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

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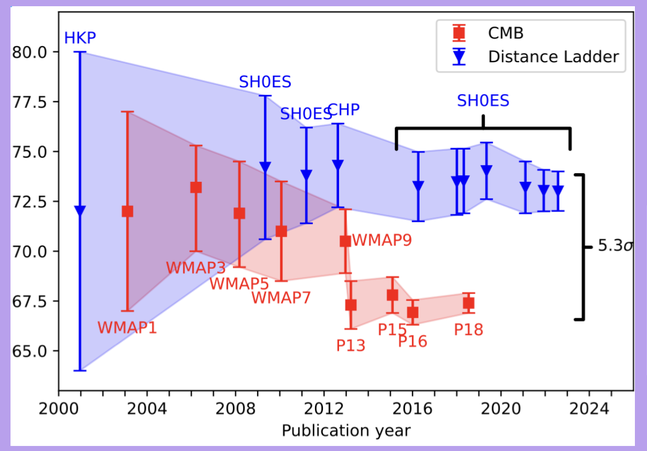
Hill's Coffee Talk - Feb 11th 2025

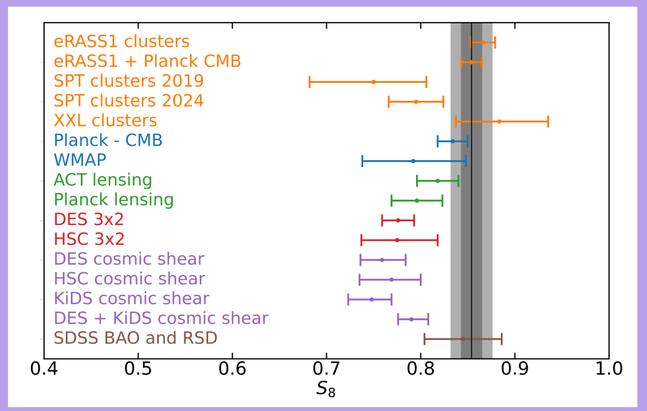
CAMBRIDGE UNIVERSITY
WOMEN IN PHYSICS SOCIETY

Happy International Day of Women and Girls in Science!

Introduction - Overview

Cosmological Tensions





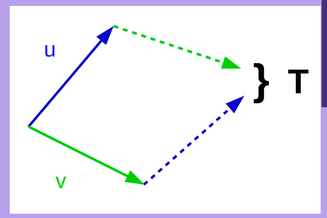
Motivates

Exploration of different theory of gravity

Constant Torsion Emergent Gravity (CTEG)

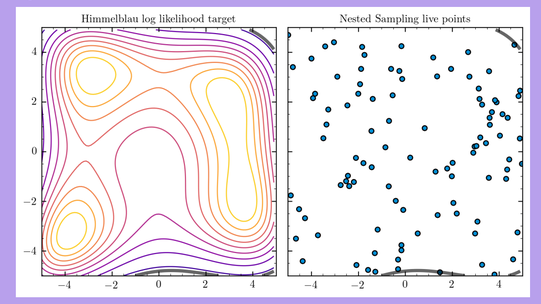
$$\mathscr{L} \propto R^2 + T^2$$

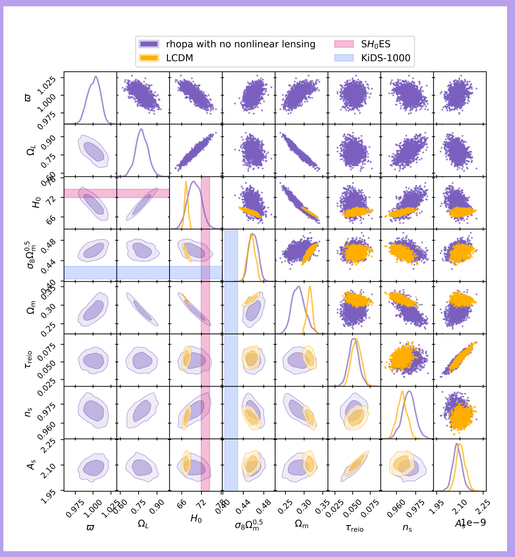
[2003.02690]



Analysis

Constraining CTEG parameters





Alleviate Tension?

Comparison with ΛCDM

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Tension in Cosmology - Hubble Tension

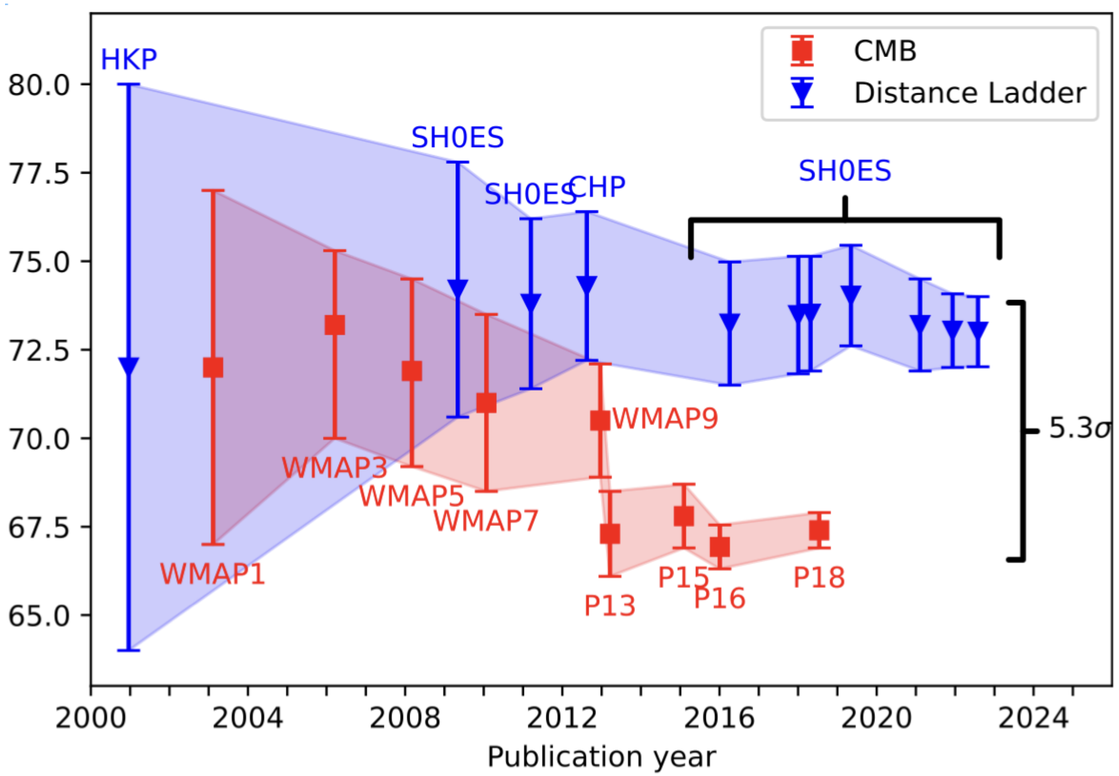
H_0: Characterises Universe's expansion today.

