Higgs inflation and Swampland Conjecture

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refs


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%\cite{Cheong:2018udx}
\bibitem{Cheong:2018udx}
  D.~Y.~Cheong, S.~M.~Lee and S.~C.~Park,
  %``Higgs Inflation and the Refined dS Conjecture,''
  Phys.\ Lett.\ B {\bf 789} (2019) 336
  doi:10.1016/j.physletb.2018.12.046
  [arXiv:1811.03622 [hep-ph]].
  %%CITATION = doi:10.1016/j.physletb.2018.12.046;%%


%\cite{Park:2018fuj}
\bibitem{Park:2018fuj}
  S.~C.~Park,
  %``Minimal gauge inflation and the refined Swampland
conjecture,''
  JCAP {\bf 1901} (2019) no.01,  053
  doi:10.1088/1475-7516/2019/01/053
  [arXiv:1810.11279 [hep-ph]].
  %%CITATION = doi:10.1088/1475-7516/2019/01/053;%%
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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…

A. Sen's argument for QG

Quantum

$$G_{\mu\nu} = T_{\mu\nu}$$

Classical?

- 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.**

String landscape

...partly because there are too many string theories

- According to the latest estimate there are (at least!) $\sim 10^{272\,000}$ 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

YONSEI

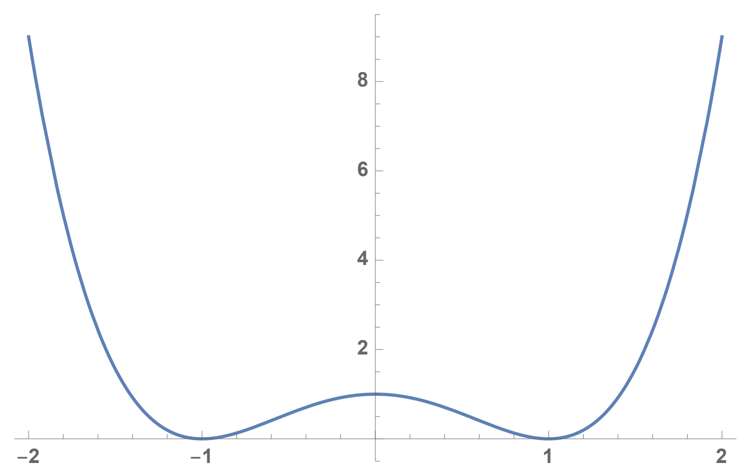
A theory living in Landscape

consistent with Quantum Gravity

A theory living in Swampland

Is Higgs in Landscape?

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



or

Swampland Conjecture

Obied, Ooguri, Spondyneikeo and Vafa, arXiv:1806.08362

The total scalar potential V(ϕ) of a low energy effective theory consistent to a quantum gravity theory needs to satisfy the following condition:

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

$$c \sim O(1)$$

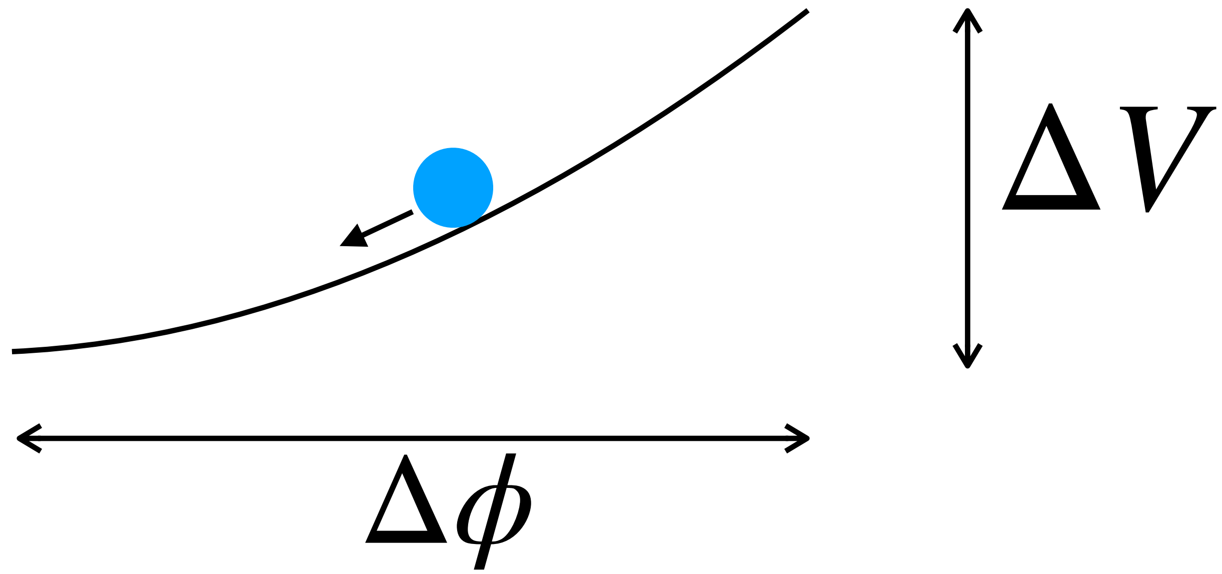
A universal parameter (unknown)

looks reasonable

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

$$c \sim O(1)$$

A universal parameter (unknown)



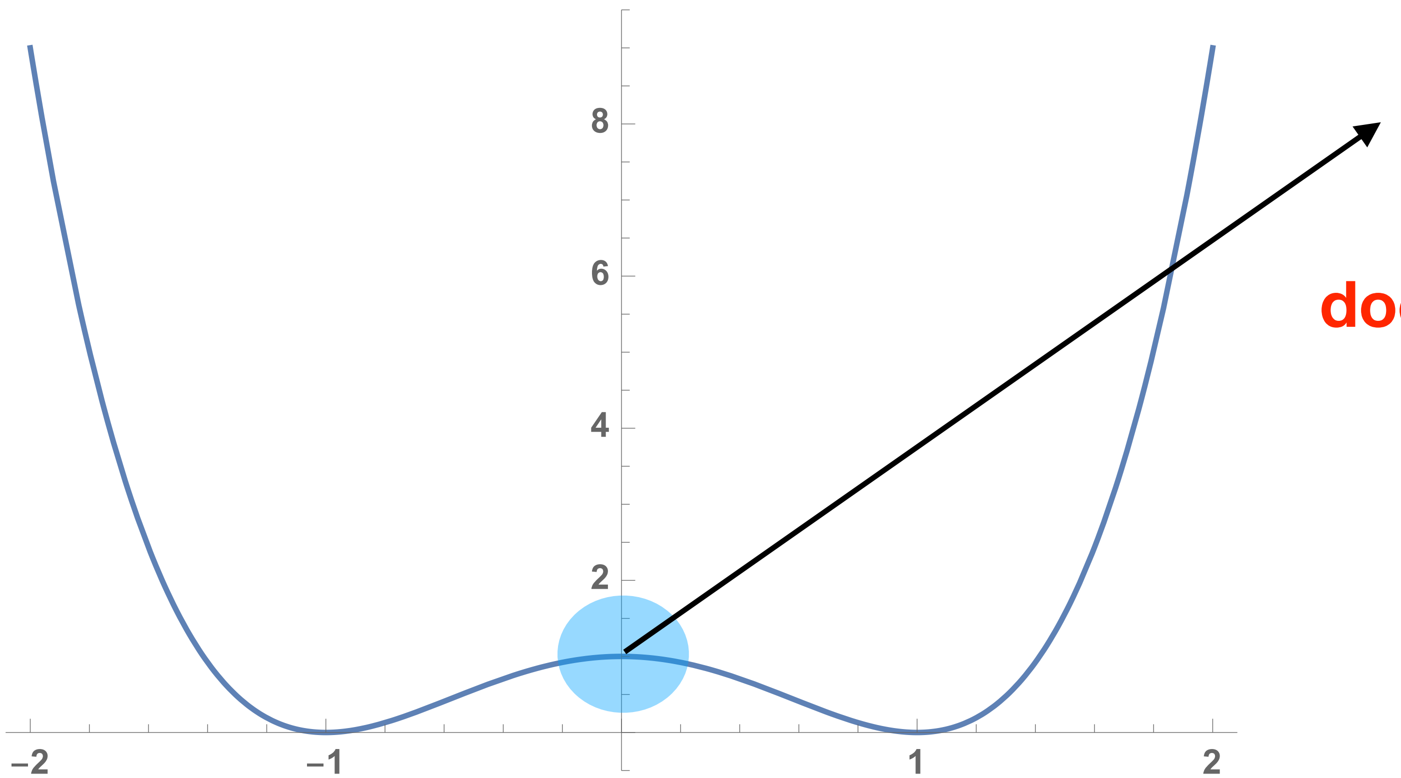
$$\frac{\Delta V}{\Delta \phi} \geq \mathcal{O}(1)\frac{V}{M_P}$$

