Shift-symmetric Horndeski models in the asymptotically safe swampland?*

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Horndeski

What?
- modification of General Relativity adding a scalar ϕ (scalar-tensor-theory)
- most general formulation with 2$^{\text{nd}}$ order field equations
  - → no Ostrogradski instabilities/ ghosts
- tightly constrained by GW170817

Why?
- dark matter
- Hubble tension
- inflation
- dynamical explanation of dark energy (in this case)

Model

What?
- shift-symmetric $\phi(x) \to \phi(x) + a$
- minimal coupling to gravity
- truncation: mass dimension < 8
- Eucl. effective action ($\chi = (\partial\phi)^2/2$):

$$\Gamma_{k,\text{H}} = \Gamma_{k,\text{EH}} + \int_x \left[Z_\phi \chi + \bar{h}\chi\Box\phi + \bar{g}\chi^2\right] \quad (1)$$

→ dim.ful couplings $\bar{h} = hk^{-3}$, $\bar{g} = gk^{-4}$

Why?
- $c_T = 1$ (complying with GW170817)
- gravity+matter: mainly monomials with symmetries of kinetic terms of interest

Cosmological constraints

Literature
- ∃ 5 Horndeski parameters α_i
- of interest for model: $\alpha_B(\bar{h}, \bar{g})$
- stable cosmological evolution under perturbations: $|\alpha_B| < 10^{-2}$ [1]

Assumptions
- scalar acts as dark energy at present
  - → equation of state: $w_{\phi,0} \simeq -1.0$
  - → density parameter: $\Omega_{\phi,0} \simeq .69$

Bounds on model parameters

$$0 < |\bar{h}| \lesssim 2 \times 10^{33}\text{eV}^{-3} \quad (2)$$
$$|\bar{g}| \simeq 9 \times 10^{7}\text{eV}^{-4} \quad (3)$$

Methods

Gravity
- Einstein-Hilbert truncation
- Landau-gauge
- (G_*, Λ_*) treated parametrically

Cosmological Constant
- here: $\Lambda_* = 0$
- also checked Λ_* arbitrary (paper)
  - → does not change argument

Derivation of beta-functions
- solutions of truncated Wetterich equation
  - → Litim-regulator
  - → $\mathcal{PF}^{-1}$-expansion

Functional renormalisation group analysis

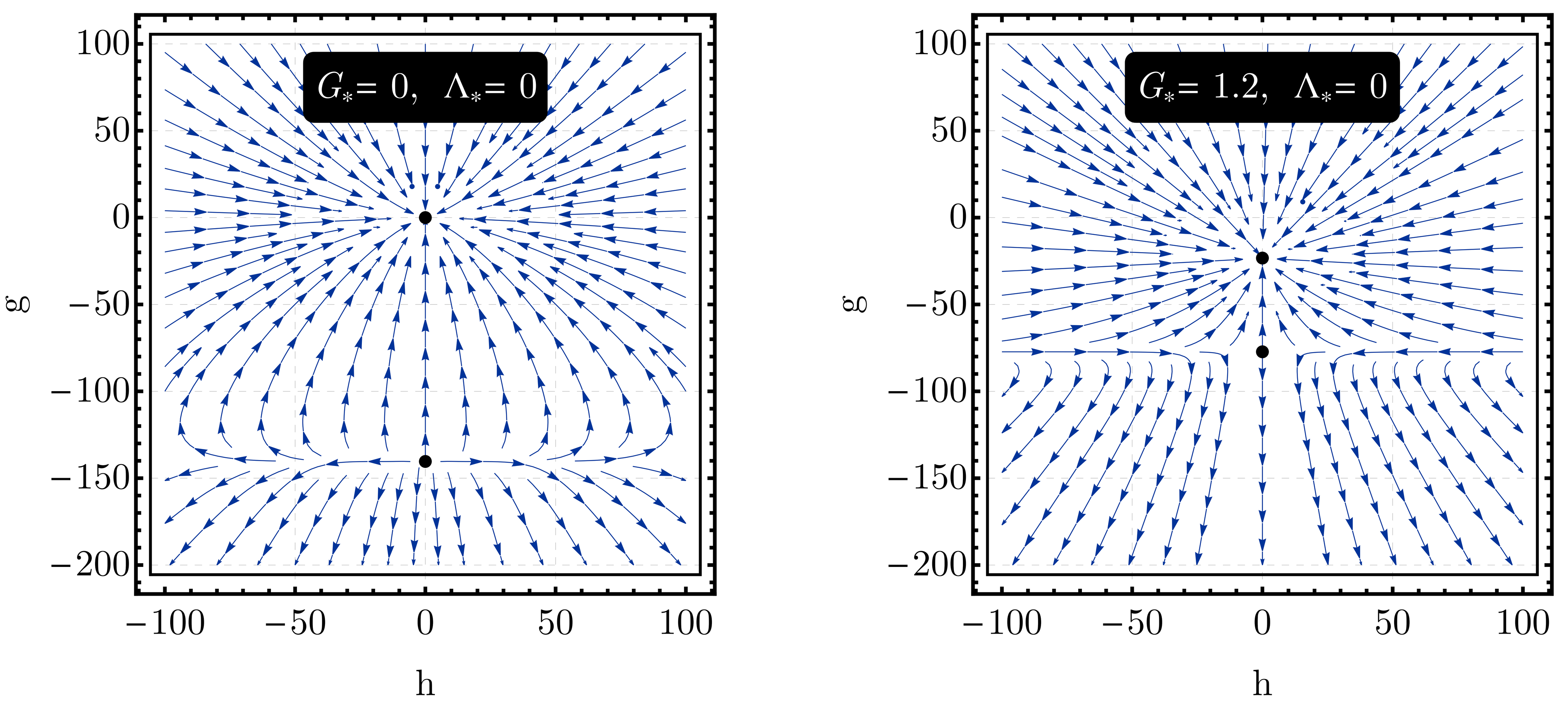

Figure 1: Phase portraits of dimensionless couplings with (right) and without (left) gravity.