Cosmic Microwave Background (CMB):

- $H_0 = 67.4 \pm 0.5$ km/s/Mpc. [1807.06209]
- CMB fluctuation data, fitted with ΛCDM model
- Measurement trusted, but ΛCDM 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



Evolution of the Hubble tension in the last 23 years

Tension in Cosmology - S8 Tension

S8: Quantifies clustering of matter on large scale

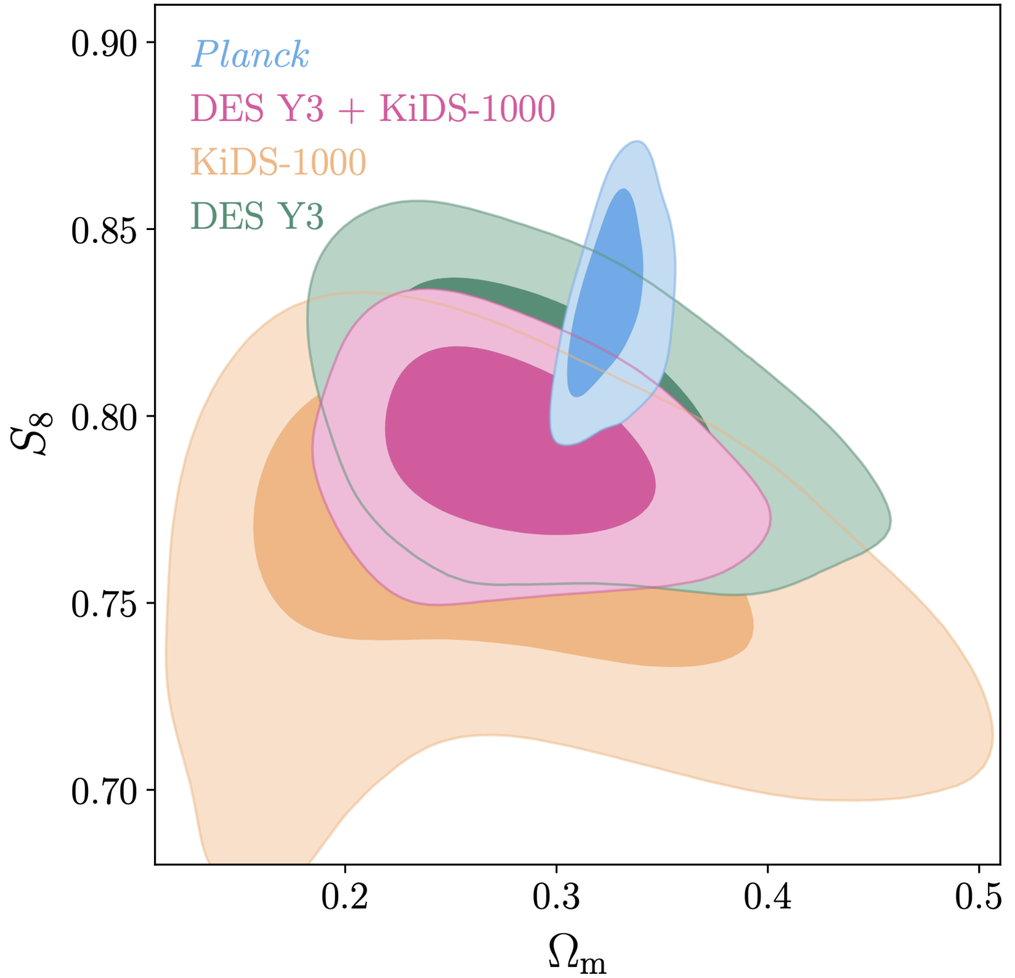
$$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$$

Cosmic Microwave Background (CMB):

- $S_8 = 0.834 \pm 0.016$ [1807.06209]

