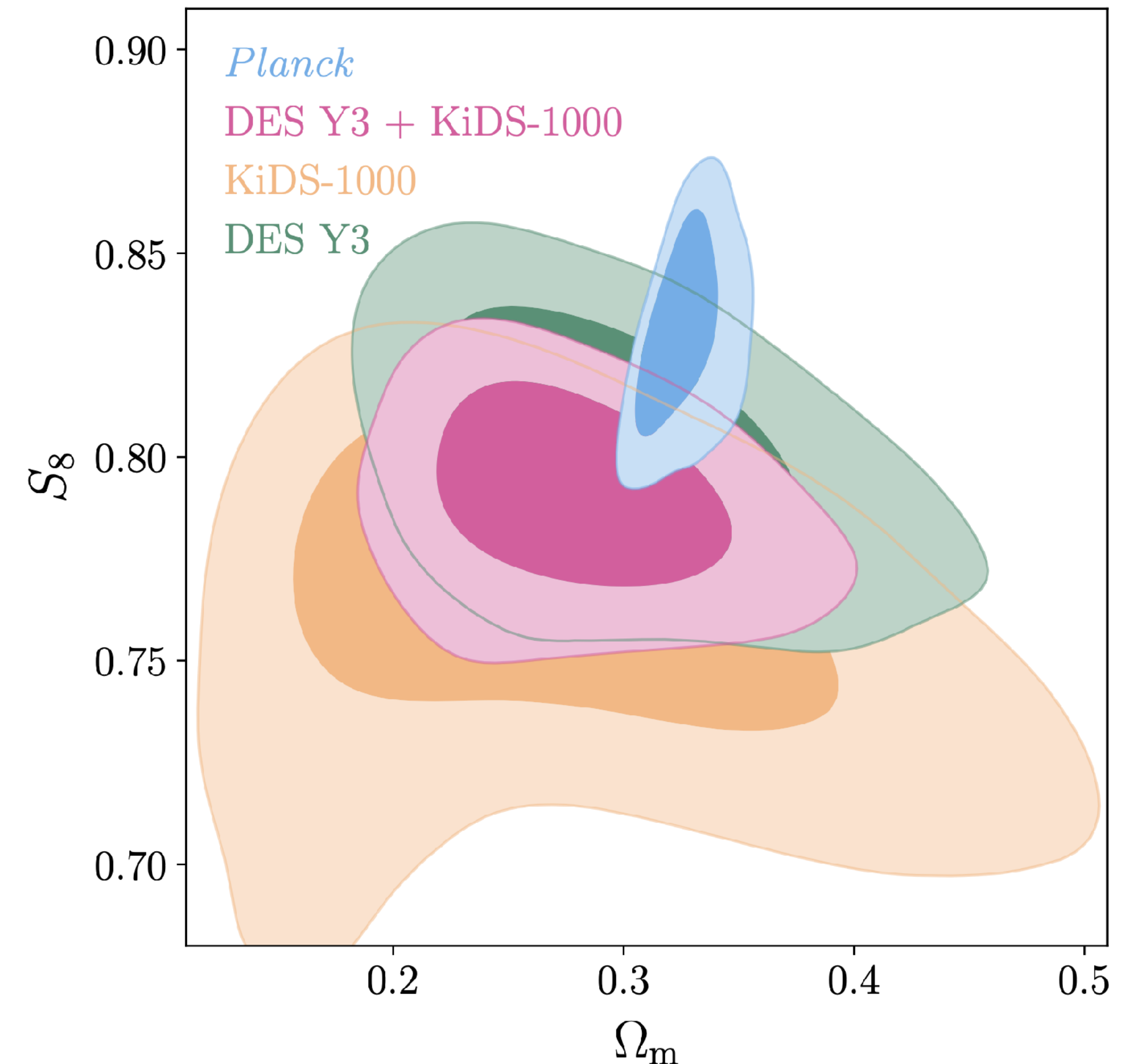
$$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$$

Cosmic Microwave Background (CMB):

- $S_8 = 0.834 \pm 0.016$ [[1807.06209](#)]

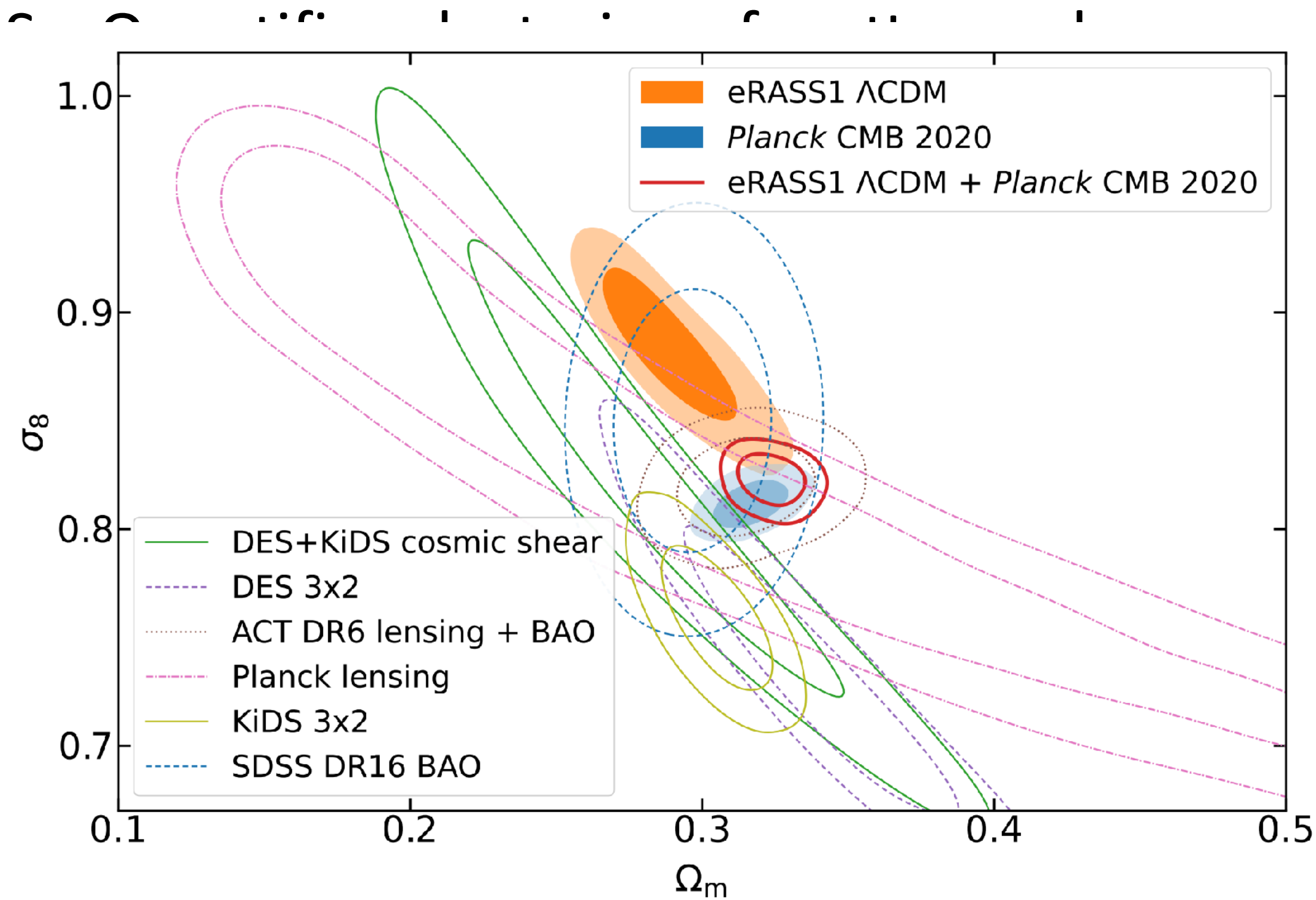
Weak Lensing (KiDS, DES):

