C01 Update

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THE UNIVERSITY OF TOKYO

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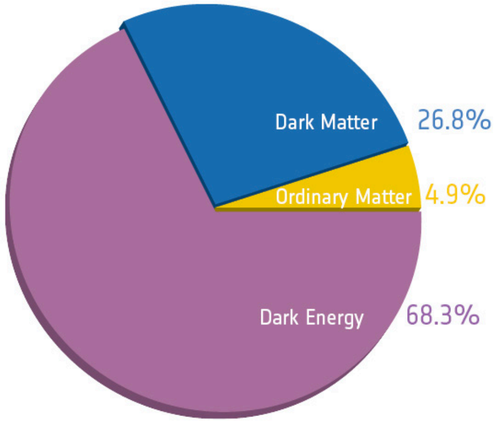
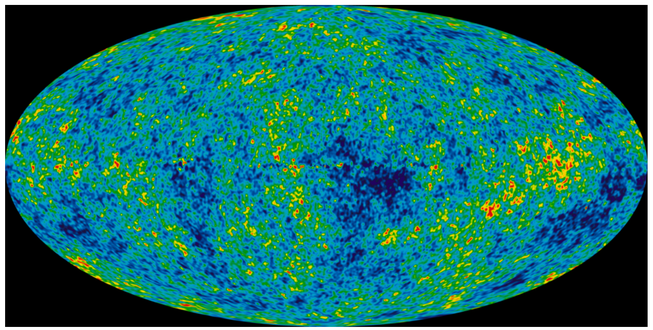
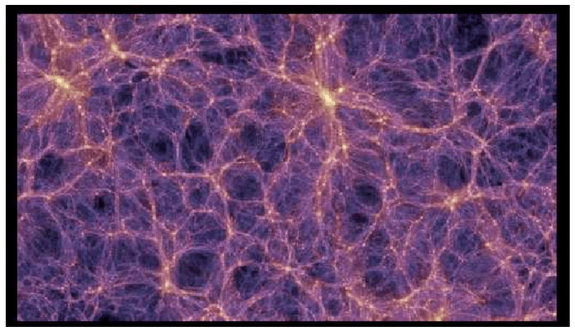
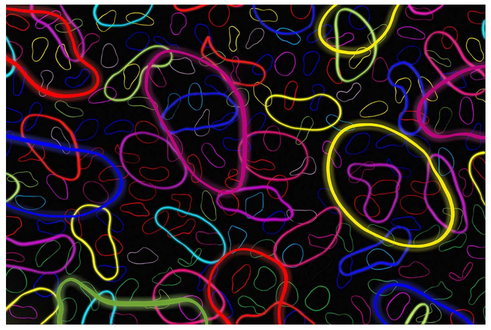
Much of our knowledge of DM (and DE) comes through gravity

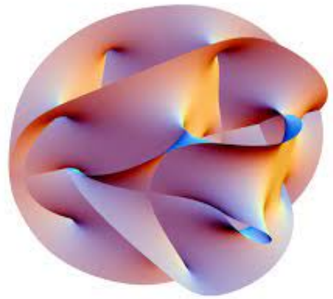






… which was quantum gravity in the early universe





QG challenges the EFT paradigm for DM

Not all EFTs have consistent UV completion in QG

Naturalness ??

Quantum gravity:

navigator for exploring DM discovery space

The Team

Yasunori Nomura (Berkeley)

Ryo Saito (Yamaguchi)

Satoshi Shirai (IPMU)

Masahito Yamazaki (IPMU)

Some recent highlights

“de Sitter Space Is Sometimes Not Empty”

V. Balasubramanian, **Y. Nomura**, T. Ugajin

“Can we explain cosmic birefringence without a light field?”

Y. Nakai, R. Namba, **I. Obata,** Y. Qiu, **R. Saito**

“Ostrogradsky mode in scalar–tensor theories with higher-order derivative couplings to matter”

A. Naruko, R. Saito, N. Tanahashi, **R. Saito**

“Constraining Neutrino-Dark Matter Interactions with Milky Way Dwarf”

S. Heston, **S. Horigome, S. Shirai**

“Revisiting Metastable Cosmic String Breaking”

A. Chitose, M. Ibe, Y. Nakayama, **S. Shirai,** K. Watanabe

"Global symmetries in ensemble averages in holography”

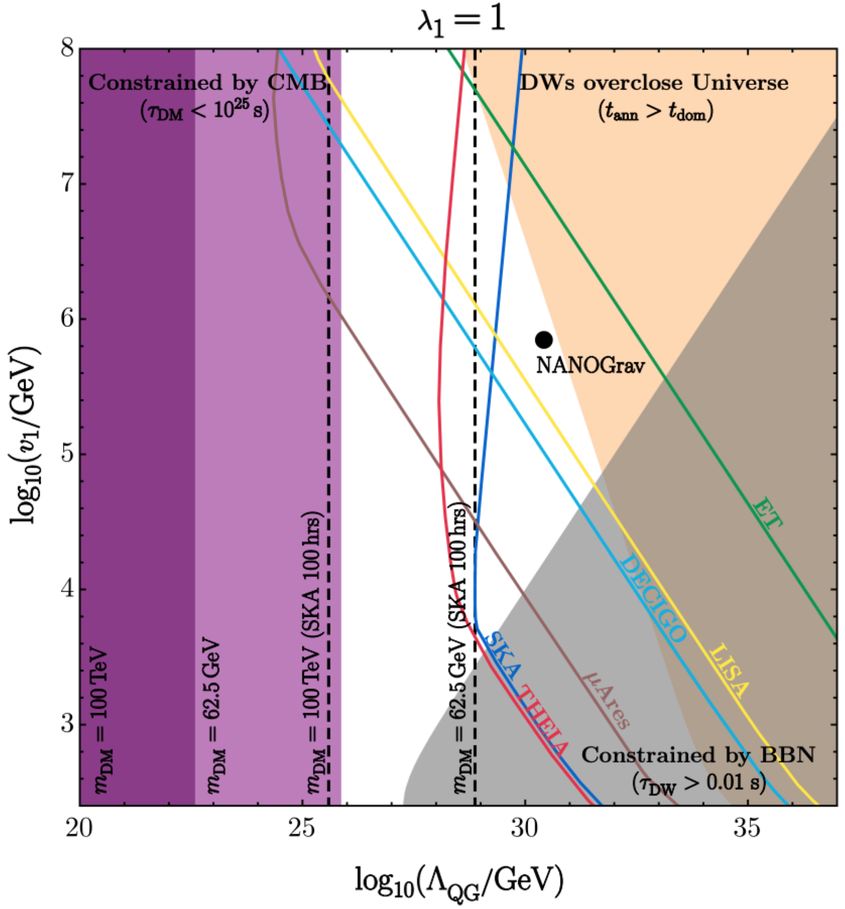
M. Ashwinkumar, J. Leedom, **M. Yamazaki**