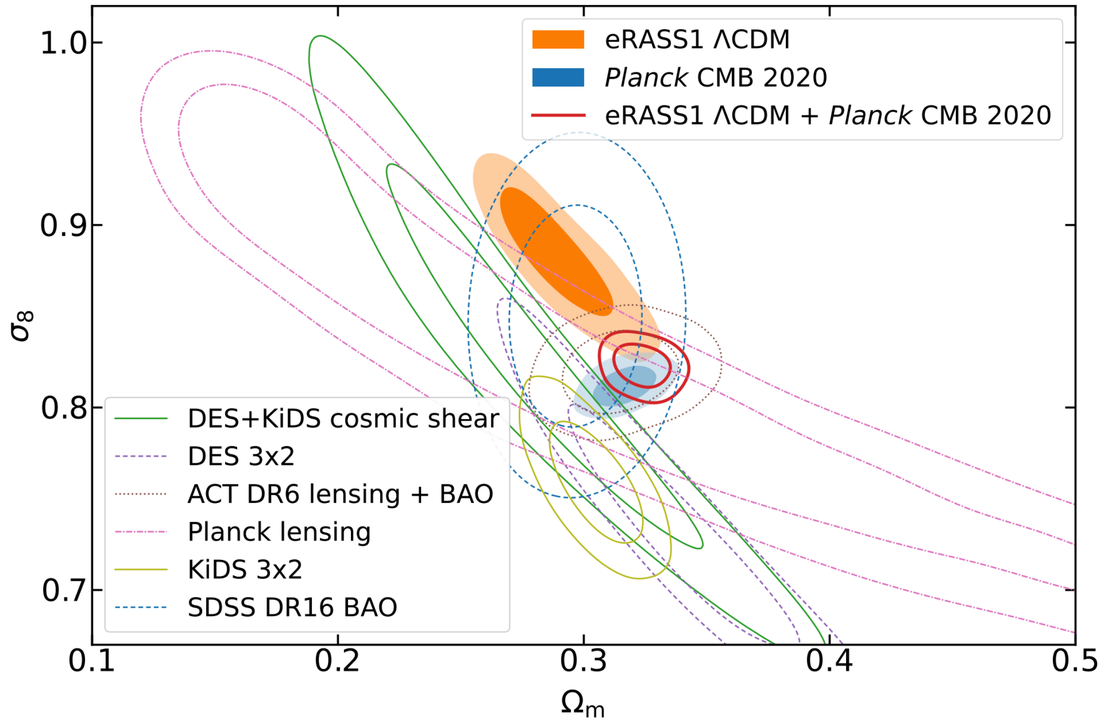
Weak Lensing (KiDS, DES):

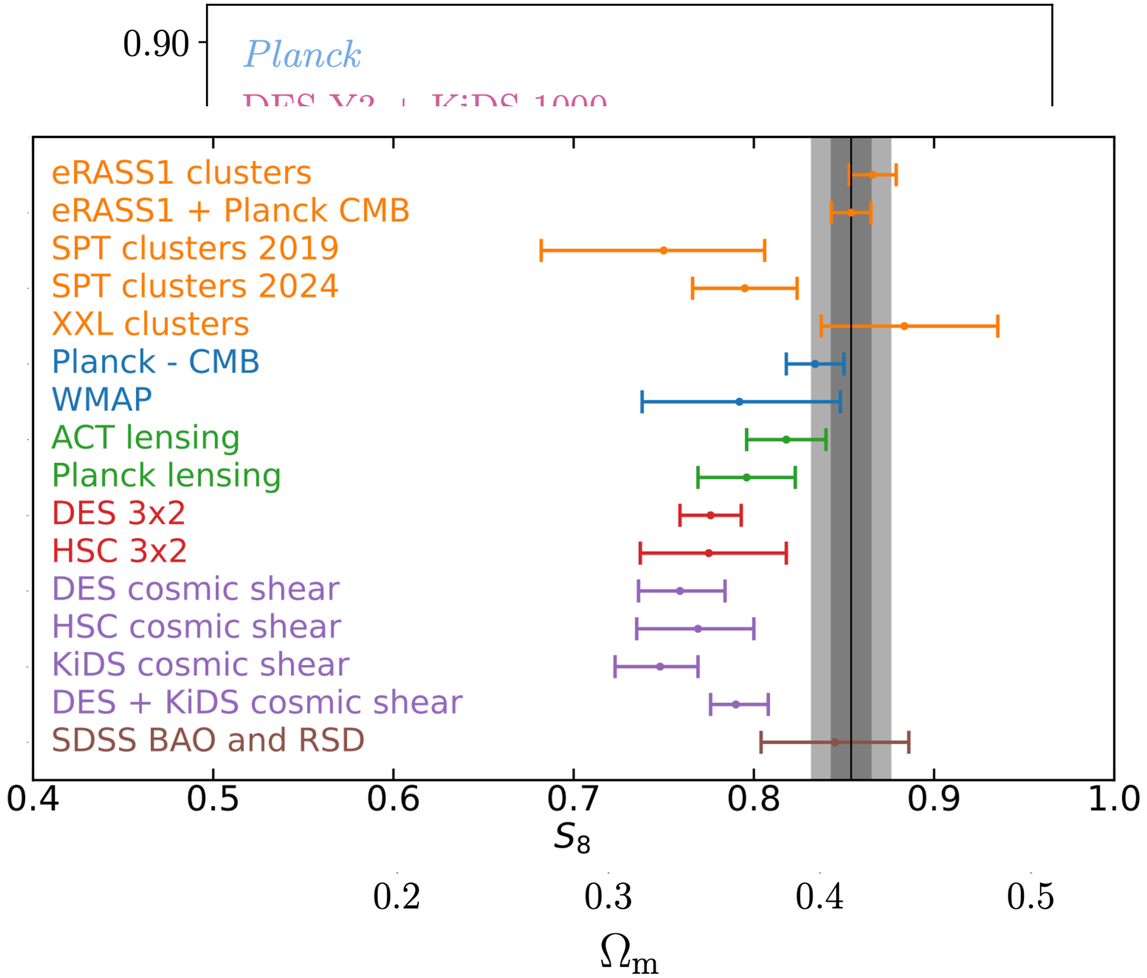
- $S_8 = 0.759^{+0.024}_{-0.021}$ [1610.04606] [1910.05336]
- Distortion of galaxy shapes by intervening matter, constraining the matter distribution.
- Tension at 2σ - 3σ



Cosmological constraints on S8 with the matter density Ωm in flat-ΛCDM. [2305.17173]

