2026/11/07@BRICS-AGAC

# Modified Gravity and the Cosmological Tensions

Gen Ye

Associate Professor

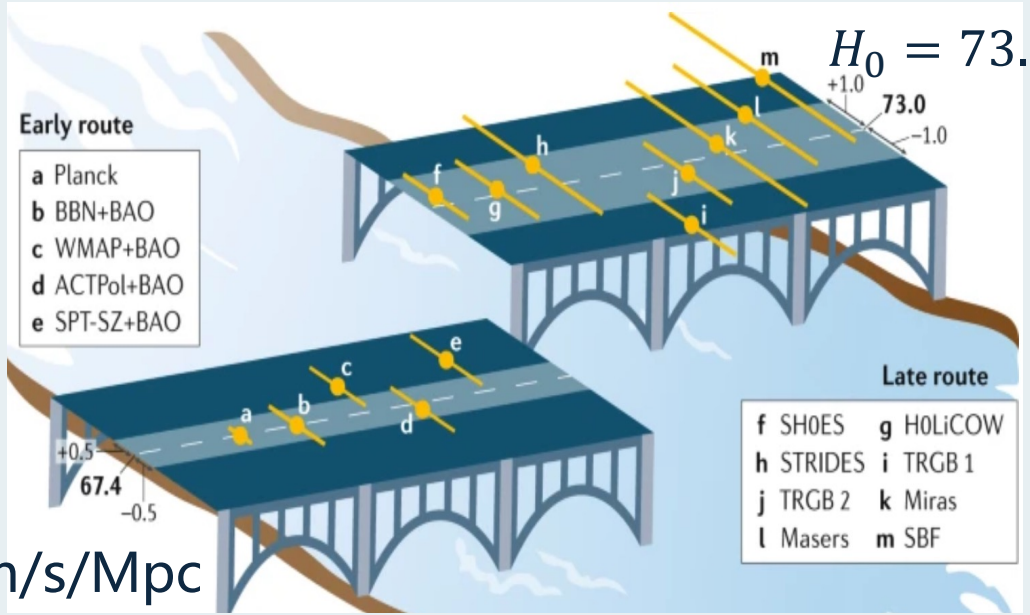
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# The Hubble Tension

Cepheids calibrated local distance ladder (Riess 2021)

$H_0 = 73.0 \pm 1.0$ km/s/Mpc

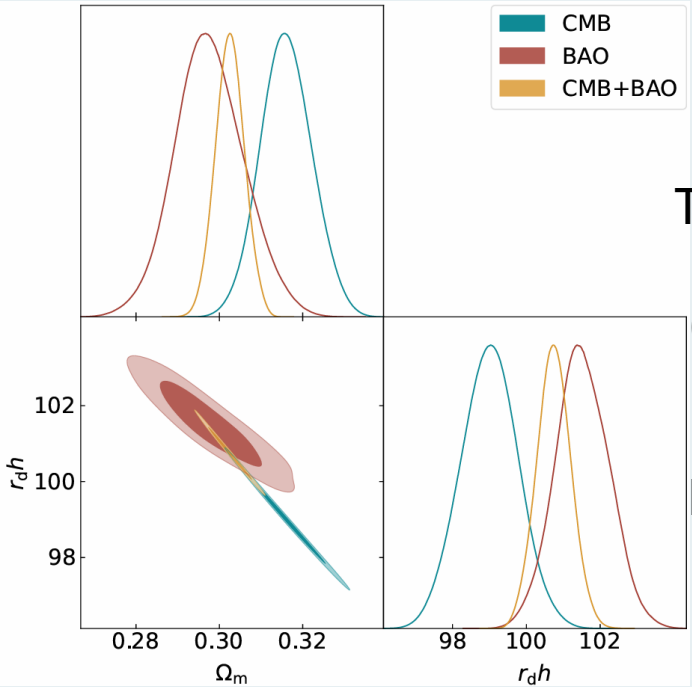



$H_0 = 67.4 \pm 0.5$ km/s/Mpc

ΛCDM prediction based on CMB (Planck 2018)

