Higgs Inflation and Primordial Gravity Waves

Mansoor Ur Rehman

in collaboration with Qaisar Shafi, Nobuchika Okada and Joshua R. Wickman

Bartol Research Institute
Department of Physics and Astronomy
University of Delaware

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Outline

- Motivation
- Higgs Inflation
- Quantum Smearing
- Non-Minimal Inflation
- Conclusions

Motivation

Higgs inflation can be interesting for a number of reasons:

- SM Higgs inflation. I will discuss this briefly because of lack of time.
- Particle physics models of inflation are easily incorporated.
- ϕ^2 and ϕ^4 inflationary potentials are limiting cases of Higgs potential.
- Last but not least PLANCK, as I will show, will test Higgs inflation models through measurement of the tensor to scalar ratio $r\,(\gtrsim 0.01)$ (measure of primordial gravity waves).

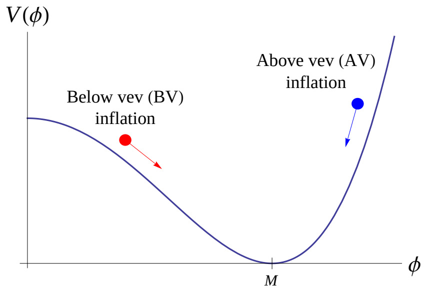
Tree Level Higgs Inflation

[Kallosh and Linde, 07; Rehman, Shafi and Wickman, 08]

- Consider the following Higgs Potential:

$$V(\phi) = V_0 \left[1 - \left(\frac{\phi}{M}\right)^2\right]^2 \quad \longleftarrow \text{(tree level)}$$

Here ϕ is a gauge singlet field.



- WMAP data favors BV inflation.

Limiting Behavior of the Higgs Model

$r \equiv \frac{\Delta_h^2}{\Delta_{\mathcal{R}}^2}$ (A canonical measure of primordial gravity waves)

$n_s - 1 \equiv \frac{d \ln \Delta_{\mathcal{R}}^2}{d \ln k}$ (n_s is spectral index/tilt)

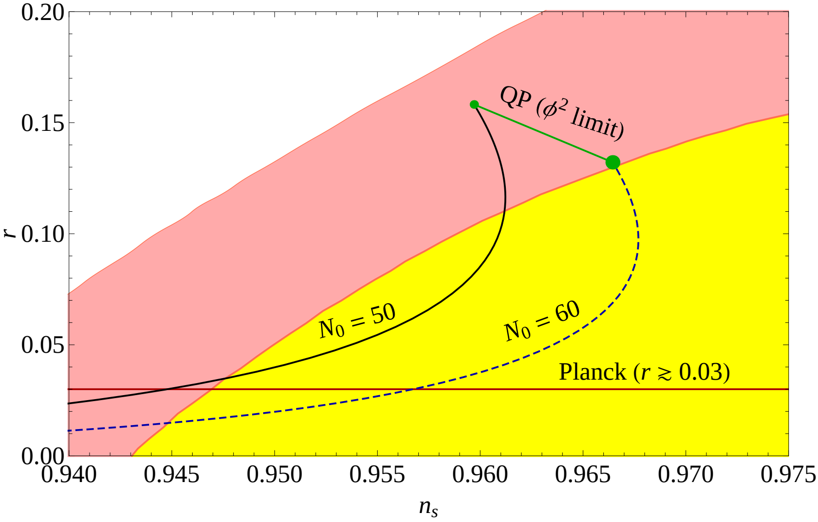
limit	$\phi \ll M$	$\phi \sim M$	$\phi \gg M$
model	new inflation	quadratic inflation	quartic inflation
V	$V_0 \left(1 - 2\left(\frac{\phi}{M}\right)^2\right)$	$\frac{1}{2} m_\phi^2 (\Delta\phi)^2$	$\left(\frac{V_0}{M^4}\right)\phi^4$
n_s	$1 - \frac{2}{N_0} \ln\left(\frac{M}{\sqrt{2}\phi_0}\right)$	$1 - \frac{2}{N_0}$	$1 - \frac{3}{N_0}$
r	$8(1-n_s)e^{-N_0(1-n_s)}$	$4(1-n_s)$	$\frac{16}{3}(1-n_s)$

In slow-roll approximation (i.e. $(\epsilon, |\eta|) \ll 1$),

$$n_s \simeq 1 - 6\epsilon + 2\eta,\ \ r \simeq 16\epsilon \text{ and } N_0 \simeq \frac{1}{m_P^2}\int_{\phi_e}^{\phi_0}\left(\frac{V}{V'}\right) d\phi$$

where, $\epsilon \equiv \frac{m_p^2}{2}\left(\frac{V'}{V}\right)^2, \quad \eta \equiv m_p^2\left(\frac{V''}{V}\right).$

