Inflation from Pure Geometry: Precision Cosmology in $R + R^2 - W^2$ Gravity

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Motivation

Starobinsky inflation provides a simple geometric mechanism for the accelerated expansion of the early Universe. Nonetheless, a complete effective theory of spacetime geometry at quadratic order in curvature must contain both R^2 and the Weyl-squared invariant:

$$\boxed{S[g_{\mu\nu}] = \frac{1}{16\pi G}\int d^4x\,\sqrt{-g}\,\left(-2\Lambda + R + \alpha R^2 - \beta W^2\right),} \tag{1}$$

where we assume the hierarchy of scales $G\hbar \ll \beta \ll \alpha \ll 1/\Lambda$. While in a FLRW background the W^2 term does not modify the inflationary solution, it has nontrivial modifications to the scalar and tensor perturbations. However, a direct higher-derivative treatment typically introduces pathological ghost solutions, threatening the consistency of the theory.

Main question: Can we isolate the physical W^2 corrections and extract self-consistent, observable predictions? We address this question in [1].

Physical setting and techniques

Inflation from geometry. In the absence of the inflaton, the background geometry itself becomes inflationary due to the contribution of the R^2 term.

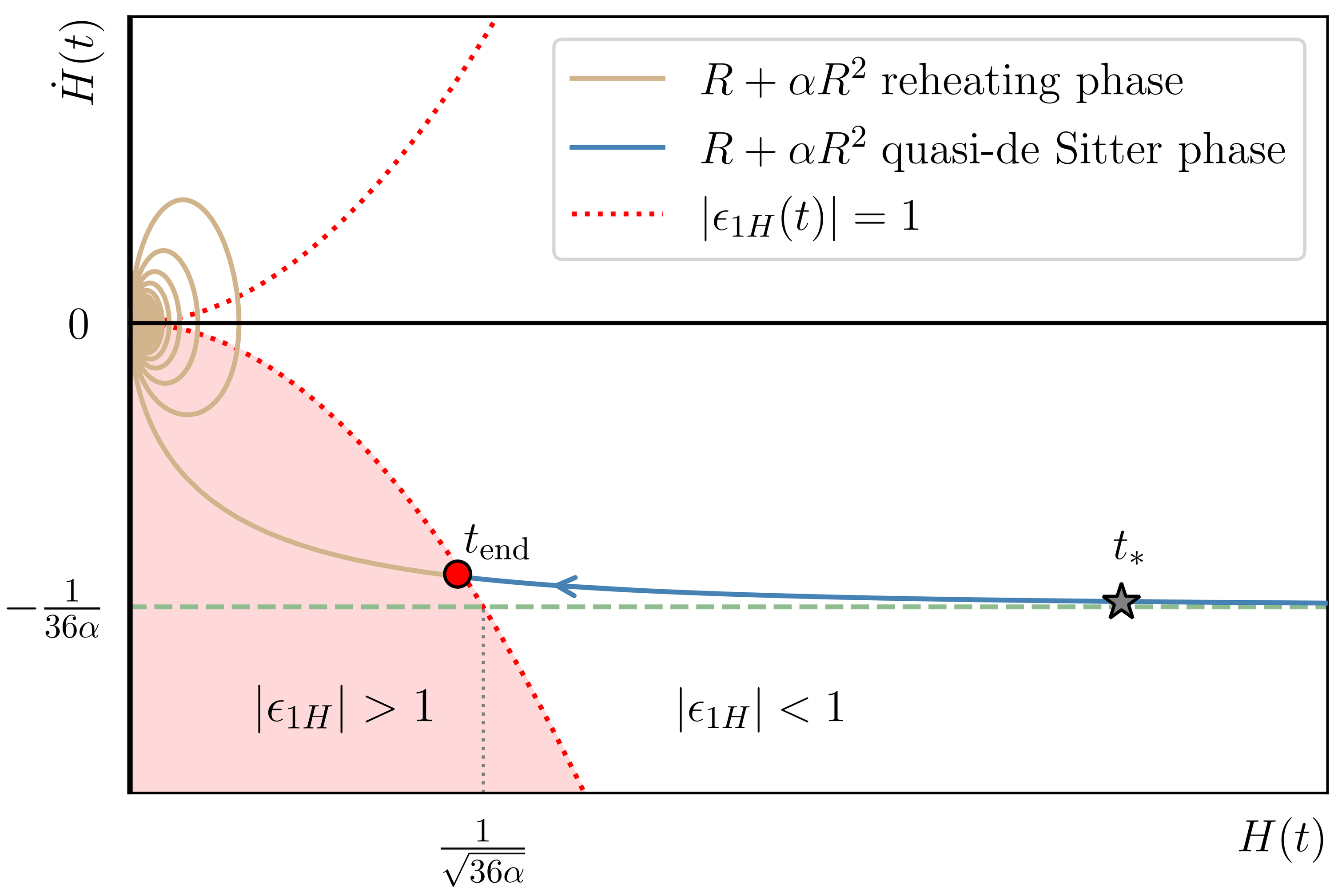

