

Thawing Gravity and The Cosmological Tensions

Gen Ye

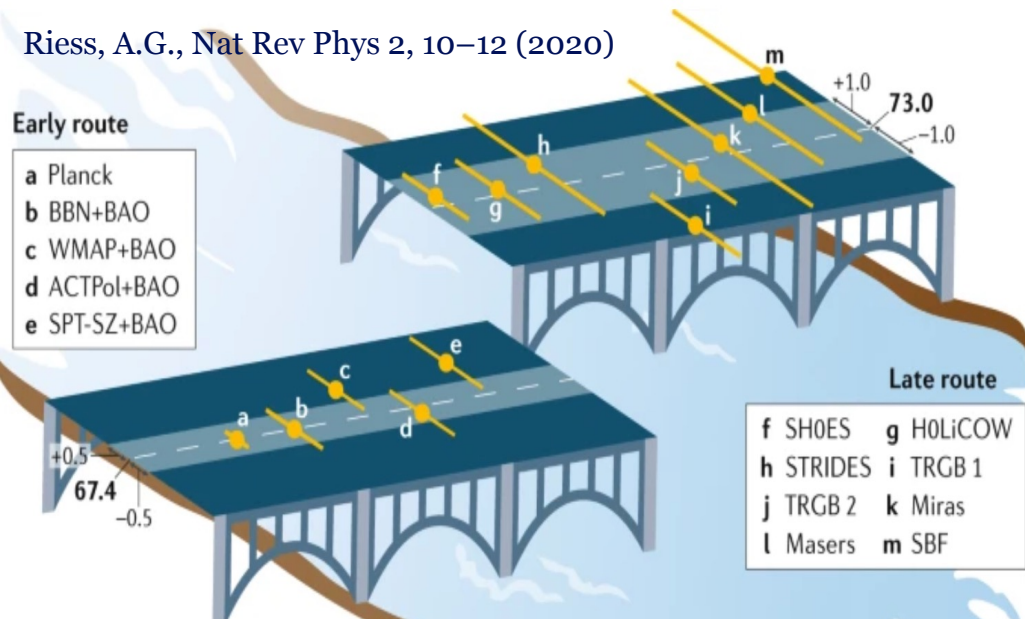


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GY, M.Martinelli, B.Hu, A. Silvestri, arXiv:2411.11743 (*PRL* 134, 18, 181002)
GY, arXiv:2411.11743

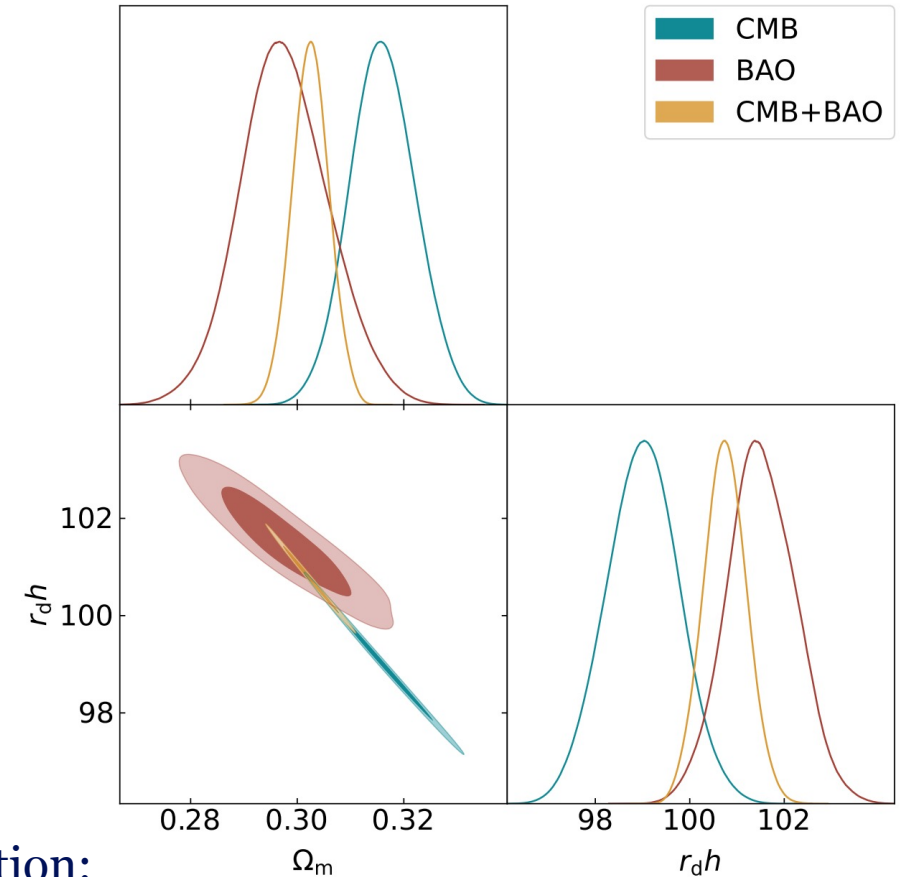
Cosmological tensions



Hubble tension ($> 5\sigma$)

CMB, BAO common assumption:
Post-recombination background
parametrized by $\Omega_m = 1 - \Omega_\Lambda, H_0$

BAO v.s. CMB tension from DESI?



2σ inconsistency

GY, SJL, 2505.02207

Phantom Crossing in DE?