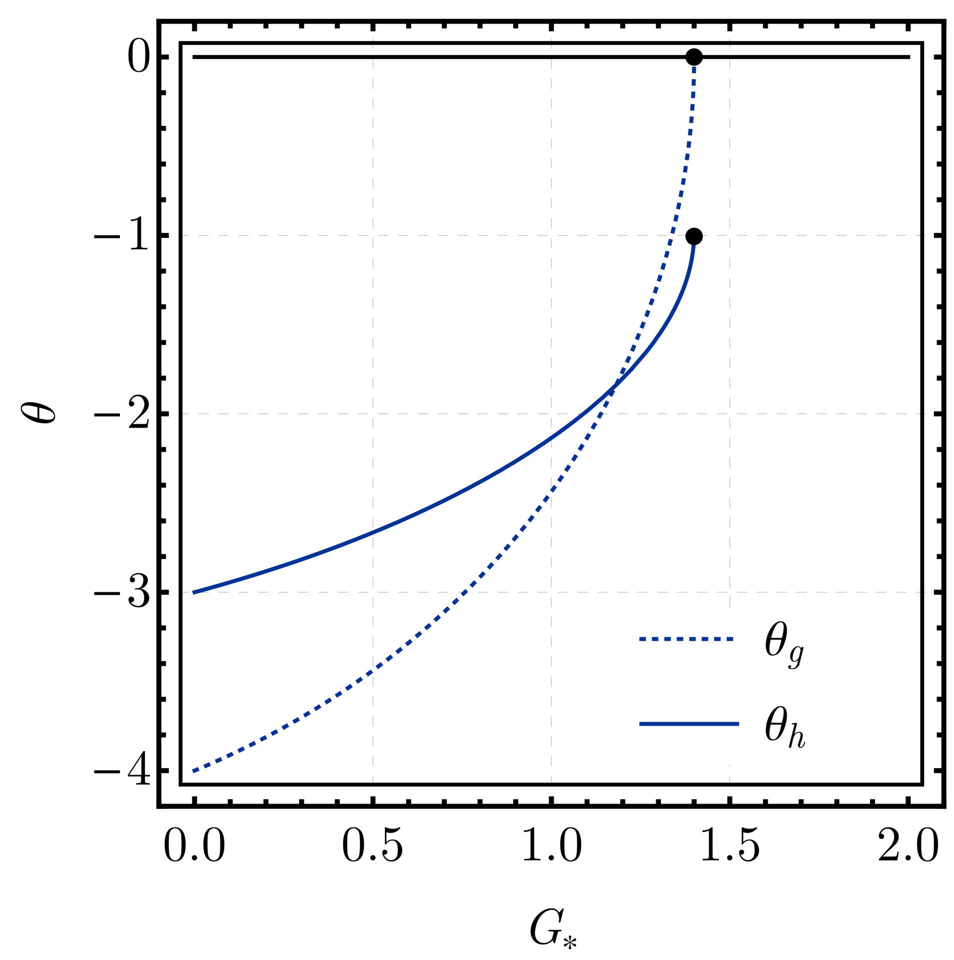

Figure 2: Critical exponents at the shifted Gaussian fixed point. Black dots indicate weak gravity bound.

Takeaways from Fig. 1
- two fixed-point candidates approaching each other with increasing G_*
  - → Gaussian fixed point gets shifted (sGFP)
- both disappear after meeting at $G_* \simeq 1.4$. → weak gravity bound
- non-Gaussian fixed point in strongly non-perturbative regime + large change in critical exponent → likely artefact of truncation
- $h = 0$ at both fixed points with and without gravity
  - → reason: cubic interaction breaks reflection symmetry $\phi \to -\phi$

Takeaway from Fig. 2
- both couplings irrelevant at sGFP ∀ G_*

Prediction from asymptotic safety:

$$\bar{h}_{\text{AS}} = 0 \quad (4)$$

Effective field theory analysis

Assumption
- Near-perturbative g at $k = m_p$

Prediction from effective field theory

$$|\bar{g}_{\text{EFT}}| < m_p^{-4} \sim 10^{-112}\text{eV}^{-4} \quad (5)$$

Additional constraint
- Landau pole-like divergence for positive g

Conclusion

shift-symmetric Horndeski model tightly constrained by imposing stability and dark energy-like behaviour

Asymptotic safety (usual caveat: in this truncation)
- → predicts vanishing cubic interaction
- → not compatible with cosmological constraints
- → not improved by next term in truncation (not shown here)

Effective field theory
- → predicts very weak quartic interaction
- → not compatible with cosmological constraints
- → solved by assuming strongly nonperturbative couplings at $k = m_p$

Asymptotically safe gravity + matter = strong constraining power!

Contact Information

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Future Research

- enlarge truncation
- fate of terms implying $c_T \neq 1$?

References

* to be on the arXiv soon!
[1] Creminelli *et al*, JCAP 05 (2020) 002