Higgs Inflation and the Refined dS Conjecture

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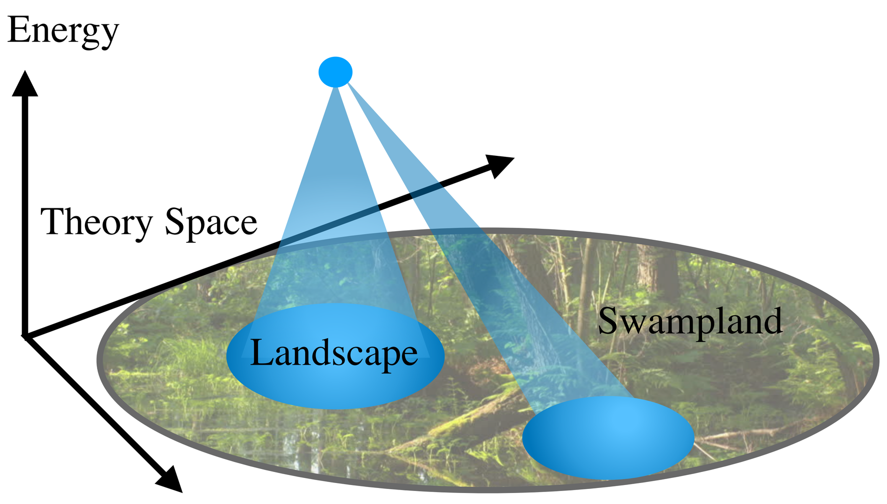
1 Abstract

The refined de Sitter derivative conjecture provides constraints to potentials that are low energy effective theories of quantum gravity. It can give direct bounds on inflationary scenarios and determine whether the theory is in the Landscape or the Swampland. We consider the 'Higgs inflation' scenario taking the refined de Sitter derivative conjecture into account. Obtaining the critical lines for the potential, we find a conjecture parameter space in which the 'Higgs inflation' is to be in the Landscape. Comparing with the model independent observational bounds from recent data we find that the observational bounds represent the Higgs inflation can be in the Landscape.

2 The Swampland Conjectures

For a low energy effective theory to have a well-defined UV completion in the quantum gravity regime, the so-called 'swampland conjectures' are necessarily satisfied. Based on theoretical predictions, these conjectures represent universal characteristics of quantum gravity [Vafa. '05],



Quantum Gravity Constructions

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Swampland Conjecture

↑

Microscopic Physics

3 (Refined) de Sitter Conjecture

For a low energy effective theory with the following Lagrangian,

$$\mathcal{L} = \sqrt{-g}\left[R + \sum D^\mu \phi D_\mu \phi + V_{total}(\phi_i) + \dots\right]$$

to be in the Landscape, the scalar field potential needs to satisfy the following conditions [Ooguri, Parti, Shiu, Vafa. '18].

$$|\nabla V| \geq \frac{c_1}{M_P} V \quad \text{or} \quad \min(\nabla_i \nabla_j V) \leq -\frac{c_2}{M_P^2} V$$

Implications of the de Sitter conjecture

- dS vacua violation ⇨ C.C invalid ⇨ Quintessence field induced D.E. $V_Q(Q) = \Lambda_Q^4 e^{-c_Q \frac{Q}{M_P}}$
- Can provide constraints to phenomenological models.

4 Higgs Inflation

Higgs inflation interprets the Standard Model Higgs boson as the inflaton, in which the Higgs field has a non minimal coupling to gravity. Being the sole scalar field in the Standard Model, this inflation model does not typically require an extension from the SM [Bezrukov, Shaposhnikov. '08].

$$S_J = \int d^4x \sqrt{-g_J}\left[\frac{1+\xi h_J^2}{2} R_J - \frac{1}{2}|D_\mu h_J|^2 - V_J(h_J)\right]_{V_J(h_J) = \lambda(h_J^2 - v^2)^2}$$

$$S = \int d^4x \sqrt{-g}\left[\frac{1}{2}R - \frac{1}{2}F(h)|\partial_\mu h|^2 - \frac{V_J(h)}{\Omega^4}\right]$$

