Higgs inflation at the hilltop

arXiv: 1802.09299

Vera-Maria Enckell, Kari Enqvist,
Syksy Räsänen and **Eemeli Tomberg**

eemeli.tomberg@helsinki.fi

COSMO-18, 29 August 2018

Higgs inflation at the hilltop

- Higgs inflation
  - Standard model Higgs field is inflaton
- Hilltop inflation
  - Slow-roll inflation near a local maximum of the scalar field potential

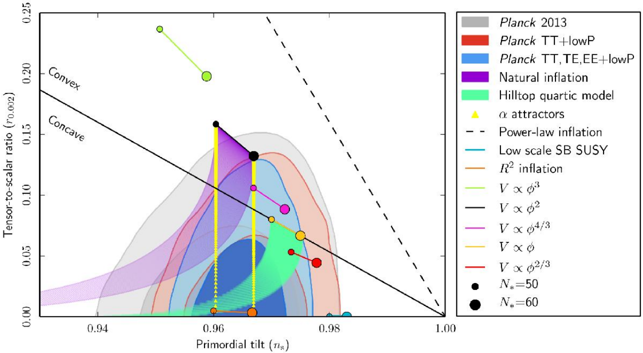
Motivation

- Higgs inflation: simple, desirable
  - Checking special cases increases parameter space for CMB-observables
  - Hilltop version not studied before in detail
- Hilltop inflation: easy to obtain enough e-folds, possibility of eternal inflation

Higgs inflation

- SM Higgs, tree-level potential:

$$V(h) = \frac{\lambda}{4} h^4$$



Not compatible with observations!

Higgs inflation with non-minimal coupling

- Introduce non-minimal coupling to gravity

$$S = \int d^4x\sqrt{-g}\left[-\frac{1}{2}\left(M^2 + \xi h^2\right) R + \frac{1}{2} g^{\mu\nu}\partial_\mu h \partial_\nu h - V(h)\right]$$

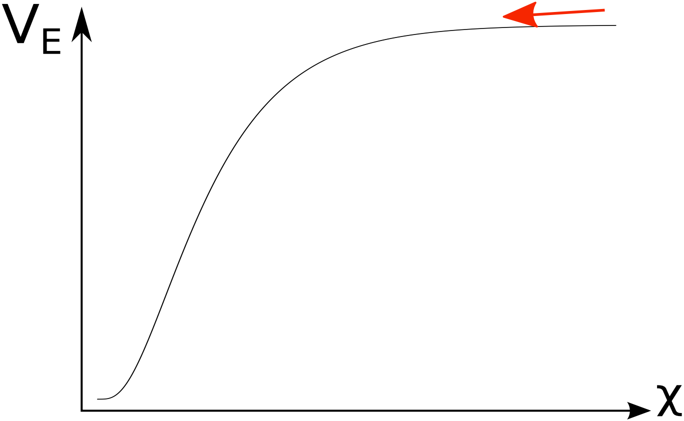
- Weyl transformation to Einstein frame, with field transformation:

$$g_{E\mu\nu} = g_{\mu\nu}\left(1 + \frac{\xi h^2}{M^2}\right), \quad \frac{dh}{d\chi} = \frac{1 + \xi h^2}{\sqrt{1 + \xi h^2 + 6\xi^2 h^2}},$$

$$S_E = \int d^4x\sqrt{-g_E}\left[-\frac{1}{2}M^2 R_E + \frac{1}{2} g_{E\mu\nu}\partial^\mu\chi\partial^\nu\chi - V_E(\chi)\right]$$

Higgs inflation with non-minimal coupling

- Einstein frame potential has a flat plateau:



Higgs inflation with non-minimal coupling

- Fits observations for $\xi \approx 49000\sqrt{\lambda}$ [0710.3755]

- Predictions:

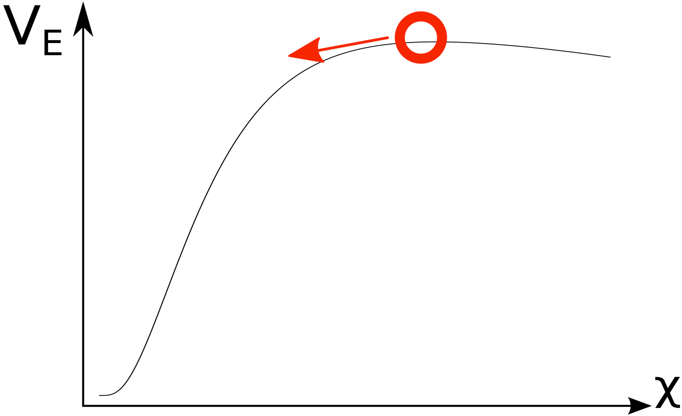
$$n_s \approx 1 - \frac{2}{N} \approx 0.96 \ , \quad r \approx \frac{12}{N^2} \approx 0.0048$$

Quantum corrections?