“Quantum Gravity Effects on Dark Matter and Gravitational Waves”

Stephen F. King, Rishav Roshan, Xin Wang, Graham White + **MY** (2308.03724 [hep-ph])

“Quantum Gravity Effects on Fermionic Dark Matter and Gravitational Waves”

Stephen F. King, Rishav Roshan, Xin Wang, Graham White + **MY** (arXiv:2311.12487 [hep-ph])



“Cosmological Hints of String Theory Axions”

D. Kondo, **H. Murayama**, R. Okabe,
S. Saito, Y. Watanabe + MY (in progress)

Q: Any observational signatures of string theory ??

Q: Any observational signatures of string theory ??

Q: Evidence Already ?????

MANY axions in String Theory

MANY axions in String Theory

e.g.

$$\int C_{p-3} \wedge \mathrm{Tr}(F \wedge F) \longrightarrow \int_{\mathbb{R}^{3,1}} a \, \mathrm{Tr}(F \wedge F)$$

Dp-brane

$\mathbb{R}^{3,1} \times \Sigma_{p-3}$

$(p-3)$-cycle in CY

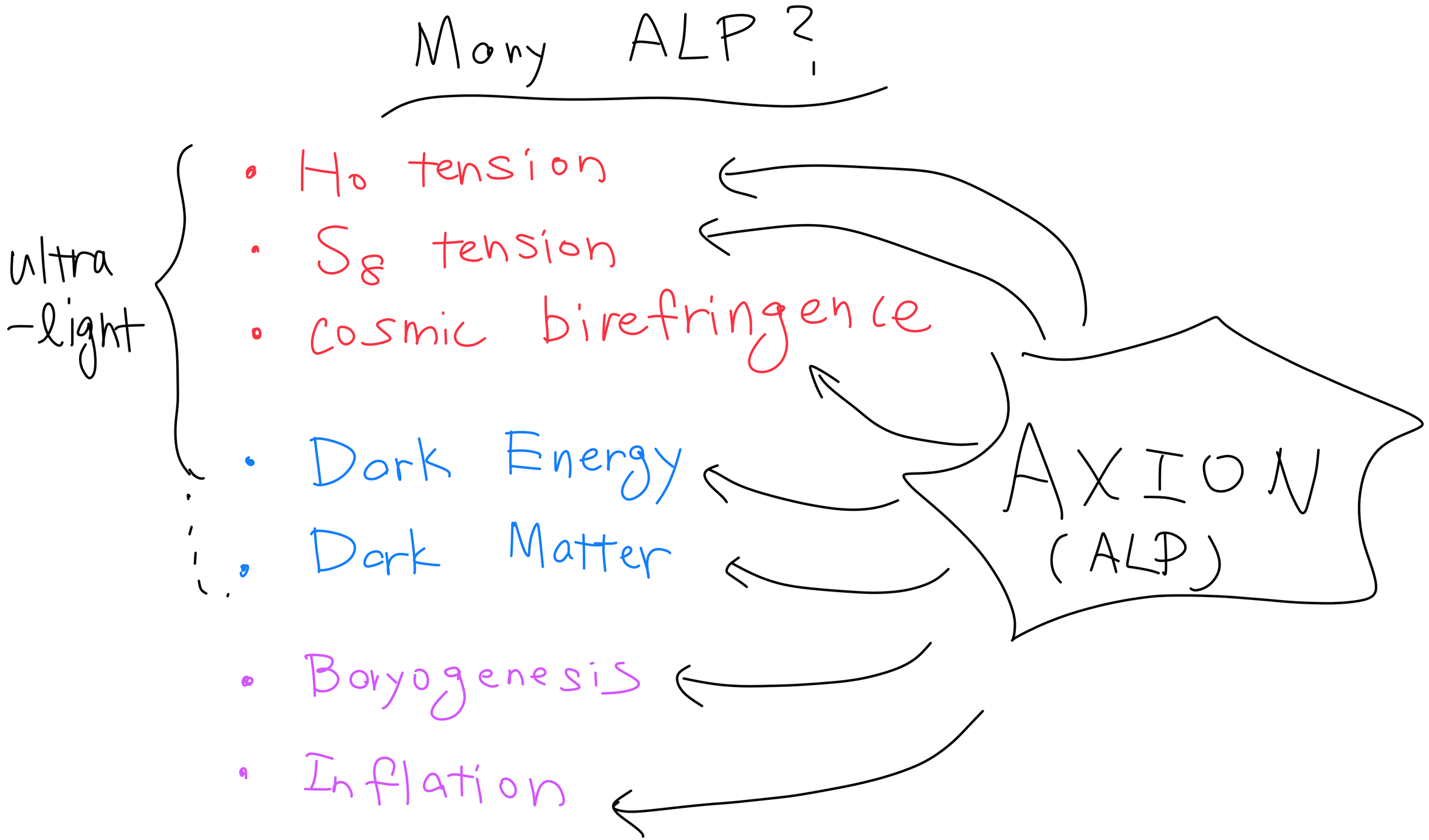
$\mathcal{O}(100)$ choices

$$a = \int_{\Sigma_{p-3}} C_{p-3}$$

Who ordered muons?

Isidor Rabi

Who ordered axions?