- $S_8 = 0.759^{+0.024}_{-0.021}$ [[1610.04606](#)] [[1910.05336](#)]
- Distortion of galaxy shapes by intervening matter, constraining the matter distribution.
- Tension at $2\sigma - 3\sigma$

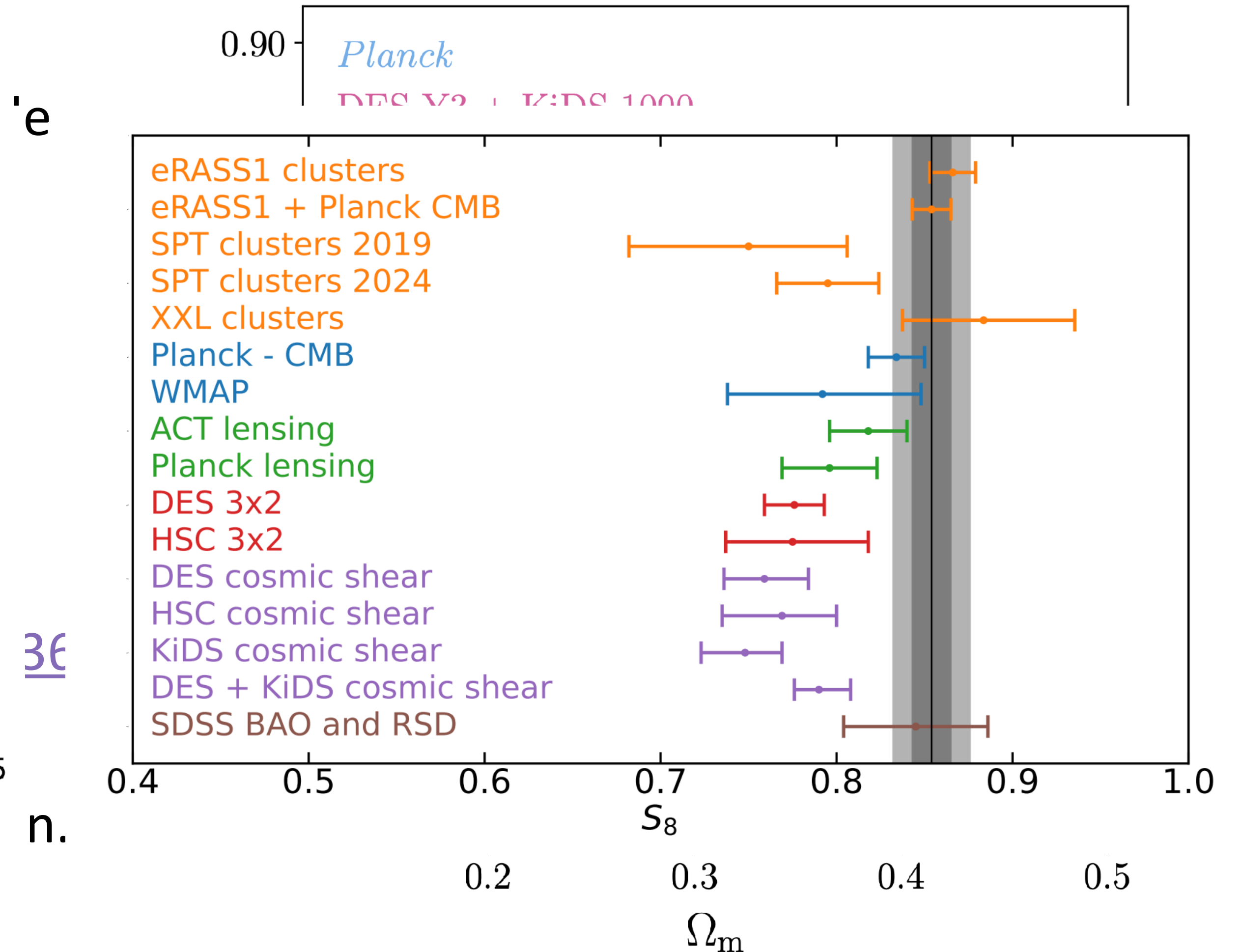


Cosmological constraints on S_8 with the matter density Ω_m in flat- Λ CDM. [[2305.17173](#)]