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

:sub-Planckian excursion
in low energy effective theory

SW ⇒ Higgs potential

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



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

does not satisfy the criterion

?

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

$$c \sim O(1)$$

A universal parameter (unknown)

SW $\Rightarrow$ ds Vacuum

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

dS vacuum is not allowed!

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

$$c \sim O(1)$$

A universal parameter (unknown)

SW $\Rightarrow$ ds Vacuum

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

dS vacuum is not allowed!

Is our universe ruled out by string theory?

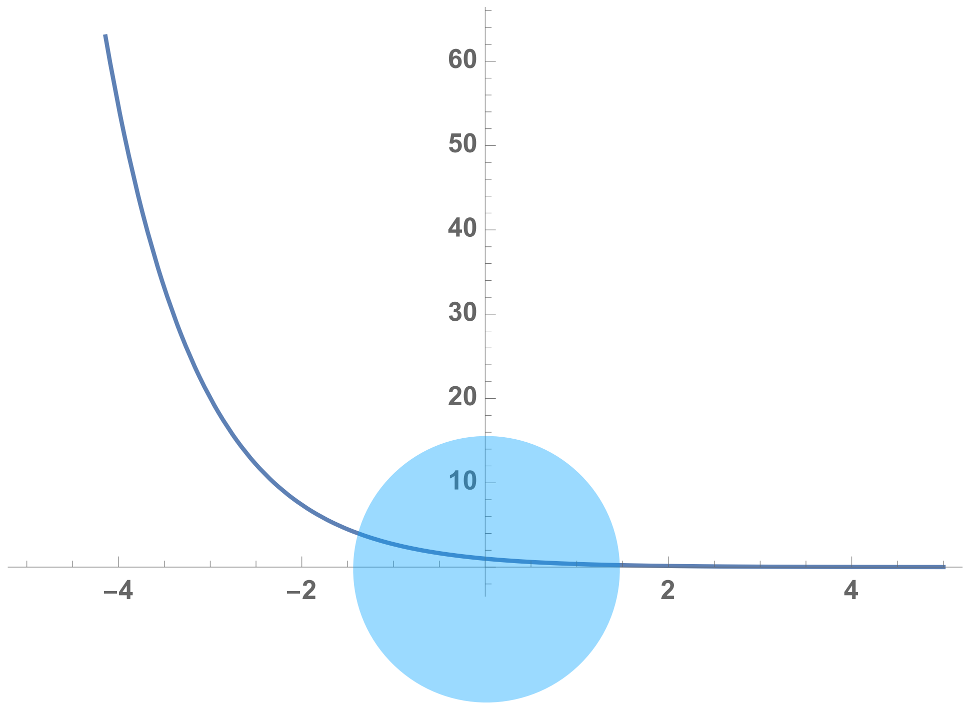
$$\left| \nabla V \right| \geq c \frac{V}{M_{\rm Pl}}$$

$$c \sim O(1)$$

A universal parameter (unknown)

Wait! Quintessence

$$V_Q = \Lambda_Q^4 e^{-C_Q Q}$$



$Q \sim 1, \Lambda_Q \sim m_\nu$

CHECK:

$$|V_Q'| = C_Q V_Q \geq c V_Q$$

$$C_Q \geq c \sim O(1)$$

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

$c \sim O(1)$

A universal parameter (unknown)

Refined Swampland Conjecture

Ooguri, Palti, Shiu and Vafa arXiv:1810.05506

S. K. Garg and C. Krishnan arXiv:1807.05193

Any scalar potential V (ϕ) for scalar fields in a low energy effective theory of a consistent quantum gravity must satisfy at least one of the following conditions:

$$\left| \nabla V \right| \geq c_1 \frac{V}{M_{\mathrm{Pl}}}$$

$$\nabla_i \nabla_j V \leq - c_2 \frac{V}{M_{\mathrm{Pl}}^2}$$

$c_1, c_2 \sim O(1)$, **positive**

looks reasonable too!

-Weak Gravity Conjecture-

Arkani-Hamed, Motl, Nocolis, Vafa 2007

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

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

$f < M_P (WGC)$

$$V'' \sim -\frac{\Lambda^4}{f^2}\cos(\phi/f) = -\frac{V}{f^2} > -\frac{V}{M_P^2}$$

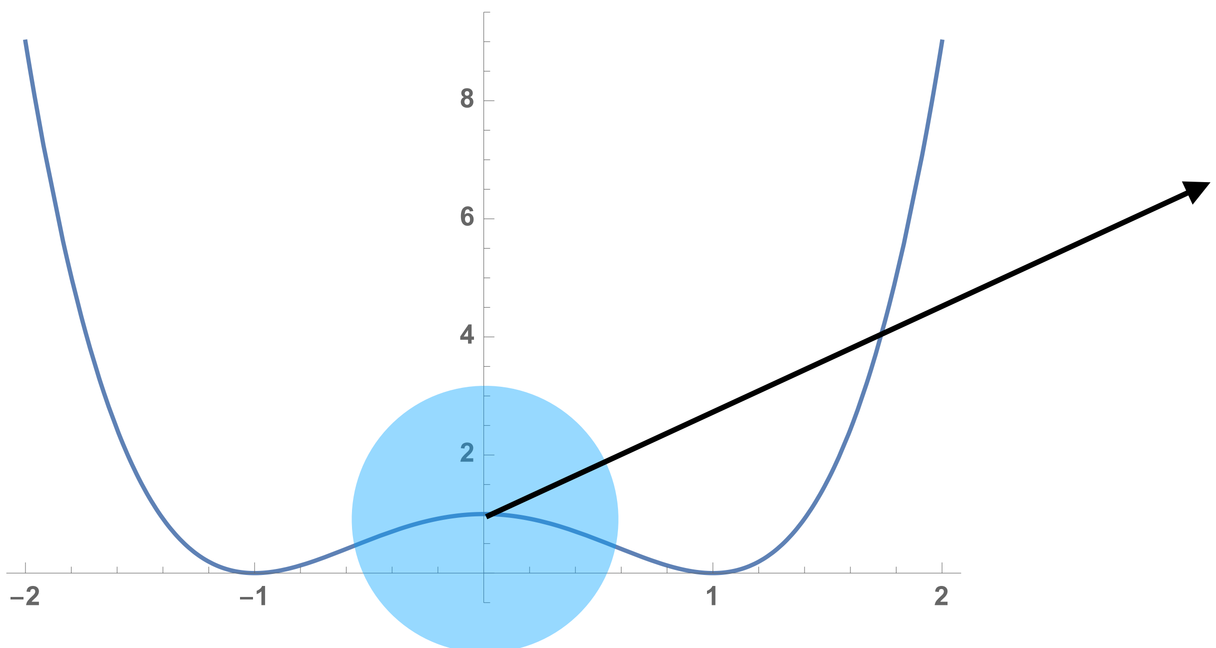
$$\left|\nabla V\right| \geq c_1 \frac{V}{M_{\text{Pl}}}$$