- Dynamical DE
- DE phantom crossing

Rule out quintessence DE due to theoretical instability

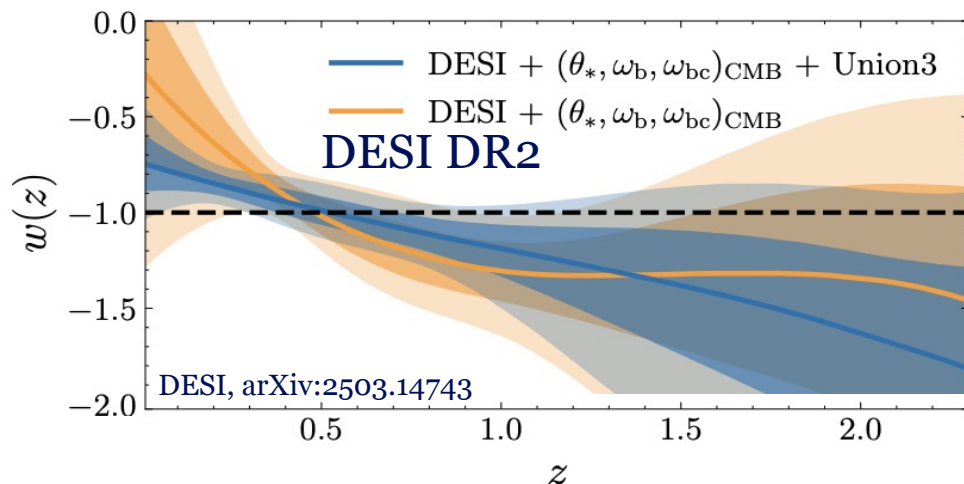
$$w_{DE} = w_0 + w_a \frac{z}{1+z} = -1$$

$$z_{pc} = -\frac{w_0 + 1}{w_a + (w_0 + 1)}.$$

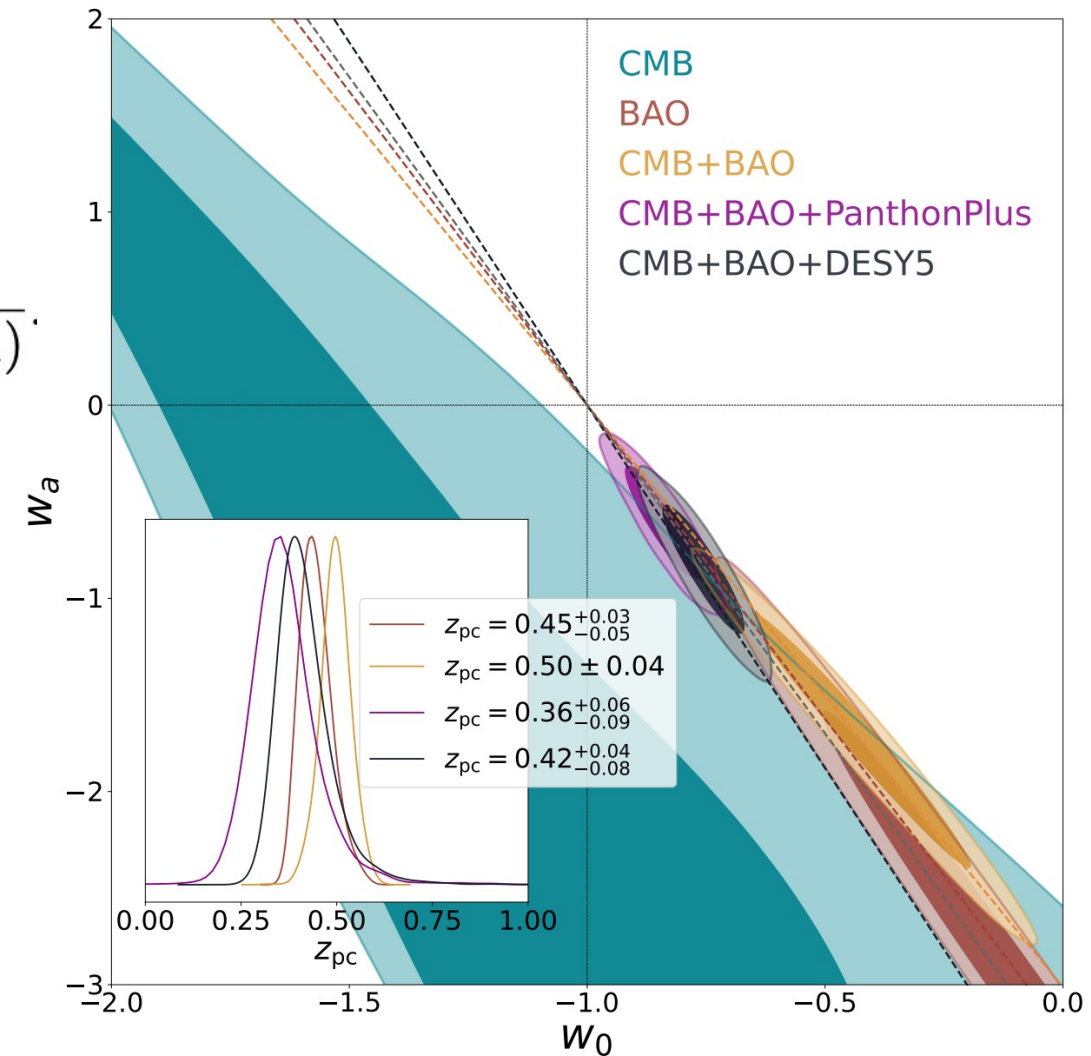
Quintessence:

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

Non-parametric
Reconstruction of w_{DE}

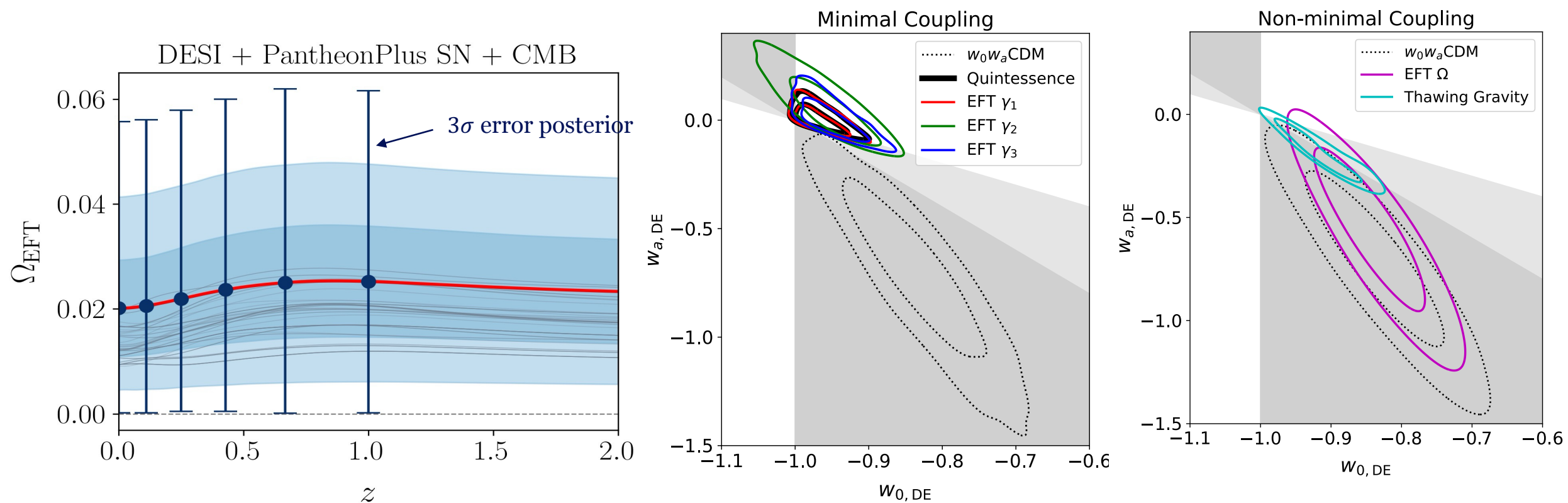


GY, SJL, arXiv:2505.02207



Hint of Modified Gravity

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



NMC Example: Thawing Gravity (TG)

$$\mathcal{S} = \int dx^4 \sqrt{-g} \left[\frac{M_p^2}{2} f(\phi) R + X - V(\phi) \right] + \mathcal{S}_m[g_{\mu\nu}]$$

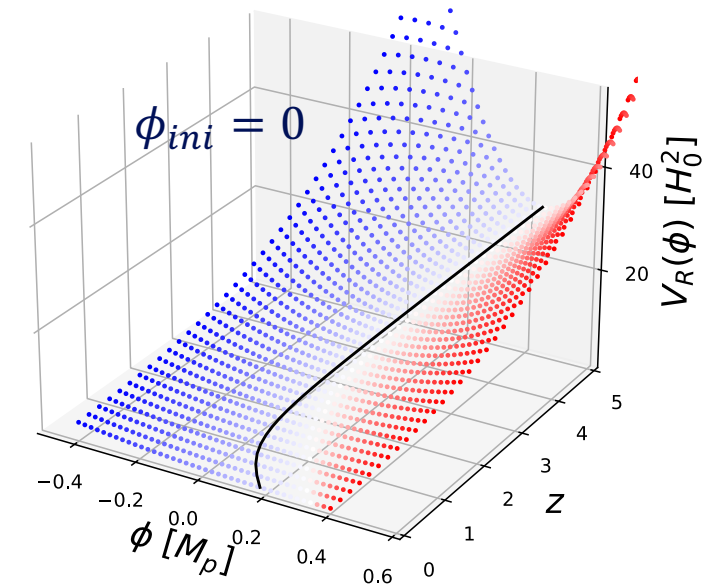
- General local structure of non-minimal coupling :

$$f(\phi) = 1 - \xi \left(\frac{\phi}{M_p} \right)^2, \quad \xi \geq 0$$

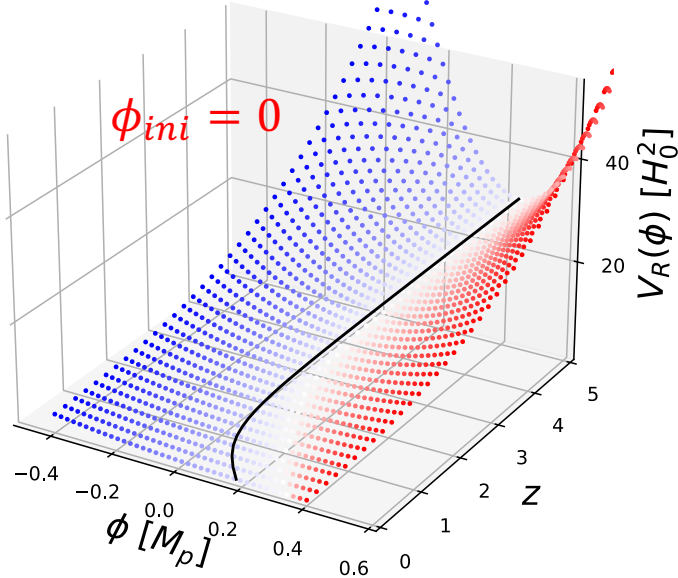
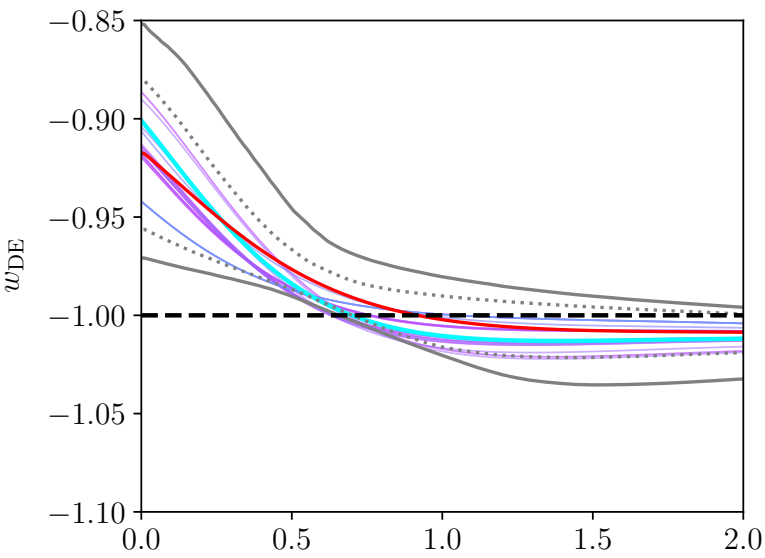
$$V_{eff} = \frac{1}{2} \xi R \phi^2 + V_0 e^{-\lambda \phi / M_p}$$