Tension in Cosmology - S8 Tension



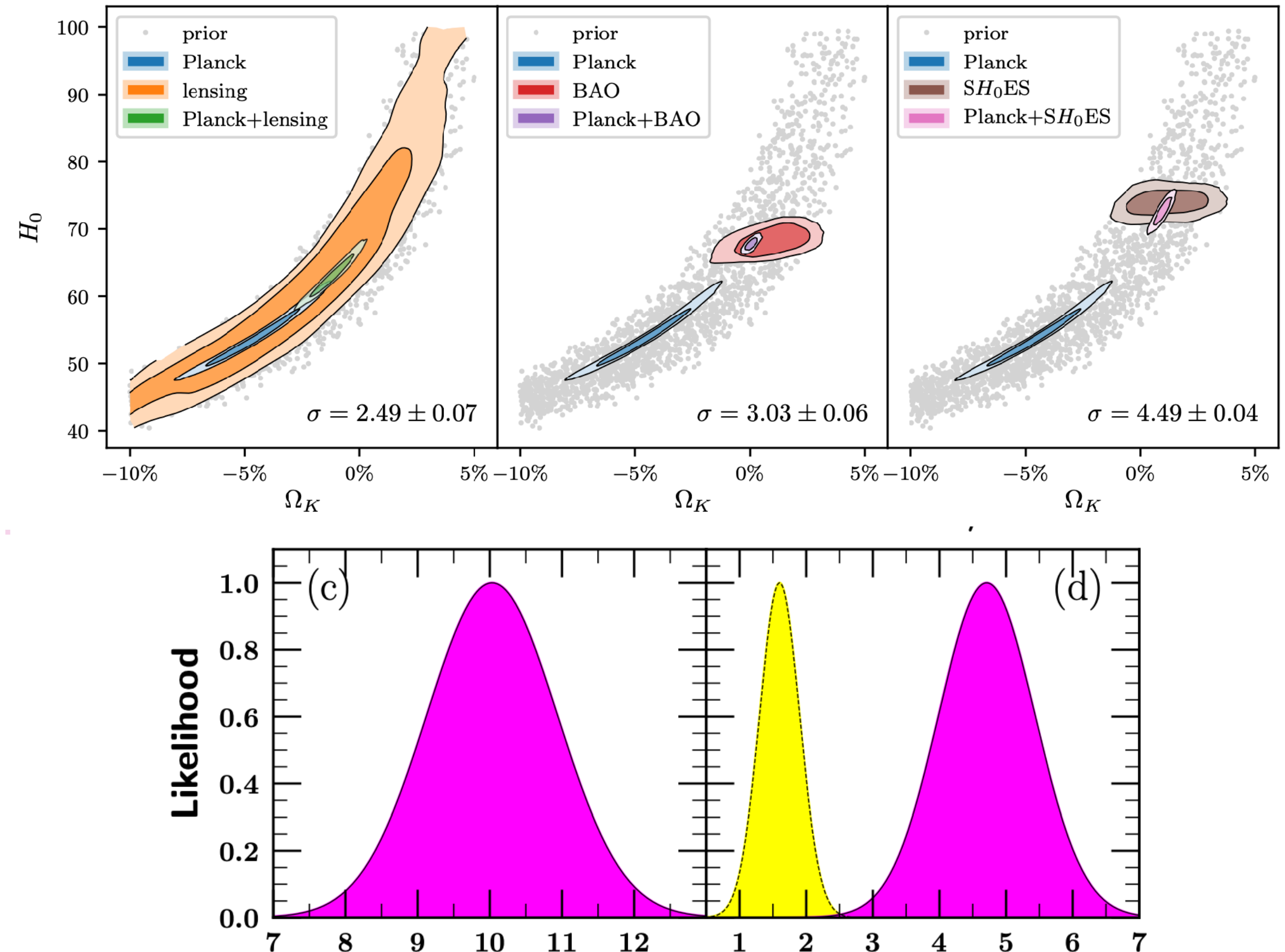
- Tension at 2σ - 3σ



Cosmological constraints on S_8 with the matter density Ω_m in flat- Λ CDM. [[2305.17173](#)]

Tension in Cosmology - other tensions

- **Curvature Tension:** CMB data (Planck) prefers closed universe [[1908.09139](#)]
- **CMB hemispherical power asymmetry:** Challenging isotropy [[1510.07929](#)]
- **BBN:** Discrepancy in light element abundance, Lithium problem [[1912.01132](#)]



If not systematics — need new theory to replace Λ CDM

Lagrangian for Gravitational Theory: CTEG

Lagrangian and action in Field Theory:

$$\mathcal{L} = \underbrace{\frac{1}{2}(\partial^\mu \phi \partial_\mu \phi)}_{\text{(Kinetic term)}} - \underbrace{V(\phi)}_{\text{(Potential term)}}$$

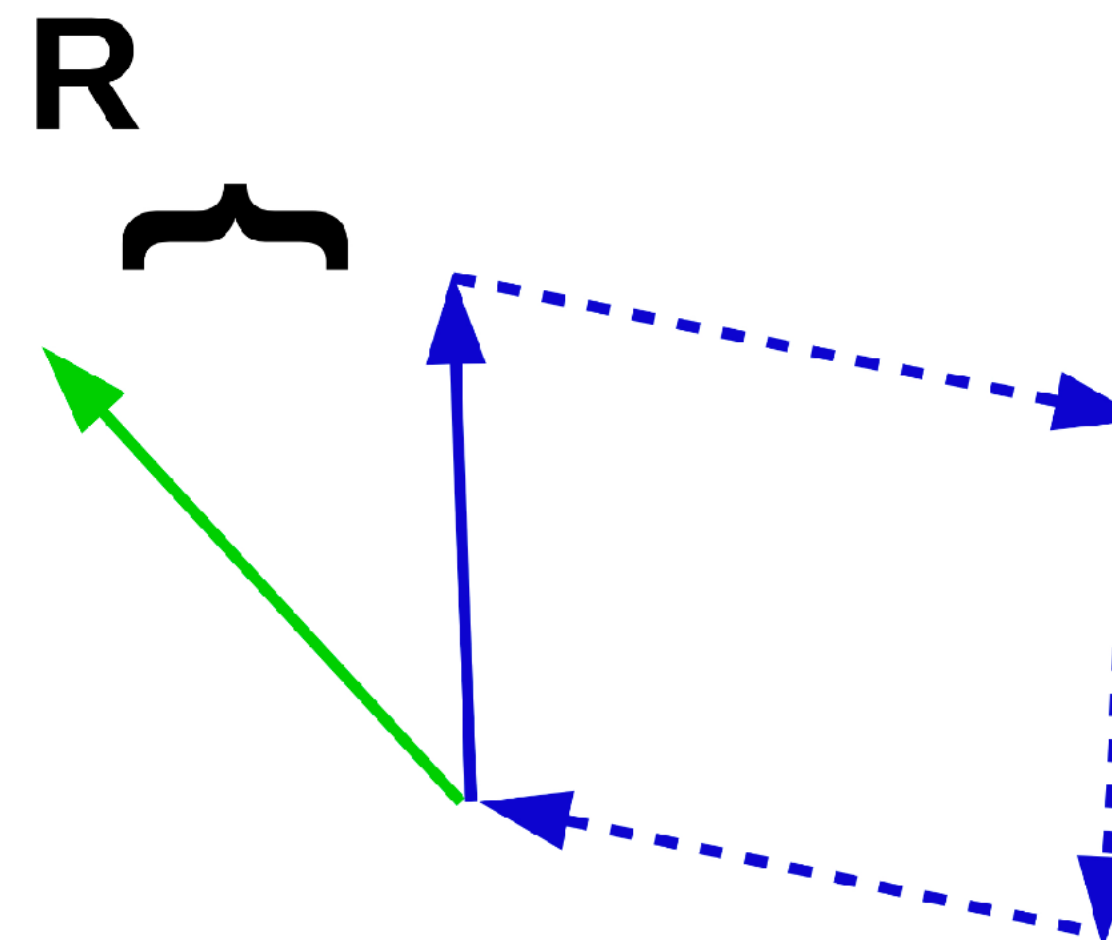
$$S = \int \mathcal{L} d^4x \quad \delta S = 0$$

Einstein's General Relativity (GR):

