# Inflation and the Swampland criteria

**Chia-Min Lin**

National Chin-Yi University of Technology

Seminar at AS on 10/12

國立勤益科技大學
NCUT
Chinyi Tech

# Reference

**Chaotic inflation on the brane and the Swampland Criteria**

**Chia-Min Lin**
**Kin-Wang Ng**
**Kingman Cheung**

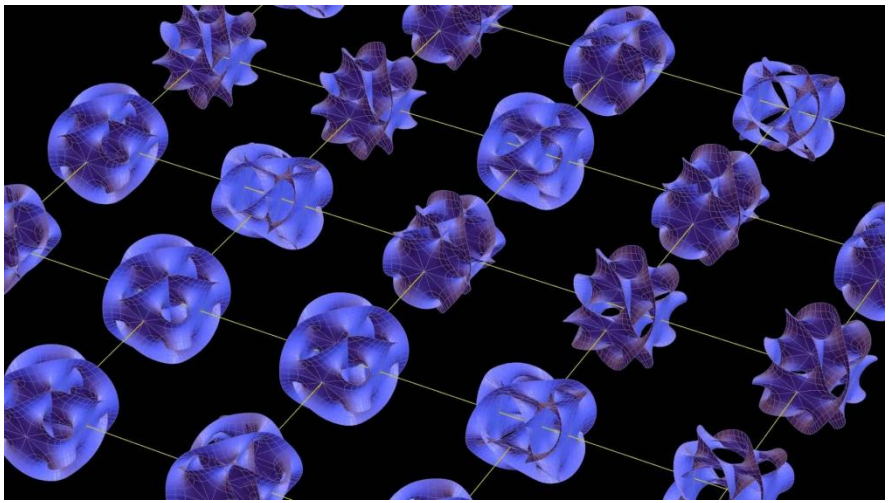
**arXiv:1810.01644**

# Outline

- The Swampland criteria
- What is the problem?
- Possible ways out
- Chaotic inflation on the brane
- Conclusion

# String theory

- A candidate of UV completed quantum gravity.
- String theory has no free parameters.
- String theory has no global symmetry.
- De Sitter space is hard to obtain.
- How to verify?



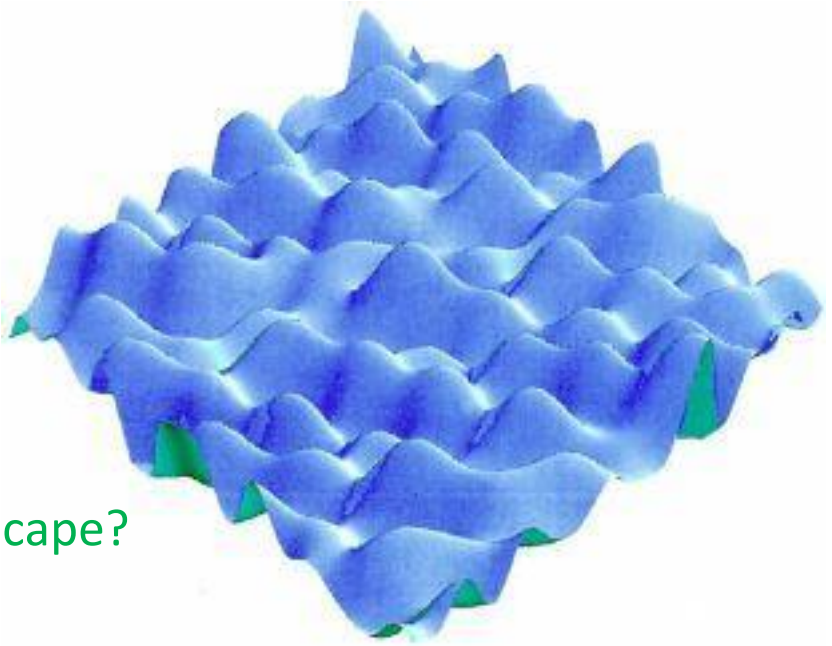
# String landscape

- No free parameter but lots of solutions!

$\sim 10^{500}$

$\sim 10^{272000}$

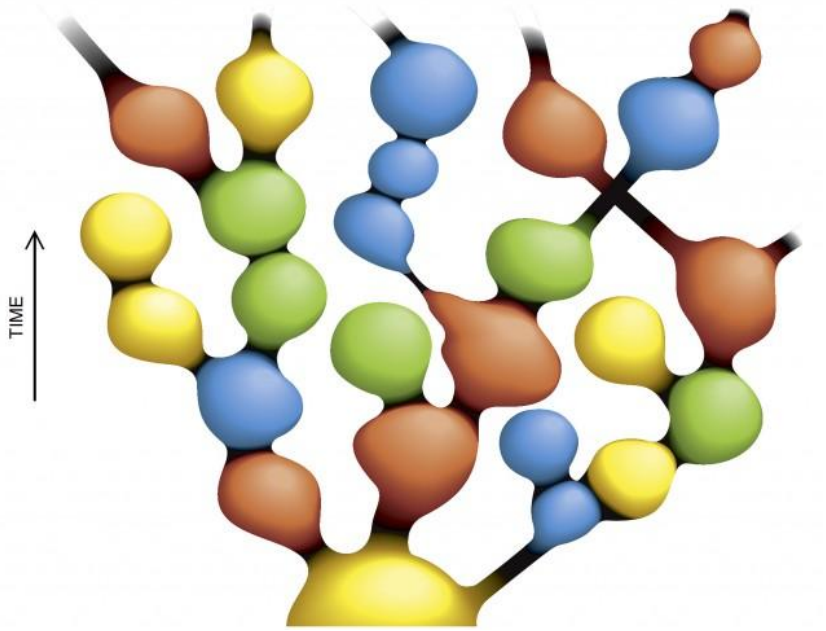
1511.03209 Taylor and Wang



Maybe any EFT can arise from the landscape?
Anything is possible?