Many ALP?
ultra
-light
• H_0 tension
• S_8 tension
• cosmic birefringence
• Dark Energy
• Dark Matter
• Baryogenesis
• Inflation
AXION
(ALP)

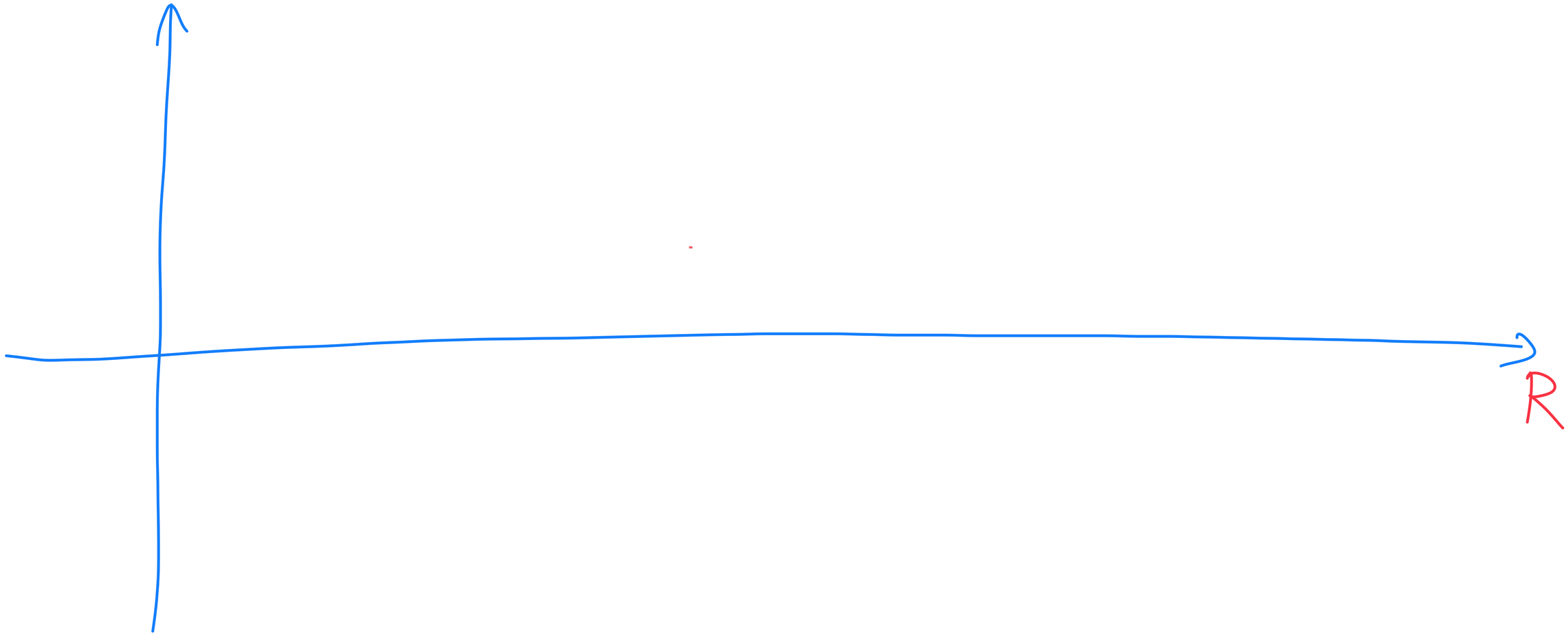
String Landscape

Landscape of SM

[Arkani-Hamed, Dubovsky, Nicolis, Villadoro '07]

Consider SM on S^1 with radius R:

non-trivial potential from Casimir energy



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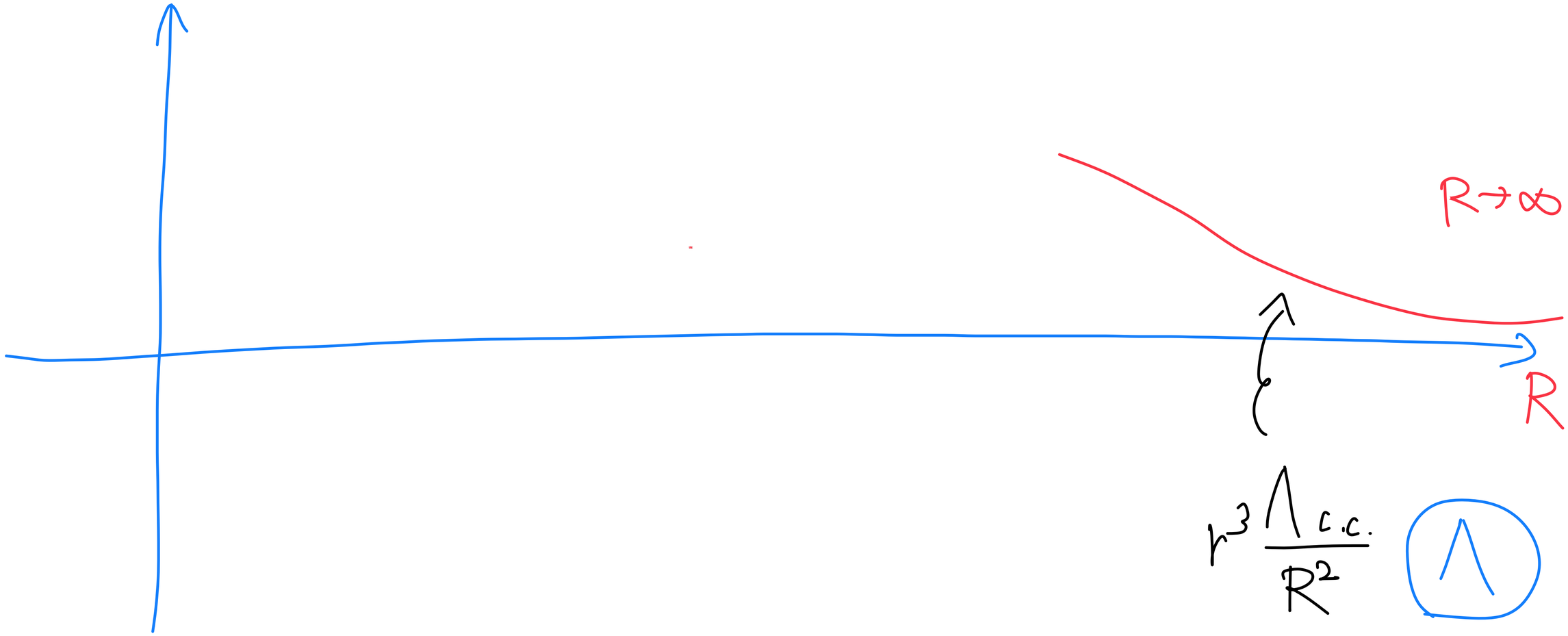

