Higgs-Dilaton inflation in Einstein-Cartan gravity

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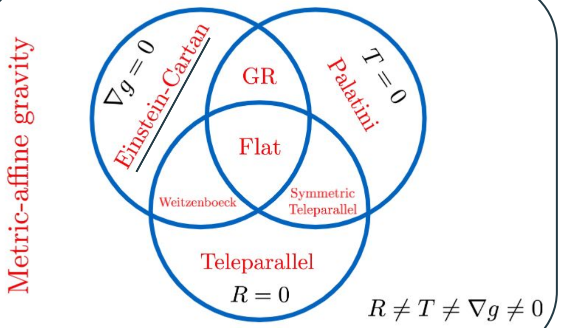
Testing the Nature of Gravity



Different formulations yield the same theory, unless… we introduce some new ingredient

Non-minimal coupling: $$\frac{\xi h^2}{2} R$$

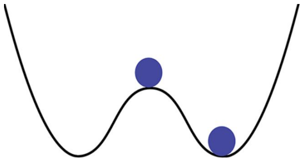
Higgs + Non-minimal coupling = Inflation

<u>WE CAN CONSTRAIN THE MODEL</u>

The Role of Scale Symmetry

$$\begin{cases} g_{\mu\nu}(x) \mapsto g_{\mu\nu}(\sigma x) \\ \Phi(x) \mapsto \sigma^{d_\Phi} \Phi(\sigma x) \end{cases}$$

Spontaneously broken symmetry



Motivations

- Protect the Higgs mass from large radiative corrections
- All the scales in the model have a common origin
- The SM+gravity is approximately scale invariant during inflation

Consequences

- 1 extra scalar degree of freedom: **DILATON**
- 6 free parameters

Why Einstein-Cartan Gravity?

- The commonly used Palatini and metric formulations can be seen as special cases of the Einstein-Cartan one

- Einstein-Cartan gravity allows for the presence of fermions that can couple with torsion

- It can be seen as the gauge theory of the Poincaré group, putting gravity on the same footing as the other fundamental forces

The Model

$$
\begin{cases}
S_0 = \int d^4x\sqrt{-g}\left[\frac{\tau\chi^2+\xi h^2}{2}R - \frac{1}{2}(\partial h)^2 - \frac{1}{2}(\partial\chi)^2 - U(\chi,h)\right] \\
S_{\rm NY} = \frac{1}{2}\int d^4x\,(\tau_\eta\chi^2+\xi_\eta h^2)\partial_\mu\left(\sqrt{-g}\epsilon^{\mu\nu\rho\sigma}T_{\nu\rho\sigma}\right) \\
S_{\rm Holst} = \frac{1}{2\bar{\gamma}}\int d^4x\sqrt{-g}\,(\tau\chi^2+\xi_\gamma h^2)\varepsilon^{\mu\nu\rho\sigma}R_{\mu\nu\rho\sigma}
\end{cases}
$$

$$\boxed{S = S_0 + S_{\rm Holst} + S_{\rm NY}}$$

SSB potential

$$U(\chi,h) = \frac{\lambda}{4}\left(h^2-\alpha\chi^2\right)^2 + \beta\chi^4$$

Einstein-Frame: original recipe

1. Remove the coupling to curvature with a Weyl rescaling of the metric
2. Solve the equation of motion for the non-dynamical anti-symmetric part of the connection
3. Plug back the solution into the action

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{2} - \frac{1}{2}g^{\mu\nu}K_{ab}\partial_\mu\varphi^a\partial_\nu\varphi^b - V(\varphi)\right]$$

$$\boxed{\varphi^a = (\chi,h)^T}$$

DANGER

There are 2 fields in the potential

Non-Gaussianities

Isocurvature Perturbations

Is it really a 2-field model?

Scale symmetry comes with a conserved current

$$J_\mu = -K_{ab}\partial_\mu\varphi^a\Delta\varphi^b$$

Change of variables

$(\chi, h) \to (\rho, \theta)$

Inflaton

Dilaton

$$\boxed{J_\mu = M_P K_{\rho\rho}(\theta)\partial_\mu \rho}$$

Final action, with only one field in the inflationary potential

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{2} - \frac{1}{2}K_\theta(\theta)(\partial\theta)^2 - \frac{1}{2}K_\rho(\theta)(\partial\rho)^2 - V(\theta)\right]$$

Holst Inflation

$$\theta = \tau \frac{h^2 + \chi^2}{\Omega^2} \longrightarrow \begin{cases} K_\theta(\theta) = -\frac{1}{4\theta}\left(\frac{1}{\kappa_H\,\theta + c} - \frac{1}{\kappa_H(\theta - 1)}\right) + F_\gamma(\theta) \\ V(\theta) \simeq \frac{\lambda}{4\kappa_H^2}(1-\theta)^2 \end{cases}$$