Comepare to $\dfrac{8.8 \times 10^{28}}{1.6 \times 10^{-33}} = 5.5 \times 10^{61}$

# Multiverse




# Weak gravity conjecture (WGC)

- Gravity is the weakest force.
- Gauge symmetries vs. Global symmetries
- gq/m > 1

No-hair theorem

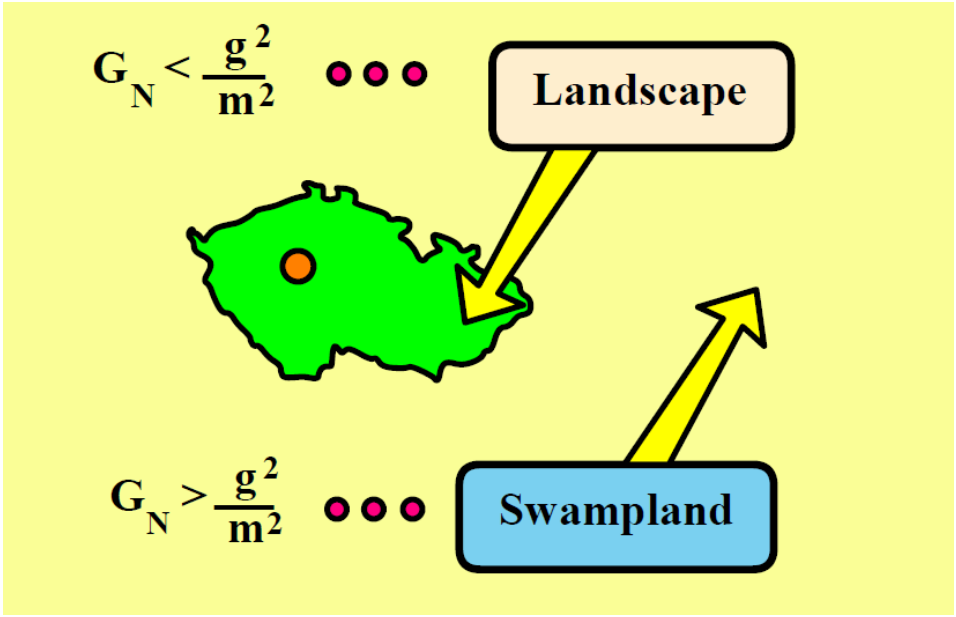
$$\Lambda = gM_{\rm Pl},$$ A hidden new UV scale

Extremal black holes
should be able to decay.

Cosmic censorship conjecture

$$F_e \sim \frac{q^2}{r^2}. \quad F_g \sim \frac{m^2}{M_p^2 r^2}.$$

$$F_g \leq F_e. \qquad \left(\frac{m}{M_p}\right) \leq q \ .$$



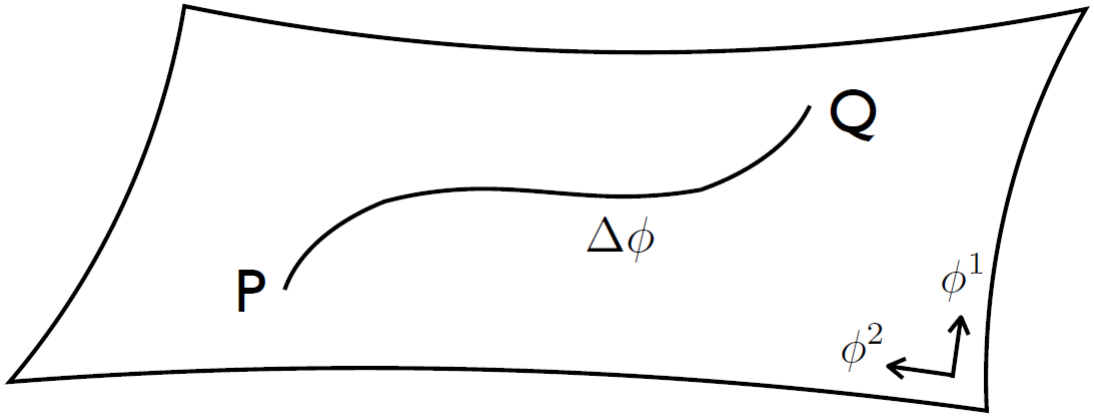
# What is a swampland?

Vafa hep-th/0509212

- Can any effective field theory be consistant with quantum gravity?
- If yes, what is the use of quantum gravity?
- Most of the EFTs are in the swampland.
- Swampland EFT cannot be UV embedded in quantum gravity.

# Swampland Distance Conjecture

Hep-th/0605264 Ooguri and Vafa




Infinite tower of states

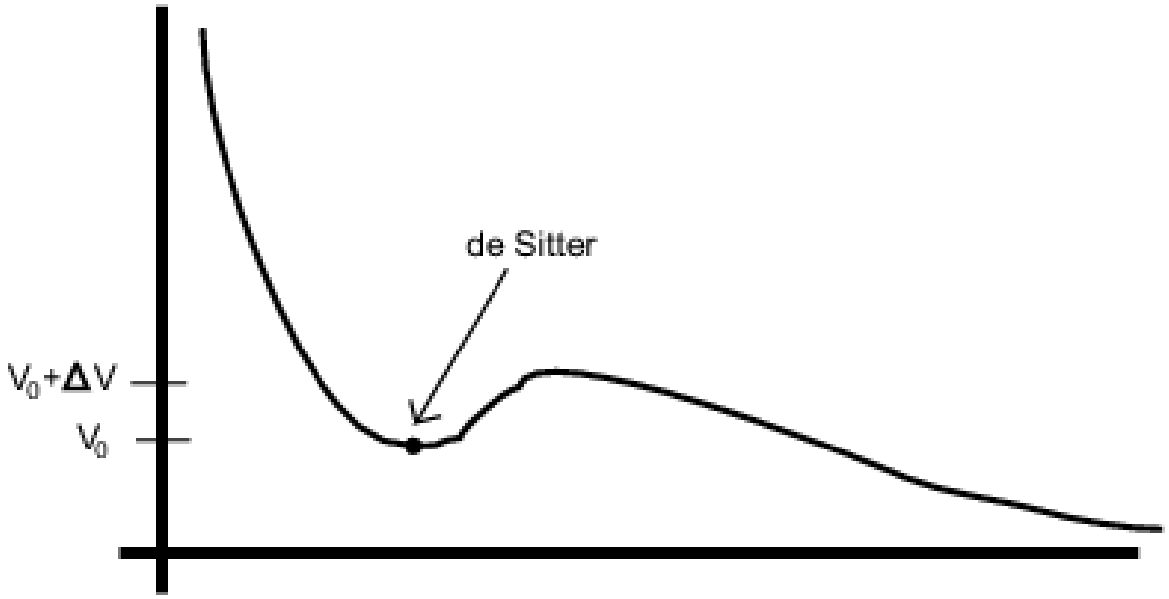
$$m(P) \lesssim m(Q) e^{-\lambda \Delta \phi}$$

$$\Lambda_{\text{cut-off}} \sim \Lambda_0 \, \exp(-\lambda \Delta \phi)$$

# Swampland de Sitter Conjecture

Obied, Ooguri, Spodyneiko, and Vafa 1806.08362

- (meta-)stable de Sitter vacuum belongs to the swampland.