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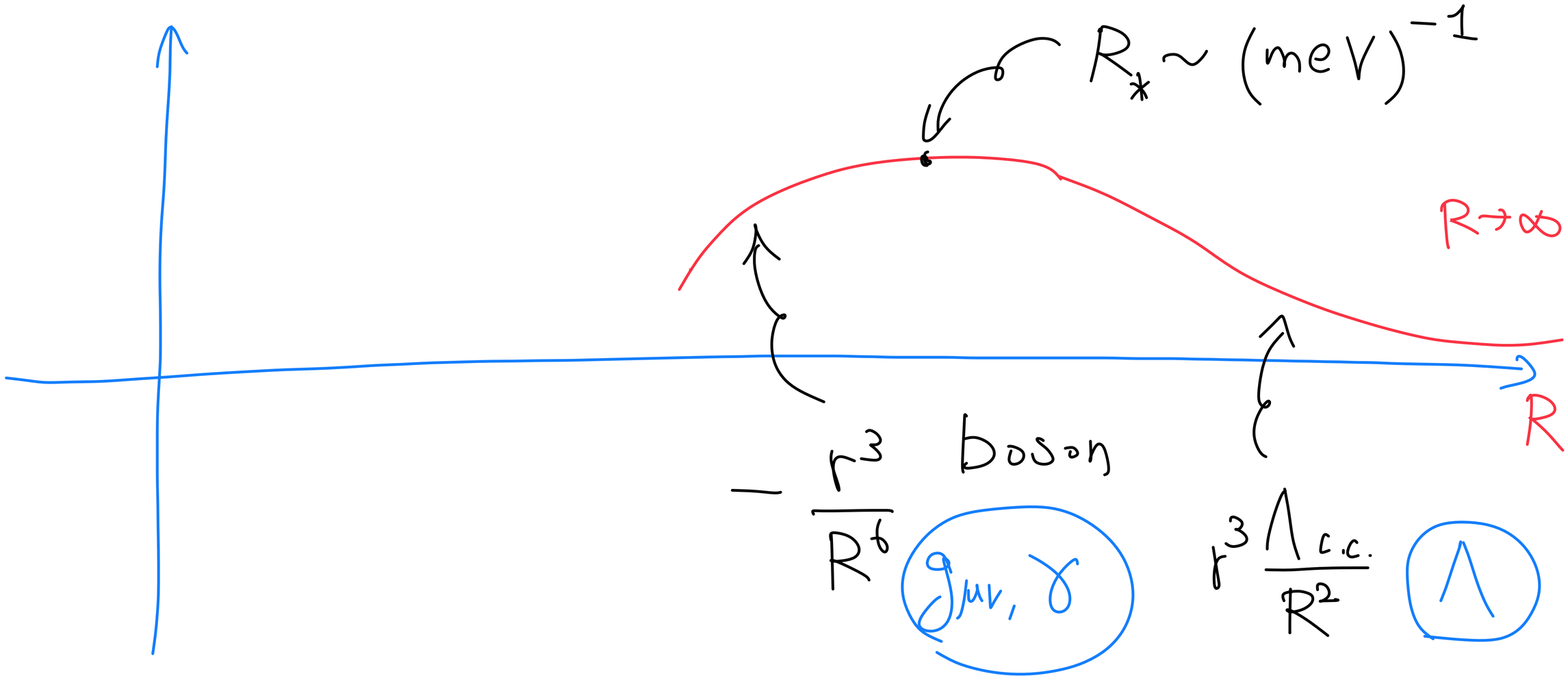