Tension in Cosmology - S8 Tension



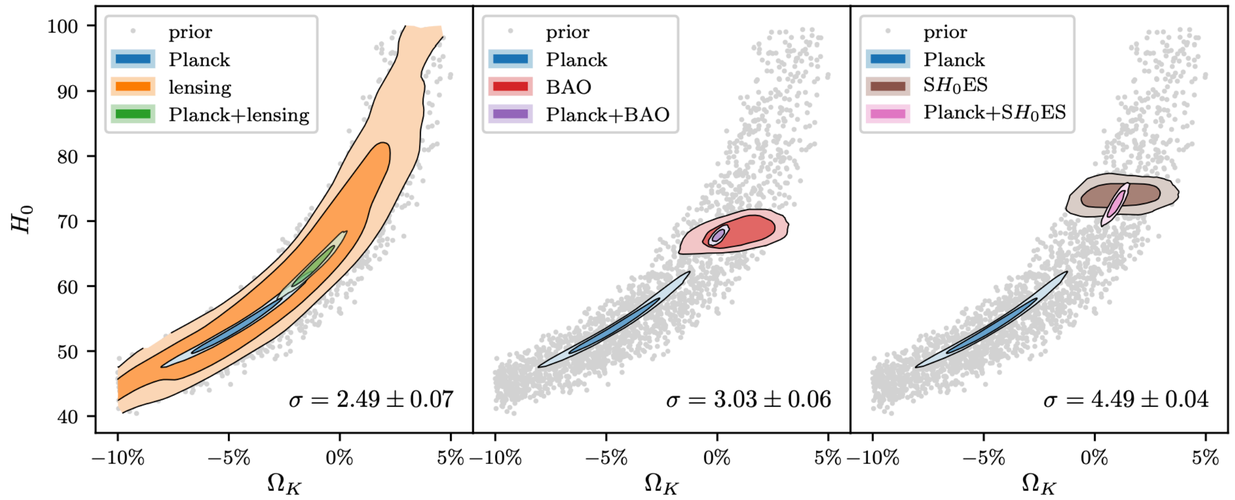


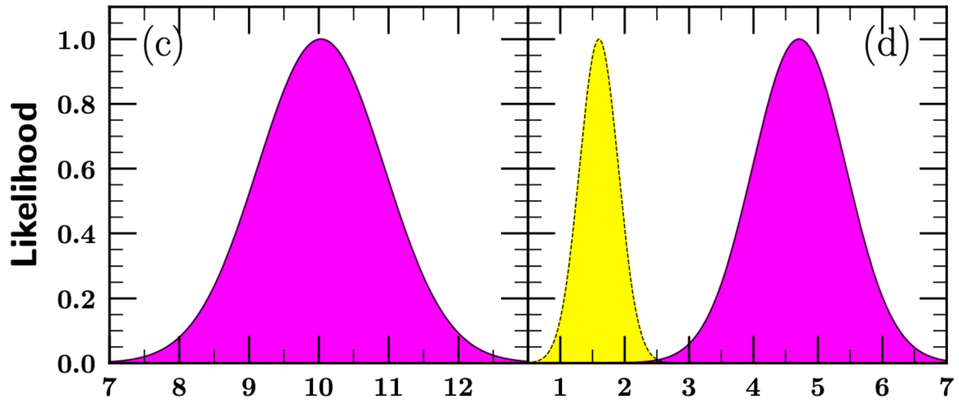
- Tension at 2σ - 3σ

Cosmological constraints on S_8 with the matter density Ω_m in flat-ΛCDM. [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 ΛCDM

Lagrangian for Gravitational Theory: CTEG

Lagrangian and action in Field Theory:

$$\mathscr{L} = \frac{1}{2}(\partial^\mu \phi \partial_\mu \phi) - V(\phi) \qquad S = \int \mathscr{L} \mathrm{d}^4 x \qquad \delta S = 0$$

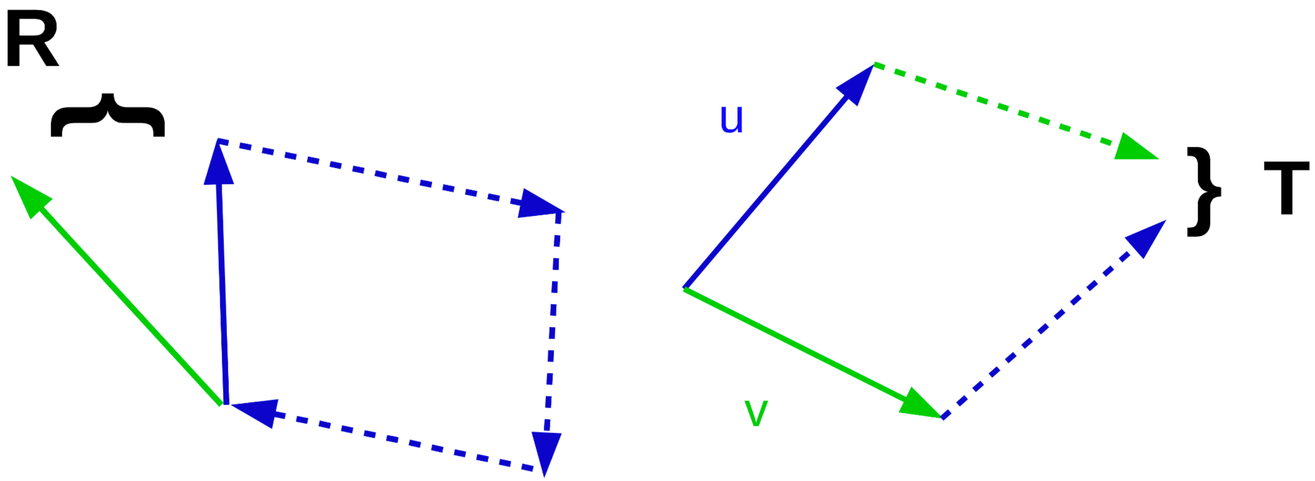
(Kinetic term) (Potential term)