Weyl Transformation

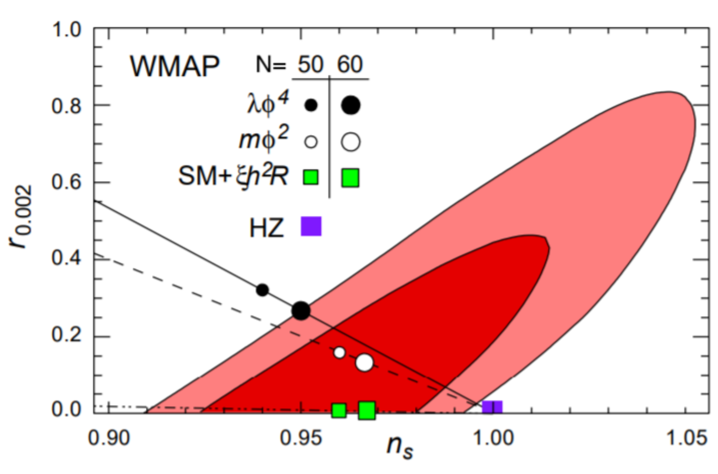
Canonical kinetic term

Field redefinition

$$V(h) \approx \frac{\lambda}{\xi^2}\left(1 + e^{-\sqrt{\frac{2}{3}}h}\right)^{-2} \qquad \sqrt{\xi}h \gg 1$$

$$\approx \lambda\left(h^2 - v^2\right)^2 \qquad \sqrt{\xi}h \ll 1$$

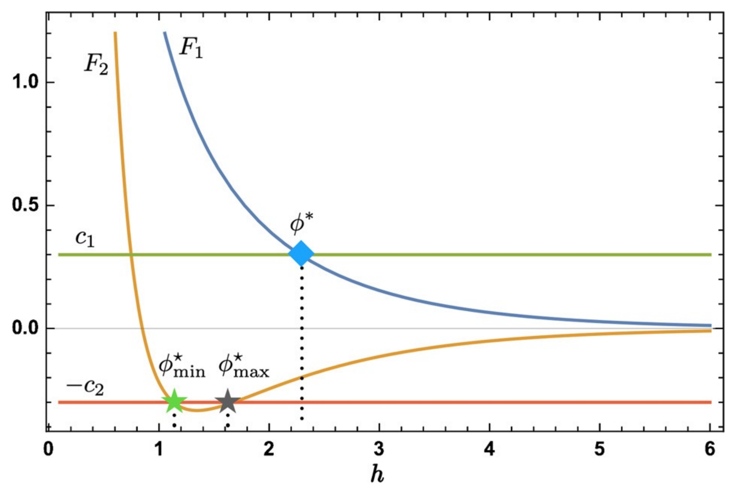
$$\lambda = 0.13, \quad \xi = 17000$$



5 Setup

We define functions regarding the conjectures.

$$F_1(h) \equiv \frac{|dV/dh|}{V} \qquad F_2(h) \equiv \frac{|d^2V/dh^2|}{V}$$



These functions evaluate the 1st and 2nd derivative conjecture until a desired field value due to the fact that F_2 is not monotonic.

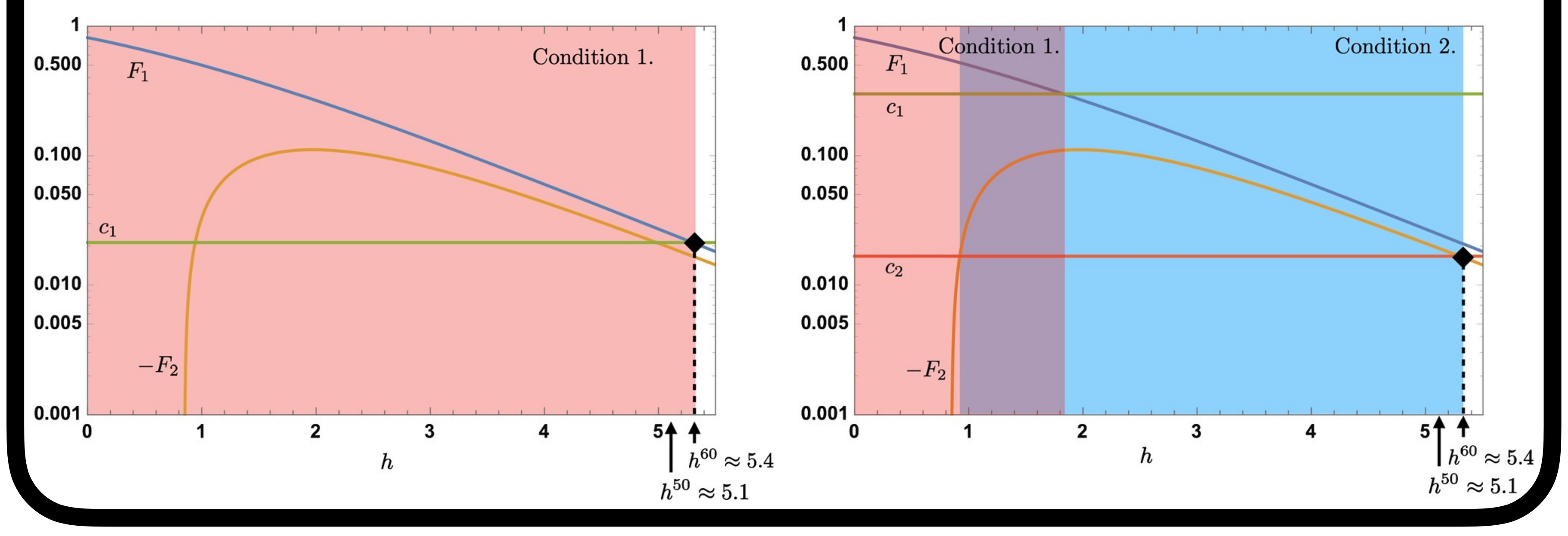
$$F_1(h) \geq c_1 \Leftrightarrow h \leq \phi^* = F_1^{-1}(c_1)$$