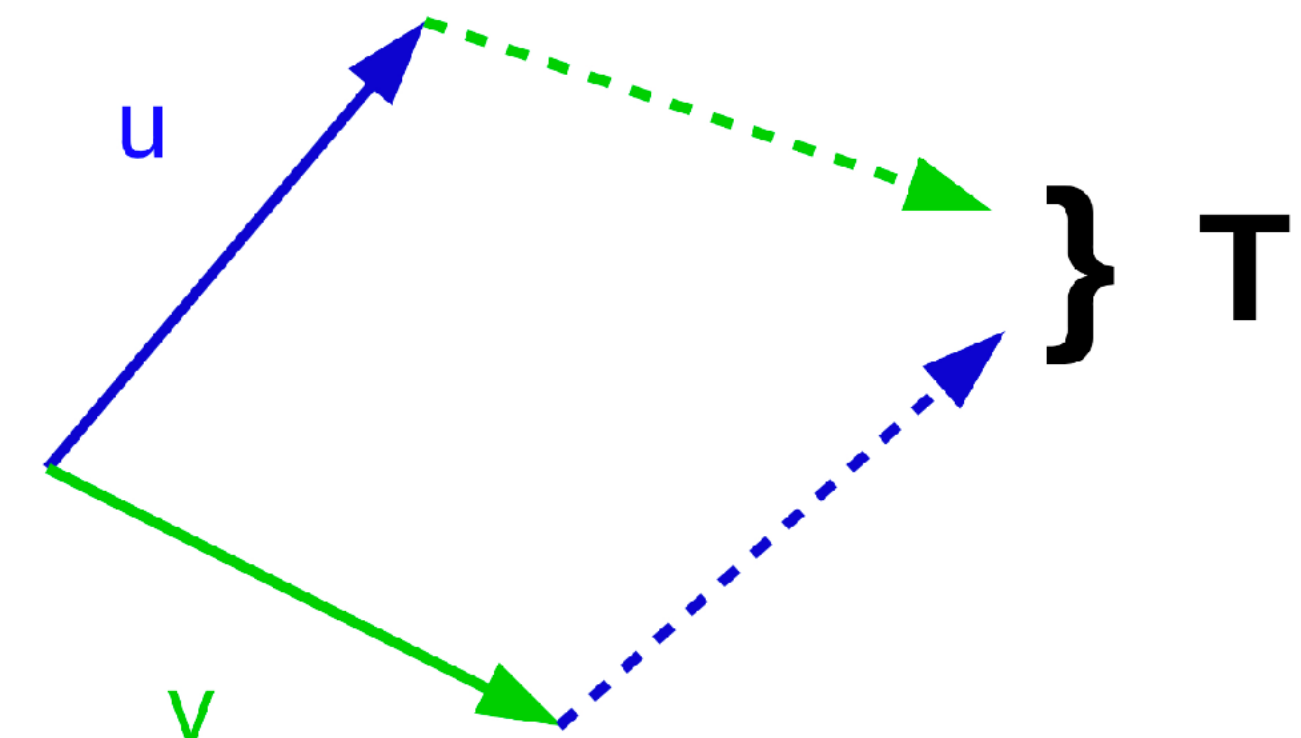
- $\mathcal{L} \propto R$
- Curvature only

Constant Torsion Emergent Gravity (CTEG):

- $\mathcal{L} \propto R^2 + T^2$ [[2003.02690](#)]
- Curvature and Torsion



Curvature



Torsion

[[1807.01725](#)]

CTEG Cosmological Parameters

- H_0 - Hubble parameter
- Ω_b - Density of baryonic matter
- Ω_c - Density of cold dark matter
- τ_{reio} - Optical depth due to reionisation
- n_s - Scalar spectral index
- A_s - Amplitude of the primordial scalar power spectrum

- ϖ_r - Initial value of the torsion scalar field ϖ
- Ω_L - Bare dark energy density parameter

Λ CDM parameters

$$\begin{aligned}\varpi_r &\rightarrow 1 \\ \Omega_L &\rightarrow \Omega_\Lambda\end{aligned}$$

CTEG parameters

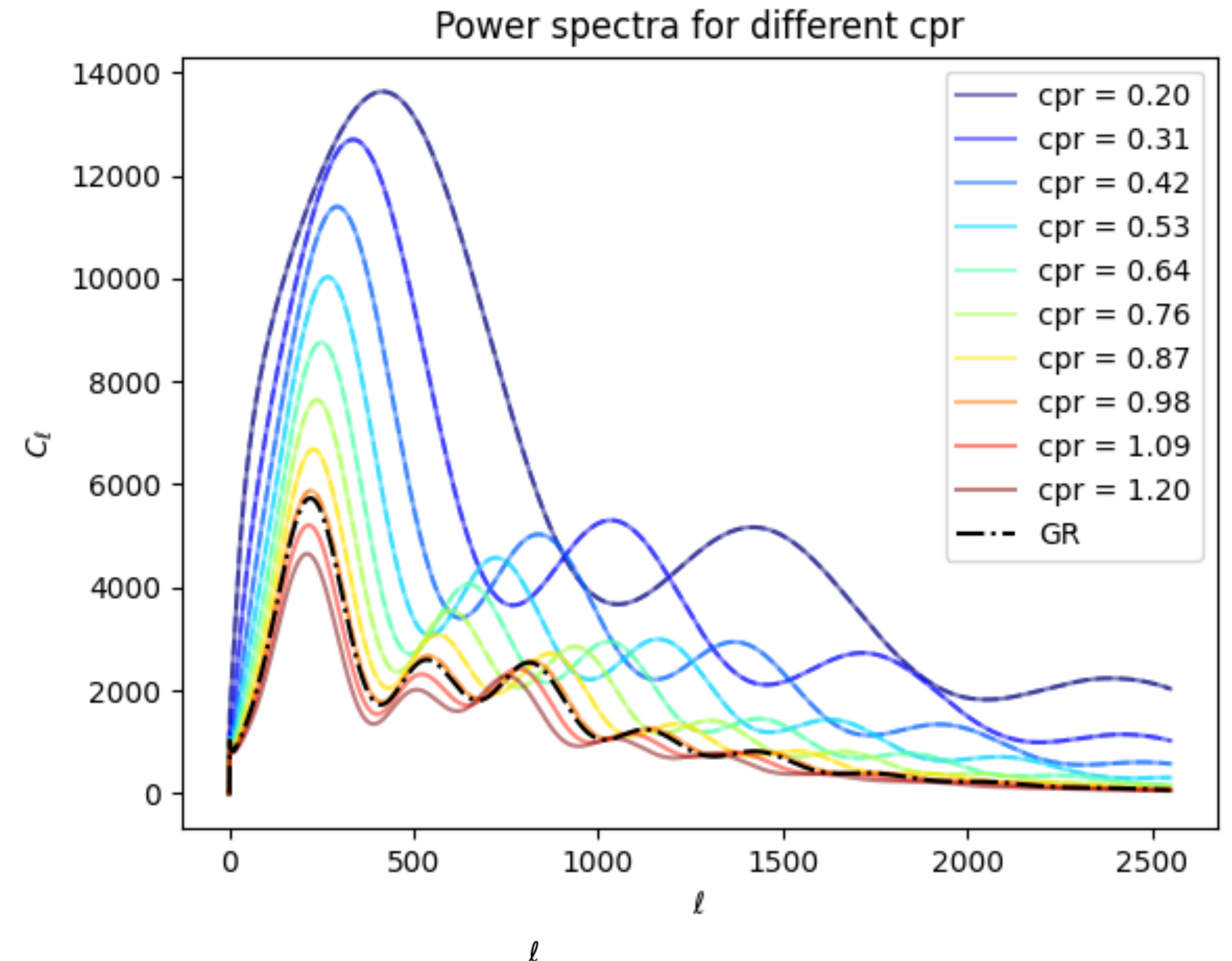
Effects of the ϖ_r and Ω_L on Cosmology

CAMB

- Boltzmann code for calculating CMB and other cosmological power spectra, given cosmological parameters.
- Modified CAMB to incorporate ϖ_r and Ω_L
- Effect of ϖ_r and Ω_L on CMB Temperature power spectrum