Einstein's General Relativity (GR):

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

Constant Torsion Emergent Gravity (CTEG):

- $\mathscr{L} \propto R^2 + T^2$ [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**

ΛCDM parameters

$$\varpi_r \to 1$$

$$\Omega_L \to \Omega_\Lambda$$

CTEG parameters

Effects of the ϖ_r and Ω_L on Cosmology

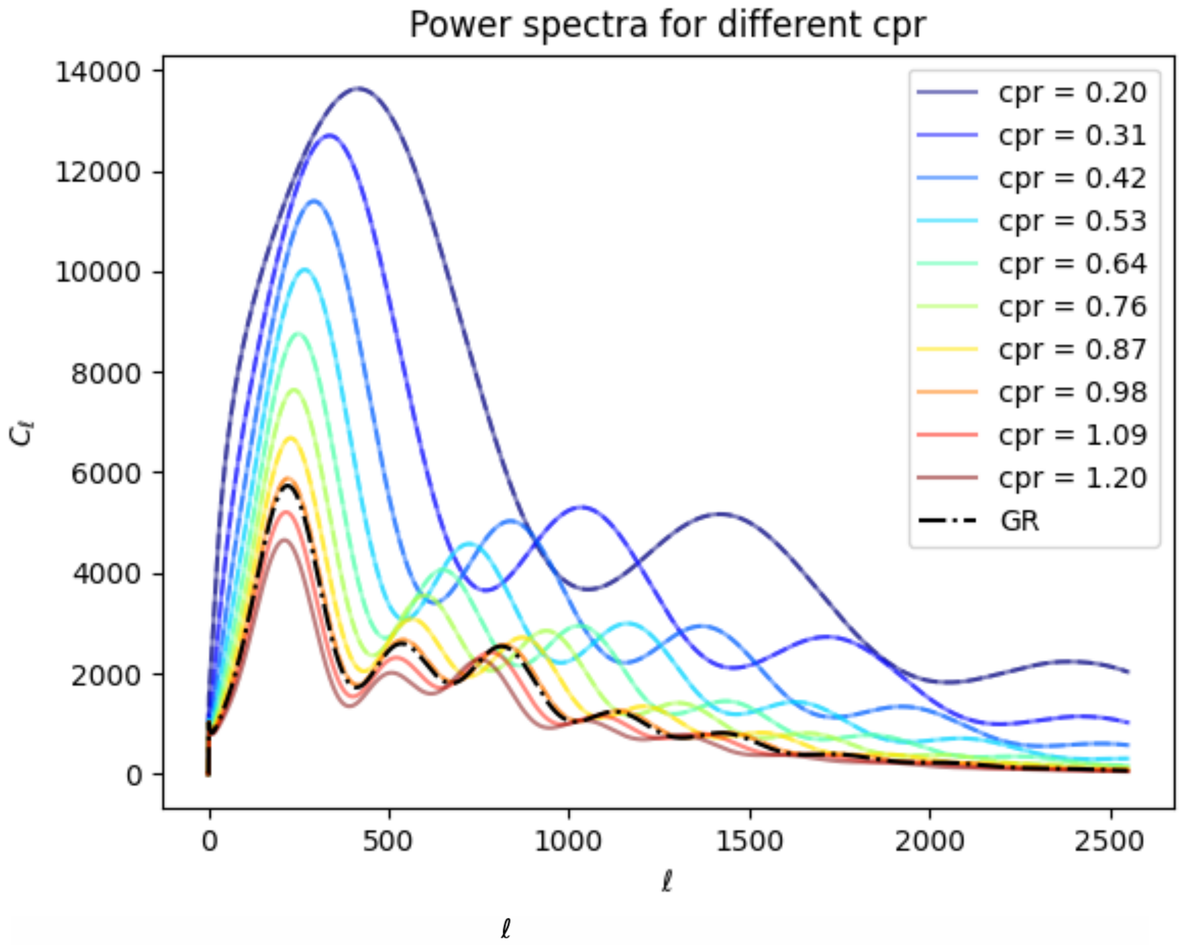
CAMB

- 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



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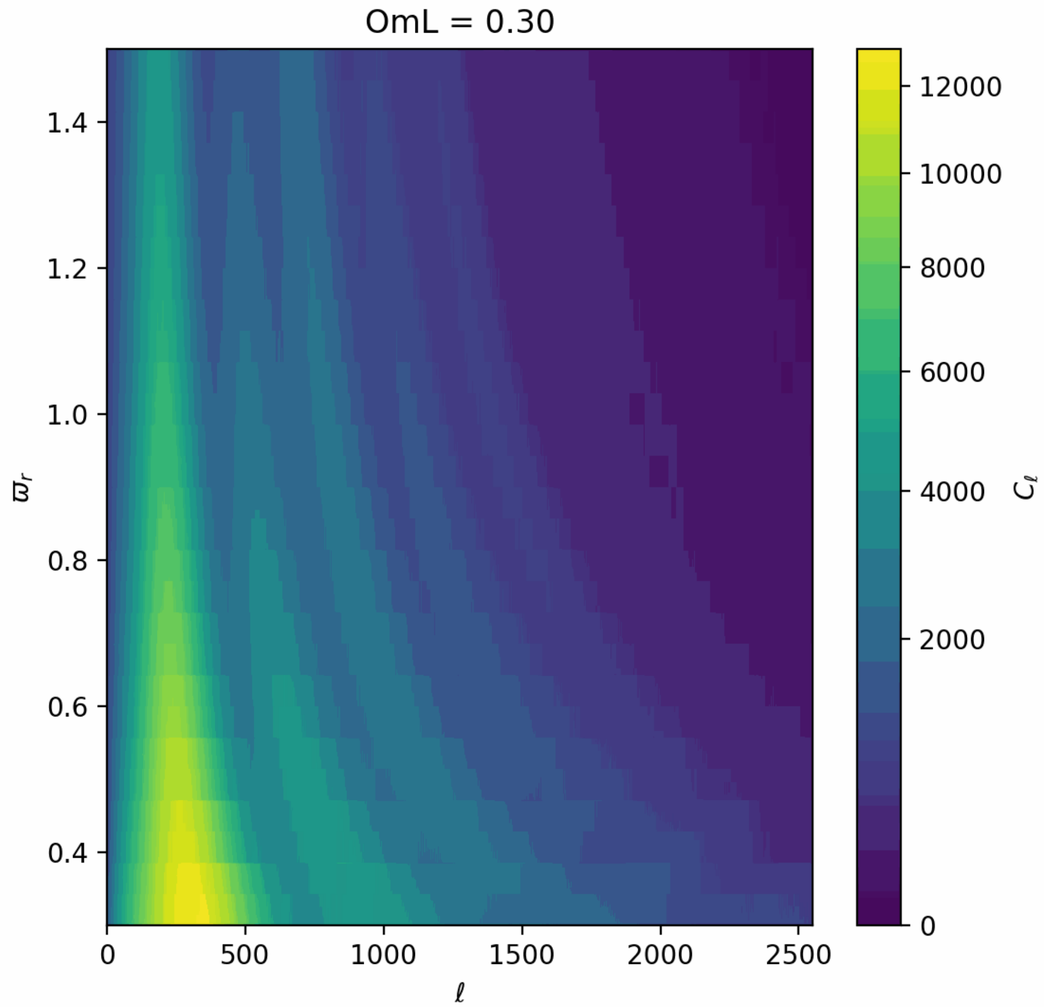