$$F_2(h) \leq -c_2 \Leftrightarrow h \in [\phi^\star_{min}, \phi^\star_{max}]$$

We require that for successful inflationary dynamics, the conjectures need to be satisfied in the field space in which the inflationary dynamics take place, assuming that the potential gets corrected by e.g. higher order operators $\mathcal{O}(h^6)$. By restricting our field space, we obtain two cases in which the Higgs potential can satisfy the conditions.

(Case-1) $\phi^* \geq h_* \Leftrightarrow c_1 \leq F_1(h_*)$

(Case-2) $\phi^\star_{max} \geq h_*$ and $\phi^* \geq \phi^\star_{min} \Leftrightarrow c_2 \leq -F_2(h_*)$ and $c_1 \leq F_1(\phi^\star_{min})$.



6 Results - Parameter Bounds

Higgs inflation scenario bounds:

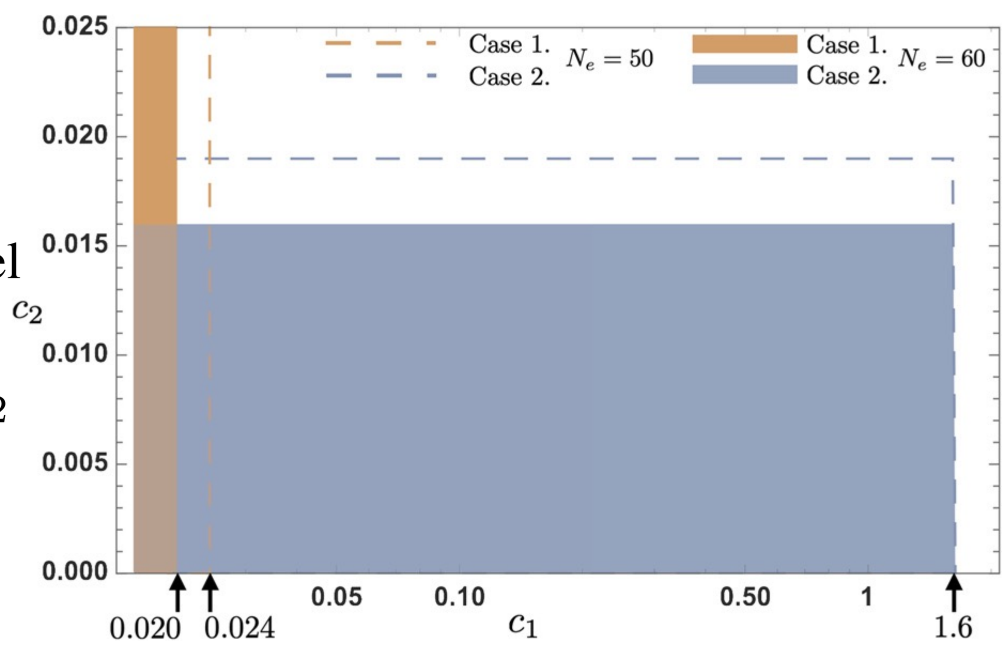
(Case-1) $c_1 \lesssim 0.02$

(Case-2) $c_1 \lesssim 1.6, \; c_2 \lesssim 0.016$

The conjectures also give model independent bounds for inflation.

