Constraining Thawing Gravity with DES Y3 in the DESI Era

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Cosmology Before DESI

1. ΛCDM has been the standard model in cosmology for over 20 years
2. Over the last decade a number of tensions appeared as observational precision had increased

H_0 Tension

1. $H^2 = H_0^2(\Omega_m(1+z)^3 + \Omega_{rad}(1+z)^4 + \Omega_{DE})$
2. Main source: Type Ia SNe
3. $2-6\sigma$ difference in M_{SN} calibration from local Cepheids and from CMB+BAO
4. Cannot be resolved by purely late-type dynamic Dark Energy

S_8 Tension

1. S_8 describes matter density fluctuation amplitude as constrained by lensing data
2. $S_8 = \sigma_8 (\frac{\Omega_m}{0.3})^\alpha, \alpha \approx 0.25..0.5$ for different lensing sources (CMB/LSS)
3. $1 - 3\sigma$ tension between various datasets

DESI and Dark Energy

1. First results published in late 2024 and early 2025
2. Claimed strong preference for deviation from the cosmological constant DE model (but not in the direction Cepheid-SNe would want)
3. Exhibits tensions with both CMB and LSS
4. Analysis is usually performed for a simple $w_{DE} = w_0 + w_a(1 - a)$ ansatz

Thawing Gravity (Ye et al. 2407.15832, 2411.11743)

TG is an *effective* Horndeski model with an auxillary field ϕ:

$$\mathcal{S}_{TG} = \int dx^4 \sqrt{-g} \left[\frac{M_p^2}{2} f(\phi) R + X - V(\phi) \right] + \mathcal{S}_m[g_{\mu\nu}], \tag{1}$$

$$X \equiv -\frac{1}{2} g^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi, \quad M_p^2 = (8\pi G_{\mathrm{N}})^{-1}$$

with the corresponding field equations

$$f G_{\mu\nu} + \Box f g_{\mu\nu} - \nabla_\mu \nabla_\nu f = \frac{1}{M_p^2} \left[T^{(\phi)}_{\mu\nu} + T^{(m)}_{\mu\nu} \right], \tag{2}$$

$$-\Box \phi = \frac{M_p^2}{2} f' R - V', \tag{3}$$

where $T^{(\phi)}_{\mu\nu} = \phi_{(\mu)} \phi_{(\nu)} + g_{\mu\nu} [X - V]$ and $T^{(m)}_{\mu\nu}$ is the matter component

Thawing Gravity

From (3) the scalar field ends up with an effective potential:

$$V_{\text{eff}} = \frac{M_p^2}{2} R f(\phi) - V(\phi). \tag{4}$$

There are no significant constraints on the shape of $V(\phi)$ and $f(\phi)$ so we'll use a simple exponential V and a quadratic f:

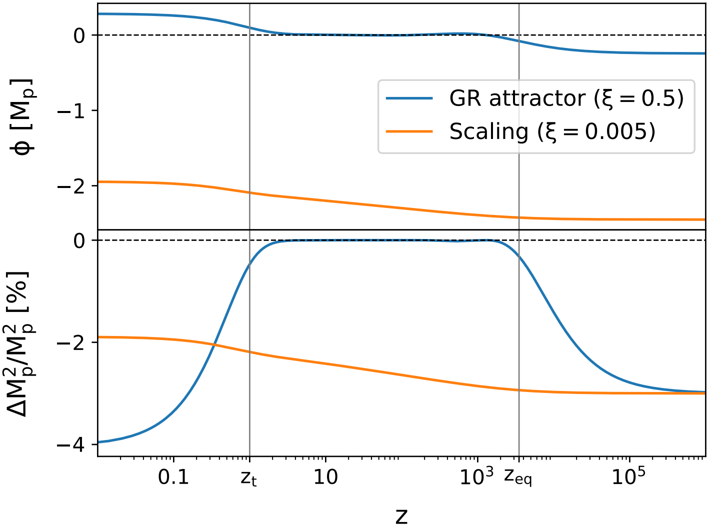
$$V(\phi) = V_0 \exp(-\lambda\phi/M_p), \quad f(\phi) = 1 - \xi(\phi/M_p)^2$$

In an FLRW background the field equations read

$$3M_p^2 H^2 \left[1 - \xi(\phi/M_p)^2\right] - 6\xi\phi\dot{\phi}H = \frac{1}{2}\dot{\phi}^2 + V(\phi) + \rho_m, \tag{5}$$

$$\ddot{\phi} + 3H\dot{\phi} + V_\phi + 6\left(2 + \frac{\dot{H}}{H^2}\right)\xi H^2\phi = 0. \tag{6}$$

Thawing Gravity behavior (from Ye 2411.11743)



Simple case: GR Attractor

1. Achieved for $\xi > 3/16$
2. ϕ is frozen at some ϕ_{ini} during RD, oscillates around 0 during MD effectively recovering GR
3. Produces an EDE-like effect between z_{eq} and z_{rec}, then acts as a weakly dynamic DE after $z_t \sim 1$
4. Just 3 new parameters: ξ, λ, V_0 (and $\frac{V_0}{3H_0^2}$ replaces Ω_Λ, so really just 2 more parameters than ΛCDM)
5. ξ, λ are sampled, V_0 is produced by shooting to match H_0