Bayesian Inference and Nested Sampling

Parameter Estimation:

- What does data tell us about parameters?
- $P(\theta \mid D, M) = \dfrac{P(D \mid \theta, M)P(\theta \mid M)}{P(D \mid M)}$

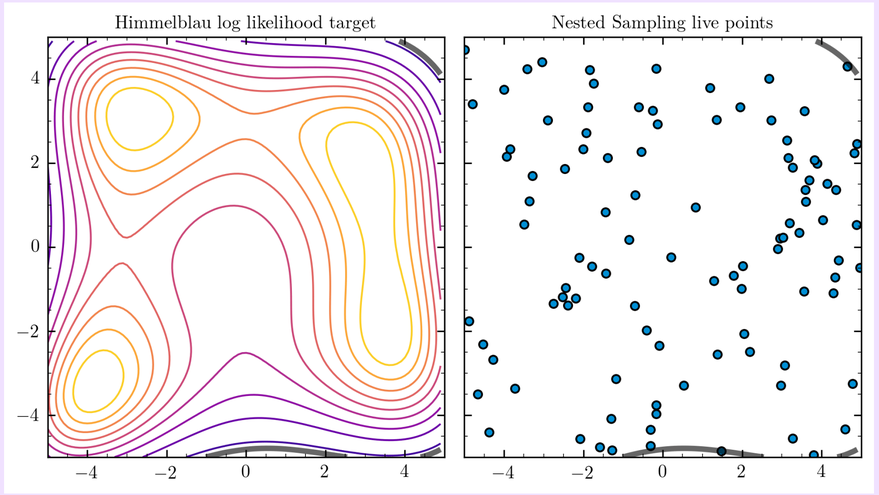
P - posterior
L - likelihood
π - prior
Z - evidence

Model Comparison:

- How much does data support the model?
- $P(M \mid D) = \dfrac{P(D \mid M)P(M)}{P(D)}$
- 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 **bay**esian **a**nalysis [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:

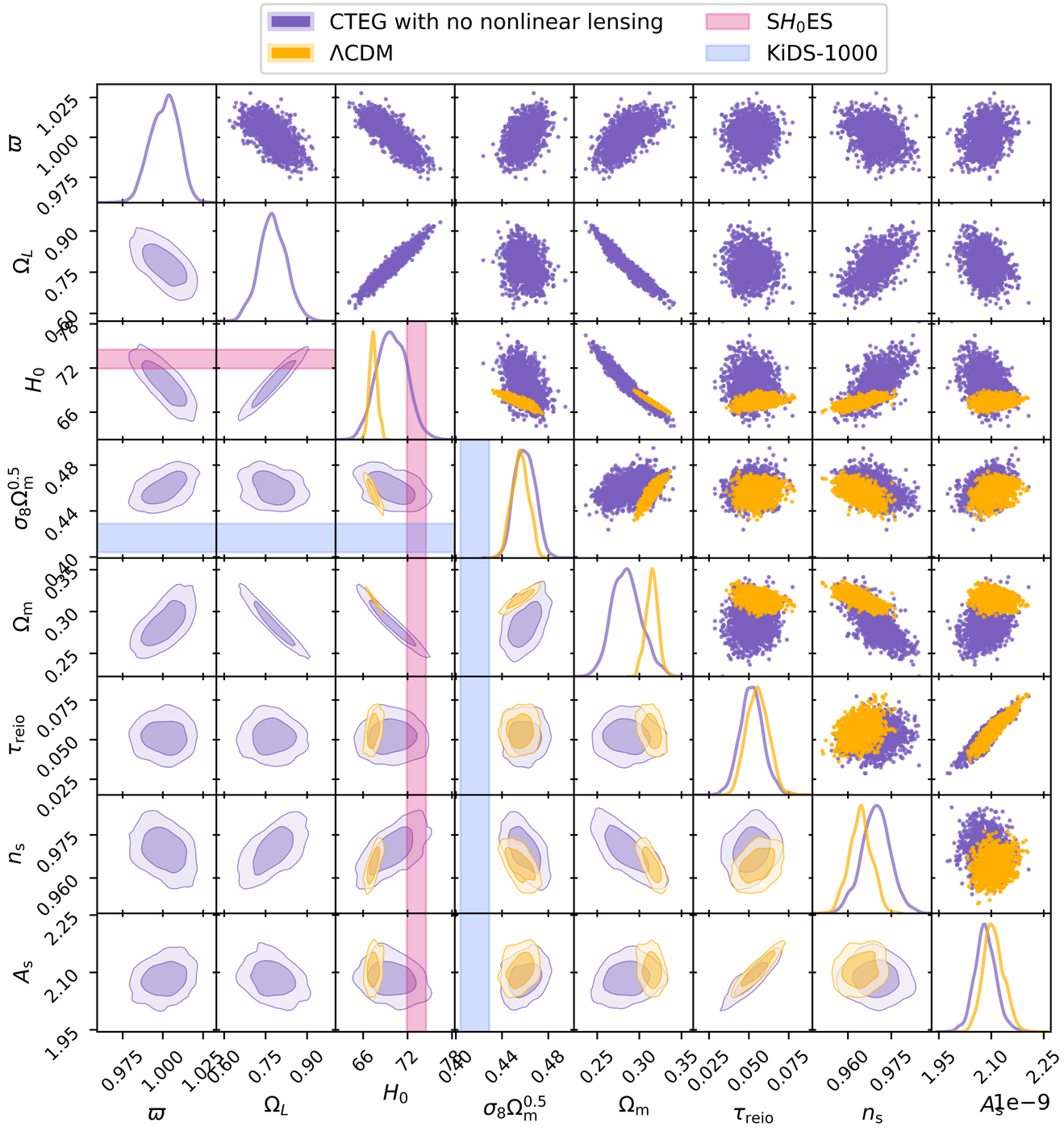
- Computes CMB Power spectrum for each parameter set.

Polychord:

- Explore parameter space with nested sampling

Result:

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



RESULT

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

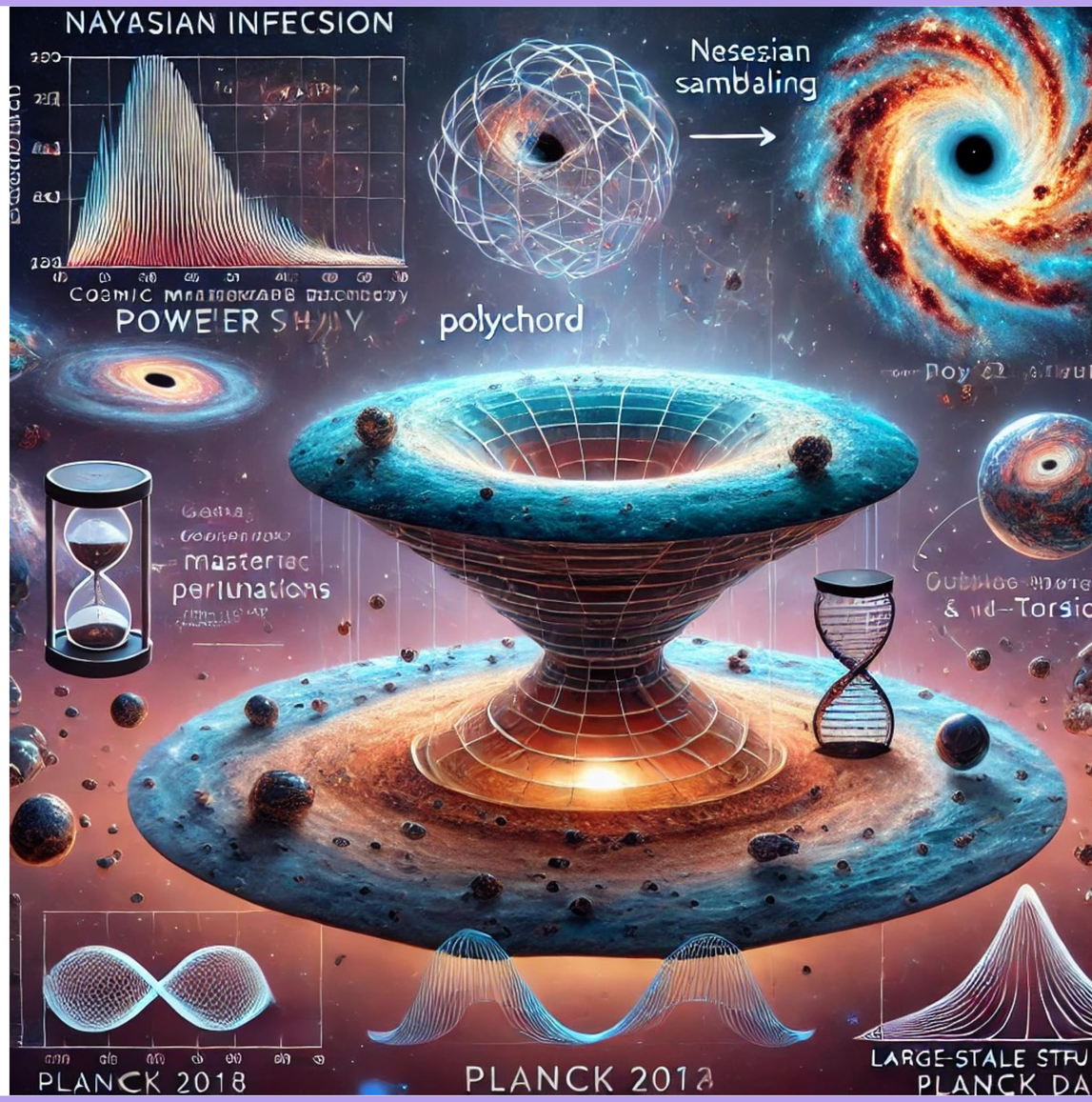
At 68% confidence level:

- $H_0 = 69.9 \pm 2.0$
- Alleviating the H0 tension.