cpr = ϖ_r

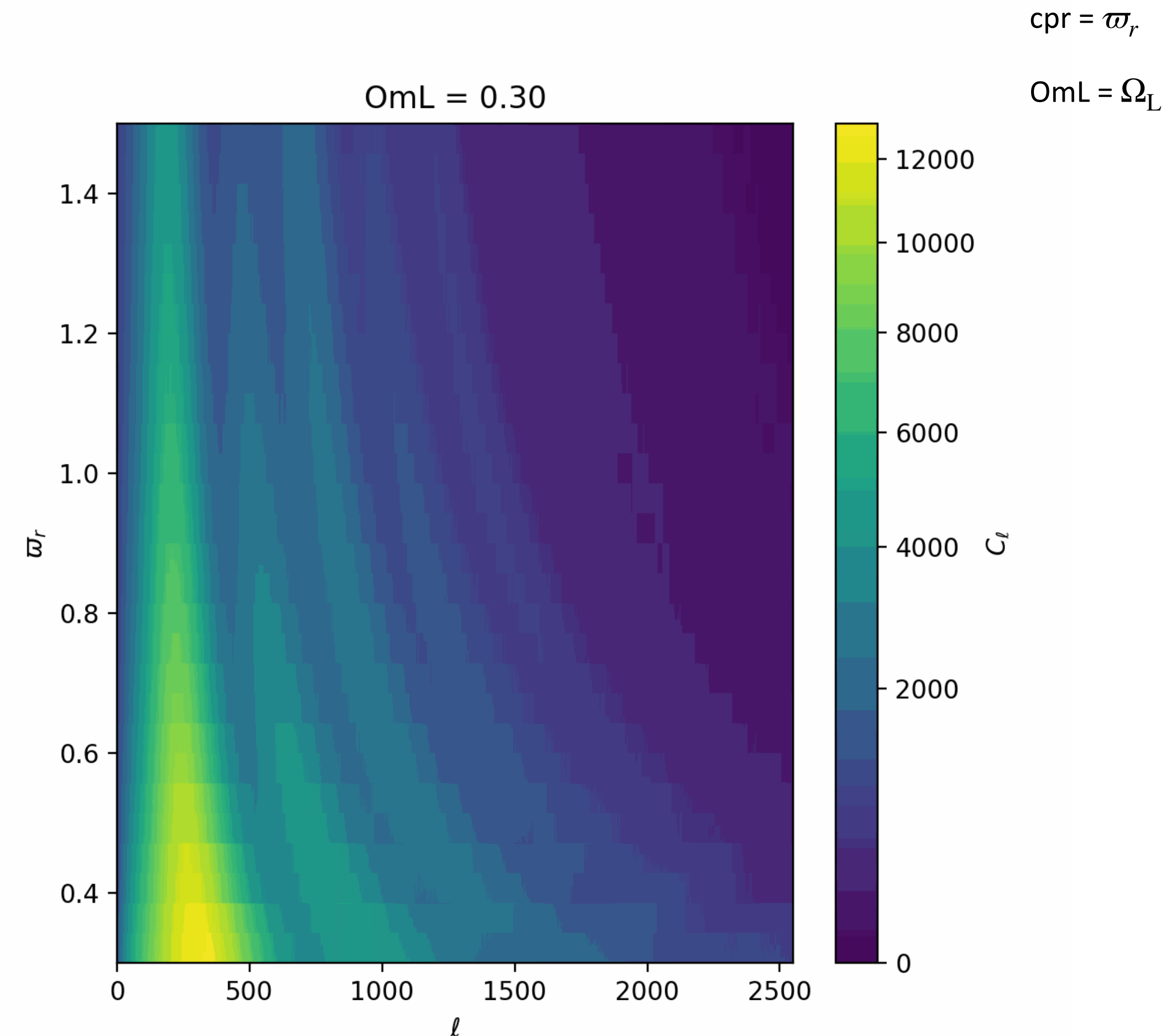
OmL = Ω_L



Effects of the ϖ_r and Ω_L on Cosmology

CAMB

- Boltzmann code for calculating CMB and other cosmological power spectra, given cosmological parameters.
- Modified CAMB to incorporate ϖ_r and Ω_L
- Effect of ϖ_r and Ω_L on CMB Temperature power spectrum



Bayesian Inference and Nested Sampling

Parameter Estimation:

- What does data tell us about parameters?

- $P(\theta | D, M) = \frac{P(D | \theta, M)P(\theta | M)}{P(D | M)}$

P - posterior
L - likelihood
 π - prior
Z - evidence

Model Comparison:

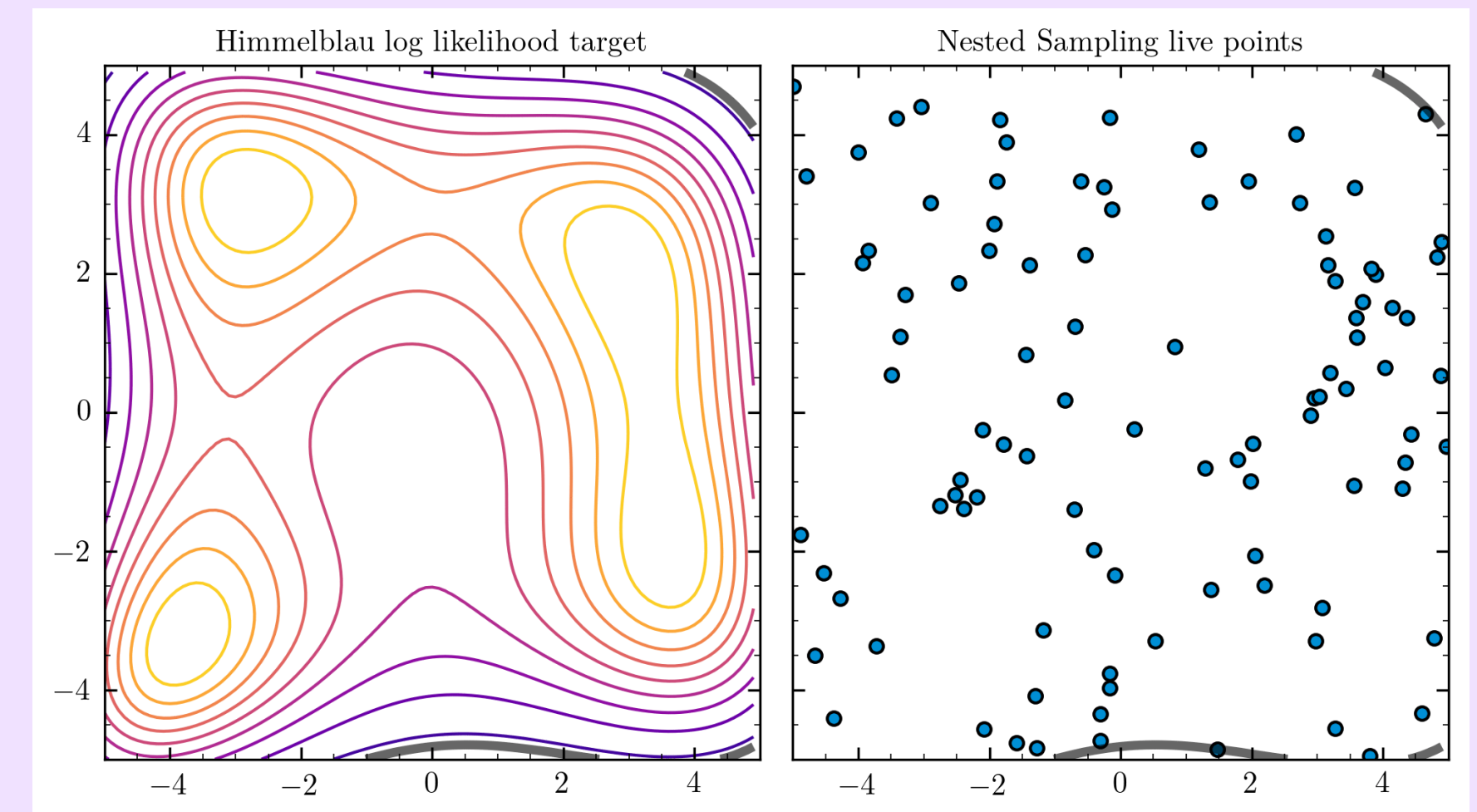
- How much does data support the model?

- $P(M | D) = \frac{P(D | M)P(M)}{P(D)}$

- Higher evidence favours a model
- Penalises complexity

Nested Sampling:

- Computes evidence directly
- Handles multimodal posteriors



Gif from David Yallup

- **Polychord**: nested sampling algorithm tailored for high-dimensional parameter spaces. [[1506.00171](#)]

Cobaya: Interface CAMB and Polychord

Cobaya - code for **bayesian** analysis [[2005.05290](#)]

- A framework for sampling and statistical modelling, providing interfaces to cosmological theory codes and likelihoods from cosmological experiments.

Cobaya:

- Sets up cosmological model
- Interface with likelihood:
e.g. Planck 2018

CAMB:

- Computes CMB Power spectrum for each parameter set.

Polychord:

- Explore parameter space with nested sampling

Result:

- Posterior distribution for cosmological parameters
- Compare models through evidence (Z)

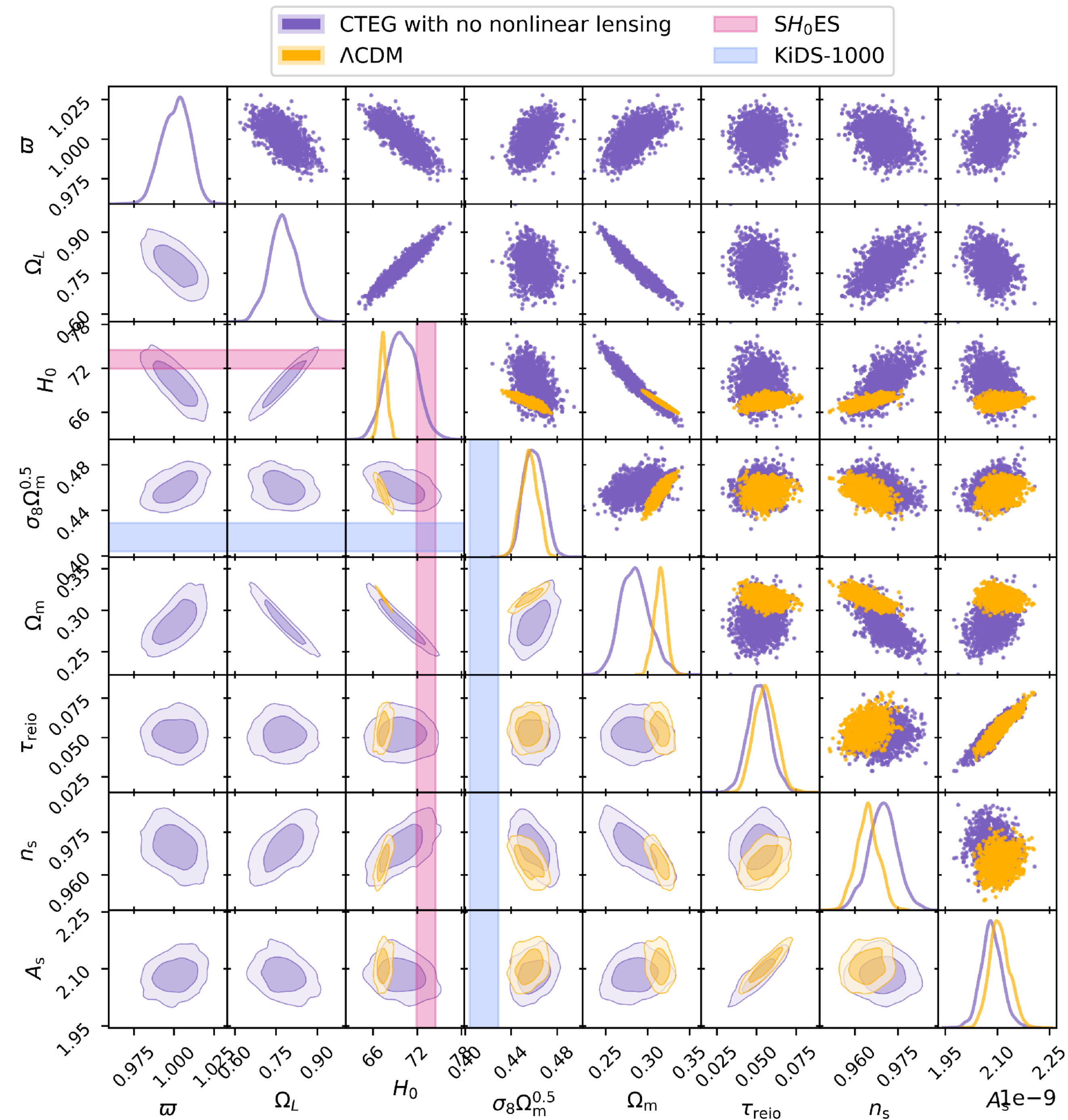
RESULT

- $\text{Log}(Z_{\text{CTEG}}) - \text{Log}(Z_{\Lambda\text{CDM}}) = 1.7275$
- $P(M|D) = 0.849$

At 68% confidence level:

- $H_0 = 69.9 \pm 2.0$
- Alleviating the H_0 tension.