- GR can be a local attractor [T.Damour, K.Nordtvedt, PRL 1993]
- $\xi = 1/6$ conformally coupled
- Typical DE potential:

$$V(\phi) = V_0 e^{-\lambda \phi / M_p}$$
 - Support accelerated expansion
 - No strong constraint on shape from observations
 - Alternative potential might fit better [W. Wolf, et al., arXiv:2409.17019, 2504.07679]



TG limited to the late Universe



CMB+DESI DR1+Pantheon+

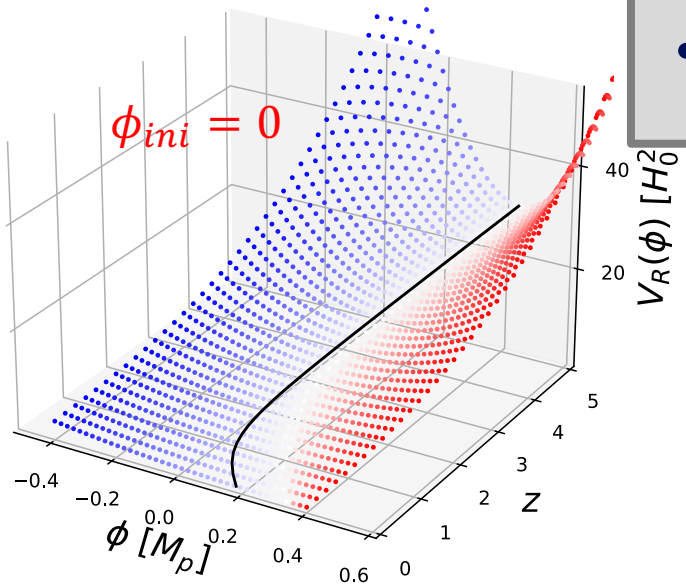
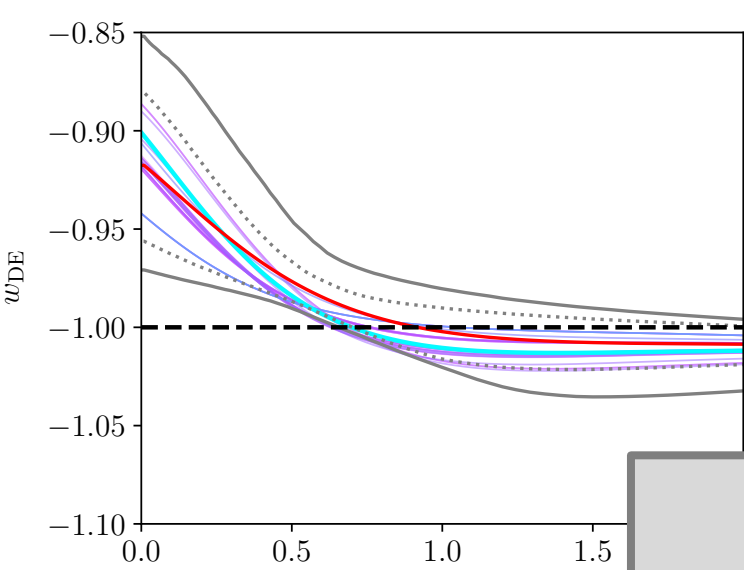
$$L = \frac{M_p^2}{2} [1 - \xi(\phi/M_p)^2] R + X - V_0 e^{-\lambda\phi/M_p},$$

Parameters	Λ CDM	$w_0 w_a$ CDM	Quintessence	Thawing Gravity
$100\omega_b$	$2.226(2.227) \pm 0.013$	$2.222(2.221) \pm 0.013$	$22.30(22.34) \pm 0.013$	$2.230(2.222) \pm 0.012$
$100\omega_c$	$11.857(11.830) \pm 0.081$	$11.924(11.913) \pm 0.091$	$11.809(11.862) \pm 0.012$	$11.810(11.759) \pm 0.077$
H_0 [km/s/Mpc]	$67.74(67.85) \pm 0.36$	$67.93(68.06) \pm 0.73$	$66.94(66.95)^{+0.58}_{-0.49}$	$66.81(66.89)^{+0.54}_{-0.41}$
n_s	$0.9662(0.9668) \pm 0.0036$	$0.9648(0.9648) \pm 0.0037$	$0.9677(0.9673) \pm 0.0037$	$0.9674(0.9672) \pm 0.0035$
$\ln 10^{10} A_s$	$3.042(3.044) \pm 0.014$	$3.035(3.030) \pm 0.014$	$3.046(3.045) \pm 0.014$	$3.044(3.058) \pm 0.013$
τ	$0.0558(0.573) \pm 0.0069$	$0.0519(0.0491) \pm 0.0071$	$0.0582(0.0506) \pm 0.0073$	$0.0571(0.0569) \pm 0.0068$
ξ	N.A.	N.A.	N.A.	$< 0.74(0.61)$
λ	N.A.	N.A.	N.A.	$1.19(1.41)^{+0.42}_{-0.30}$
$V_0/3H_0^2$	N.A.	N.A.	N.A.	$0.723(0.723)^{+0.008}_{-0.021}$

With DESI DR2 (DESI, 2503.14738)

Model/Dataset	Ω_m	H_0 [km s ⁻¹ Mpc ⁻¹]	$10^3 \Omega_K$	w or w_0	w_a
DESI+CMB+Pantheon+	0.3114 ± 0.0057	67.51 ± 0.59	—	-0.838 ± 0.055	$-0.62^{+0.22}_{-0.19}$
DESI+CMB+Union3	0.3275 ± 0.0086	65.91 ± 0.84	—	-0.667 ± 0.088	$-1.09^{+0.31}_{-0.27}$
DESI+CMB+DESY5	0.3191 ± 0.0056	66.74 ± 0.56	—	-0.752 ± 0.057	$-0.86^{+0.23}_{-0.20}$