# The swampland criteria

$$\frac{\Delta\phi}{M_P} < \mathcal{O}(1).$$

Swampland Distance Conjecture

$$M_P \frac{|V'|}{V} > c \sim \mathcal{O}(1)$$

Swampland de Sitter Conjecture

# Objection to swampland conjectrues

- The landscape, the swampland and the era of precision cosmology, Akrami, Kallosh, Linde, Vardanyan, 1808.09440
- De Sitter vacua in string theory, Kachru, Kallosh, Linde, Trivedi, hep-th/0301240 (known as the KKLT construction)

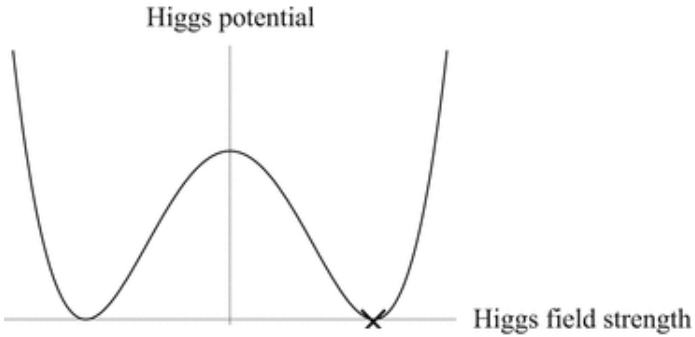
"We explain why we consider these conjectures problematic and not well motivated, …"

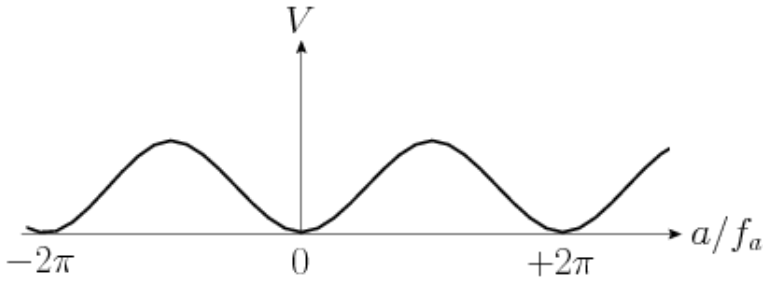
Eva Silverstein: They [Vafa and others] essentially just speculate that those things don't exist, citing very limited and in some cases highly dubious analyses.

Will Kinney: The landscape is a conjecture. The "swampland" is a conjecture built on a conjecture.

# What is the problem?

- Higgs
- QCD axion
- Cosmological constant
- (metastable) De Sitter vacua
- Inflation



# What is the problem?

$$N = \frac{1}{M_P^2}\int \frac{V}{V'}d\phi \simeq \frac{\frac{\Delta\phi}{M_P}}{\frac{V'}{V}}$$

Inflation does not happen?

# Tensor to scalar ratio

$$\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 = \frac{1}{2}c^2$$

$$M_P \frac{|V'|}{V} > c \sim \mathcal{O}(1)$$

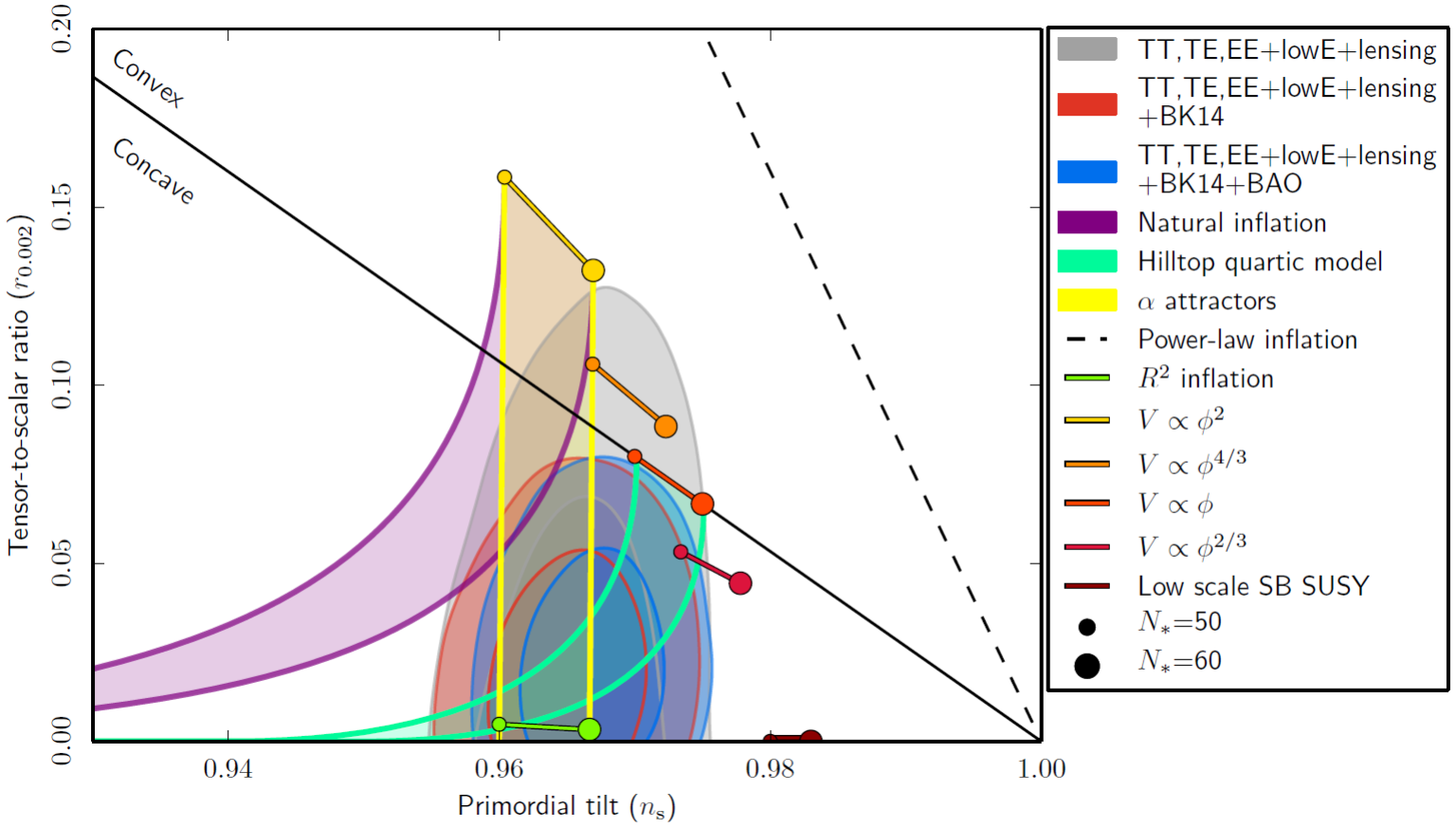
$$r = 16\epsilon = 8c^2 \lesssim 0.06$$

$$c \lesssim 0.087$$

Too big?