- $S_8 = 0.839 \pm 0.016$
- Tension remains.



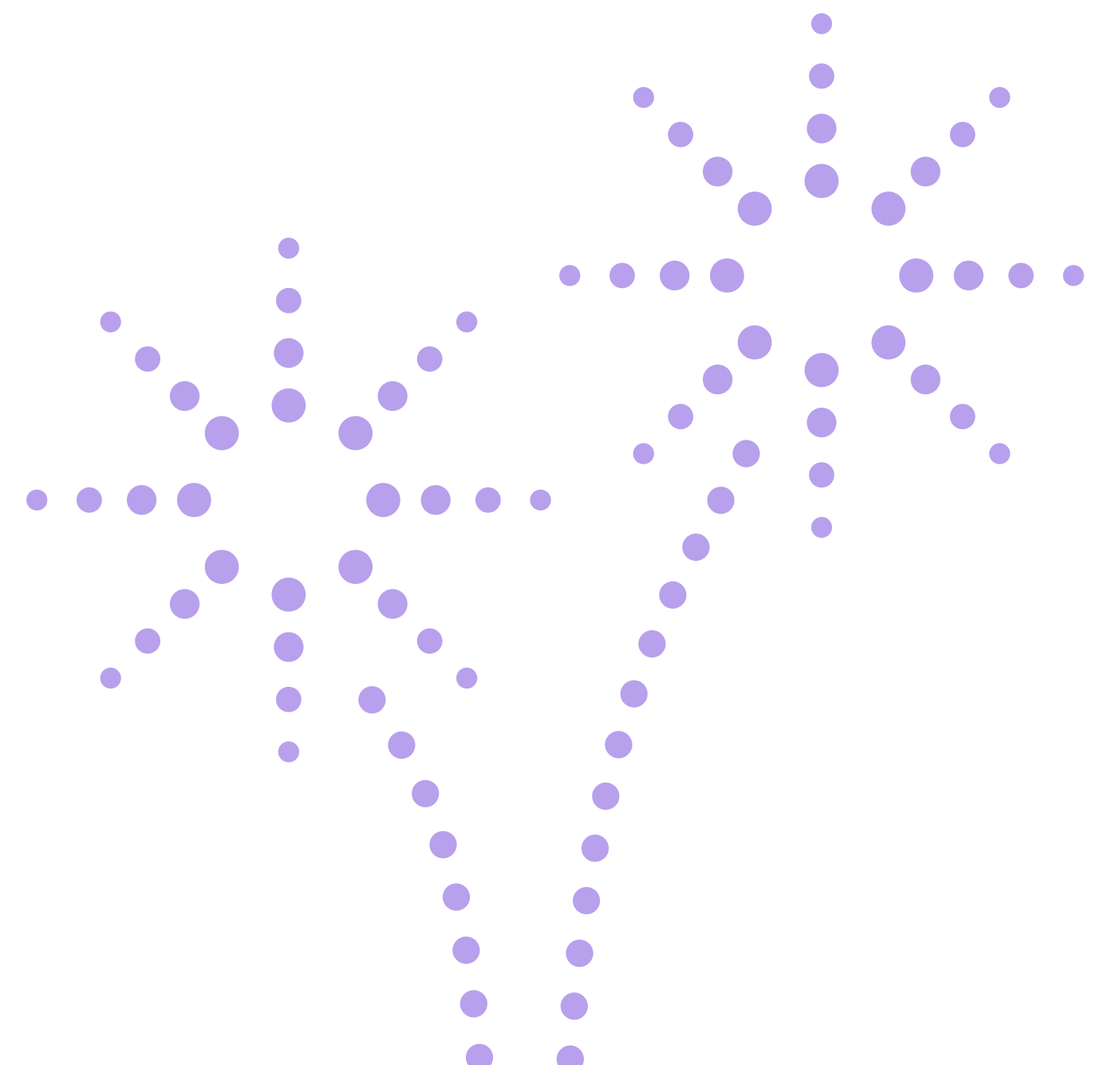
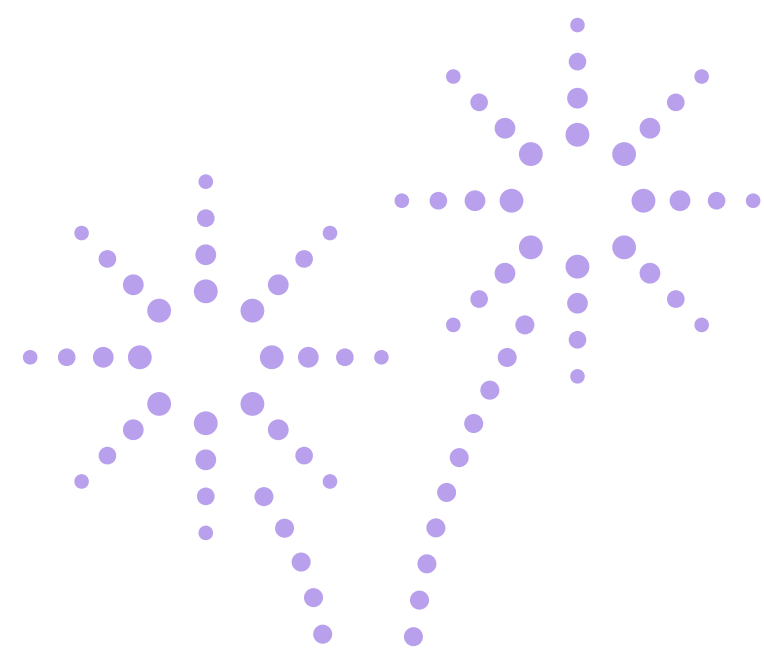
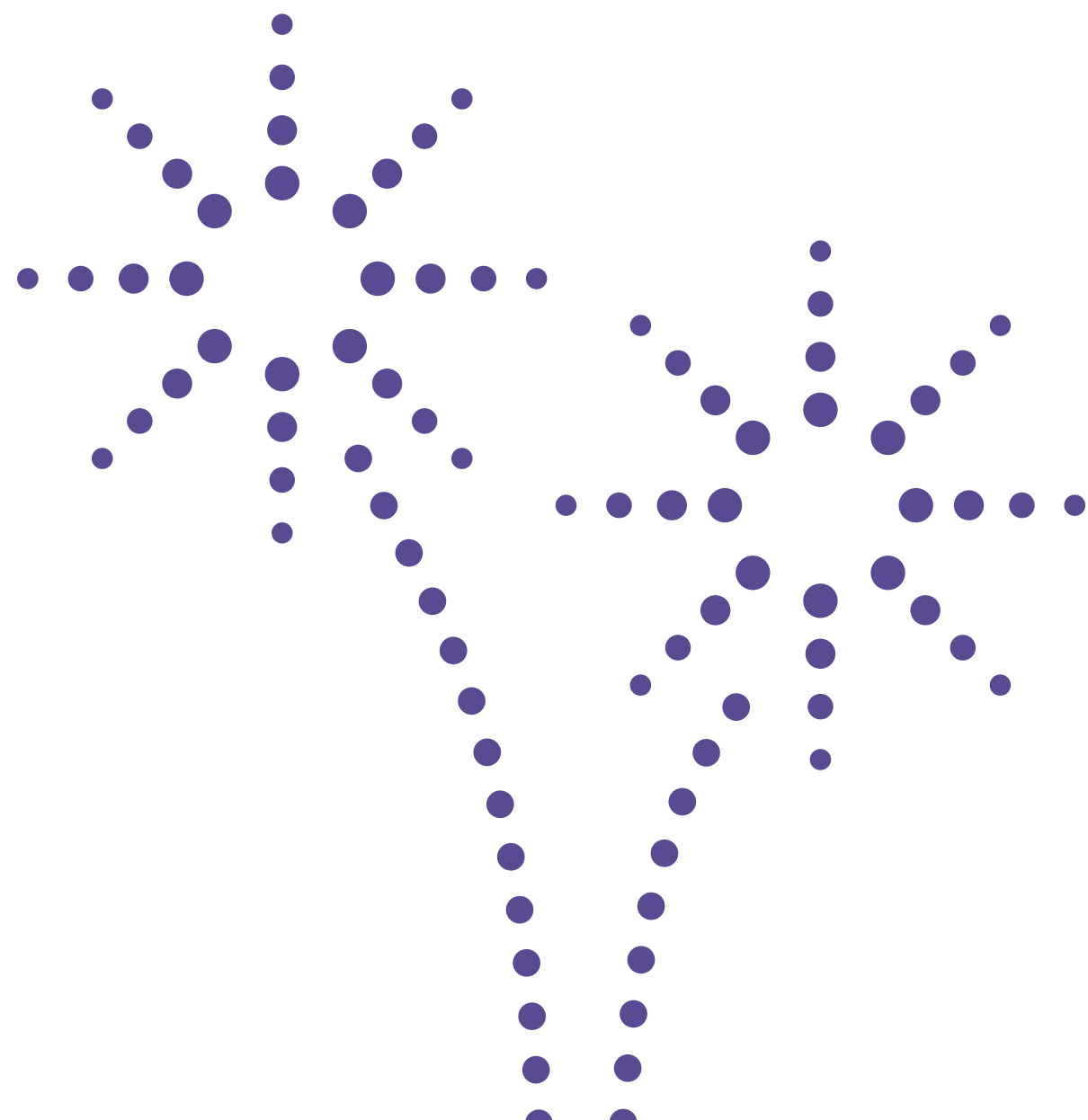
Future Plan