Figure 1. Inflationary solution in the geometric framework.

Reduction of order. We work at linear order in $\frac{\beta}{\alpha} \ll 1$, and retain only solutions that are analytic in β and continuously connected to the Starobinsky sector as $\beta \to 0$. This removes the nonanalytic higher-derivative branch from the effective description while preserving the healthy DOFs.

Effective perturbation theory. After expanding around the inflationary background, both scalar and tensor perturbations can be written as

$$S^{(2)}[\psi] = \int dt\,\frac{d^3k}{(2\pi)^3}\,a(t)^3 Z_\psi(t)\left[\frac{|\dot\psi|^2}{2} - c_\psi(t)^2\frac{k^2}{a(t)^2}\frac{|\psi|^2}{2}\right], \tag{2}$$

where the SVT mode $\psi = \mathcal{R},\gamma$, and Z_ψ and c_ψ are sector-dependent kinetic amplitudes and propagation speeds. We find $c_t/c_s \simeq 1 + \frac{\beta}{6\alpha}$.

Precision calculation. The Green's-function method [2] is used to compute the scalar and tensor power spectra up to next-to-next-to-next-to-leading order (N3LO) in the Hubble-flow expansion:

$$\mathcal{P}^{(\psi)}_{\rm qBD} = \frac{\hbar\, H_*^2}{4\pi^2 Z_*^{(\psi)} c_*^{(\psi)3}}\left[p_{0*}^{(\psi)} + p_{1*}^{(\psi)}\ln(\tfrac{k}{k_*}) + p_{2*}^{(\psi)}\ln(\tfrac{k}{k_*})^2 + p_{3*}^{(\psi)}\ln(\tfrac{k}{k_*})^3\right]. \tag{3}$$