# PLANCK 2018

1807.06211



# Literatures

- A note on Inflation and the Swampland (1807.05445), Kehagias and Riotto
- The string swampland constraints require multi-field inflation (1807.04390), Achucarro and Palma
- A note on Single-field Inflation and the Swampland Criteria (1809.03962), Das
- Avoiding the string swampland in single-field inflation: Excited initial states (1809.01277) (Brahma and Hossain)
- The Zoo Plot Meets the Swampland: Mutual (In)Consistency of Single-Field Inflation, String Conjectures, and Cosmological Data (1808.06424), Kinney, Vagnozzi, and Visinelli

Here, we show that the swampland conjectures are inconsistent with existing observational constraints on single-field inflation. … Extension to non-canonical models such as DBI Inflation does not significantly weaken the bound.

# Inflation on the brane

$$H^2 = \frac{1}{3M_P}\rho\left[1+\frac{\rho}{2\Lambda}\right],$$

Maartens, Wands, Bassett, and Heard
hep-ph/9912464

$$M_4 = \sqrt{\frac{3}{4\pi}}\left(\frac{M_5^2}{\sqrt{\Lambda}}\right)M_5,$$

At high energies, Hubble expansion is faster.

$$\epsilon \equiv \frac{1}{2}\left(\frac{V'}{V}\right)^2 \frac{1}{\left(1+\frac{V}{2\Lambda}\right)^2}\left(1+\frac{V}{\Lambda}\right),$$

$$\eta \equiv \left(\frac{V''}{V}\right)\left(\frac{1}{1+\frac{V}{2\Lambda}}\right).$$

# Inflation on the brane

$$N = \int_{\phi_e}^{\phi_i} \left(\frac{V}{V'}\right)\left(1+\frac{V}{2\Lambda}\right) d\phi.$$