TG limited to the late Universe



CMB+DESI DR1+Pantheon+

$$L = \frac{M_p^2}{2} [1 - \xi(\phi/M_p)^2] R + X - V_0 e^{-\lambda\phi/M_p},$$

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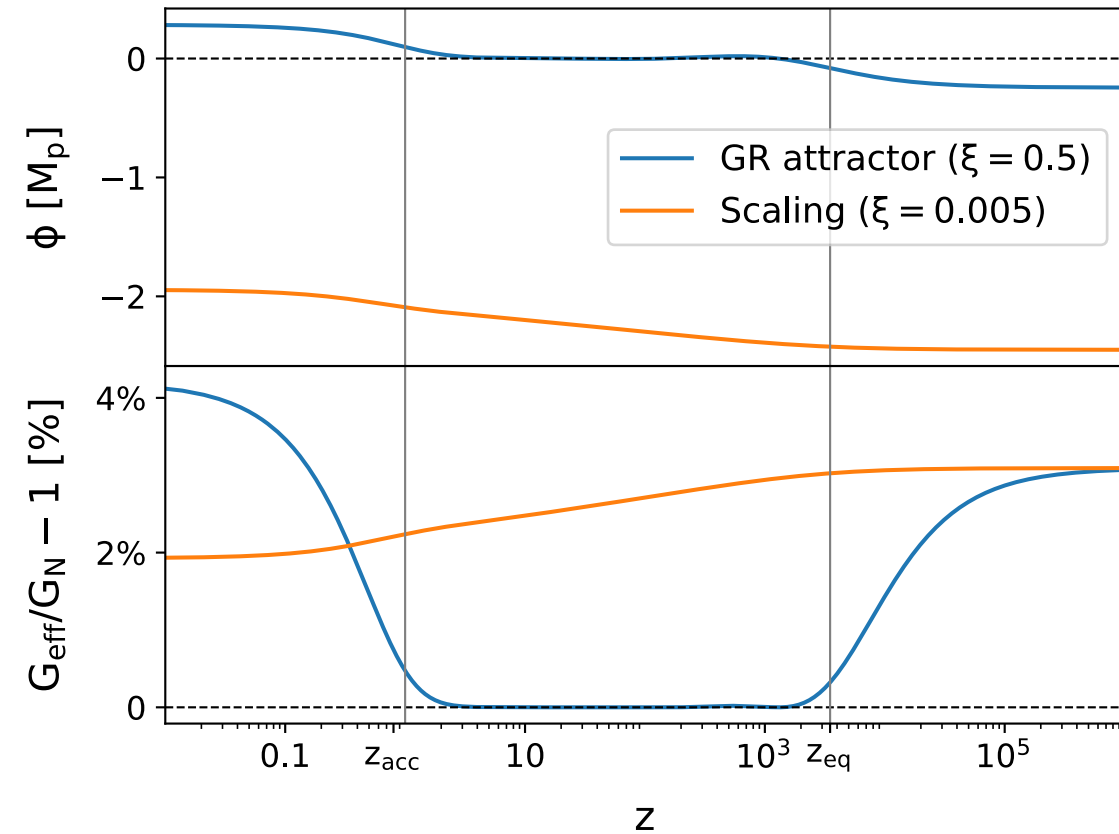
- Gravity has no preferred scale
- Non-minimal coupling is universal

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Full TG: 2 thawing point

- Gravity has no preferred scale
 - Non-minimal coupling is universal
- 1st thawing: $z = z_{eq}$
 - Transition: $R \ll H^2 \rightarrow R \sim O(H^2)$
 - $\phi \simeq \phi_i$ frozen $\rightarrow \phi$ rolling (EDE like)
 - 2nd thawing: $z = z_{acc}$
 - Transition: deceleration $\rightarrow$ acceleration
 - Matter dominance $\rightarrow \phi$ dominance (DE/MG)

$$L = \frac{M_p^2}{2} [1 - \xi(\phi/M_p)^2] R + X - V_0 e^{-\lambda\phi/M_p},$$



Full TG: 2 dynamical cases

$$L = \frac{M_p^2}{2} [1 - \xi(\phi/M_p)^2] R + X - V_0 e^{-\lambda\phi/M_p},$$

- Approximate solution

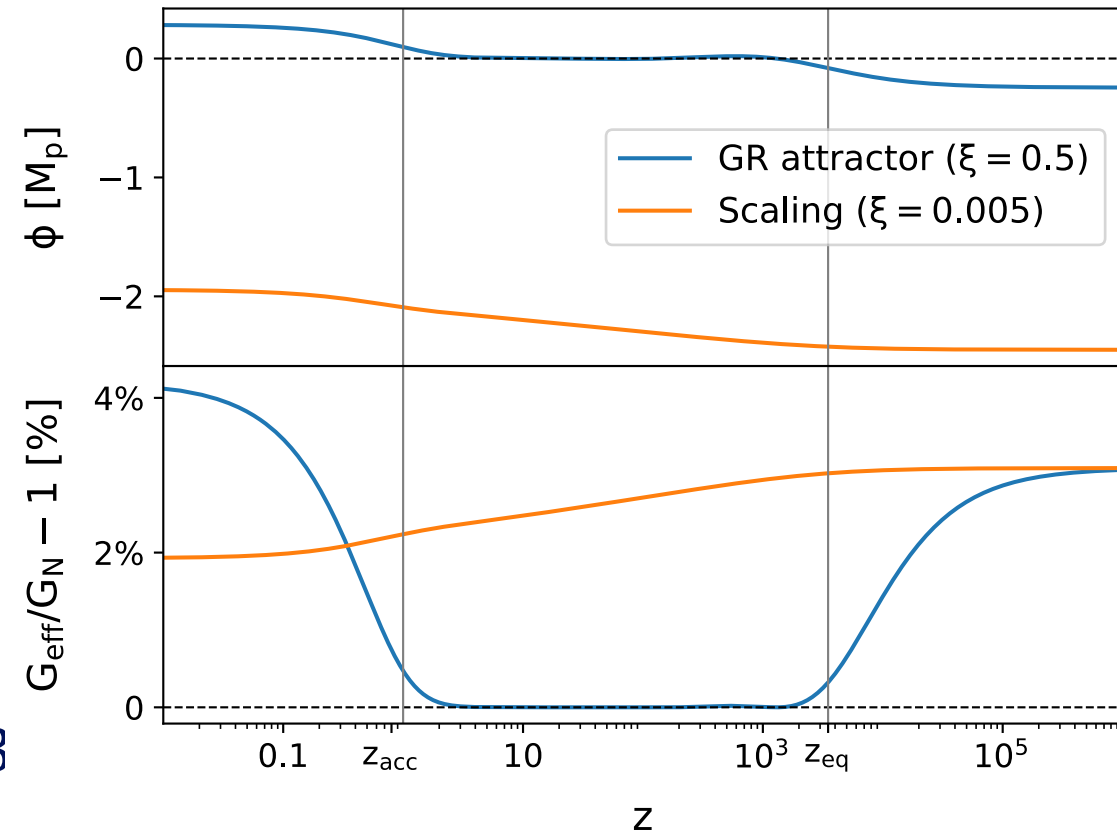
$$\phi \simeq \begin{cases} \phi_{\text{ini}} & \text{RD,} \\ \phi_{\text{ini}} \exp \left[\frac{-3 \pm \sqrt{9 - 48\xi}}{4} (N - N_i) \right] & \text{MD,} \end{cases} \quad N = \ln \frac{a}{a_0}$$

