Higgs inflation and Swampland Conjecture

S. C. Park (Yonsei University)
21 Feb 2019
\cite{Cheong:2018udx}
\bibitem{Cheong:2018udx}
D.~Y.~Cheong, S.~M.~Lee and S.~C.~Park,
``Higgs Inflation and the Refined dS Conjecture,''

\cite{Park:2018fuj}
\bibitem{Park:2018fuj}
S.~C.~Park,
``Minimal gauge inflation and the refined Swampland conjecture,''
JCAP \textbf{1901} (2019) no.01, 053
doi:10.1088/1475-7516/2019/01/053
\%\%CITATION = doi:10.1088/1475-7516/2019/01/053;\%
Goal

- Introduce the basic idea of ‘(string) Landscape’ and ‘(string) Swampland Conjecture’

- Explain why the conjecture is reasonable in terms of particle physics

- Then illustrate how to use the conjecture for particle physics models e.g. Higgs, Higgs inflation
Quantum Gravity

• Probably, gravity is also quantized…

• The prime candidates are string theories

• even though mathematically beautiful but they never get experimentally tested

• …unfortunately, we don’t really know what to test.

\[ G_{\mu\nu} = T_{\mu\nu} \]

A. Sen’s argument for QG

Quantum

Classical?
String landscape

…partly because there are too many string theories

According to the latest estimate there are (at least!) \( \sim 10^{27^{2000}} \) vacua, typically with gauge groups like

\[
G = (E_8)^{38} \times (F_4)^{94} \times (G_2)^{288} \times SU(2)^{432}
\]

[W.Taylor, Y.Wang, "Scanning the skeleton of the 4D F theory landscape", 1710.11235[hep-th]]

quote from H. Nicoli’s talk @CSI CERN TH 2019 Feb

Practically, it is not possible to look into details of all these vacua
String Landscape
Swampland

The swampland is the set of (seemingly consistent) effective field theories, which cannot be obtained from a consistent string construction.
Eagle & Crocodile

A theory living in Landscape
consistent with Quantum Gravity

A theory living in Swampland
Is Higgs in Landscape?

\[ V = \frac{\lambda}{4} (h^2 - v^2)^2 \]
The total scalar potential $V(\phi)$ of a low energy effective theory consistent to a quantum gravity theory needs to satisfy the following condition:

$$\left| \nabla V \right| \geq c \frac{V}{M_{Pl}}$$

$c \sim O(1)$

A universal parameter (unknown)
looks reasonable

\[ \left| \nabla V \right| \geq c \frac{V}{M_{\text{Pl}}} \]

\( c \sim \mathcal{O}(1) \)

A universal parameter (unknown)

\[ \frac{\Delta V}{\Delta \phi} \geq \mathcal{O}(1) \frac{V}{M_P} \]

\[ \frac{\Delta \phi}{M_P} \leq \mathcal{O}(1) \times \frac{\Delta V}{V} \leq \mathcal{O}(1) \]

:sub-Planckian excursion in low energy effective theory
SW $\Rightarrow$ Higgs potential

$$V = \frac{\lambda}{4}(h^2 - v^2)^2$$

$$V' = 0, V > 0$$

does not satisfy the criterion
SW $\Rightarrow$ ds Vacuum

$V' = 0, V > 0$

dS vacuum is not allowed!
$SW \Rightarrow ds \text{ Vacuum}$

$V' = 0, V > 0$

dS vacuum is not allowed!

Is our universe ruled out by string theory?
Wait! Quintessence

\[ V_Q = \Lambda_Q^4 e^{-C_QQ} \]

CHECK:

\[ |V'_Q| = C_Q V_Q \geq c V_Q \]

\[ C_Q \geq c \sim O(1) \]

\[ \nabla V \geq c \frac{V}{M_{Pl}} \]

\[ c \sim O(1) \]

A universal parameter (unknown)
Any scalar potential $V(\phi)$ for scalar fields in a low energy effective theory of a consistent quantum gravity must satisfy at least one of the following conditions:

\[ |\nabla V| \geq c_1 \frac{V}{M_{Pl}} \]

\[ \nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{Pl}^2} \]

$c_1, c_2 \sim O(1), \text{positive}$
looks reasonable too!