$$P_R = \frac{1}{12\pi^2}\frac{V^3}{V'^2}\left(1+\frac{V}{2\Lambda}\right)^3.$$

$$n_s = 1 + 2\eta - 6\epsilon.$$

$$\alpha = \frac{dn_s}{d\ln k} = -\frac{dn_s}{dN}.$$

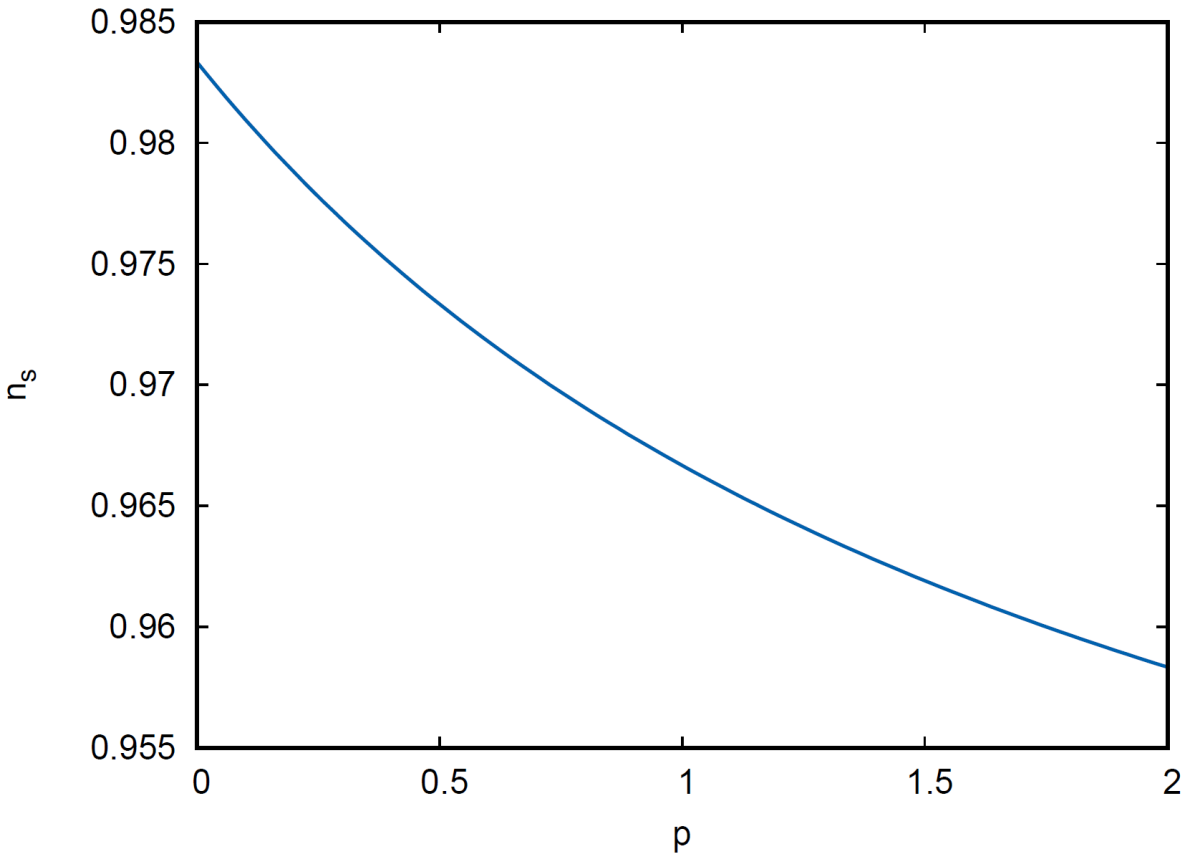
# Chaotic inflation on the brane

$$V = a\phi^p.$$

$$V/\Lambda \gg 1$$

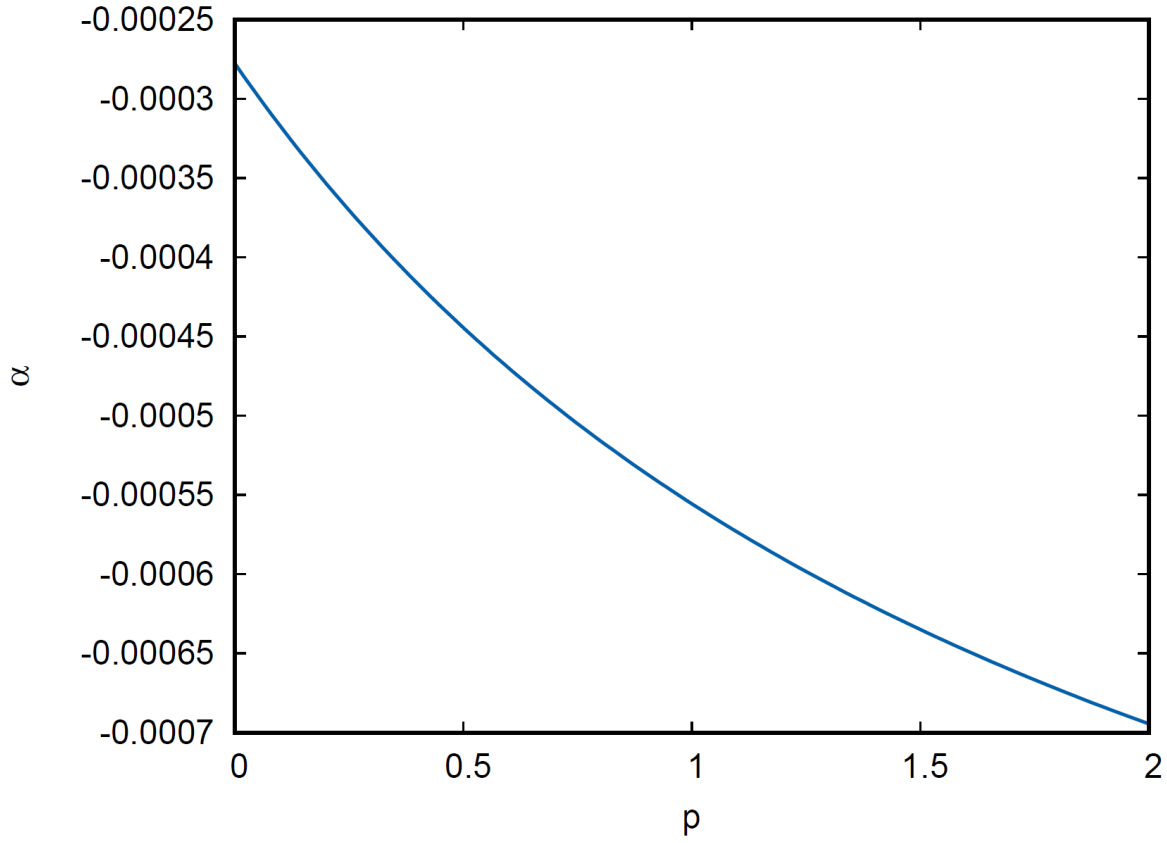
High energy limit.