- GR attractor $\xi > \frac{3}{16}$

damped oscillation around $\phi \simeq 0$

- Scaling $\xi < \frac{3}{16}$

scales with scale factor $\phi \propto a^\gamma, 0 < \gamma < 3$



Full TG: Model Comparison

	$w_0 w_a$ CDM	EDE	TG
CMB+BAO+SNIa	-1.4	-0.6	+0.7
CMB+BAO+SNIa+ H_0	+4.6	+9.5	+11.3

→ DESI BAO tension

→ Hubble tension

Bayes Factor $\ln B = \ln Z_{model} - \ln Z_{\Lambda CDM}$

Jeffreys' scale:

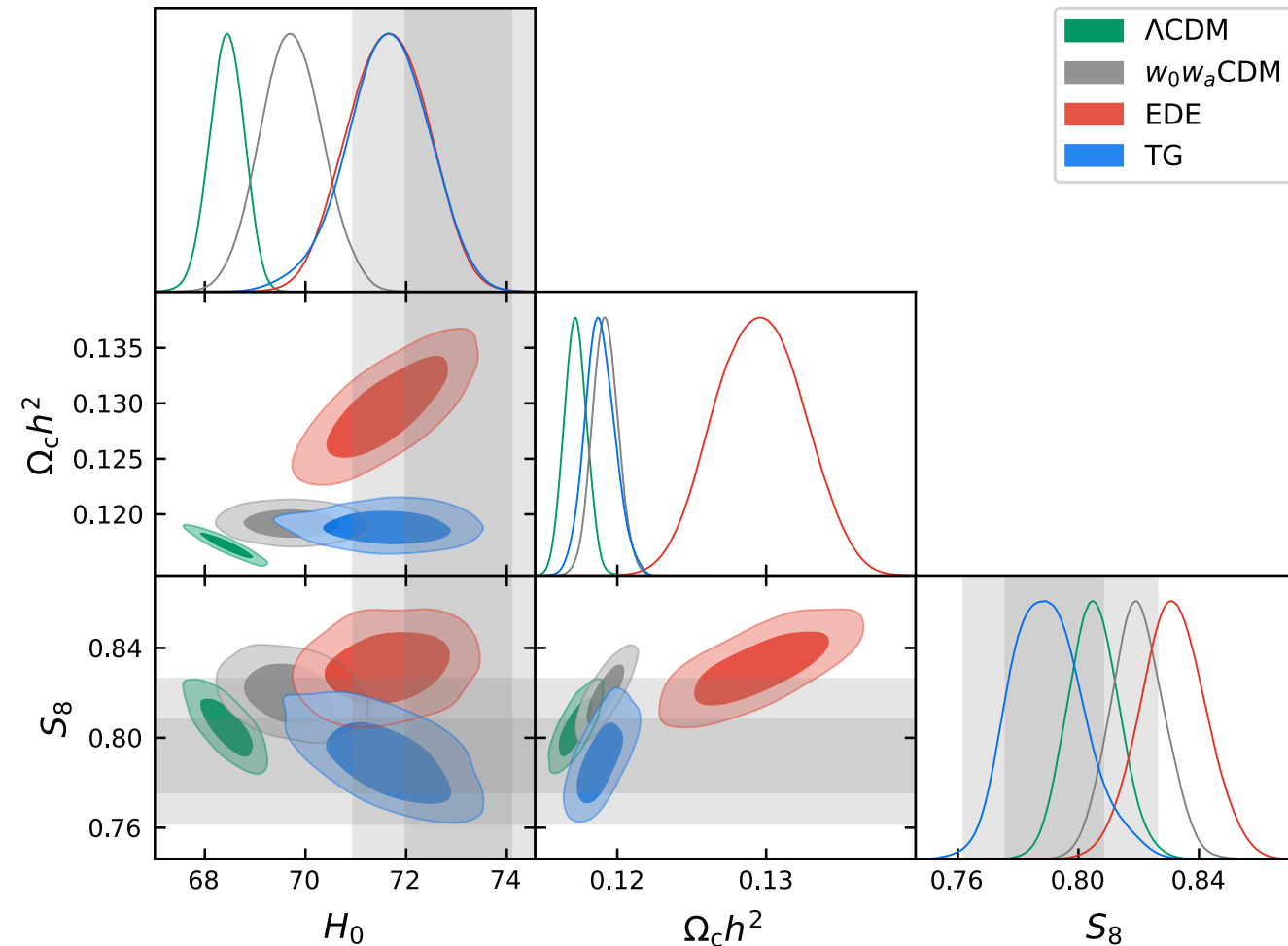
- Weak $\leftrightarrow \ln B < +1 \leftrightarrow < 2.1\sigma$
- Moderate $\leftrightarrow \ln B < +2.5 \leftrightarrow < 2.7\sigma$
- Strong $\leftrightarrow \ln B < +5 \leftrightarrow < 3.6\sigma$
- $\ln B = 11 \leftrightarrow 5\sigma$

Nested Sampling:

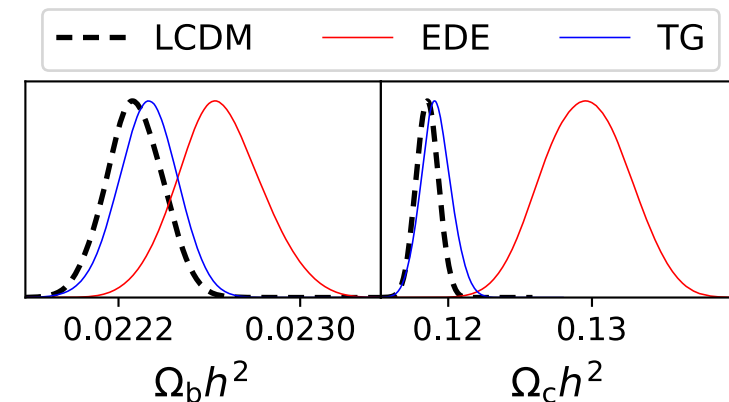
- Better performance with non-Gaussian posterior
- Bayes evidence and model comparison

- CMB: Planck PR4 TTTEEE, low l TTEE, PR4 lensing
- BAO: DESI DR1
- SNIa: Pantheon+
- H_0 : SHoES calibrated Pantheon+
- Baseline = CMB+DESI BAO+SNIa

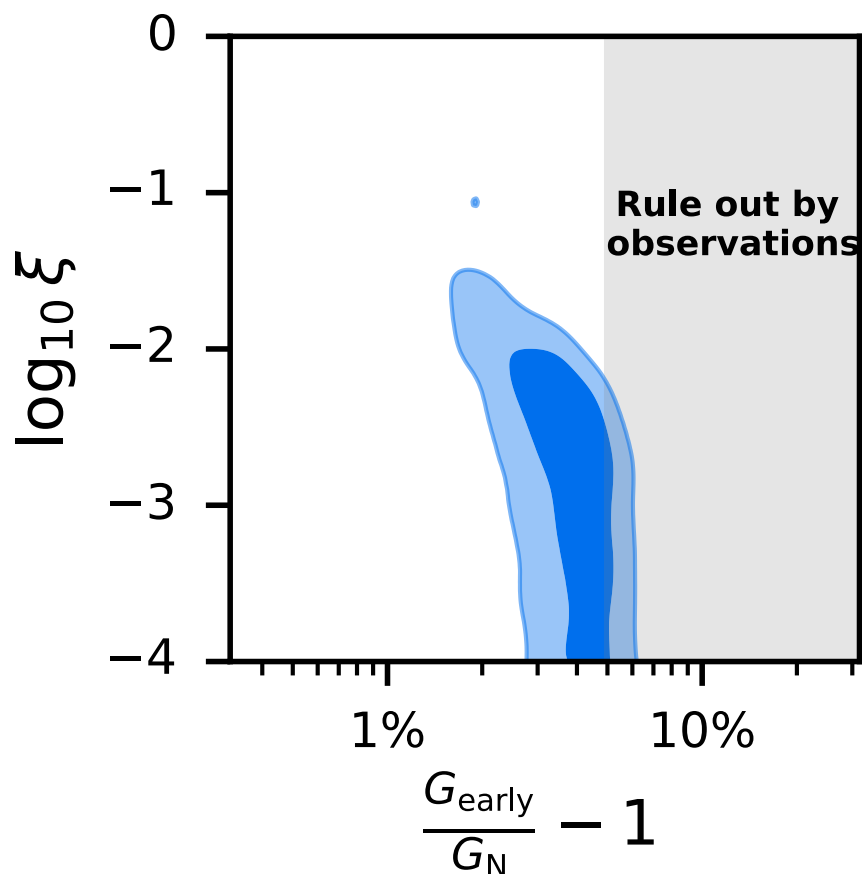
Full TG: Cosmological parameters



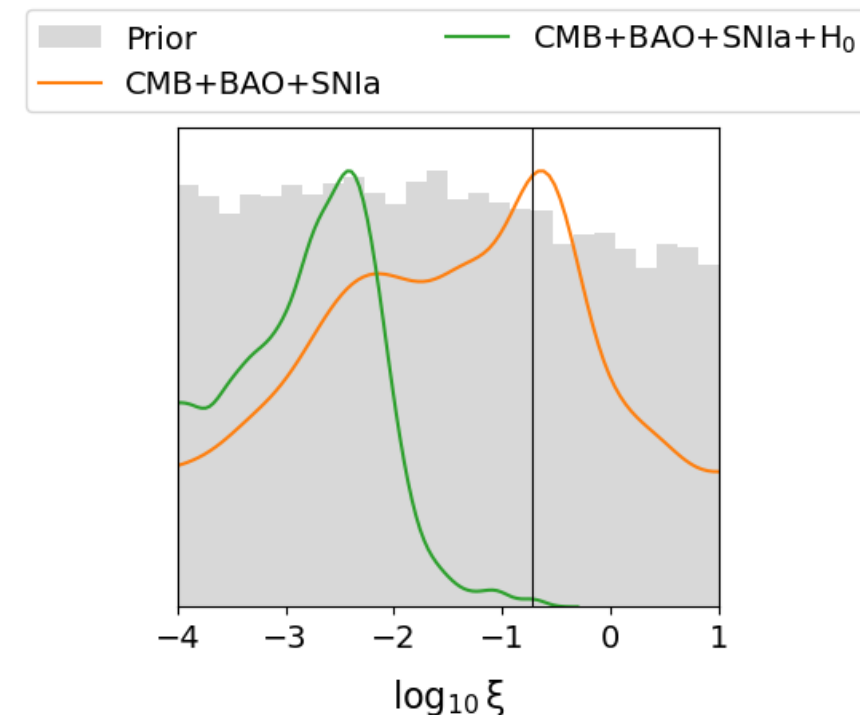
- Pre-recombination NMC important
 - $H_0 = 66.8 \pm 0.5 \Rightarrow H_0 = 71.8 \pm 0.9$
 - Stronger gravity in CMB negates the need to increase $\omega_{c,b}$
- Post-recombination NMC important
 - BAO no longer fixes Ω_m , thus compatibility does require $\Omega_m h^2$ increasing with H_0
 - Address DESI BAO inconsistency with CMB