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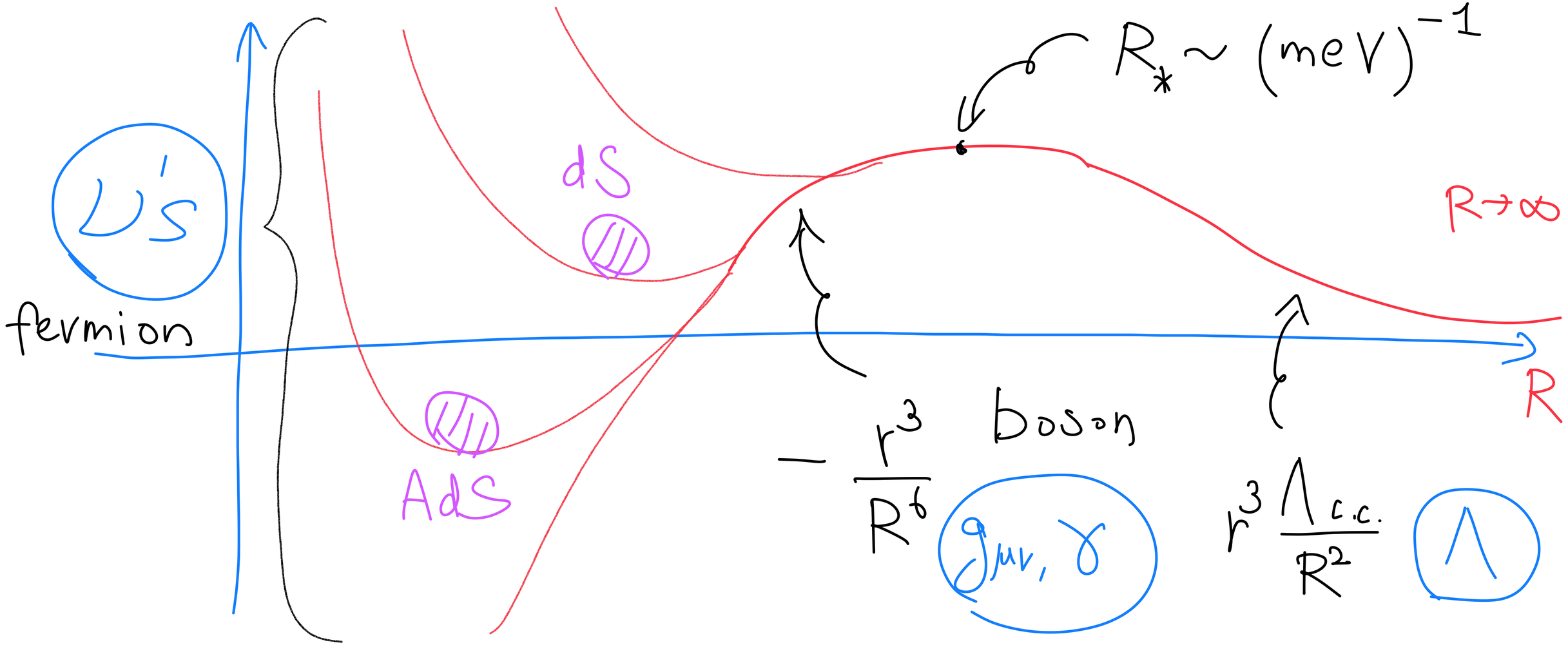
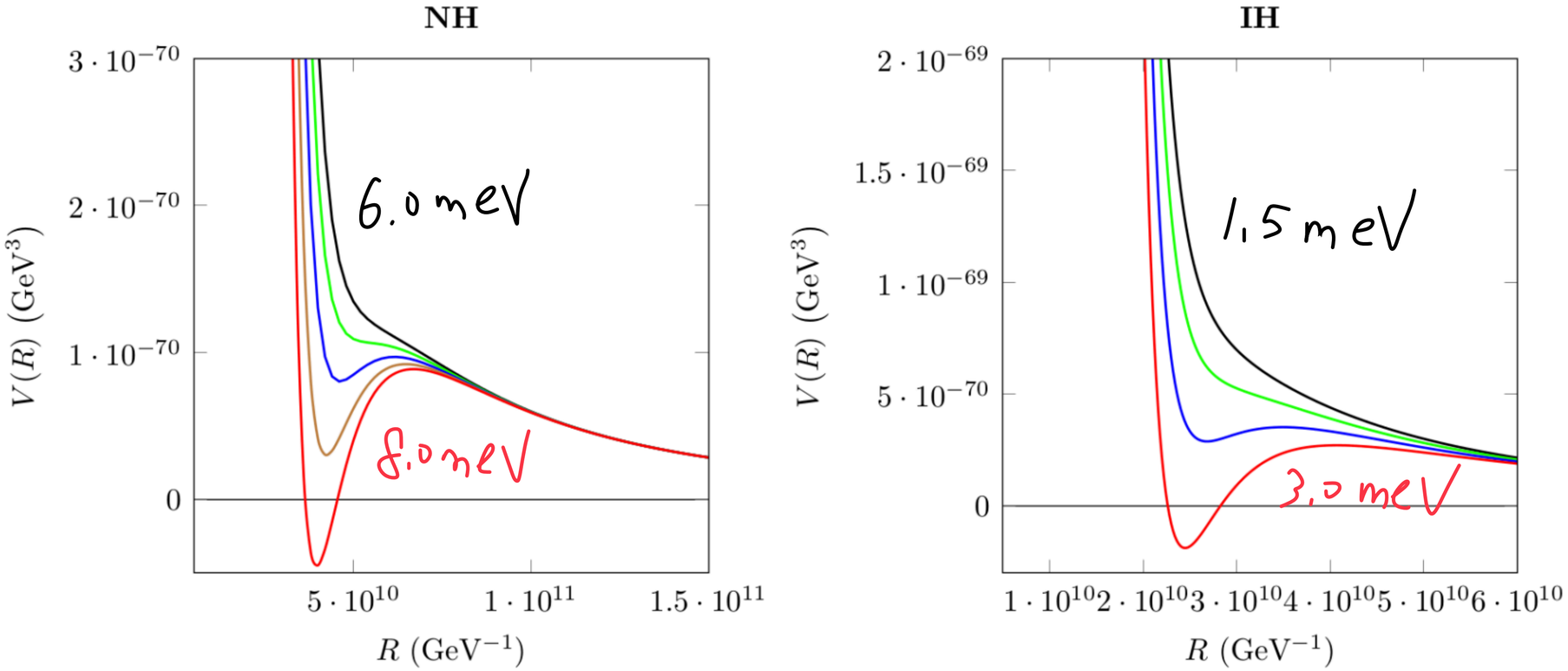