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

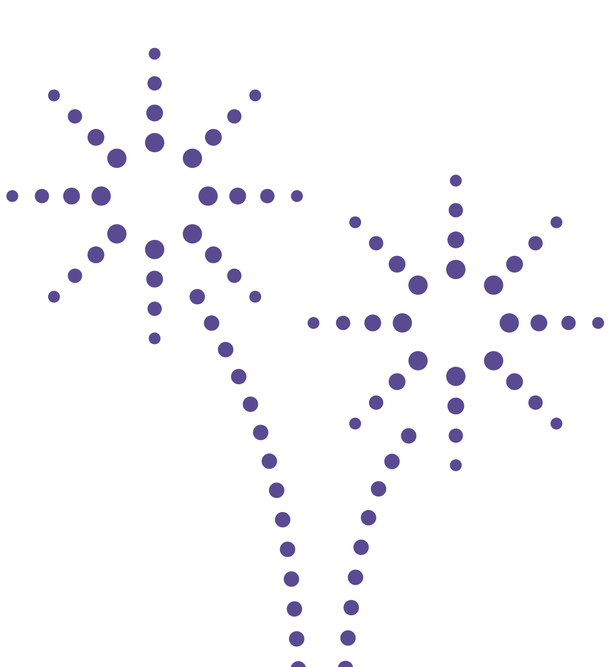
Future Plan

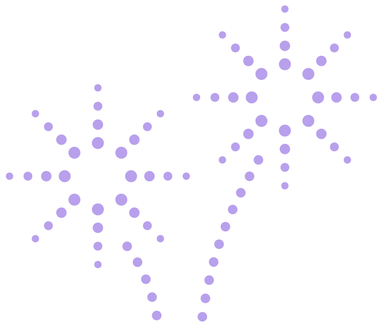
- Cosmology run with curvature
- Include perturbation theory
- Tensions analysis (in hpc queue)

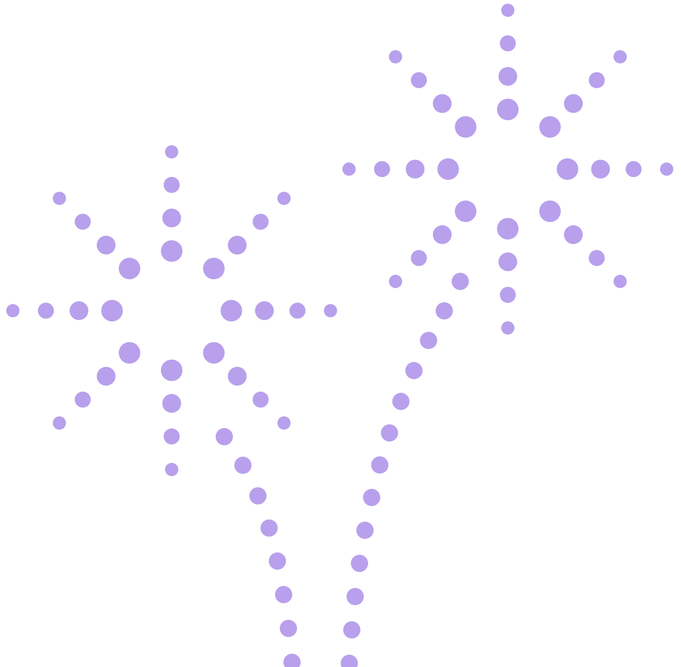


Chatgpt’s drawing based on my slides’ content

Thank you!







Backup Slides:

PGT Lagrangian

PGT Lagrangian is obtained via enforcing local Poincare transformation.

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

$$\begin{aligned}
L_{\mathcal{R}} &= -\frac{1}{2}\alpha_0 \mathcal{R}, \\
L_{\Lambda} &= -\Lambda, \\
L_{\mathcal{R}^2} &= \alpha_1 \mathcal{R}^2 + \alpha_2 \mathcal{R}_{ab}\mathcal{R}^{ab} + \alpha_3 \mathcal{R}_{ab}\mathcal{R}^{ba} + \alpha_4 \mathcal{R}_{abcd}\mathcal{R}^{abcd} + \alpha_5 \mathcal{R}_{abcd}\mathcal{R}^{acbd} \\
&\quad + \alpha_6 \mathcal{R}_{abcd}\mathcal{R}^{cdab}, \\
L_{\mathcal{T}^2} &= \beta_1 \mathcal{T}_{abc}\mathcal{T}^{abc} + \beta_2 \mathcal{T}_{abc}\mathcal{T}^{bac} + \beta_3 \mathcal{T}_a \mathcal{T}^a.
\end{aligned}$$

Gauge Fields:

h_a^{μ} Translational

A_{μ}^{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:

$$\widetilde{\mathcal{L}} = \mathrm{M}_{\mathrm{p}}^2 \upsilon_2 \left[\frac{1}{2}\left(1 - \frac{\varpi^2}{4\varsigma}\right)\mathcal{R} - \frac{3}{2\varsigma} X^{\varpi\varpi} + \sqrt{|\widetilde{J}_\mu \widetilde{J}^\mu|} + \frac{3}{4}\phi^2 - \frac{3}{4\varsigma}\phi^2\varpi^2 \right],$$

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

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

- ϖ_r : Initial value of the scalar field ϖ.
- Coincident with LCDM when $\varpi_r = 1$.

- Field Equation (1st Friedmann Eq.):

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

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

- Ω_L : bare dark energy density parameter
- Coincident with LCDM when $\Omega_L = \Omega_\Lambda$.