A. Riess, Nature Reviews Physics volume 2, pages10–12 (2020)

# The BAO Tension



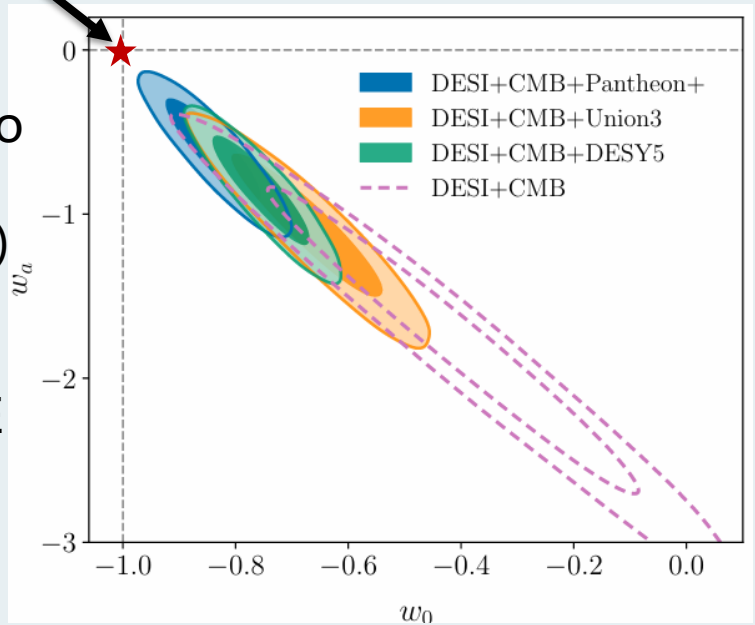

GY, S. Lin, arXiv:2505.02207

In CMB calibrated ΛCDM:
BAO in $2\sigma$ tension

ΛCDM $(w_0 = -1, w_a = 0)$

Tensions project to extended model (CPL dark energy)

Preference for DE




DESI collaboration, PRD, arXiv:2503.14738

# Theory prediction of $H_0$

Tight constraint from BAO, SNIa

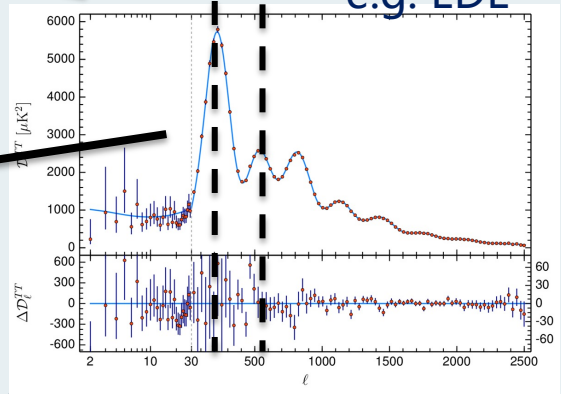
$$D_A = H_0^{-1} \int_0^{z_*} \frac{dz}{E(z)}$$