Dirac neutrino

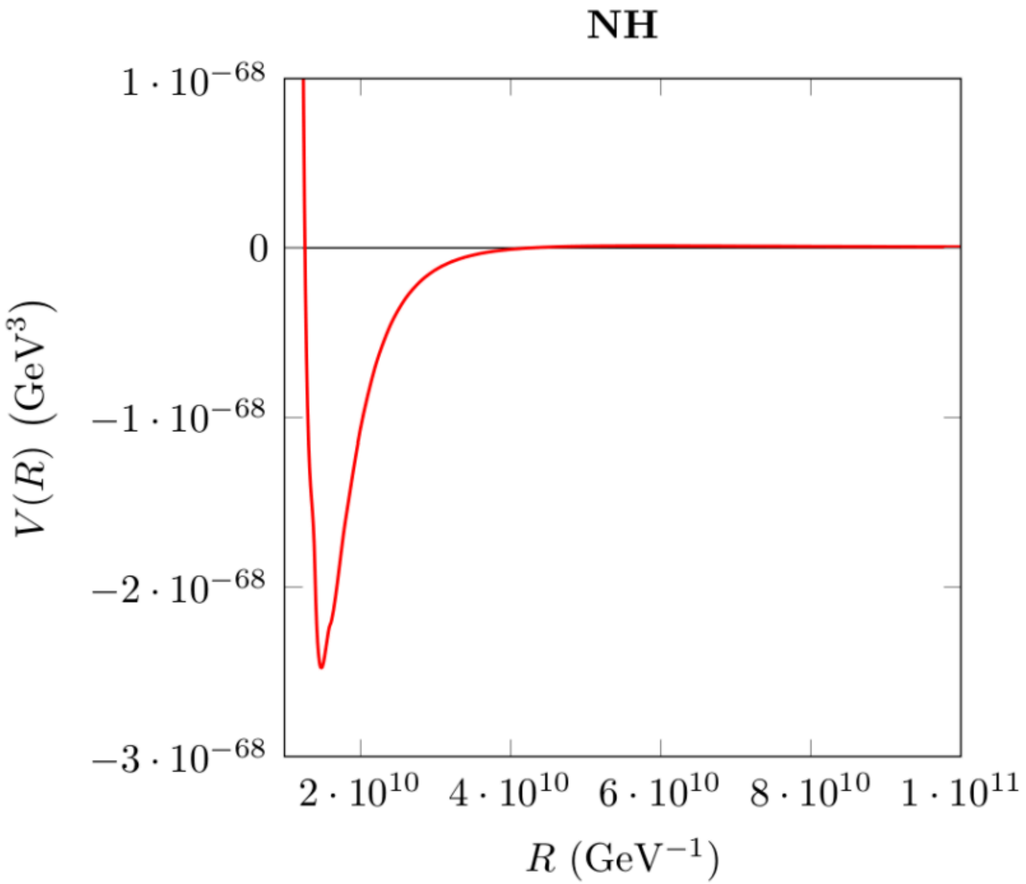
[Ibanez, Martín-Lozano, Valenzuela '17]

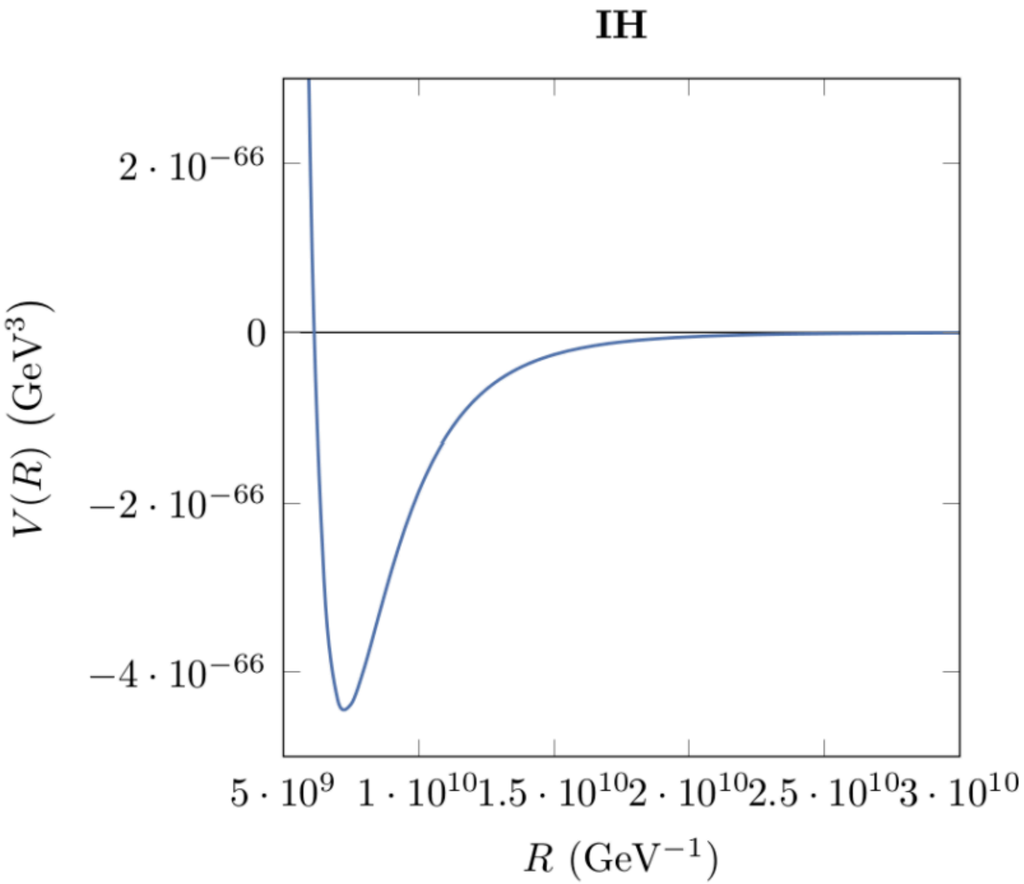


	NH	IH
No vacuum	$m_{\nu_1} < 6.7$ meV	$m_{\nu_3} < 2.1$ meV
dS_3 vacuum	6.7 meV $< m_{\nu_1} <$ 7.7 meV	2.1 meV $< m_{\nu_3} <$ 2.56 meV
AdS_3 vacuum	$m_{\nu_1} > 7.7$ meV	$m_{\nu_3} > 2.56$ meV

Majorana neutrino

[Ibanez, Martín-Lozano, Valenzuela '17]