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

$c_1, c_2 \sim O(1)$, **positive**

Refined version is more generous

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



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

$$V'|_{h=0} = 0$$

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

$$\left|\nabla V\right| \geq c_1 \frac{V}{M_{\rm Pl}}$$

$$\nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\rm Pl}^2}$$

$c_1, c_2 \sim O(1)$, **positive**

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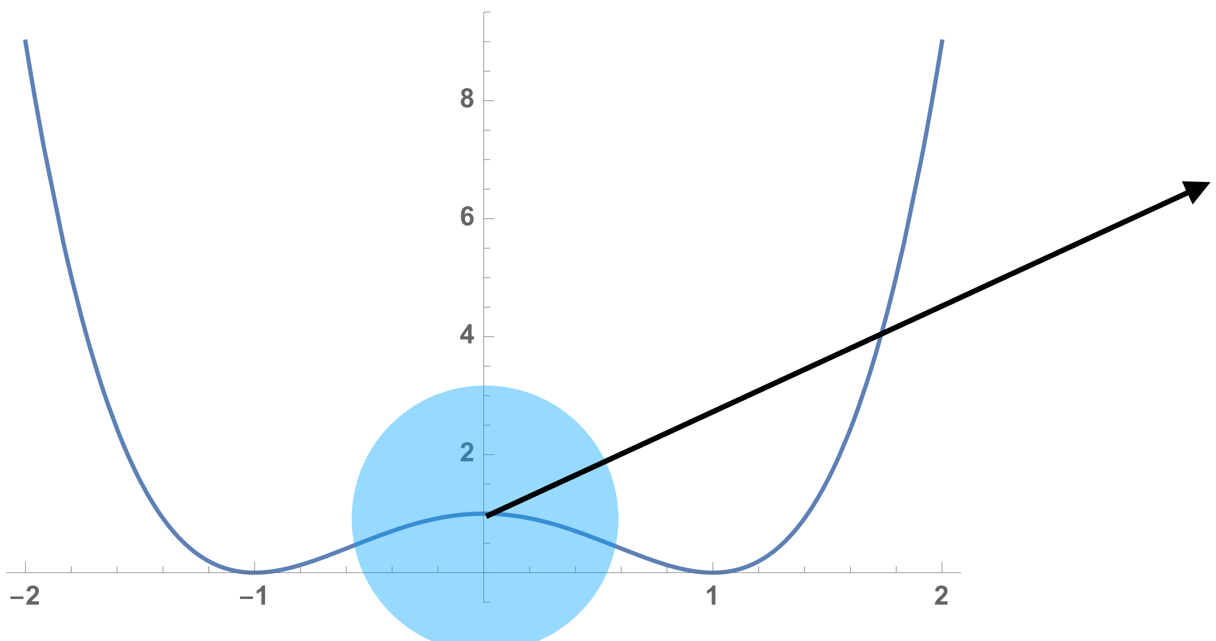


$$V|_{h=0} = \frac{\lambda}{4}v^4 > 0$$

$$V'|_{h=0} = 0$$

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

$M_{\rm Pl}\,|\nabla V| \geq c_1 V$ ⟶ **not satisfied**

$M_{\rm Pl}^2 \nabla_i \nabla_j V \leq -c_2 V$ ⟶ **satisfied!**

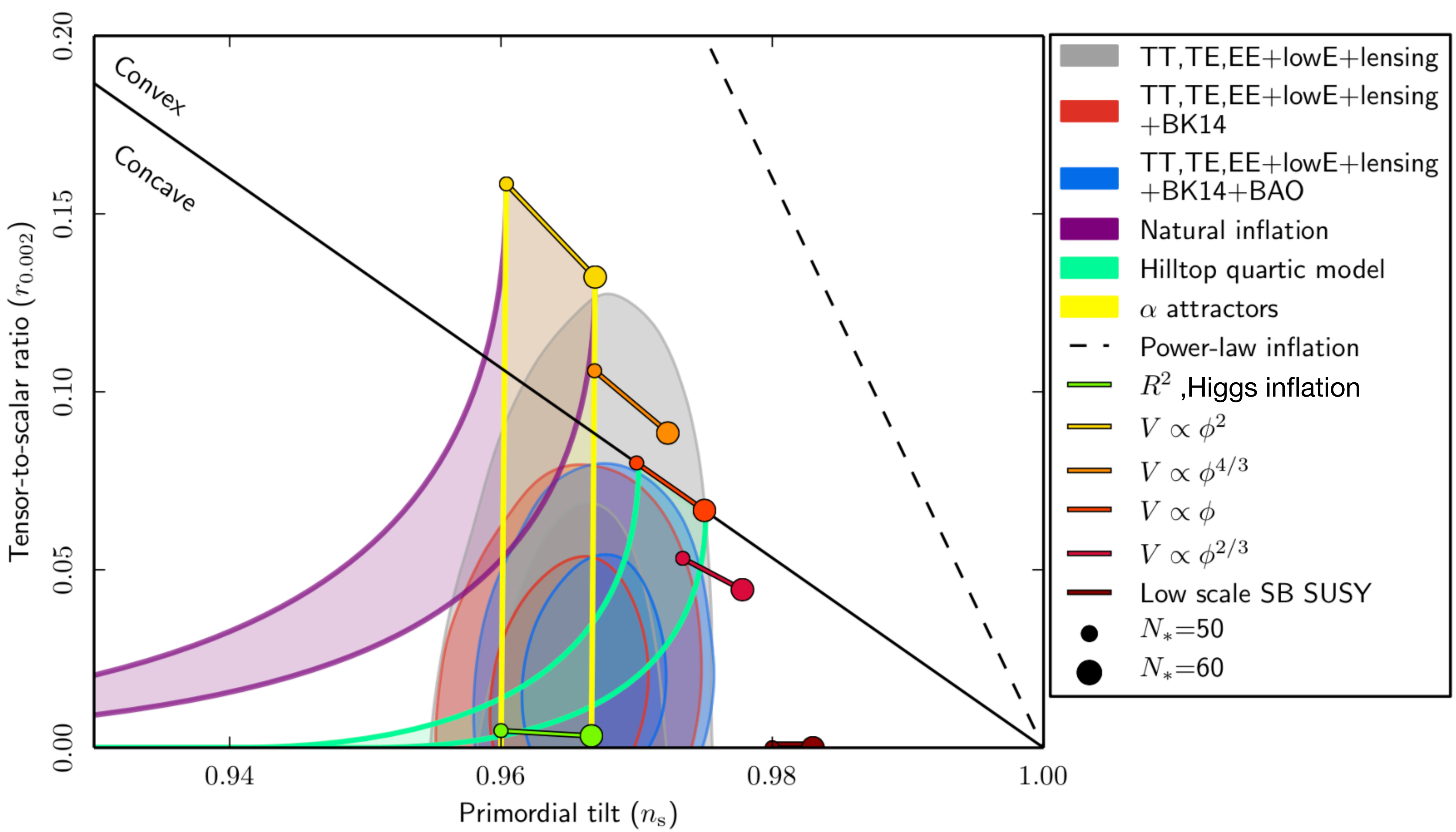
$$|\nabla V| \geq c_1 \frac{V}{M_{\rm Pl}}$$