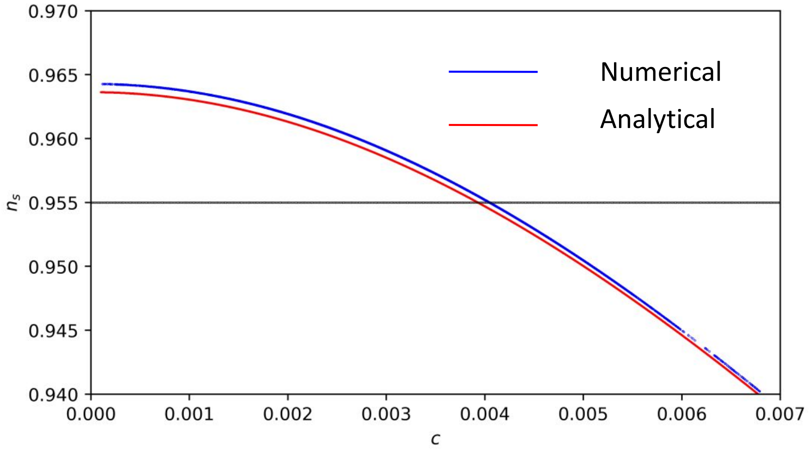
$$\boxed{\begin{array}{c} \kappa_H = -\xi\left(1 - \frac{\tau}{\xi}\right) \\ c = \tau\left(1 - \frac{\tau}{\xi}\right) \end{array}}$$

Prediction for the inflationary observables

Spectral tilt: $$n_s \simeq 1 - 8c$$

Tensor-to-scalar ratio $$r \simeq \frac{2}{-\kappa_H N^2}$$

N = number of e-folds



Nieh-Yan Inflation

$$K_\theta(\theta) = -\frac{1}{4\theta}\left[\frac{1}{\kappa_H\,\theta + c} - \frac{1}{\kappa_H(\theta-1)} - \frac{a^2}{(\theta-\theta_+)(\theta-\theta_-)}\right]$$

$$V(\theta) \simeq \frac{\lambda}{4\kappa_H^2}(1-\theta)^2$$

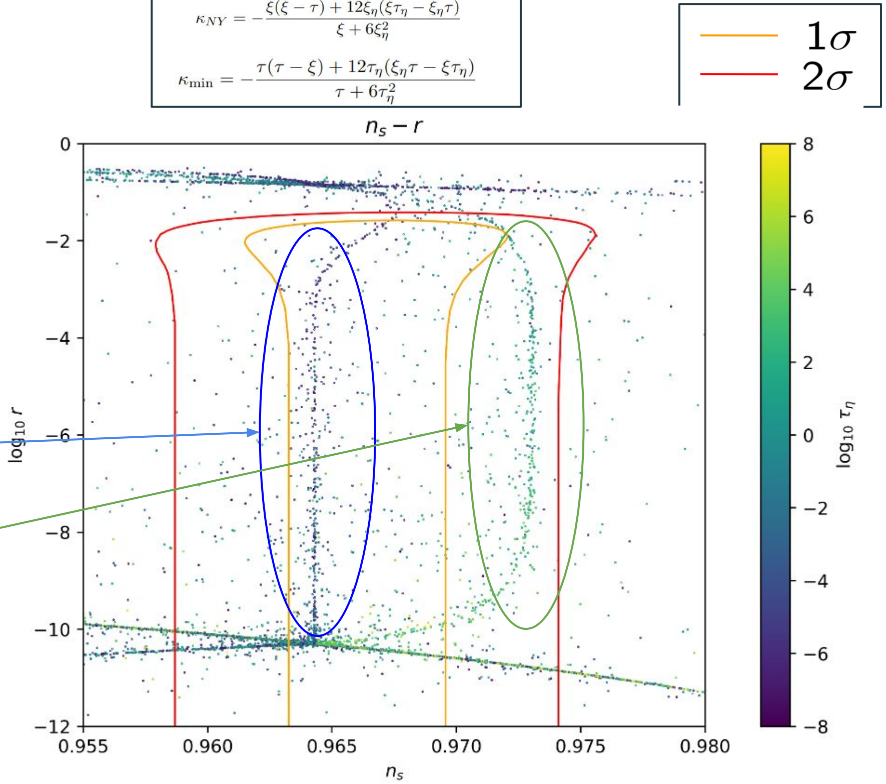
$$\theta_\pm = T \mp \Delta \quad a^2 = 12\,\sigma(\tau_\eta - \xi_\eta)^2$$

$$T = \sigma\left[\kappa_{NY}\left(\xi + 6\xi_\eta^2\right) + \kappa_{\min}\left(\tau + 6\tau_\eta^2\right)\right]$$

$$\Delta = \sigma\,\kappa_H(2T - \kappa_H^2)^{1/2} \qquad \sigma = \frac{\tau}{12\left(\xi_\eta\,\tau - \xi\tau_\eta\right)^2}$$

$$\kappa_{NY} = -\frac{\xi(\xi-\tau) + 12\xi_\eta(\xi\tau_\eta - \xi_\eta\tau)}{\xi + 6\xi_\eta^2}$$

$$\kappa_{\min} = -\frac{\tau(\tau-\xi) + 12\tau_\eta(\xi_\eta\tau - \xi\tau_\eta)}{\tau + 6\tau_\eta^2}$$