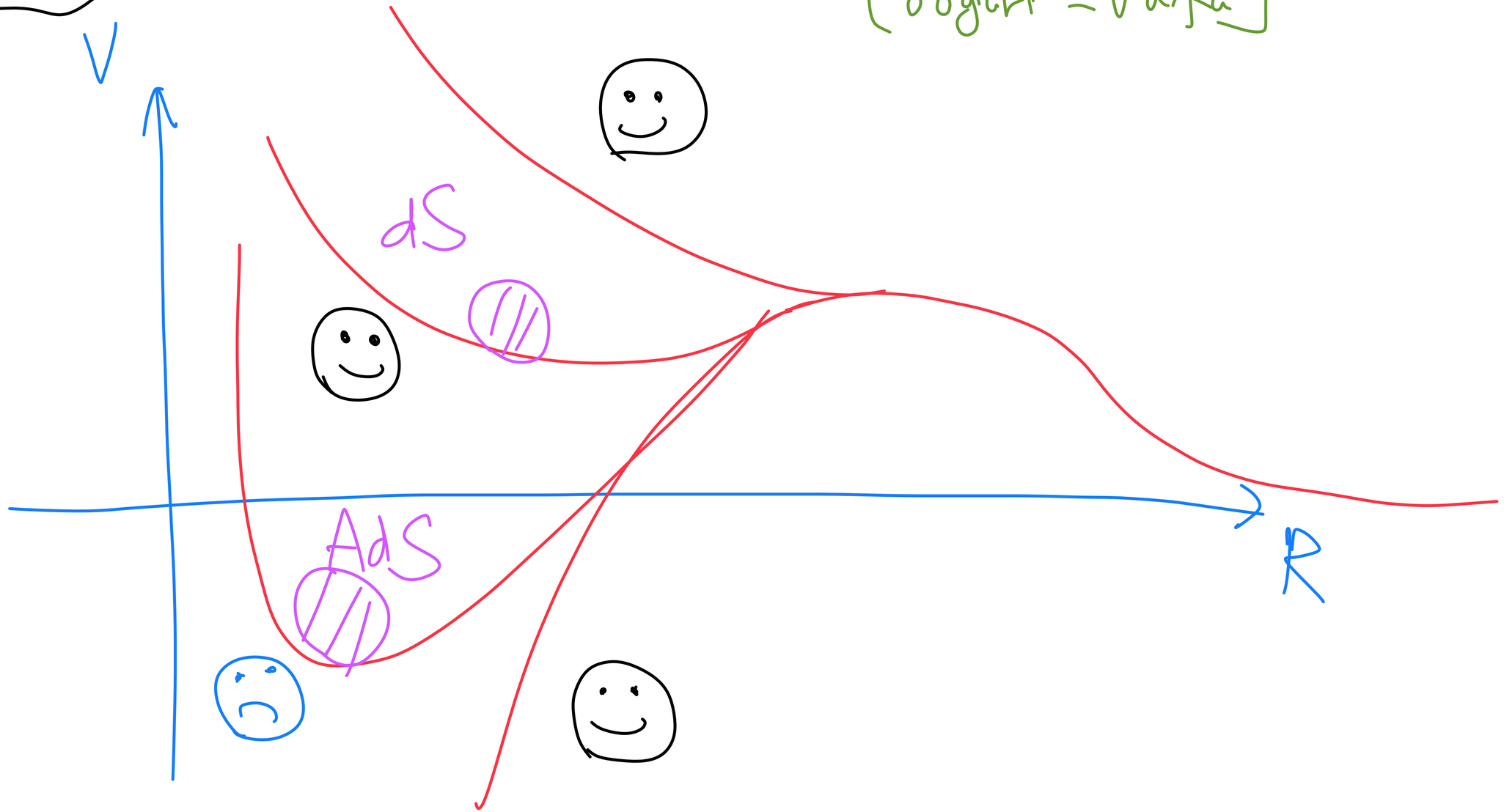




Swampland ?

Option 1: "No Non-SUSY AdS"

[Ooguri-Vafa]



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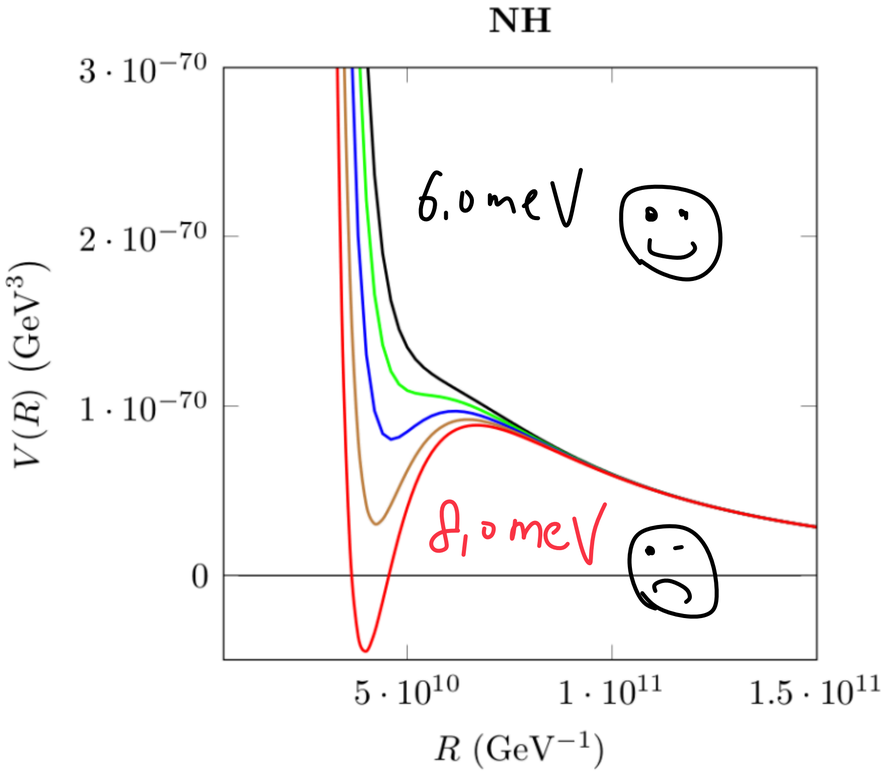