$$\nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\rm Pl}^2}$$

$c_1, c_2 \sim O(1)$, **positive**

Higgs inflation

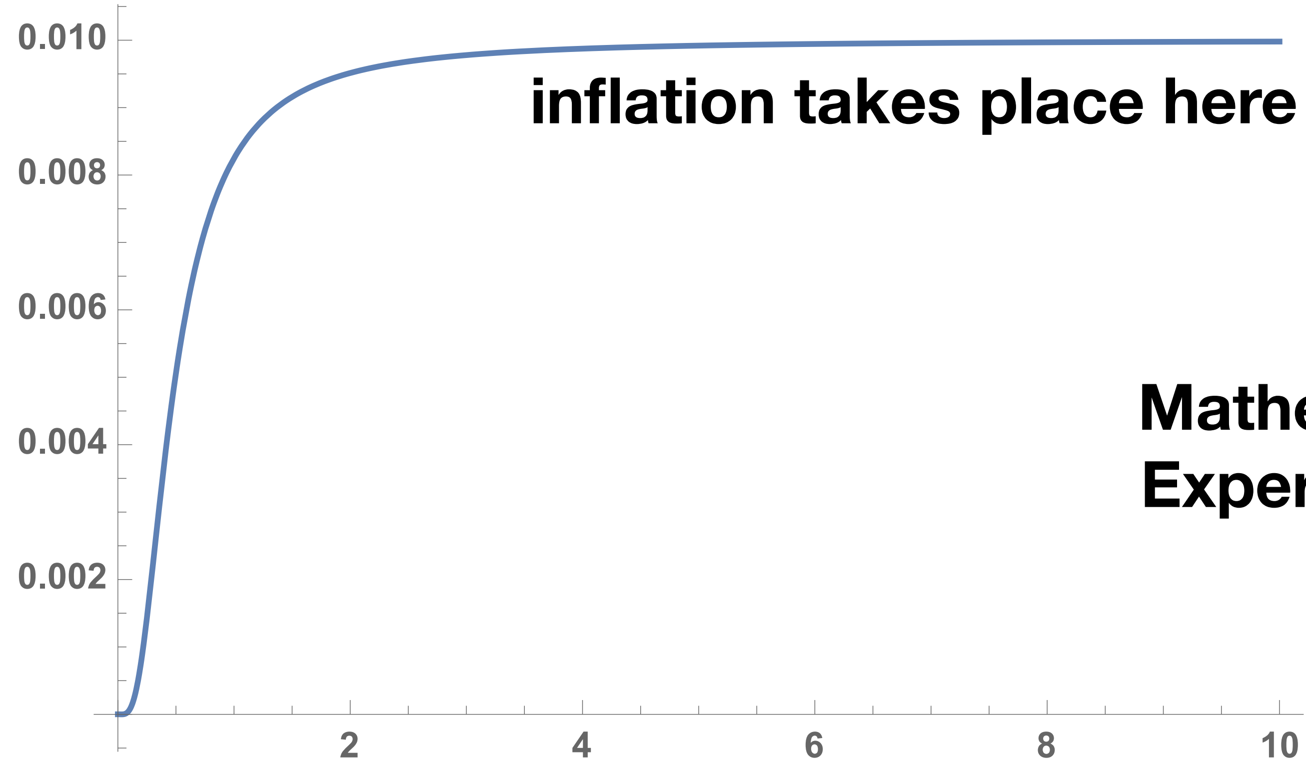
the best fit model of cosmology!



Y. Akrami et.al [Planck Collaboration], arXiv:1807.06211 [astro-ph.CO]

Higgs inflation

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



Mathematically Beautiful
Experimentally verifiable

Higgs inflation

[Bezrukov-Shaposhnikov, PLB(2007)], [**SCP**, S.Yamaguchi, JCAP(2008)]
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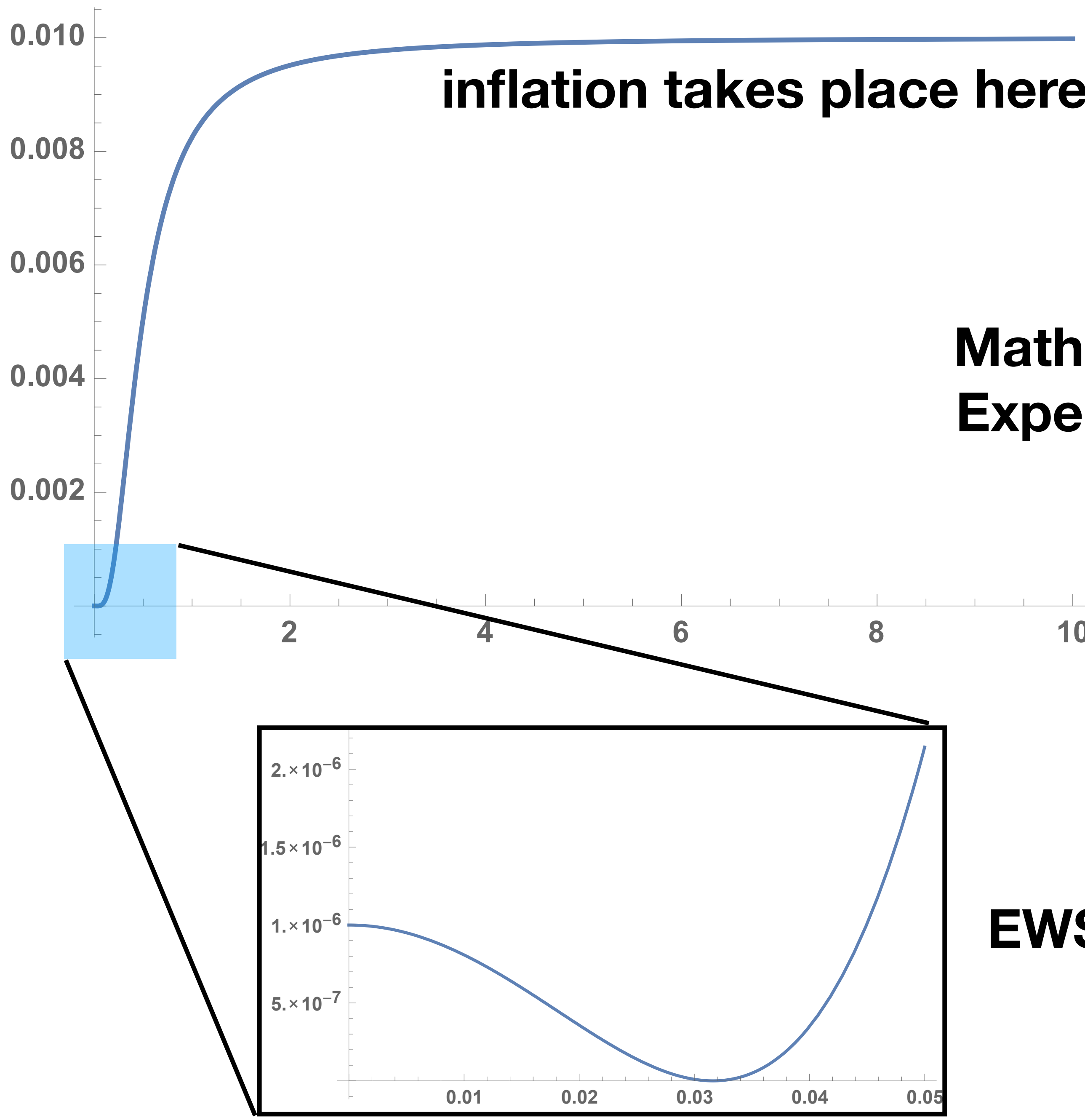


Mathematically Beautiful
Experimentally verifiable

EWSB is here

Is HI eagle or crocodile?