- Cosmology run with curvature
- Include perturbation theory
- Tensions analysis (in hpc queue)

Chatgpt's drawing based on my slides' content



Thank you!



Backup Slides:

PGT Lagrangian

PGT Lagrangian is obtained via enforcing local Poincare transformation.

$$\mathcal{L}_{\text{PGT}} = h^{-1} \left[L_{\mathcal{R}^2} + \kappa^{-1} (L_{\mathcal{R}} + L_{\mathcal{T}^2} + L_{\Lambda}) + L_m(\Phi, \Psi; h, A) \right]$$

$$L_{\mathcal{R}} = -\frac{1}{2} \alpha_0 \mathcal{R},$$

$$L_{\Lambda} = -\Lambda,$$

$$L_{\mathcal{R}^2} = \alpha_1 \mathcal{R}^2 + \alpha_2 \mathcal{R}_{ab} \mathcal{R}^{ab} + \alpha_3 \mathcal{R}_{ab} \mathcal{R}^{ba} + \alpha_4 \mathcal{R}_{abcd} \mathcal{R}^{abcd} + \alpha_5 \mathcal{R}_{abcd} \mathcal{R}^{acbd} \\ + \alpha_6 \mathcal{R}_{abcd} \mathcal{R}^{cdab},$$

$$L_{\mathcal{T}^2} = \beta_1 \mathcal{T}_{abc} \mathcal{T}^{abc} + \beta_2 \mathcal{T}_{abc} \mathcal{T}^{bac} + \beta_3 \mathcal{T}_a \mathcal{T}^a.$$

Gauge Fields:

$$h_a^\mu$$

Translational

$$A_\mu^{ab}$$

Lorentz

Field Strength Tensors:

$$\mathcal{R}^{ab}_{cd} = 2h_c^\mu h_d^\nu \left(\partial_{[\mu} A^{ab}_{\nu]} + A^a_{e[\mu} A^{ae}_{\nu]} \right),$$

$$\mathcal{T}^a_{bc} = -2b^a_\mu D_{[b} h_{c]}^\mu.$$

Constant Torsion Emergent Gravity (CTEG)

- Lagrangian density:

$$\tilde{\mathcal{L}} = M_{\text{p}}^2 v_2 \left[\frac{1}{2} \left(1 - \frac{\varpi^2}{4\varsigma} \right) \mathcal{R} - \frac{3}{2\varsigma} X^{\varpi\varpi} + \sqrt{|\tilde{J}_\mu \tilde{J}^\mu|} + \frac{3}{4} \phi^2 - \frac{3}{4\varsigma} \phi^2 \varpi^2 \right],$$

$$\tilde{J}_\mu = 4\varpi^3 \partial_\mu (\phi / \varpi) + \partial_\mu \phi.$$

$$X^{\pi\pi} = 1/2 g^{\mu\nu} \partial_\mu \pi \partial_\nu \pi.$$

- Field Equation (1st Friedmann Eq.):

$$\text{GR: } H(t)^2 = H_0^2 (\Omega_r a(t)^{-4} + \Omega_m a(t)^{-3} + \Omega_\Lambda)$$

$$\text{CTEG: } H(t)^2 = H_0^2 \left(\frac{\Omega_r a(t)^{-4} + \Omega_m a(t)^{-3} + \Omega_L}{\varpi(t)^2} \right) - \frac{\dot{\varpi}(t) \left(6H(t)\varpi(t) + \frac{(1 + 3\varpi(t)^2)\dot{\varpi}(t)}{\varpi(t)^2 - 1} \right)}{3\varpi(t)^2}$$

- ϖ_r : Initial value of the scalar field ϖ .

- Coincident with LCDM when $\varpi_r = 1$.

- Ω_L : bare dark energy density parameter

- Coincident with LCDM when $\Omega_L = \Omega_\Lambda$.