- Quantum corrections $\Rightarrow$ features in potential?
- Problem: model not renormalizable!
  - Effective theory 'chiral standard model'
  - Quantum corrections calculable order by order
  - Threshold corrections at transition from SM to chiral SM

Higgs inflation at the hilltop

- Quantum corrections can produce a hilltop:



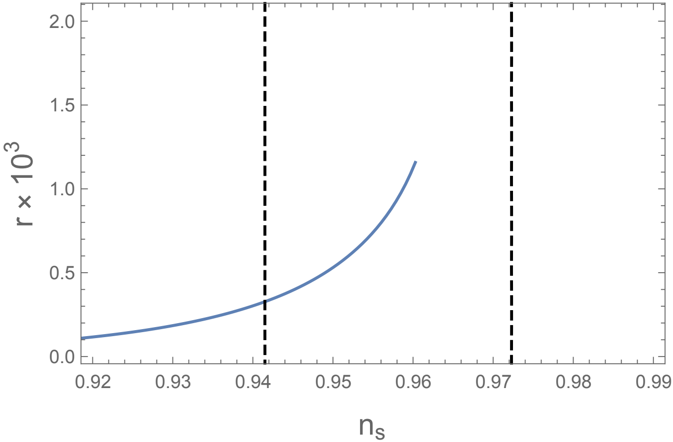
Higgs inflation at the hilltop

- Analytical approximation: tree-level potential with running coupling

$$\delta \equiv \frac{1}{\xi h^2} \, , \qquad V_E(\delta) = \frac{\lambda(\delta)}{4\xi^2(1+\delta)^2}$$

$$\lambda(\delta) = \lambda_0(1 - 2[\delta_0 - \delta])$$

Analytical approximation

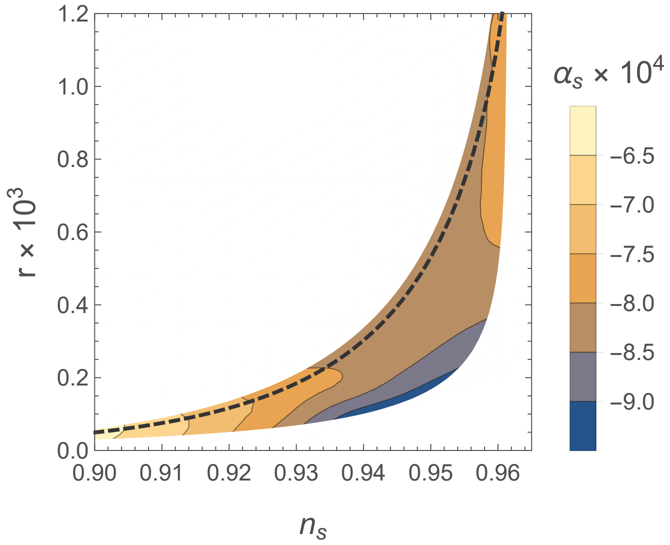


$$n_s < 1 - 2/N, \quad r < 3/N^2$$

Higgs inflation at the hilltop

- Numerical simulations also performed
  - Effective potential to 1-loop order, improved with 1-loop RGE running
  - Location of hilltop varied, couplings at hilltop varied, with the condition that a hilltop must be formed

Numerical simulations



Palatini formulation

- Alternate formulation of GR: metric and connection independent variables
  - Usually, e.o.m. lead to Levi-Civita connection
  - With non-minimal coupling ξ, this is not the case

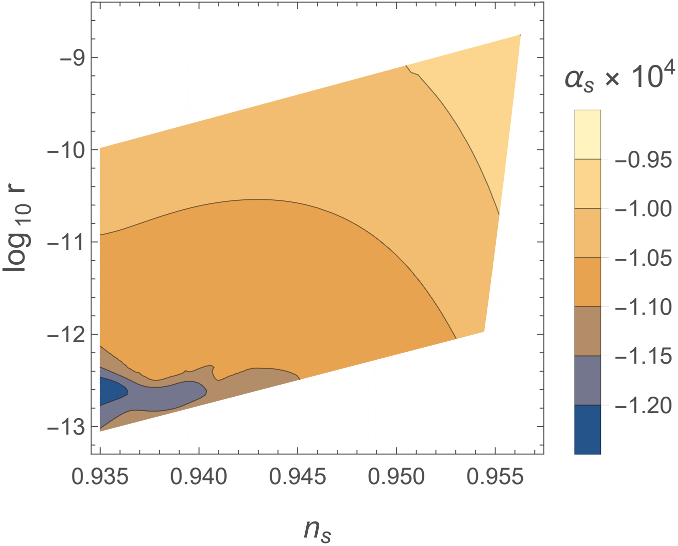
Palatini formulation

- Higgs inflation: canonical variable χ changes:

$$\frac{dh}{d\chi} = \sqrt{1 + \xi h^2}$$

- Potential and observables change

Numerical simulations (Palatini)



Conclusions

- Higgs inflation at a hilltop is possible when quantum corrections are taken into account

- Tensor-to-scalar ratio lower than in usual Higgs inflation: $r < 1.2 \times 10^{-3}$

- Palatini formulation of GR changes predictions; there $r \lesssim 10^{-9}$

Thank you for your attention!

Numerical table

	Tree-level metric	Hilltop metric	Hilltop Palatini	Observed (Planck 2015)
n_s	0.96	$\lesssim 0.96$	$\lesssim 0.96$	0.9569 ± 0.0077
r^*	4.8×10^{-3}	$1.3 \times 10^{-4} \ldots$ 1.2×10^{-3}	$2.2 \times 10^{-13} \ldots$ 2.2×10^{-9}	< 0.9
α_s^*	-8×10^{-4}	$-0.93 \times 10^{-3} \ldots$ -0.76×10^{-3}	$-1.2 \times 10^{-3} \ldots$ -0.94×10^{-3}	$0.011^{+0.014}_{-0.013}$
β_s^*	-3.2×10^{-5}	$-3.8 \times 10^{-5} \ldots$ -3.1×10^{-5}	$-5.5 \times 10^{-5} \ldots$ -4.1×10^{-5}	$0.029^{+0.015}_{-0.016}$
ξ	$\sim 10^3 \ldots$ 10^4	$180 \ldots$ 1.7×10^7	$1.0 \times 10^5 \ldots$ 5.2×10^8	-
$\Delta\lambda$	-	~ 0.02	~ 0.03	-
Δy_t	-	~ 0.06	~ 0.02	-

*Conditioned on $n_s \in [0.942, 0.972]$ (Planck 2015 2σ)