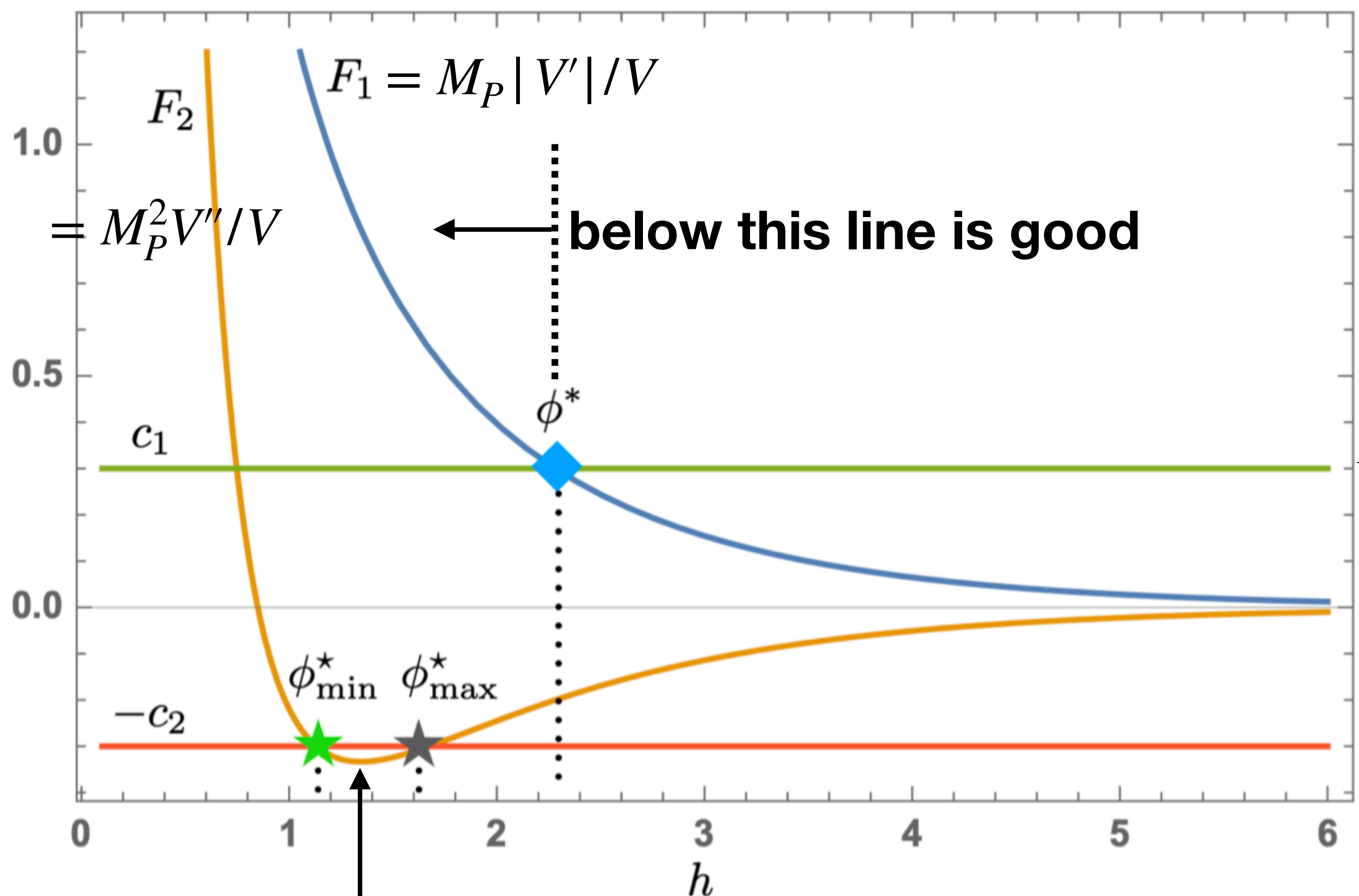
D. Y. Cheong, S. M. Lee and **SCP**,
arXiv:1811.03622, Phys. Lett. B789 (2019) 336-340

Sung Mook Lee
(M1)
poster

DY Cheong
(undergrad 4)

Is HI eagle or crocodile?

D. Y. Cheong, S. M. Lee and **SCP**,
arXiv:1811.03622, Phys. Lett. B789 (2019) 336-340



$M_{\rm Pl} \left| \nabla V \right| \geq c_1 V$

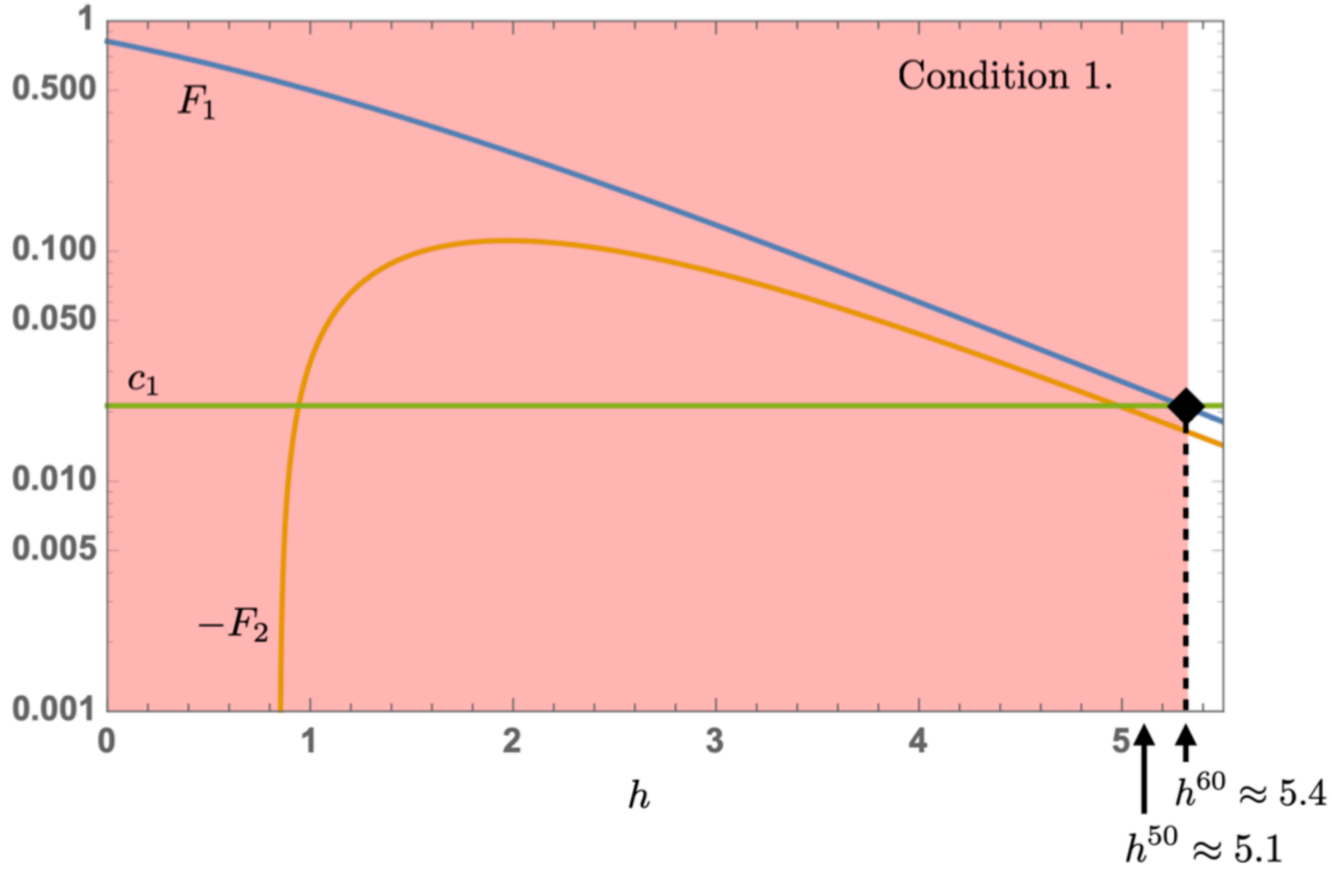
$M_{\rm Pl}^2 \nabla_i \nabla_j V \leq -c_2 V$