Model of pre-recombination evolution

$$r_s = \int_{z_*}^{\infty} \frac{c_s}{H(z)} dz$$

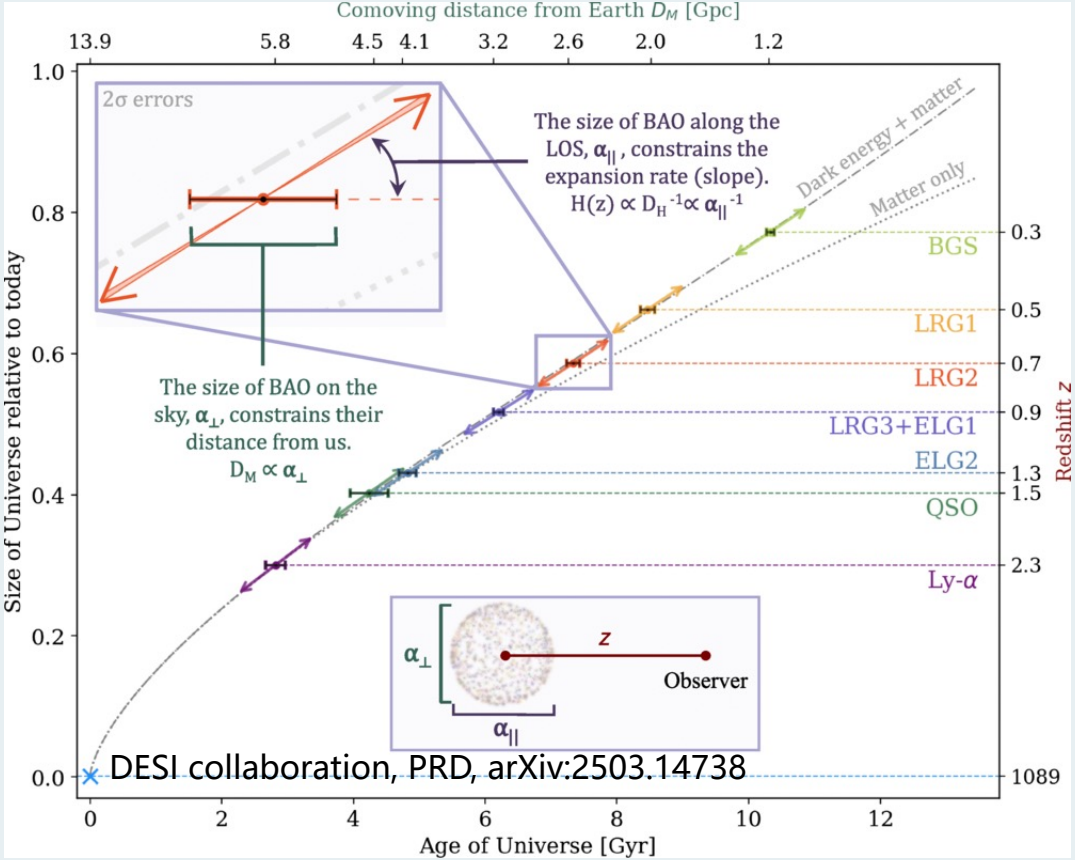
$$\theta_s = \frac{r_s}{D_A}$$

Early-time modification e.g. EDE




$100\theta_s = 1.0417 \pm 0.0006$ rad
(Planck 2018)
Relative error $O(10^{-4})$

# Geometric constraint from BAO

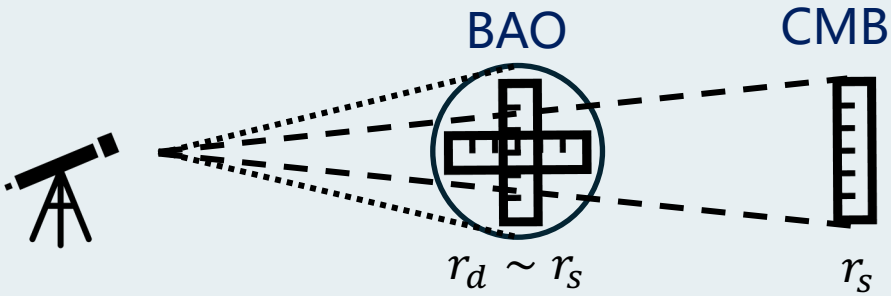



DESI collaboration, PRD, arXiv:2503.14738

Tight constraint on late-time distance

$$D_A(z) = \frac{1}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

# (Dis)Connection

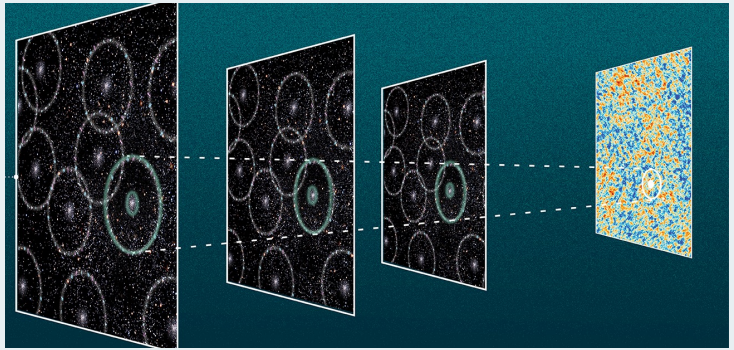



BAO Tension

Dynamical dark energy?

**Energy scale**

$\sim \left(10^{-3} eV\right)^4$



The same physics at different time (separated by billions of years)

Hubble Tension

Early dark energy?

**Energy scale**

$\sim (1eV)^4$

# Gravity the missing puzzle?

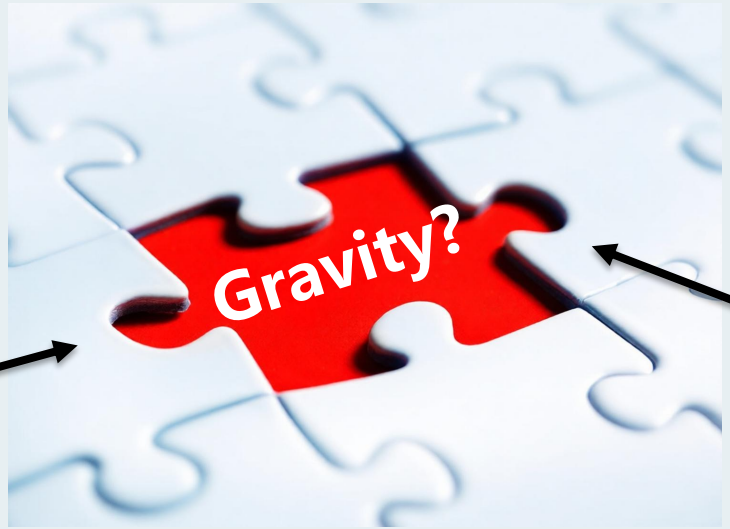
Gravity is universally coupled at all scales (below Planck)

BAO Tension

Dynamical dark energy?