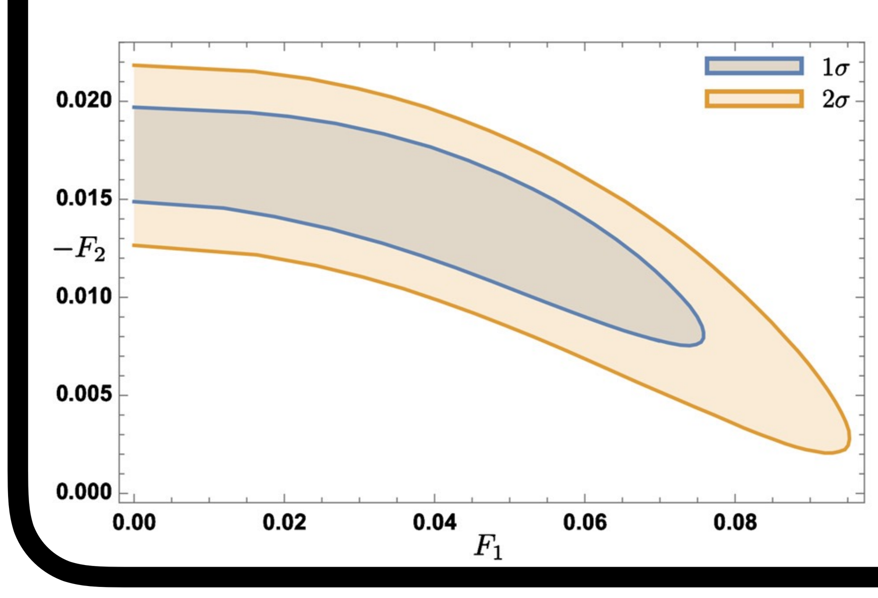
$$\epsilon_V = \frac{1}{2}\left(\frac{V'}{V}\right)^2 = \frac{1}{2}F_1(h_*)^2$$

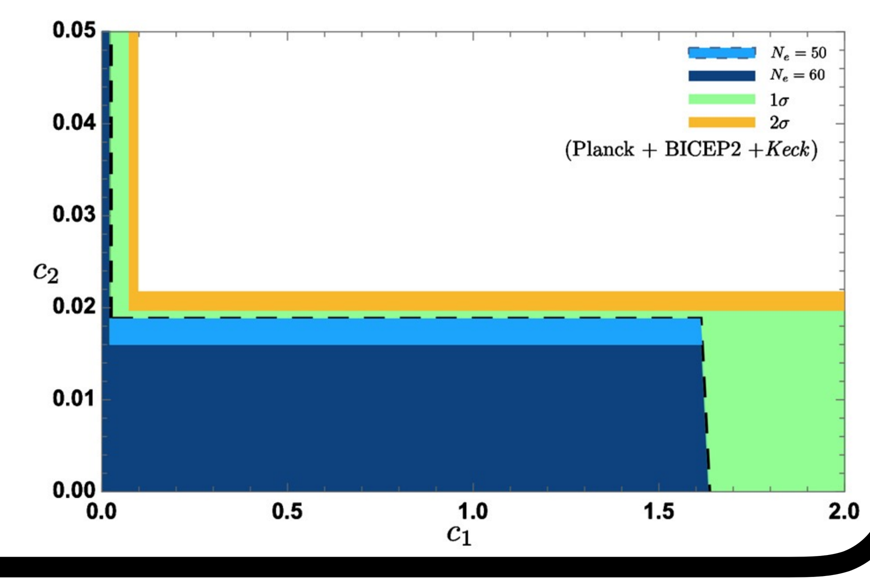
$$\eta_V = \left(\frac{V''}{V}\right) = F_2(h_*)$$



$$\begin{cases} n_s = 1 - 3F_1(h_*)^2 + 2F_2(h_*) \\ r = 8F_1(h_*)^2 \end{cases} \Leftrightarrow \begin{cases} F_1(h_*) = \sqrt{\frac{r}{8}} \geq c_1 \\ F_2(h_*) = \frac{n_s - 1 + 3r/8}{2} \leq -c_2 \end{cases}$$

By applying the conditions to recent observational data (Planck+BICEP2+Keck), we obtain a model independent bound on the parameters. The Higgs inflation sits well inside the observational region, with an upper bound on $c_1 \lesssim 1.6$.





7 Conclusion

- The dS conjecture can provide constraints to phenomenological models.
- The parametric region for Higgs inflation shares a $c_1 \sim \mathcal{O}(1)$ region
- The observational bound makes it impossible for both constants to simultaneously be $\mathcal{O}(1)$.
- Emphasizing that both parameters can be tuned, the Higgs inflation scenario can be in the Landscape, with some caveat.

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