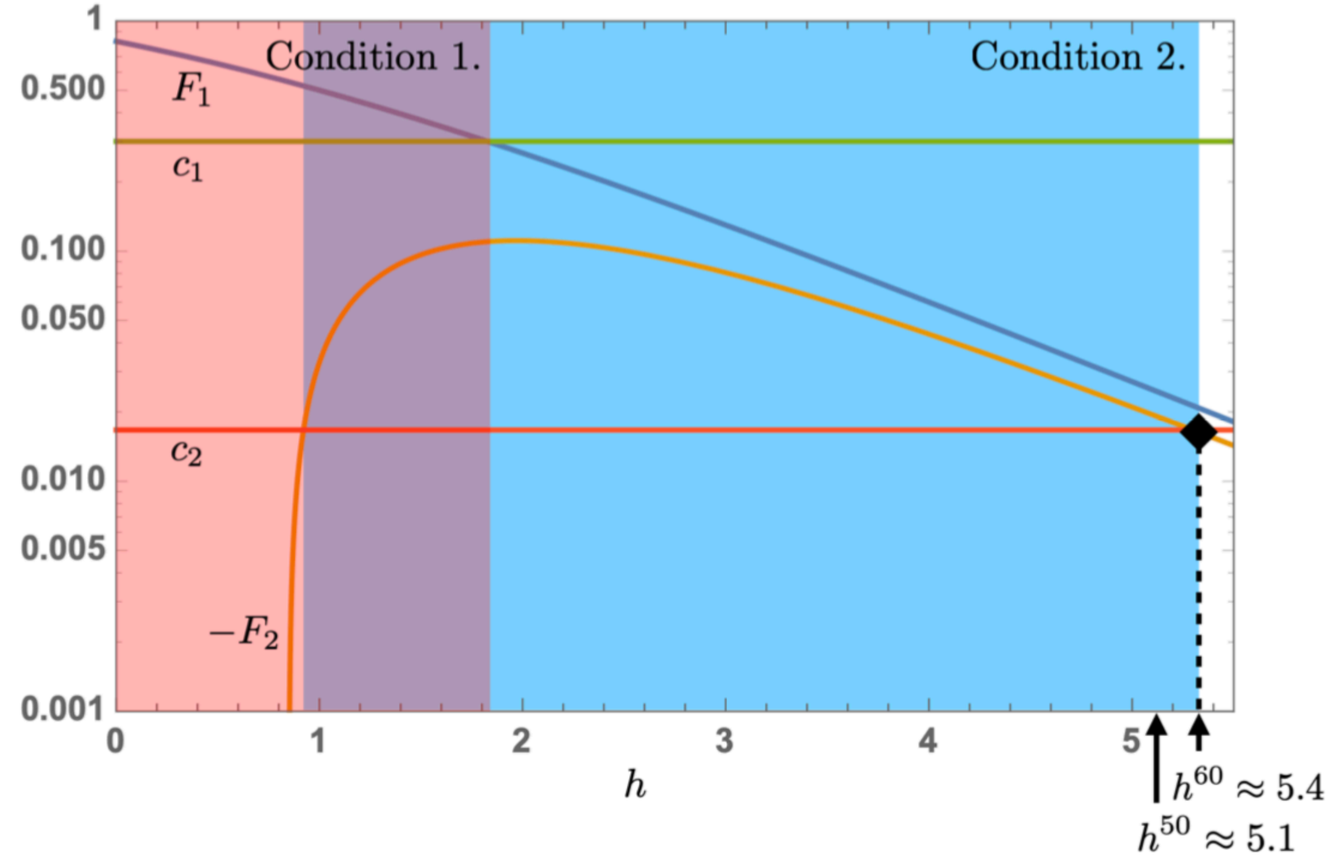
only this part is good

$$\left| \nabla V \right| \geq c_1 \frac{V}{M_{\rm Pl}}$$

$$\nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\rm Pl}^2}$$

$c_1, c_2 \sim O(1)$, positive



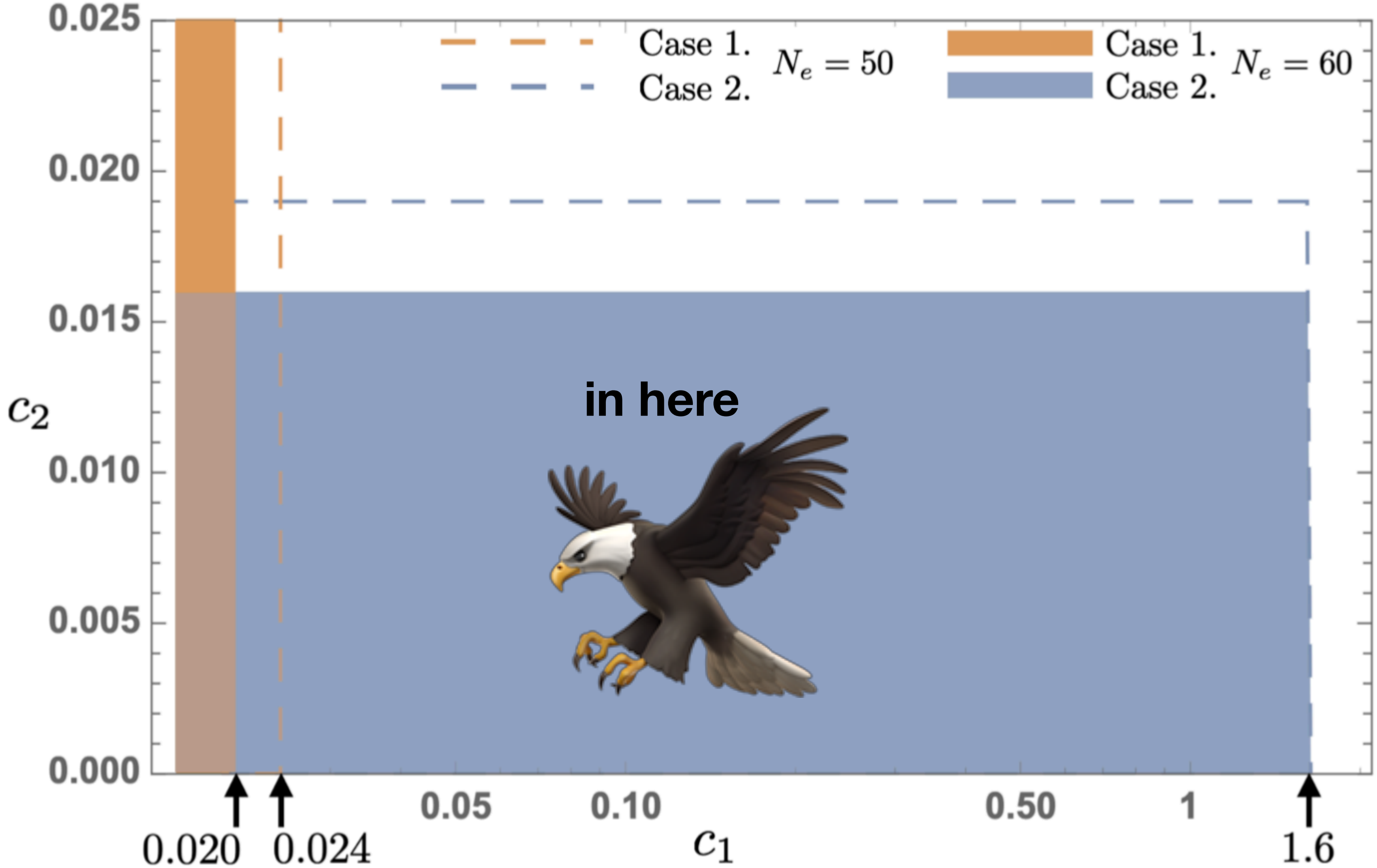


$$\left| \nabla V \right| \geq c_1 \frac{V}{M_{\rm Pl}}$$

$$\nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\rm Pl}^2}$$

$c_1, c_2 \sim O(1)$, **positive**

So, this is the result



out there

$$\left|\nabla V\right| \geq c_1 \frac{V}{M_{\rm Pl}}$$

$$\nabla_i \nabla_j V \leq -c_2 \frac{V}{M_{\rm Pl}^2}$$

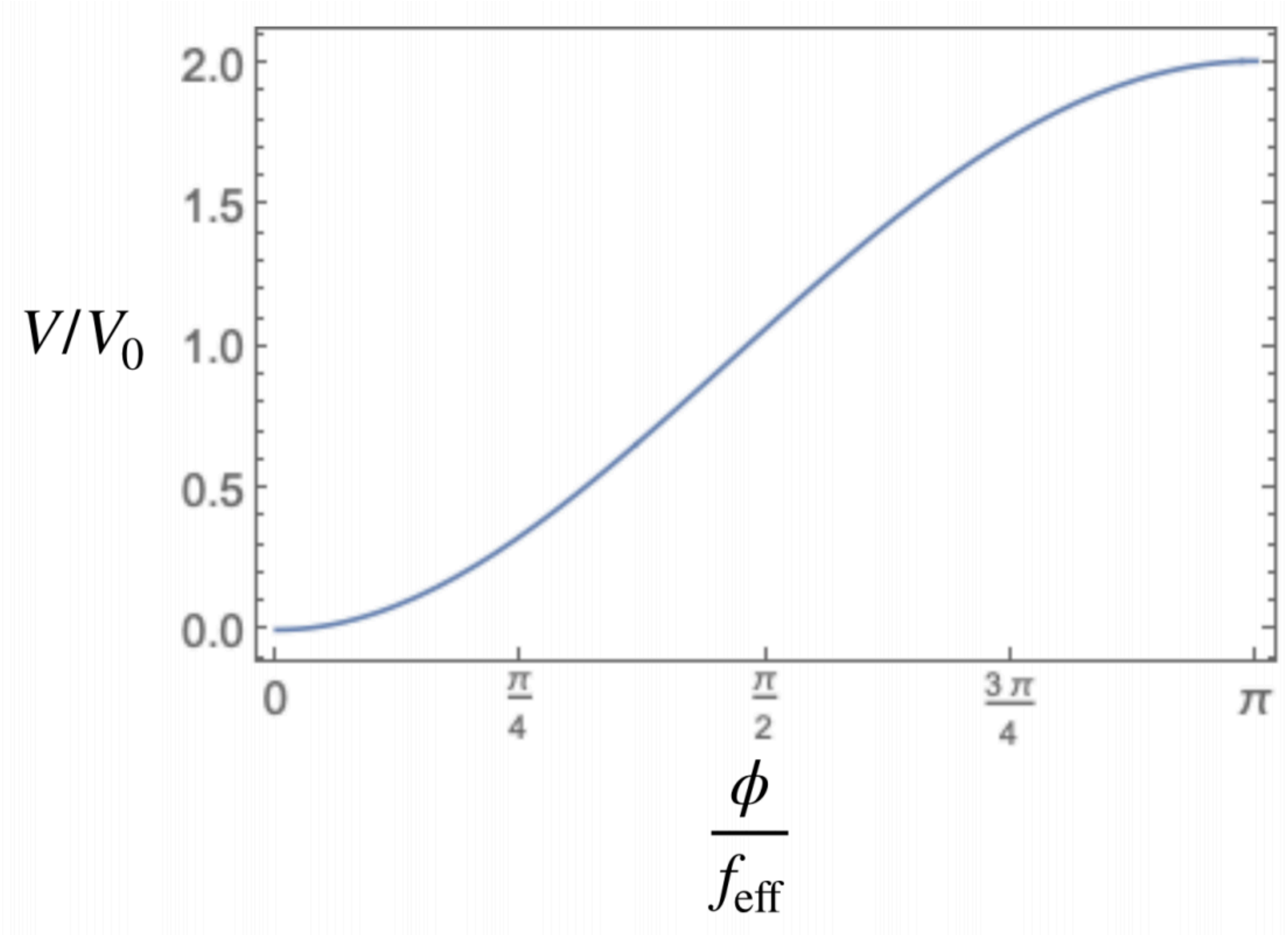
$c_1, c_2 \sim O(1)$, **positive**

D. Y. Cheong, S. M. Lee and **SCP**,