**Energy scale**

$\sim (10^{-3} eV)^4$




Hubble Tension

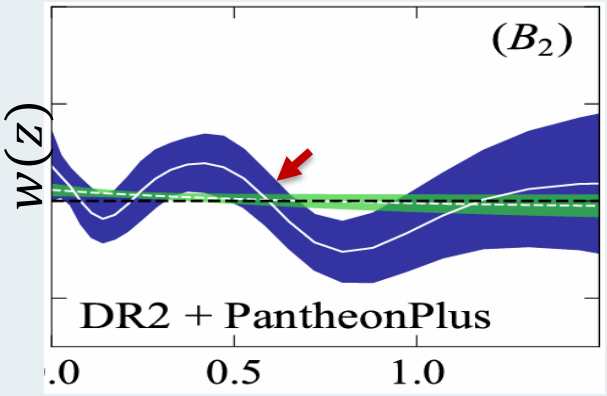
Early dark energy?

**Energy scale**

$\sim (1eV)^4$

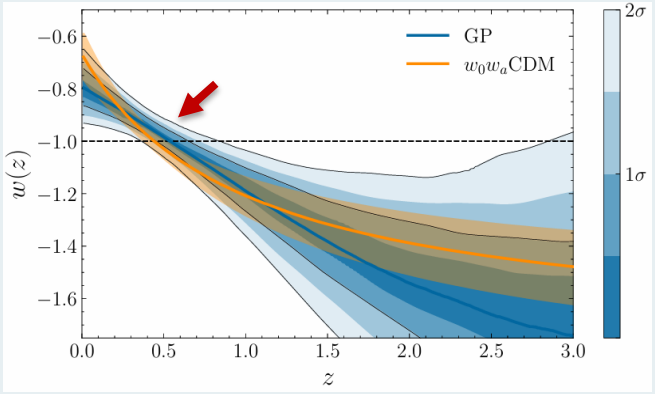
# Hint for evolving dark energy

## Theoretical prior reconstruction



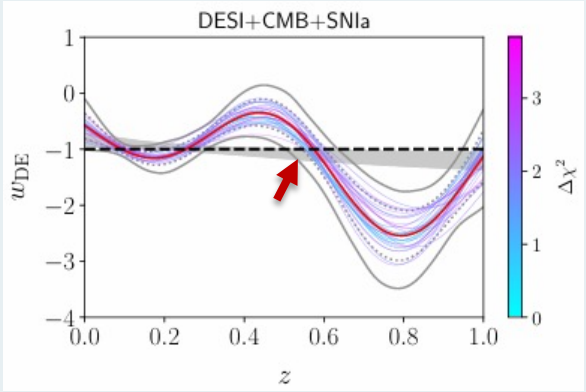

G. Gu et al. Nature Astron, arXiv:2504.06118

## Gaussian Process reconstruction




K. Lodha, et al. PRD, arXiv:2503.14738

## Uniform prior reconstruction




**GY** et al. PRL, arXiv: 2407.15832

Dark energy crosses $w = -1$ at $z \sim 0.5$
from different reconstruction methods

# Theoretical difficulty

## Phantom crossing / quintom dark energy

B. Feng, X.L. Wang, X.M. Zhang, PLB, arXiv: astro-ph/0404224
W. Hu, PRD, arXiv: astro-ph/0410680
H. Wei, R.G. Cai, D.F. Zeng, CQG, arXiv: hep-th/0501160

## Canonical scalar field:

$$L = -\frac{1}{2}(\partial\phi)^2 - V(\phi)$$

$$\rho_{DE} + P_{DE} = (1 + w_{DE})\rho_{DE} = \dot{\phi}^2 \geq 0$$

## No-Go Theorem:

Analogously, this divergence phenomenon extends to generic single scalar field without higher derivatives. In general, the No-Go theorem states: in the Friedmann-Robertson-Walker (FRW) universe described by a single perfect fluid or a single scalar field $\phi$ with a Lagrangian $L = L(\phi, \partial_\mu\phi\partial^\mu\phi)$, which minimally couples to Einstein gravity, its equation of state $w$ cannot cross the cosmological constant boundary [146, 147, 152, 153].

Review by Y.F. Cai, et al. 2505.24732

# Reconstructing stable theory from data

EFT Describing a single propagating d.o.f (limited to Horndeski Gravity)

$$S=\int d^4x\,\sqrt{-g}\Bigg\{\frac{M_p^2}{2}\Big[1+\Omega^{\rm EFT}(\tau)\Big]R+\Lambda(\tau)-c(\tau)\,a^2\,\delta g^{00}$$
$$+\frac{M_p^2H_0^2}{2}\,\gamma_1(\tau)\left(a^2\,\delta g^{00}\right)^2-\frac{M_p^2H_0}{2}\,\gamma_2(\tau)\,a^2\,\delta g^{00}\,\delta K^{\mu}{}_{\mu}$$
$$-\frac{M_p^2}{2}\,\gamma_3(\tau)\left[\left(\delta K^{\mu}{}_{\mu}\right)^2-\delta K^{\mu}{}_{\nu}\,\delta K^{\nu}{}_{\mu}-\frac{a^2}{2}\,\delta g^{00}\,\delta R\right]\Bigg\}+S_m\left[g_{\mu\nu},\chi_m\right]$$