Tree Level Higgs Inflation



Radiative Corrections in Higgs Inflation

[Rehman and Shafi, 2010]

- Consider the following interaction of inflaton ϕ with some GUT symmetry breaking scalar boson Φ:

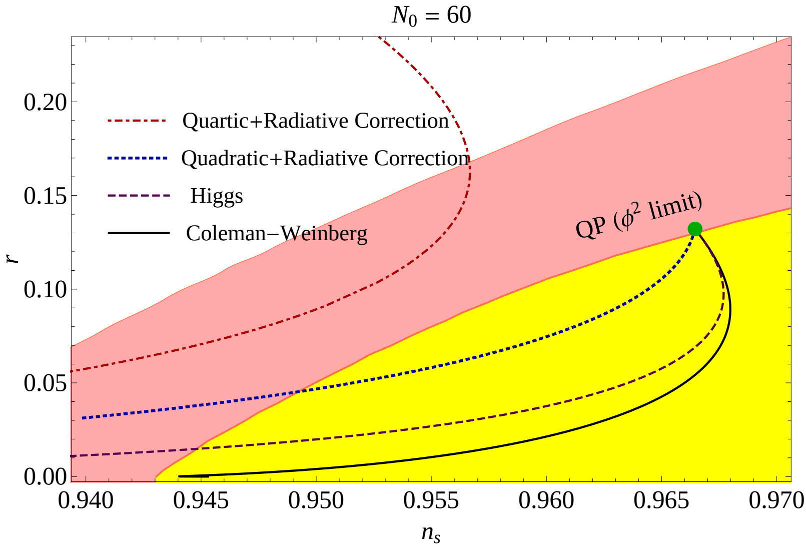
$$\mathcal{L}_{int} = \frac{\lambda_\Phi^2}{2}\,\phi^2\,\Phi^2$$

- Include Radiative Corrections (Quantum Smearing):

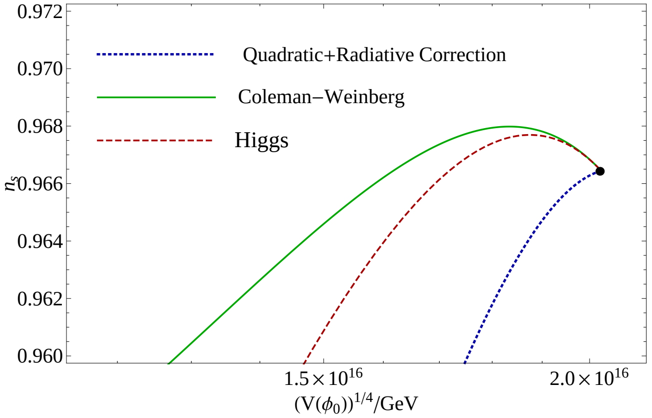
$$V = \left(\frac{m^2\,M^2}{4}\right)\,\left[1 - \left(\frac{\phi}{M}\right)^2\right]^2 + A\,\phi^4\,\left[\ln\left(\frac{\phi}{M}\right) - \frac{1}{4}\right] + \frac{A\,M^4}{4},$$

where $V(\phi = 0) \equiv V_0 = \frac{m^2\,M^2}{4} + \frac{A\,M^4}{4}$ and $A = \frac{\mathcal{N}\lambda_\Phi^4}{32\,\pi^2}$.

Quantum Smearing



Quantum Smearing



The vacuum energy scale during observable inflation is well below m_P. This implies that the quantum gravity effects are relatively unimportant here.

ϕ^4 Inflation with non-minimal coupling to gravity

[Okada, Rehman, Shafi, 2010]

- Consider the following action in the Jordan frame:

$$S_J = \int d^4x \sqrt{-g} \left[\left(\frac{m_P^2 + \xi\phi^2}{2} \right) \mathcal{R} - \frac{1}{2}(\partial\phi)^2 - \frac{\lambda}{4!}\,\phi^4 \right],$$

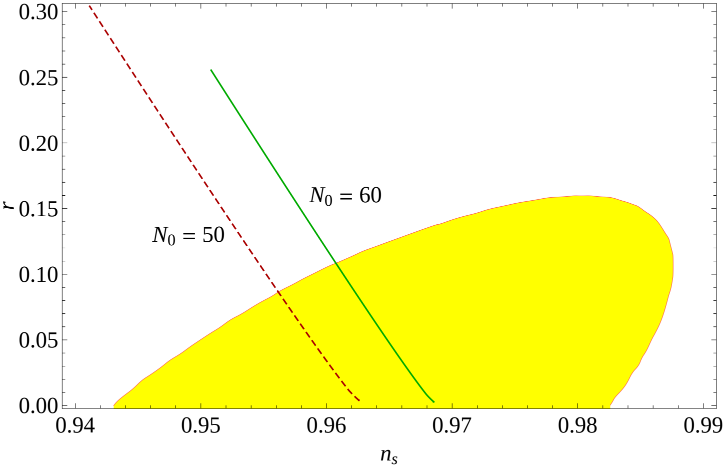
where ϕ is SM gauge singlet.