Quadratic pole attractor

Cubic pole attractor

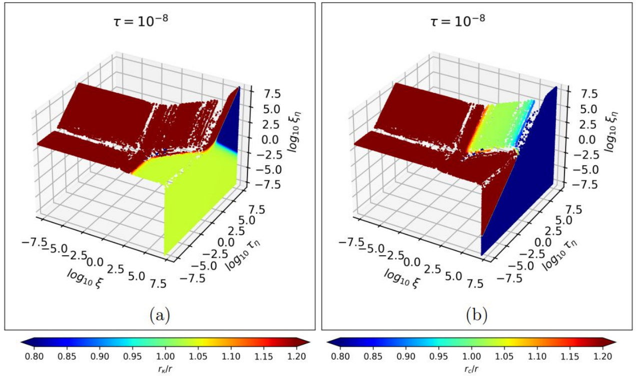
Quadratic pole VS Cubic pole

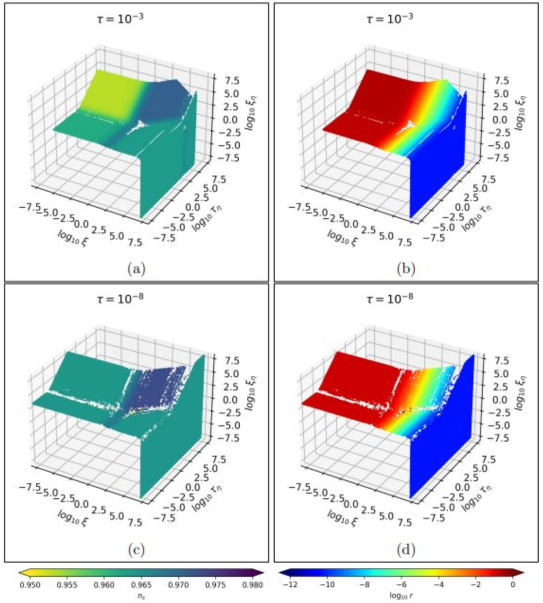
Quadratic pole prediction

$$\begin{cases} n_s \simeq 1 - \dfrac{2}{N} \\ r \simeq \dfrac{2}{-\kappa_H N^2} \end{cases}$$

Cubic pole prediction

$$\begin{cases} n_s \simeq 1 - \dfrac{3}{2N} \\ r \simeq \dfrac{2\,a}{N^{1/3}} \end{cases}$$





Future prospects

- Study particle production in the heating stage, after the end of inflation
- Study how the four-legs fermion-fermion interactions could mediate the production of feebly interacting species
- Include quantum corrections for the running of the Higgs quartic coupling

Thank you for the attention

BACKUP

Inflationary Observables

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{2} - \frac{1}{2}K_\theta(\theta)(\partial\theta)^2 - \frac{1}{2}K_\rho(\theta)(\partial\rho)^2 - V(\theta)\right]$$

$$\tilde{\theta} = \int \sqrt{K_\theta(\theta)}\, d\theta$$

$$\epsilon_V = \frac{1}{2}\left(\frac{V_{,\tilde{\theta}}}{V(\tilde{\theta})}\right)^2 \qquad \eta_V = \frac{V_{,\tilde{\theta}\tilde{\theta}}}{V(\tilde{\theta})}$$

$$\xi_V^2 = \frac{V_{,\tilde{\theta}}}{V^2(\tilde{\theta})}V_{,\tilde{\theta}\tilde{\theta}\tilde{\theta}} \qquad \varpi_V^3 = 2\epsilon_V\frac{V_{,\tilde{\theta}\tilde{\theta}\tilde{\theta}\tilde{\theta}}}{V(\tilde{\theta})}$$

Slow-roll parameters

Observables

$$\begin{cases} r = 16\epsilon_V \\ n_s = 1 - 6\epsilon_V + 2\eta_V \\ \alpha_s = -24\epsilon_V^2 + 16\epsilon_V\eta_V - 2\xi_V^2 \\ \beta_s = -192\epsilon_V^3 + 192\epsilon_V^2\eta_V - 32\epsilon_V\eta_V^2 - 24\epsilon_V\xi_V^2 + 2\eta_V\xi_V^2 + 2\varpi_V^3 \end{cases}$$