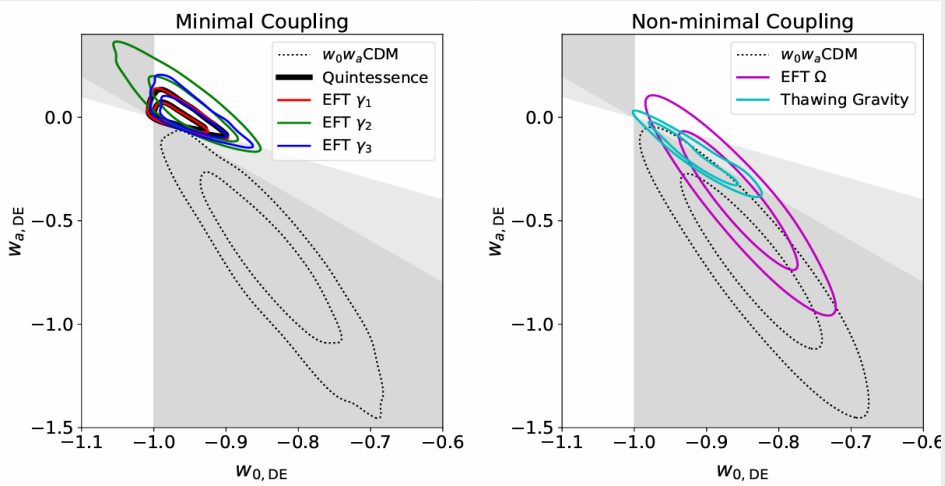
Background & Perturbation

Perturbation only

EFT functions $\Omega, \Lambda, c, \gamma_i$, arbitrary functions of time

Modified gravity (non-minimal coupling) $\Omega \neq 0$

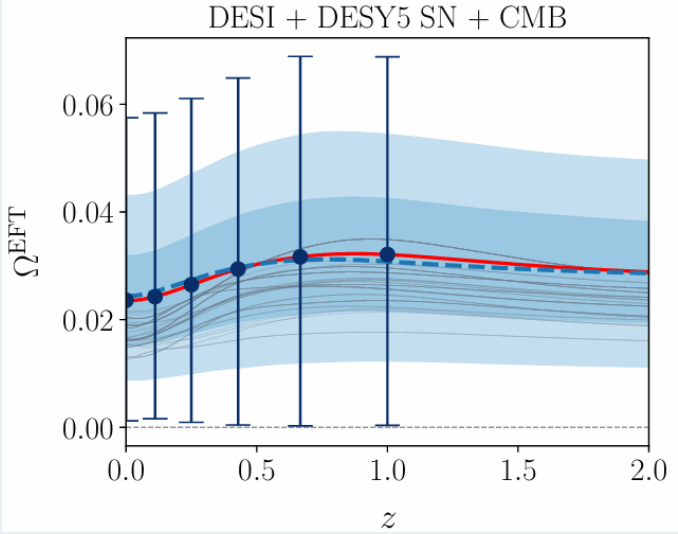
# Hint for modified gravity




**GY** et al. PRL, arXiv:2407.15832

Only modified gravity stabilized the observed DE

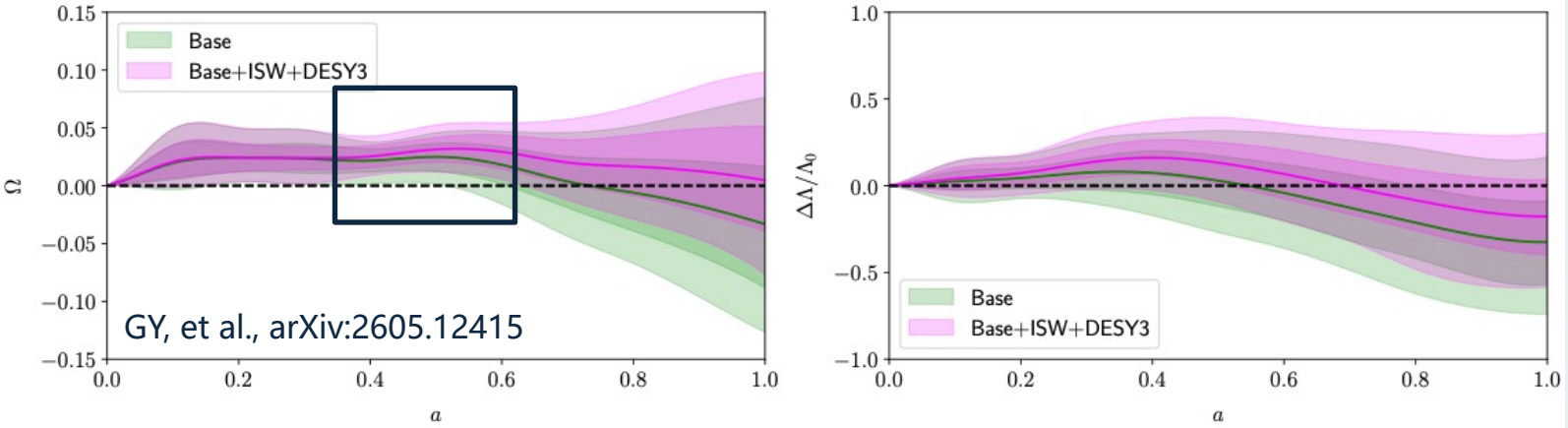
- CPL background
- Ghost + Gradient stability
- Reconstructing one EFT function at a time