# The spectral index



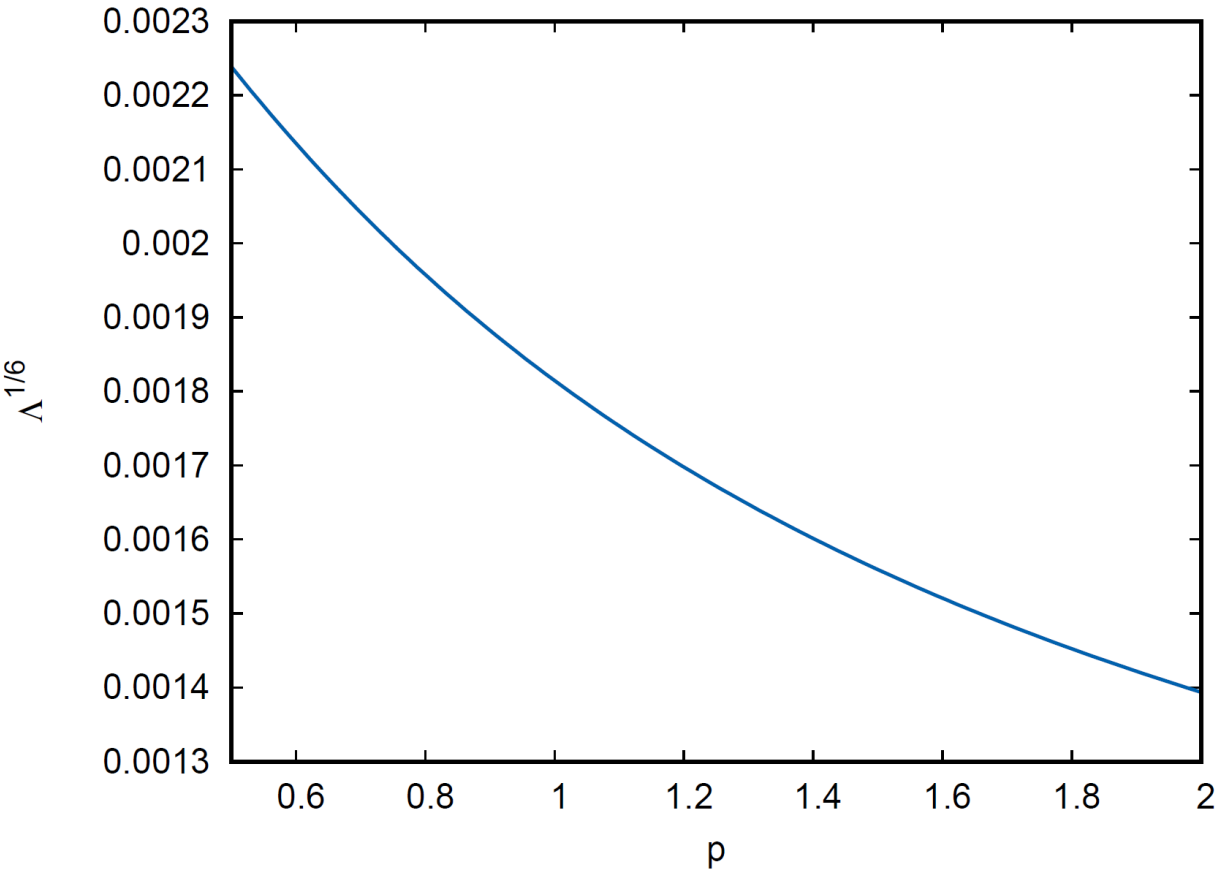

$$n_s = 1 - \frac{2+4p}{N(p+2)} = 1 - \frac{1+2p}{30(p+2)}.$$

# The running spectral index




$$\alpha = -\frac{2+4p}{N^2(p+2)} = -\frac{2+4p}{3600(p+2)},$$

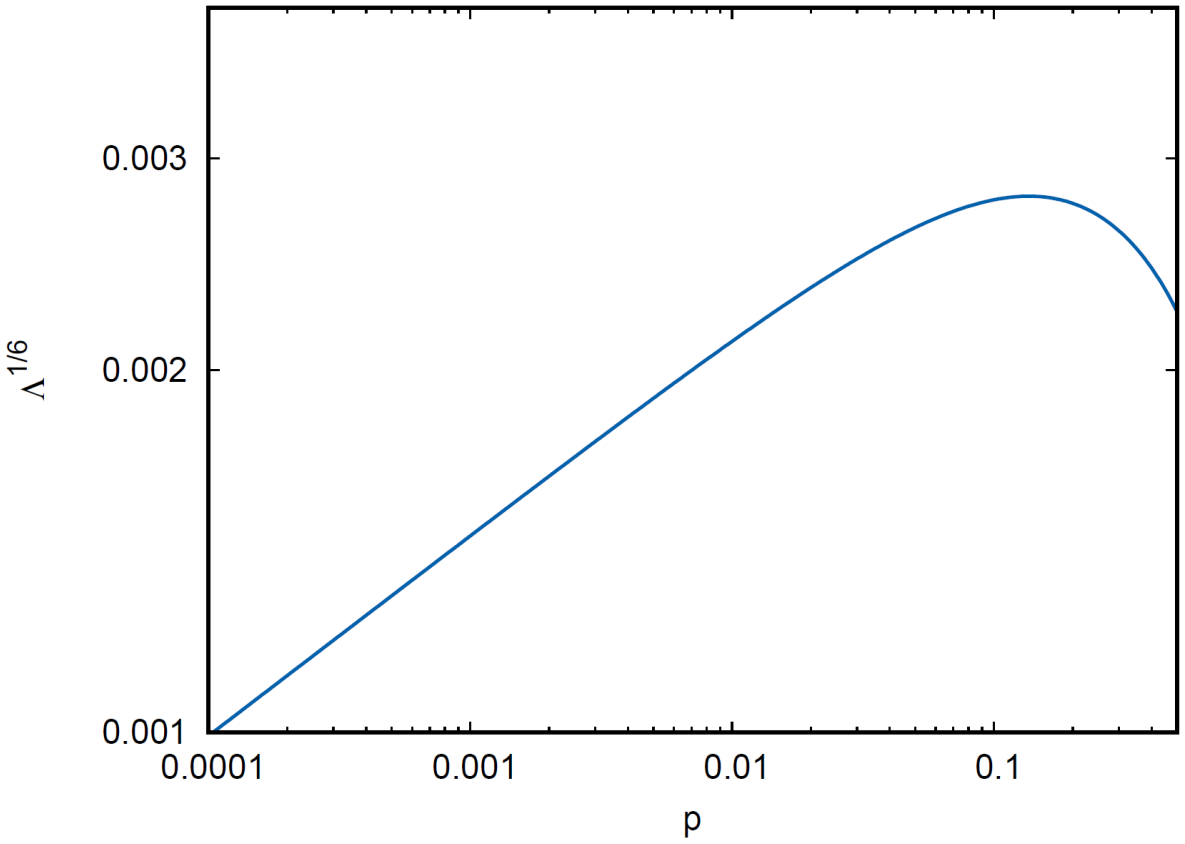
# The upper bound of Λ




$$V/\Lambda > 100,$$

$$\Lambda^{\frac{1}{6}} < 1.15 \times 10^{-2} \times 2^{\frac{p}{2p+4}} \left[\frac{p}{120(p+2)}\right]^{\frac{2p+1}{3p+6}}.$$

# The upper bound of Λ



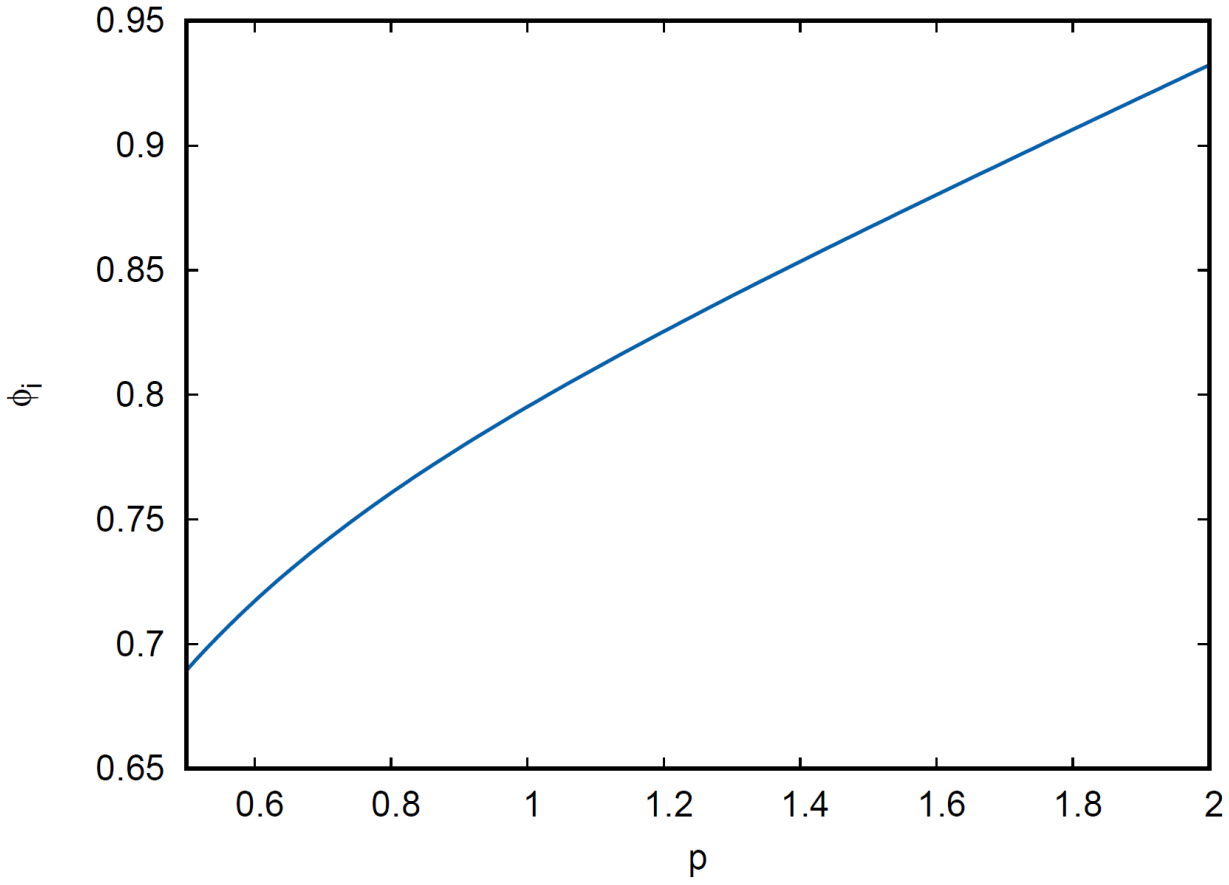

$$V/\Lambda > 100,$$

$$\Lambda^{\frac{1}{6}} < 1.15 \times 10^{-2} \times 2^{\frac{p}{2p+4}} \times p^{\frac{1}{6}} (1-p)^{\frac{p}{2p+4}} [120(p+2)]^{-\frac{2p+1}{3p+6}}.$$