- In the Einstein frame the potential turns out to be:

$$V_E(\phi) = \frac{\frac{1}{4!}\lambda\phi^4}{\left(1 + \frac{\xi\,\phi^2}{m_P^2}\right)^2}.$$

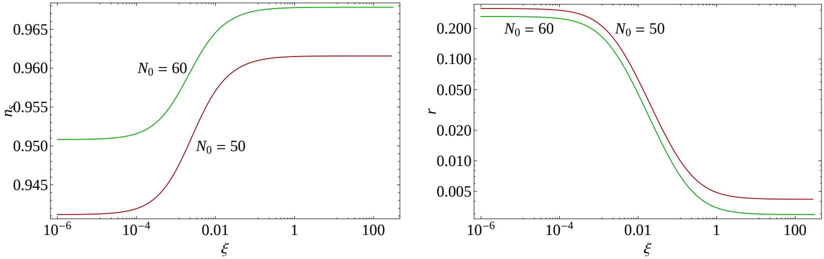
ϕ^4 Inflation with non-minimal coupling to gravity

[Okada, Rehman, Shafi, 2010]



ϕ^4 Inflation with non-minimal coupling to gravity

[Okada, Rehman, Shafi, 2010]



[Okada, Rehman, Shafi, 2010]

- Consider the following interaction of inflaton ϕ with the right handed Majorana neutrino N:

$$\mathcal{L}_{int} = \frac{1}{2}\, y_N\, \phi\, \overline{N}\, N$$

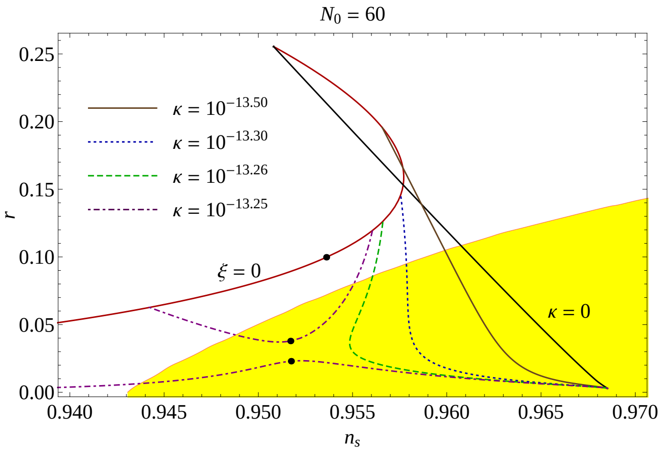
- Include Radiative Corrections (Quantum Smearing):

$$V_E(\phi) = \frac{\frac{1}{4!}\lambda\phi^4 - \kappa\phi^4 \ln(\phi/\mu)}{\left(1+\frac{\xi\,\phi^2}{m_P^2}\right)^2},$$

where $\kappa = y_N^4/(4\pi)^2$.

Non-Minimal ϕ^4 Inflation

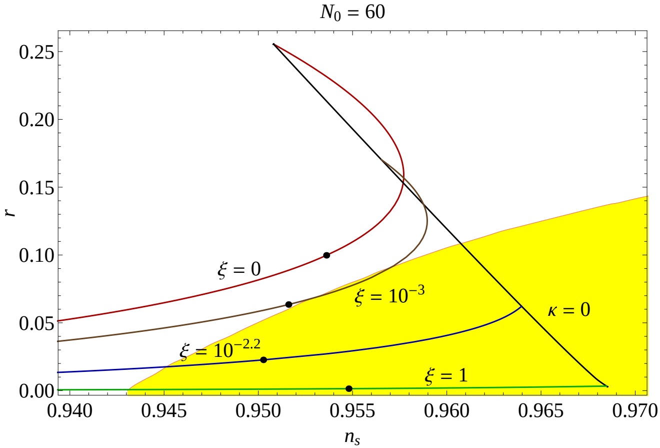
[Okada, Rehman, Shafi, 2010]



The black dots represent the meeting points of the hilltop and the ϕ^4 branches and correspond to the maximum value of κ for a given ξ.