$\mathcal{H}$-EFTCAMB

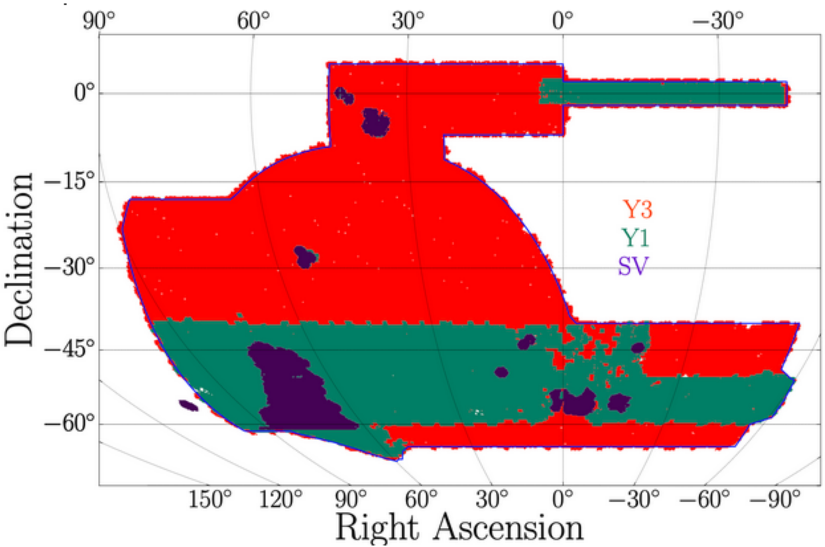
EffectiveFieldTheory with CAMB

1. EFTCAMB is an extention of CAMB (Code for Anisotropies in the Microwave Background)
2. Allows for modeling linear perturbations in various modified gravity/generic DE models
3. $\mathcal{H}$-EFTCAMB introduced several ways of implementing Horndeski-type models

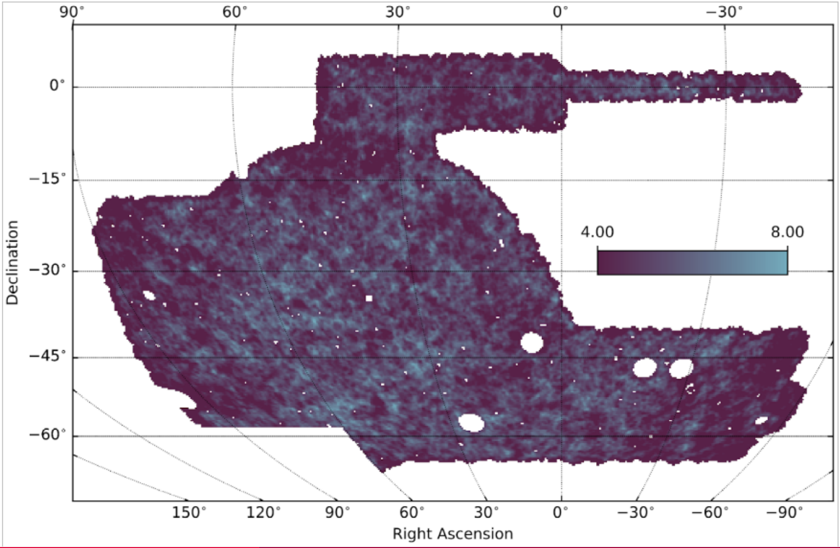
DES Y3

1. Results from the first three years of the Dark Energy Survey collaboration *(not to be confused with the Dark Energy Spectroscopic Instrument (DESI) collaboration)*
2. 10^8 galaxies mapped in the southern hemisphere
3. A LOT of data products handled by a complex "in-house" suite called `CosmoSIS`
4. We are interested in the $3 \times 2pt$ analysis (cross-correlations between weak lensing observables and galaxy clustering)

DES Y3 coverage map (2011.03407)



DES Y3 source n_{eff} $(gal/arcmin^2)$ map (2011.03408)



CosmoSIS and Cobaya

1. $\mathcal{H}$-`EFTCAMB` is easily interfaced with the `Cobaya` sampling/analysis suite (with a separate module for shooting at V_0)
2. `CosmoSIS` is *not so easily* interfaced with `Cobaya` using the `cosmosis2cobaya` package
3. Additional scale cuts (removing non-linear scales) are applied to `CosmoSIS` data when working in modified gravity

CMB, BAO, SN

1. Standard Planck PR3 primary CMB spectra and PR4 lensing
2. BAO measurements from DESI DR2
3. Uncalibrated Type Ia SNe from the Pantheon+ catalog

Nikolay Nikolayevich Govorun ate my homework

All necessary measures are currently being taken to restore the operation of /lustre/projects.

We apologize for any inconvenience caused.

HybriLIT Team

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Approximate results so far

1. Without DES: $\lambda \sim 1.5, \xi \sim 0.5, \frac{V_0}{3H_0^2} \sim 0.7$
2. Ω_m has a bimodal distribution (and therefore H_0 and S_8 do too), DES seems to dampen one of the peaks
3. Standard MCMC is ill-fit for the task, switching to nested sampling...

Thank you for your attention!

Scaling solution

In general, the behavior of ϕ during RD and MD (where V and V_ϕ are both $\ll H^2$) can be approximated as

$$\phi \simeq \begin{cases} \phi_{\text{ini}} & \text{RD}, \\ \phi_{\text{ini}} \exp\left[\frac{-3 \pm \sqrt{9 - 48\xi}}{4}(N - N_i)\right] & \text{MD}, \end{cases} \tag{7}$$

where $N = \ln a/a_0$
For $\xi > 3/16$ the MD part of the solution is an oscillator (this is the GR attractor), while for $\xi < 3/16$ it's a (slowly) decaying mode with $\phi \propto a^{-\gamma},\ 0 < \gamma < 3/4$