J.M. Pan and **GY,** PRD Lett., arXiv:2503.19898

Modified gravity / Non-minimal coupling $(\Omega, \dot{\Omega} \neq 0)$ at $\sim 3\sigma$

# Hint for modified gravity




Modified gravity / Non-minimal coupling ($\Omega, \dot{\Omega} \neq 0$) reduced significance, but remains

Non-parametrized background, dynamically determined from $\Lambda, \Omega$ (the complete set to determine background in EFT)

- Non-parametrized background
- Ghost + Gradient stability
- Reconstructing two EFT functions

# Example: A non-minimal coupled theory

$$\mathcal{S} = \int dx^4 \sqrt{-g} \left[ \frac{M_p^2}{2} \left[1 - \xi(\phi/M_p)^2\right] R + X - \Lambda e^{-\lambda\phi/M_p} \right] + \mathcal{S}_m[g_{\mu\nu}]$$

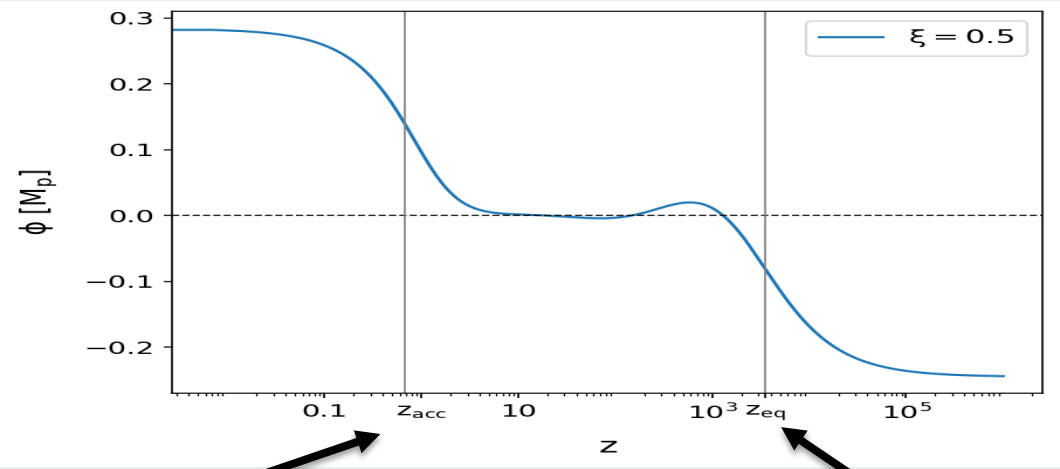
Non-minimal coupling (Jordan frame)

Dark energy

"Thawing Gravity"