-Weak Gravity Conjecture-

Arkani-Hamed, Motl, Nocolis, Vafa 2007

\[ V \sim \Lambda^4 \cos(\phi/f) \]

\[ V' \sim -\frac{\Lambda^4}{f} \sin(\phi/f) \]

\[ V'' \sim -\frac{\Lambda^4}{f^2} \cos(\phi/f) = -\frac{V}{f^2} \]

\[ f < M_P(WGC) \]

\[ \nabla V \geq c_1 \frac{V}{M_{Pl}} \]

\[ \nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{Pl}^2} \]

\[ c_1, c_2 \sim O(1), \text{positive} \]
Refined version is more generous

\[ V = \frac{\lambda}{4} (h^2 - v^2)^2 \]

\[ V|_{h=0} = \frac{\lambda}{4} v^4 > 0 \]

\[ V'|_{h=0} = 0 \]

\[ V''|_{h=0} = -\lambda v^2 = -4 \frac{V}{v^2} \]
Refined version is more generous

\[ V = \frac{\lambda}{4}(h^2 - v^2)^2 \]

\[ V|_{h=0} = \frac{\lambda}{4}v^4 > 0 \]
\[ V'|_{h=0} = 0 \]
\[ V''|_{h=0} = -\lambda v^2 = -4\frac{V}{v^2} \]

\[ M_{\text{Pl}} \left| \nabla V \right| \geq c_1 V \]
\[ M_{\text{Pl}}^2 \nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\text{Pl}}^2} \]

\( c_1, c_2 \sim O(1), \text{positive} \)}
Higgs inflation
the best fit model of cosmology!

Y. Akrami et al. [Planck Collaboration],
Higgs inflation

[Bezrukov-Shaposhnikov, PLB(2007)], [SCP, S.Yamaguchi, JCAP(2008)]
[Hamada, Kawai, Oda, SCP, PRL(2014), PRD(2015)]

inflation takes place here

Mathematically Beautiful
Experimentally verifiable
Higgs inflation

[Bezrukov-Shaposhnikov, PLB(2007)], [SCP, S.Yamaguchi, JCAP(2008)]
[Hamada, Kawai, Oda, SCP, PRL(2014), PRD(2015)]
Is HI eagle or crocodile?

Is HI eagle or crocodile?


\[
\left| \nabla V \right| \geq c_1 \frac{V}{M_{\text{Pl}}} \\
\nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\text{Pl}}^2}
\]

\[c_1, c_2 \sim O(1), \text{positive}\]
\[ |\nabla V| \geq c_1 \frac{V}{M_{\text{Pl}}} \]
\[ \nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\text{Pl}}^2} \]

\( c_1, c_2 \sim O(1), \) positive
So, this is the result

D. Y. Cheong, S. M. Lee and SCP,
Gauge inflation

- Inflaton = $A_5$

- Potential is protected by higher dimensional gauge symmetry, SU(2)...

- which is broken at $1/R$ (~GUT) scale

- Potential developed via gauge self interactions, $\text{Pot}=\text{CW}$

- A minimal version constructed ...[SCP, J.-O. Gong 08’] then tested by Swampland conjecture recently [SCP18’]
\[ V(\phi) = V_0 \sum_{n=1}^{\infty} \frac{1}{n^5} \left[ 1 - \cos \frac{n\phi}{f_{\text{eff}}} \right] \]
\[ = -\frac{V_0}{2} \left[ \text{Li}_5(e^{i\phi/f_{\text{eff}}}) + \text{Li}_5(e^{-i\phi/f_{\text{eff}}}) - 2\zeta(5) \right] \]

\[ V/V_0 \]

\[ \frac{\phi}{f_{\text{eff}}} \]

[SCP, J-O. Gong 08’]
If $\phi_* \geq \phi_*$, the theory is good.
\[ \phi_\ast \geq \phi_\star \]

\[ \left| \nabla V \right| \geq c_1 \frac{V}{M_{\text{Pl}}} \]

\[ \nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\text{Pl}}^2} \]

\( c_1, c_2 \sim O(1), \text{positive} \)
conclusion

- Recently proposed ‘Swampland conjecture’ provides us a theoretical playground to test our effective theory models.

- A theory is either an eagle living in Landscape or a crocodile living in Swampland.

- We checked
  - Higgs
  - Quintessence
  - Higgs inflation
  - Minimal gauge inflation

  and showed that they are in Landscape.

- You may want to check your own favorite EFT model too.