# The range of Λ

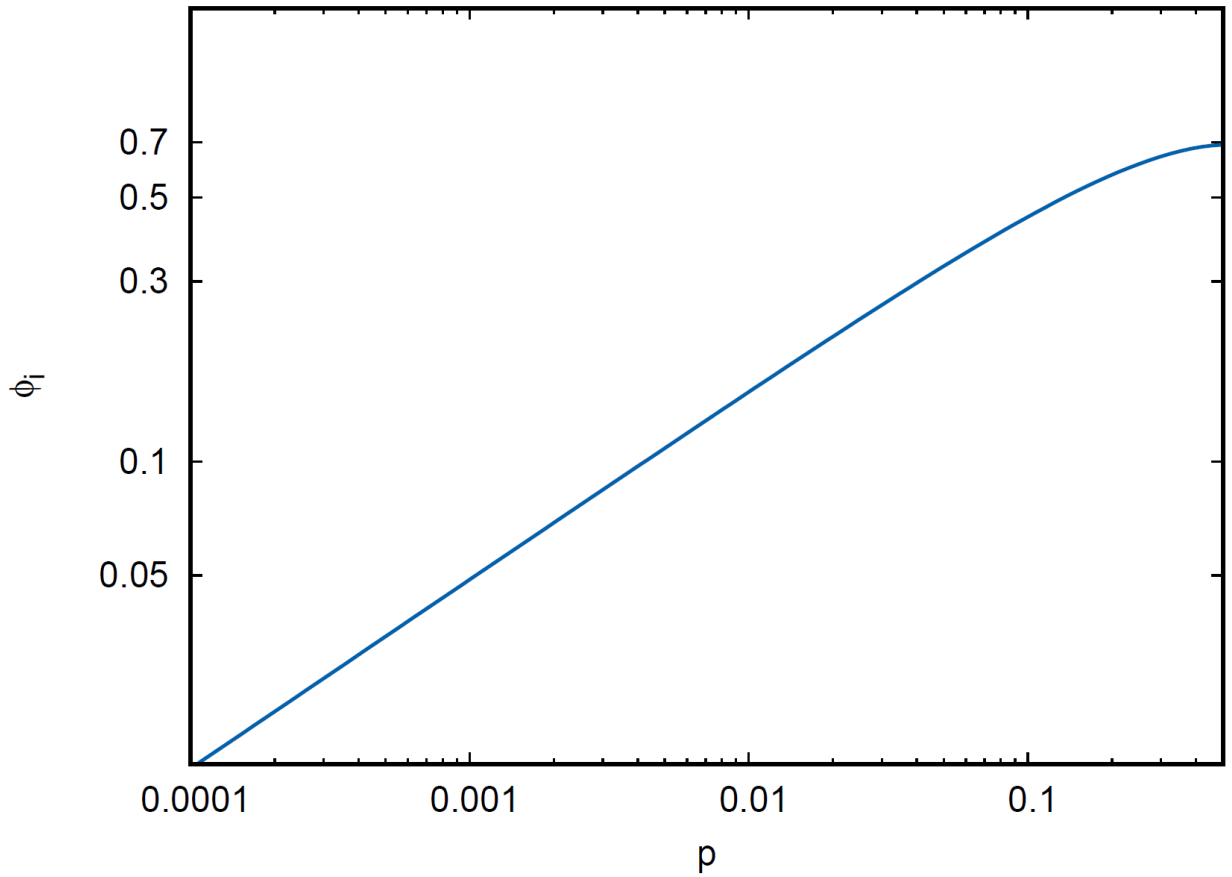
$$1.92 \times 10^{-9} \lesssim \Lambda^{\frac{1}{6}} \lesssim 10^{-3}.$$

# The upper bound of $\phi_i$



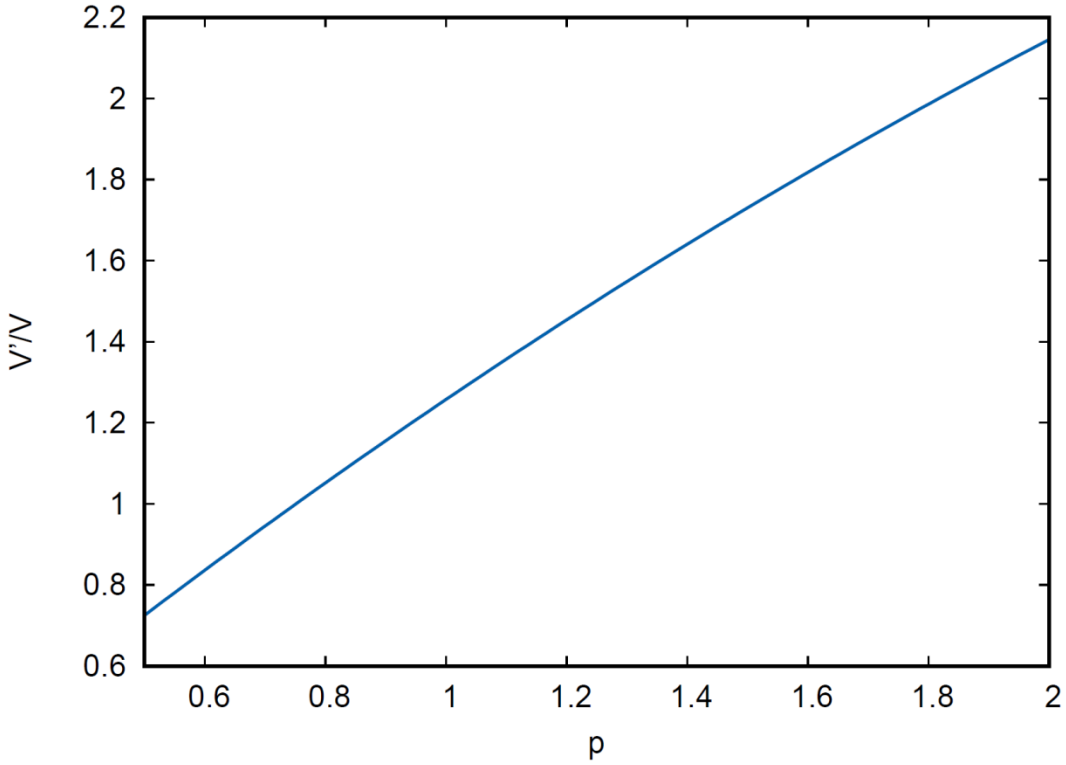

$$\phi_i = 8.66 \times p^{\frac{1}{3}} [120(p+2)]^{\frac{2}{3}} \Lambda^{\frac{1}{6}}.$$