**GY** et al. PRL, arXiv:2407.15832
**GY**, PRD Lett., arXiv:2411.11743

# Modified gravity connecting the early and late Universe



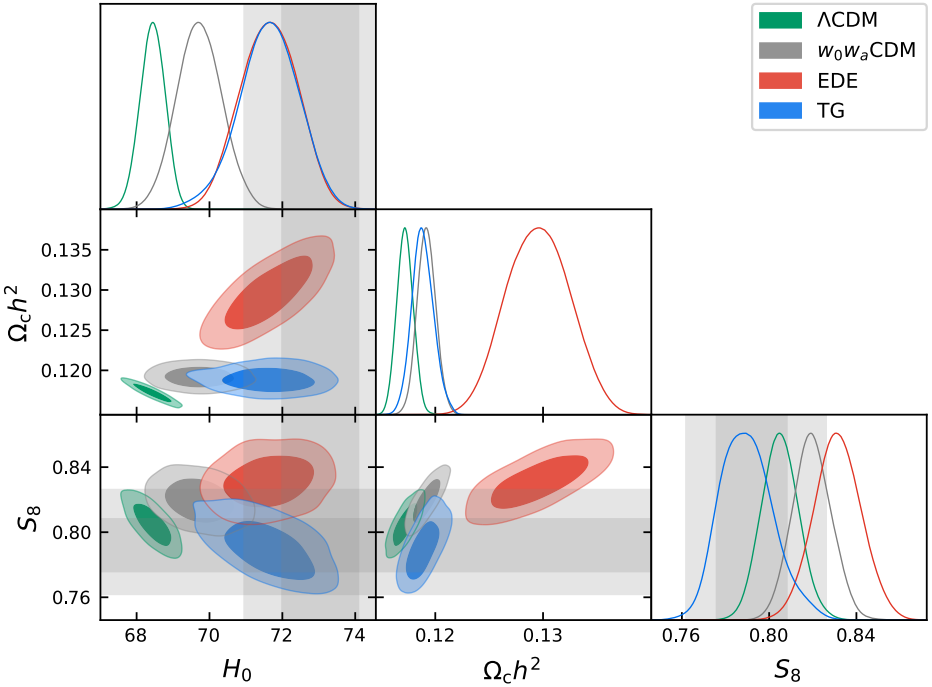

$z_{acc}$
matter dominance => DE dominance
Deceleration -> Acceleration
Phantom crossing / Quintom DE
**BAO Tension**

$z_{eq}$:
radiation dominance => matter dominance
$R \sim o(H^2) \rightarrow R \sim O(H^2)$
Early DE / MG
**Hubble Tension**

**GY** et al. PRL, arXiv:2407.15832
**GY**, PRD Lett., arXiv:2411.11743

# Compatibility with CMB、BAO、SNIa

| Dataset | ΛCDM | $w_0w_a$CDM | EDE | TG |
|---|---|---|---|---|
| | | $\Delta \ln B$ | | |
| CMB+BAO+SNIa | - | $-2.0 \pm 0.2$ | $-3.4 \pm 0.2$ | $+1.7 \pm 0.2$ |
| CMB+BAO+SNIa+$H_0$ | - | $+1.0 \pm 0.2$ | $+8.6 \pm 0.2$ | $+12.1 \pm 0.2$ |
| | | $\Delta$AIC | | |
| CMB+BAO+SNIa | - | $-6.2$ | $+1.2$ | $-6.2$ |
| CMB+BAO+SNIa+$H_0$ | - | $-8.8$ | $-23.6$ | $-30.5$ |
| | | $\Delta\chi^2$ | | |
| CMB+BAO+SNIa | - | $-10.2$ | $-4.8$ | $-12.2$ |
| CMB+BAO+SNIa+$H_0$ | - | $-12.8$ | $-29.6$ | $-36.5$ |
| | | Bestfit $\chi^2$ | | |
| CMB | 10975.4 | 10970.5 | 10970.6 | 10970.3 |
| +BAO | 13.6 | 10.4 | 13.6 | 9.2 |
| +SNIa | 1405.3 | 1403.3 | 1405.3 | 1402.6 |
| CMB | 10979.3 | 10970.9 | 10975.7 | 10974.9 |
| +BAO | 10.6 | 15.0 | 10.7 | 9.3 |
| +SNIa+$H_0$ | 1485.0 | 1476.2 | 1458.8 | 1454.1 |