Full TG: Modified Gravity



CMB+BAO+SN Ia+SHoES:
 $> 4\sigma$ indication of
stronger gravity $\frac{G_{CMB}}{G_N} =$
 1.04 ± 0.01 at CMB



- Double peak in CMB+BAO+SN Ia
- Local Hubble measurement picks out the scaling case $\xi < 3/16$

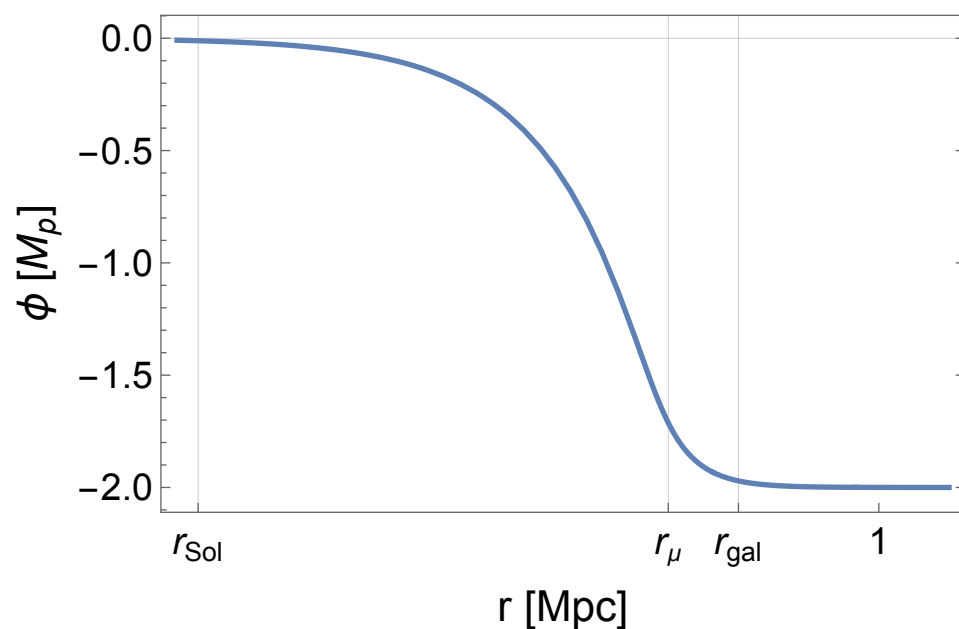
Consistent with BBN constraint $\frac{G_{BBN}}{G_N} = 0.99^{+0.06}_{-0.05}$ [J.Alvey et al. 2019]

Full TG: Screening?

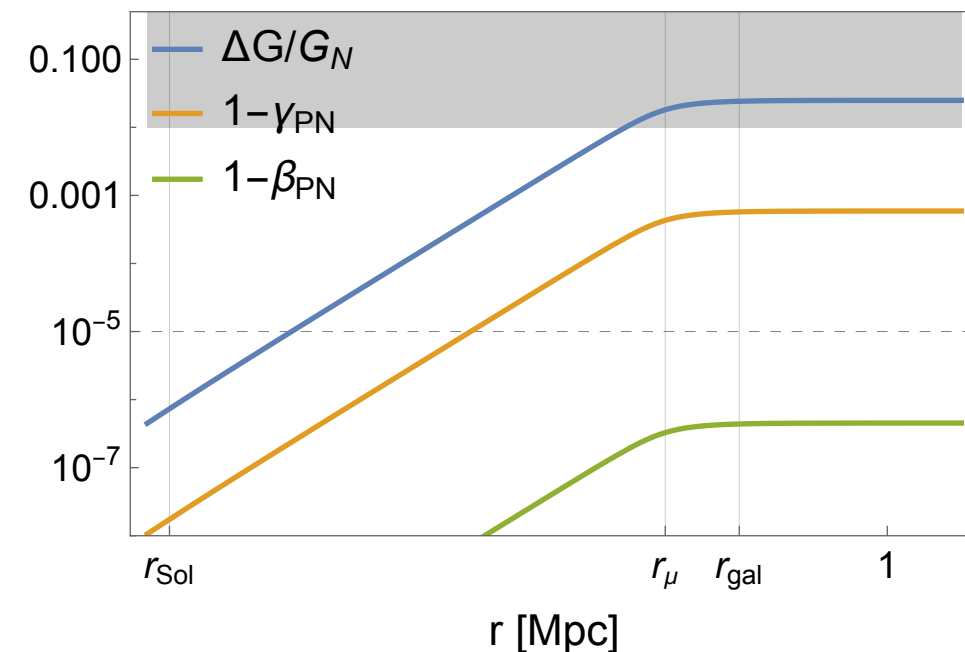
TG as an EFT of gravity on cosmological scales, screening can happen for new operators appearing on small scales.

- Example:

$$\mathcal{L} = \frac{M_p^2}{2} [1 - \xi(\phi/M_p)^2] R + X - \frac{1}{M_p^2 \mu^2} X^2 - V_0 \exp(-\lambda\phi/M_p)$$



$$r_\mu = \mu^{-1} = 1 \text{ kpc}$$



Summary

- Thawing Gravity: $L = \frac{M_p^2}{2} [1 - \xi(\phi/M_p)^2] R + X - V_0 e^{-\lambda\phi/M_p},$
 - Consistency between DESI BAO and CMB
 - Consistency between local Hubble measurement and CMB
 - NMC is universal: coupled to all matter forms; relevant in all epochs of Universe evolution
 - Two natural “thawing points” z_{eq} and z_{acc} when curvature R changes behavior
 - Possibility to screen MG effects on small scales

Thank You!



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	Λ CDM	$w_0 w_a$ CDM	Quintessence	Thawing Gravity
CMB	10972.6	10970	10972.9	10970.8
DESI BAO	15.8	12.4	18.6	13.7
SNIa	1404.8	1403.4	1402.8	1402.9
Total	12393.2	12385.8	12394.3	12387.4