arXiv:1811.03622, Phys. Lett. B789 (2019) 336-340

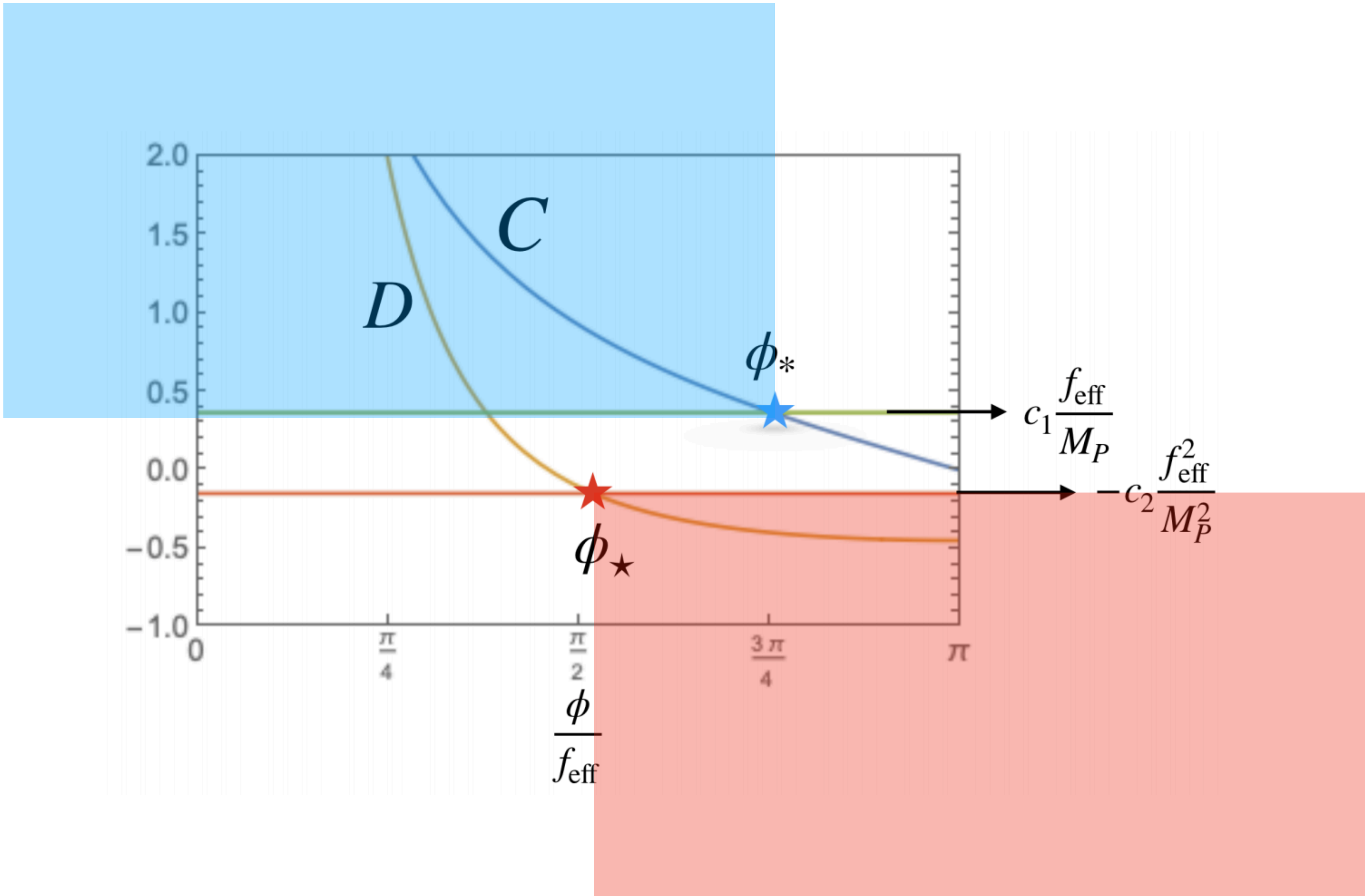
Gauge inflation

- Inflaton = A_5 Hosotani-san's talk
- Potential is protected by higher dimensional gauge symmetry, SU(2)…
- which is broken at 1/R (~GUT) scale
- Potential developed via gauge self interactions, Pot=CW
- A minimal version constructed …[**<u>SCP</u>**, J.-O. Gong 08'] then tested by Swampland conjecture recently [**<u>SCP</u>**18']

$$
\begin{aligned}
V(\phi) &= V_0 \sum_{n=1}^{\infty} \frac{1}{n^5}\left[1-\cos\frac{n\phi}{f_{\rm eff}}\right] \\
&= -\frac{V_0}{2}\left[\mathrm{Li}_5(e^{i\phi/f_{\rm eff}}) + \mathrm{Li}_5(e^{-i\phi/f_{\rm eff}}) - 2\zeta(5)\right]
\end{aligned}
$$



[<u>SCP</u>, J-O. Gong 08']