# The upper bound of $\phi_i$



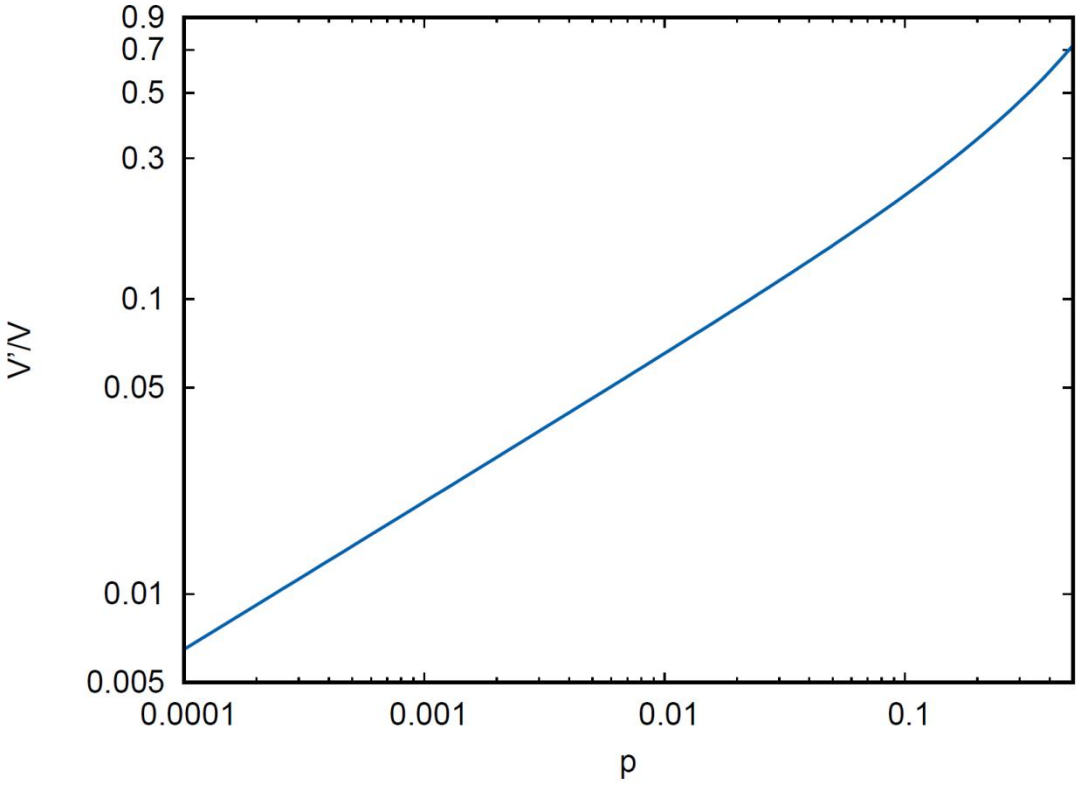

$$\phi_i = 8.66 \times p^{\frac{1}{3}} [120(p+2)]^{\frac{2}{3}} \Lambda^{\frac{1}{6}}.$$

# V’/V




$$\frac{V'}{V} = \frac{p}{\phi},$$

# V’/V




$$\frac{V'}{V} = \frac{p}{\phi},$$

# The tensor to scalar ratio

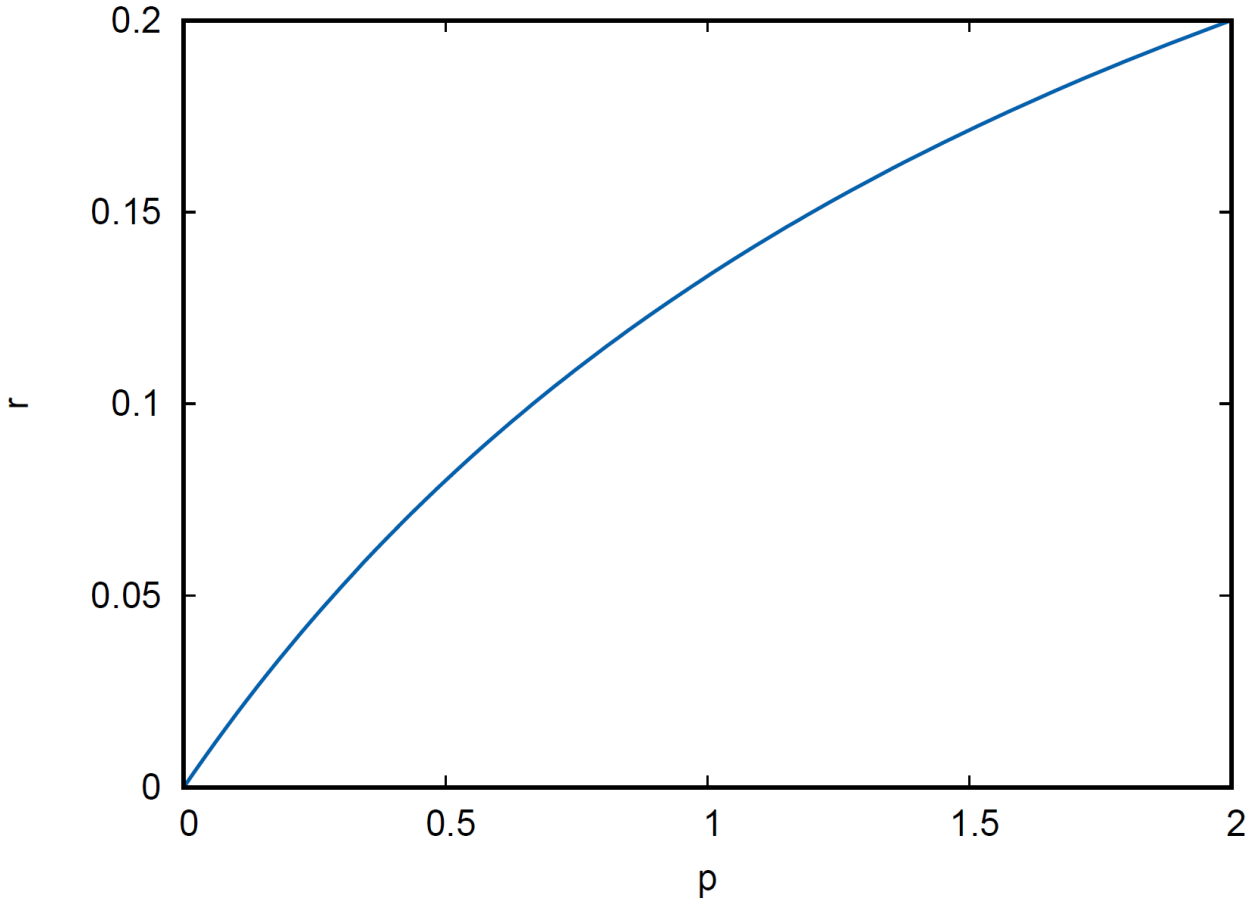
$$r = 16\epsilon.$$

For $V/\Lambda \ll 1,$

$$r = 24\epsilon = \frac{2p}{5(p+2)},$$

For $V/\Lambda \gg 1.$

# The tensor to scalar ratio r




$$p = 0.35, \quad r = 0.06.$$

$$r < 0.064$$

# Conclusion

- Chaotic inflation on the brane is a single field inflation which can satisfy the Swampland criteria with the Bunch-Davies initial state.
- If $p<0.35$, we have $r<0.06$.