Predictions vs Observations

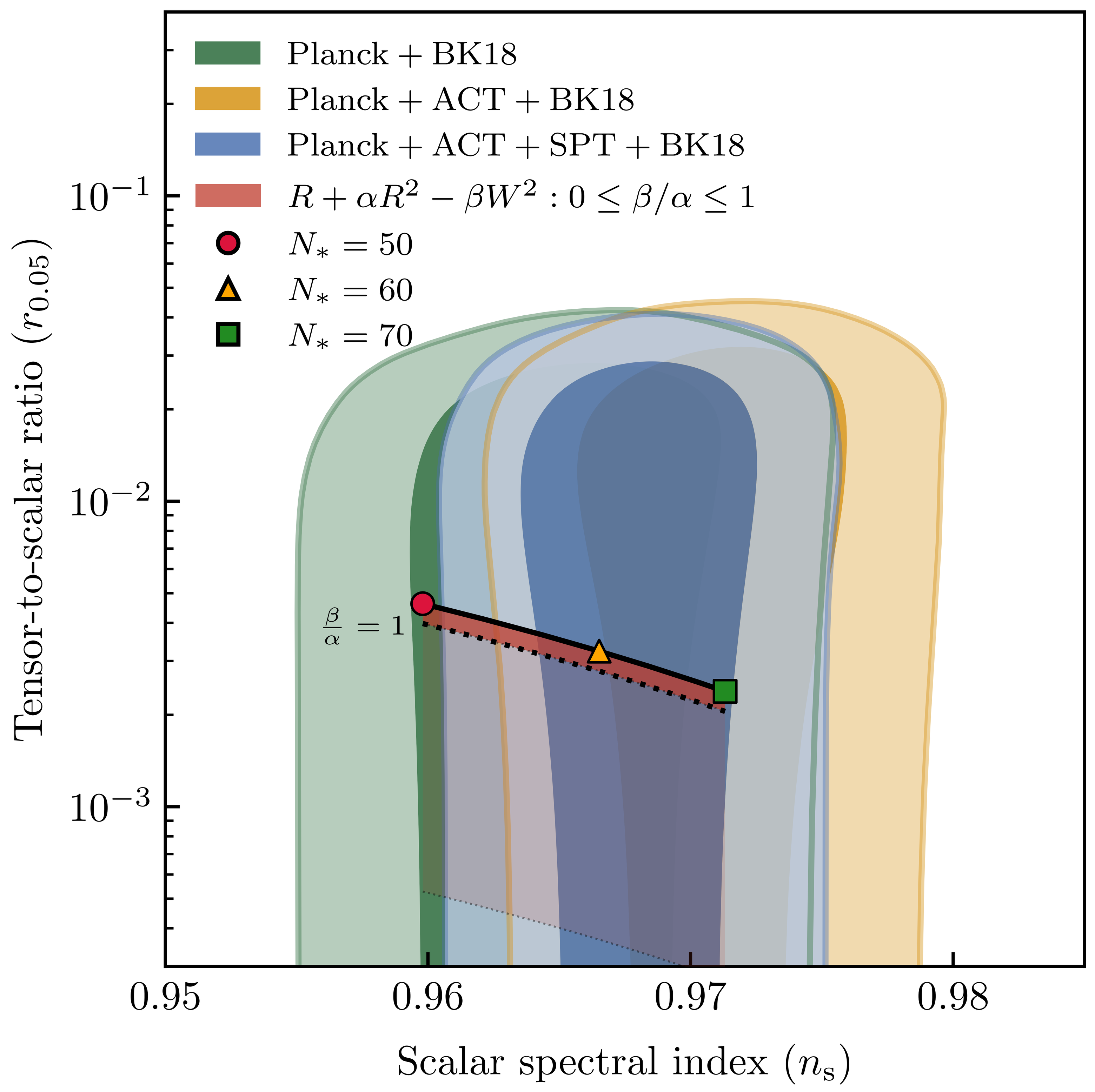

Figure 2. Predictions in the (n_s, r) plane compared with joint ACT DR6, Planck, BICEP/Keck, BAO, and lensing constraints.

Expressing the predictions for the tensor-to-scalar ratio r directly in terms of the observable scalar tilt n_s gives the following relation:

$$\boxed{r = 3\left(1-\frac{1}{6}\frac{\beta}{\alpha}\right)(n_s-1)^2 - \frac{7}{2}\left(1-\frac{23}{84}\frac{\beta}{\alpha}\right)(1-n_s)^3.} \tag{4}$$

The scalar and tensor runnings take the form

$$\frac{dn_s}{d\ln k} = -\tfrac{1}{2}(1-n_s)^2 - \tfrac{5}{48}(1-n_s)^3, \qquad \frac{dn_t}{d\ln k} = -\tfrac{3}{8}(1-\tfrac{\beta}{6\alpha})(1-n_s)^3. \tag{5}$$

Conclusions

- The W^2 term modifies both the scalar and tensor perturbations. Reduction of order provides a self-consistent treatment of the corrections without propagating the pathological higher-derivative DOFs.
- The main signature is a suppression of r relative to Starobinsky inflation. While the measurements of the scalar amplitude and n_s fix the inflationary scale α, a measurement of r would constrain β/α. Further CMB observations can definitely put the theory to the test.

This EFT provides a purely geometric mechanism for inflation and yields precise and falsifiable predictions.

References

[1] E. Bianchi and **M. Gamonal**, Phys. Rev. D **112**, 12 124006 (2025). [arXiv:2506.10081].

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