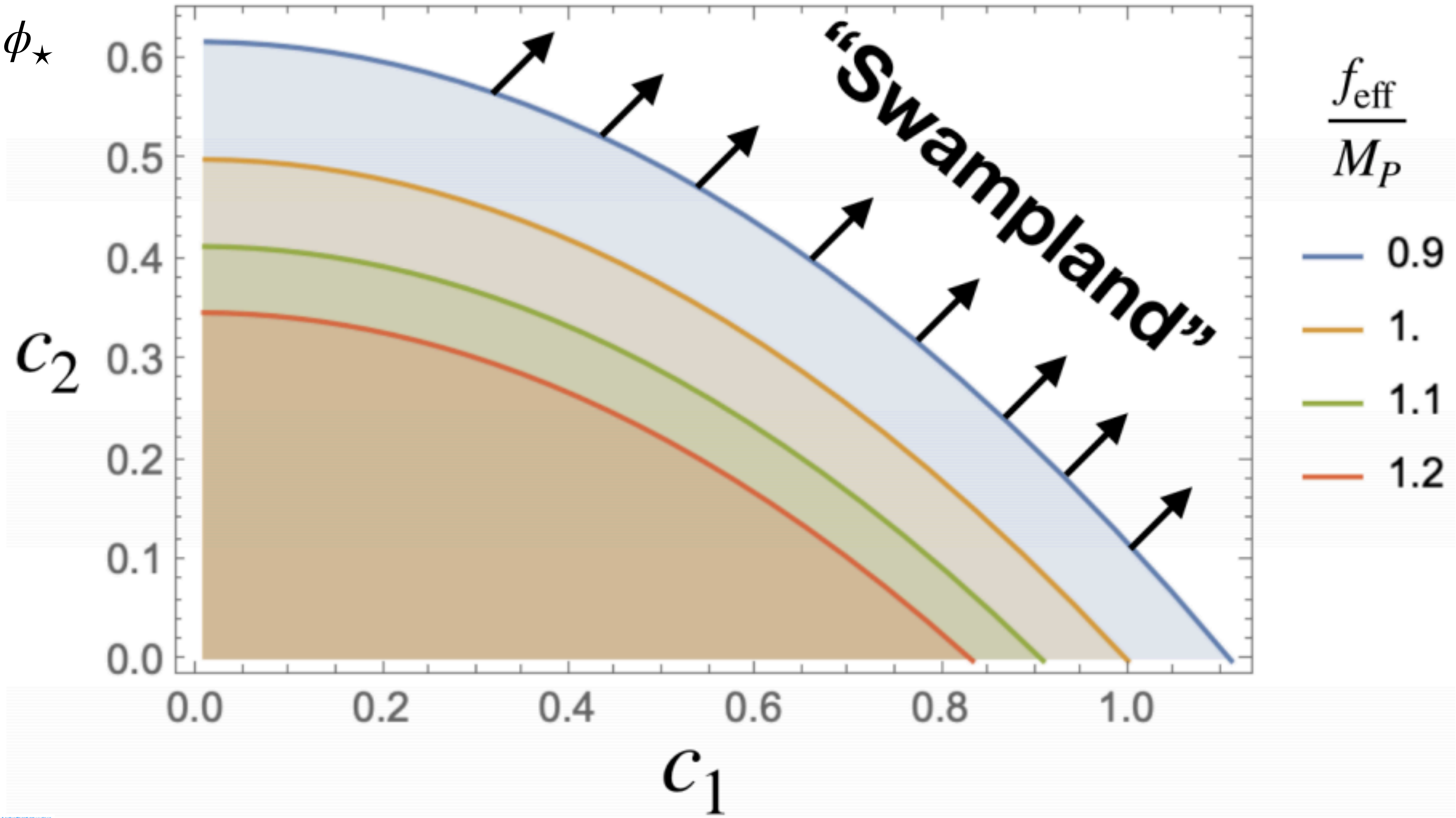
$$\left| \nabla V \right| \geq c_1 \frac{V}{M_{\text{Pl}}}$$

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

$c_1, c_2 \sim O(1)$, **positive**

If $\phi_* \geq \phi_\star$, the theory is good.

$\phi_* \geq \phi_\star$



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

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

$c_1, c_2 \sim O(1)$, **positive**

SCP 1810.11279, JCAP 1901 (2019) no.01, 053

conclusion

$$\left|\nabla V\right| \geq c_1 \frac{V}{M_{\rm Pl}}$$

$$\nabla_i \nabla_j V \leq - c_2 \frac{V}{M_{\rm Pl}^2}$$

$c_1, c_2 \sim O(1)$, **positive**

looks reasonable

- 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