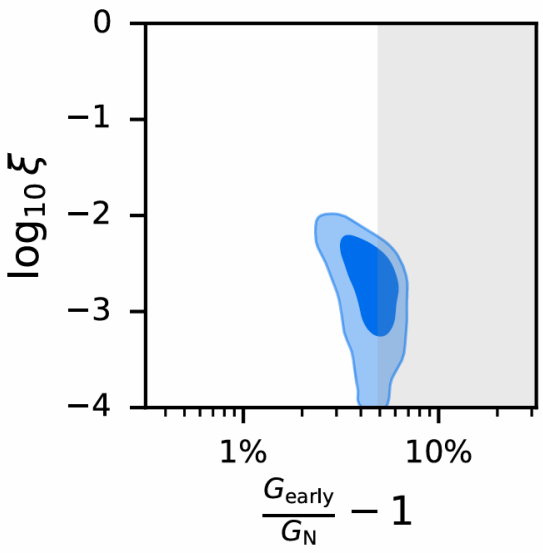

$\Delta\chi^2$: Improved fit

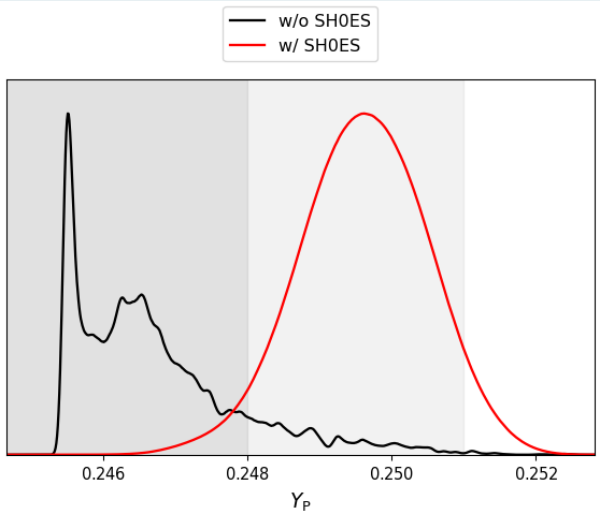
$\Delta \ln B$: Strong Bayes evidence

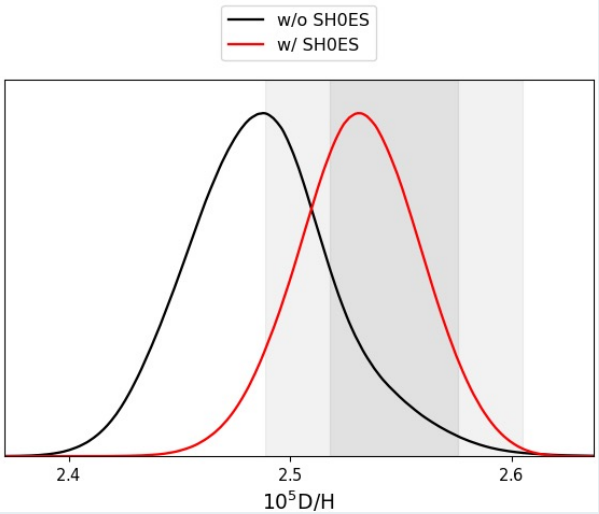
A simultaneous explanation to the BAO and Hubble Tensions

**GY**, PRD Lett., arXiv:2411.11743

# Compatibility with BBN




~5% stronger gravity in the early time ⇒ Modify light element abundance from BBN

$$\mathrm{Y_P} = 0.245 \pm 0.003$$

$$10^5 D/H = 2.569 \pm 0.0027$$

(Data from PDG 2024)

**GY**, PRD Lett., arXiv:2411.11743

# Compatibility with Solar System Experiment

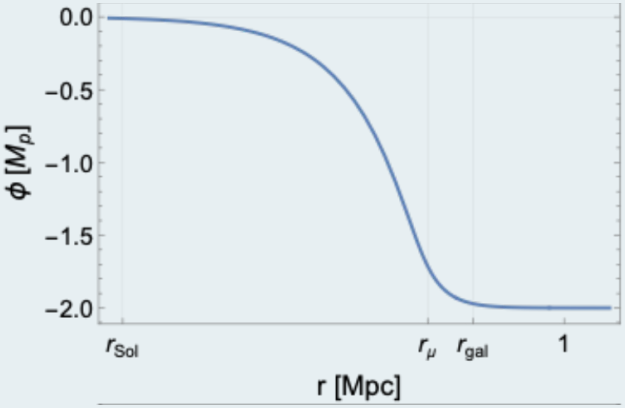
$$\mathcal{S} = \int dx^4\sqrt{-g}\left[\frac{M_p^2}{2}\left[1-\xi(\phi/M_p)^2\right]R + X - \Lambda e^{-\lambda\phi/M_p}\right] + \mathcal{S}_m[g_{\mu\nu}]$$

No Screening

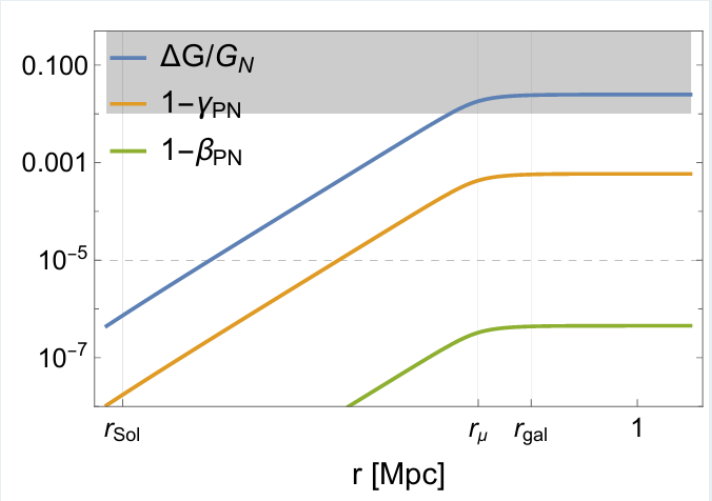
$$\mathcal{L} = \frac{M_p^2}{2}\left[1-\xi(\phi/M_p)^2\right]R + X - \frac{1}{M_p^2\mu^2}X^2 - \Lambda e^{-\lambda\phi/M_p}$$

With Screening

$$\mu = 1\ kpc^{-1}$$
$$r_\mu = 1\ kpc$$
$$r_{sol} \simeq 10^{-10}\ Mpc$$
$$r_{gal} \simeq 8\ kpc$$




Screened 5th force




**GY**, PRD Lett., arXiv:2411.11743



# THANKS

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