Non-Minimal ϕ^4 Inflation

[Okada, Rehman, Shafi, 2010]



The black dots represent the meeting points of the hilltop and the ϕ^4 branches and correspond to the maximum value of κ for a given ξ.

Non-Minimal B-L Inflation

- Consider the gauge group $SM \times U(1)_{B-L}$ with a SM gauge singlet inflaton ϕ charged under $B - L$.
- This simple extension of SM naturally requires the presence of three right handed (RH) neutrinos due to gauge anomaly cancellations. With Z_2 parity one of the three RH neutrinos can be cold dark matter. [Okada, Seto, 2010]
- The origin of the baryon asymmetry can be explained through resonant leptogenesis with TeV scale RH neutrinos.

[Okada, Rehman and Shafi 2011]

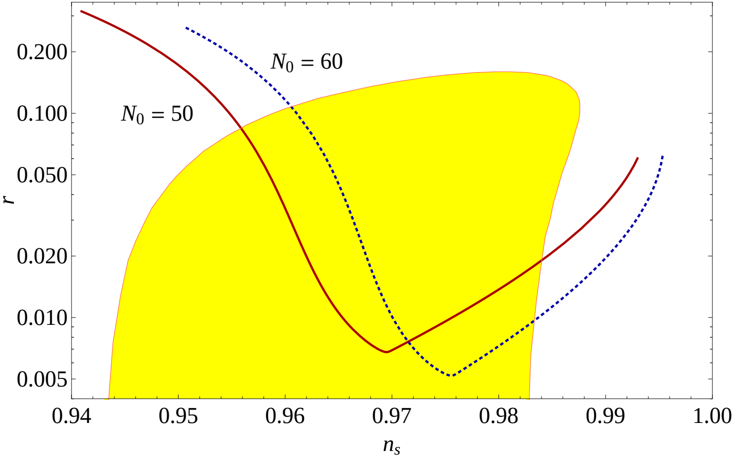
- Using non-minimal ϕ^4 inflation discussed in previous slides, the inflationary effective potential, in the leading-log approximation, can be written as

$$V(\phi) \simeq \left(\frac{\lambda(TeV)}{4} + \frac{96\, g_{B-L}^4}{16\, \pi^2}\, \ln\left[\frac{\phi}{TeV} \right] \right) \phi^4$$

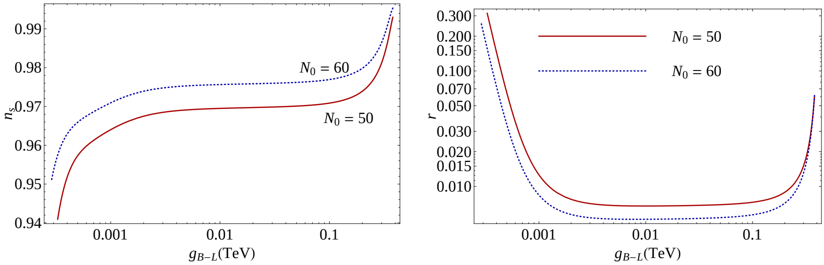
where g_{B-L} is the value of the $B-L$ gauge coupling.

Non-Minimal B-L Inflation

[Okada, Rehman and Shafi 2011]



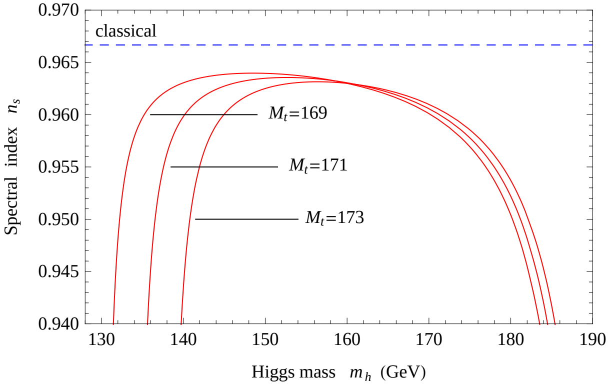
Non-Minimal B-L Inflation



SM Higgs Inflation

[Bezrukov, Magnin and Shaposhnikov; De Simone, Hertzberg and Wilczek.]

[Barvinsky, Kamenshchik, Kiefer, Starobinsky and Steinwachs.]



$$r \lesssim 0.003$$

Conclusions

- One of the most important challenges is to find a “Standard Model of Inflationary Cosmology”.
- Higgs inflation models typically predict an ‘observable’ value for the tensor to scalar ratio r (≥ 0.02, with $n_s \geq 0.95$)
- Radiative and gravitational corrections are important in the context of precision cosmology.
- Results from PLANCK are eagerly awaited!