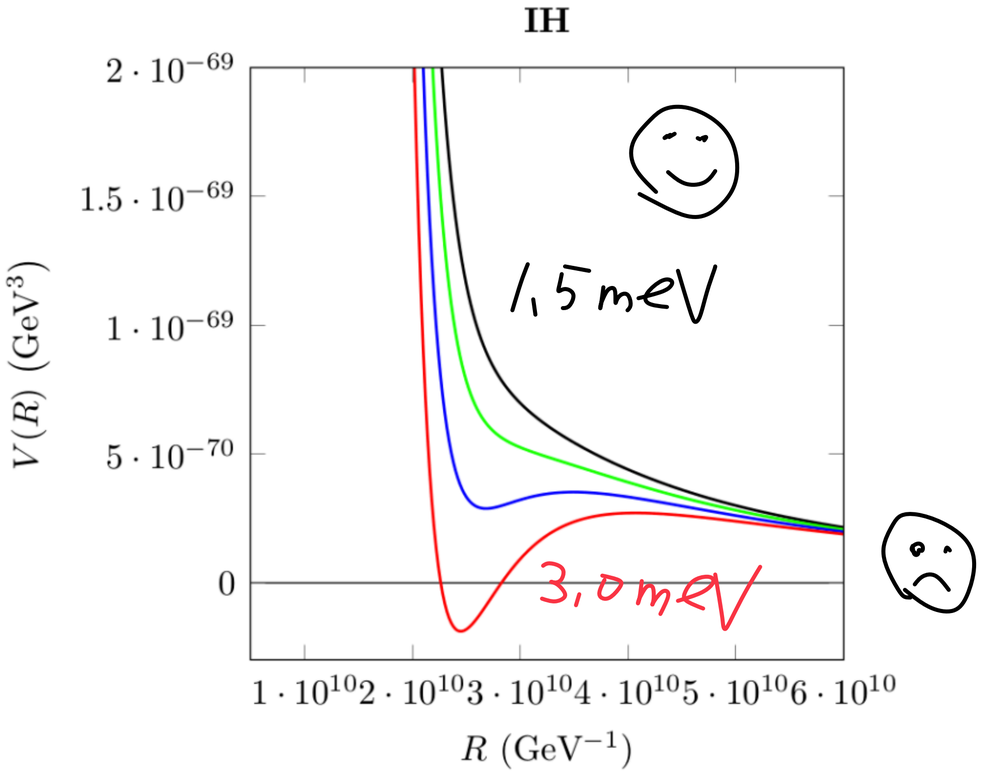

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Majorana neutrino

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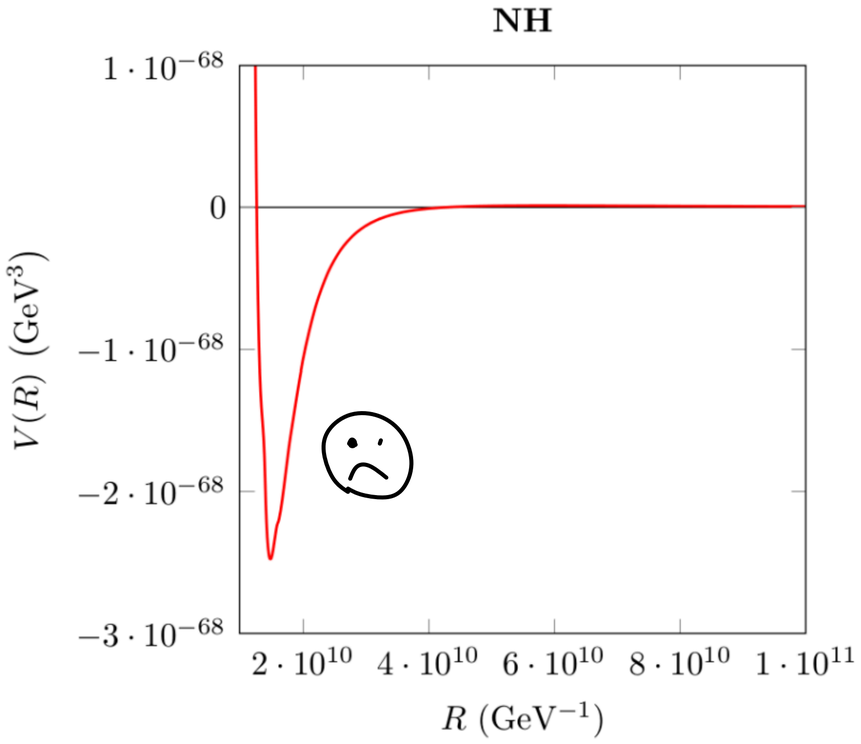
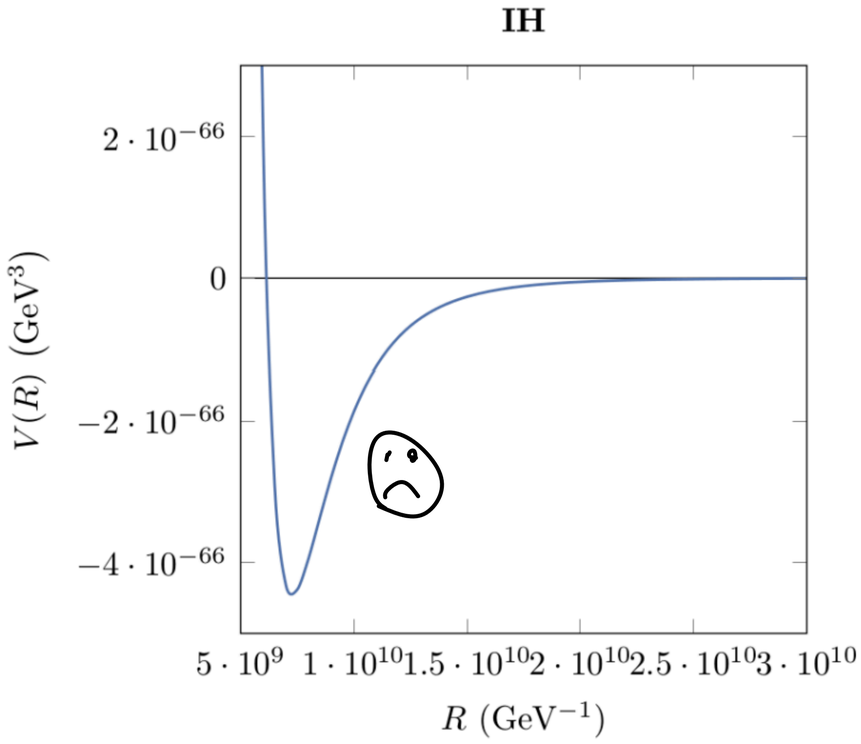




"excluded"

Majorana neutrino

Simple reason :

☹ boson ($g_{\mu\nu}, \gamma$) DoF 4 < fermion DoF 6

Majorana neutrino

Simple reason :

boson $(g_{\mu\nu}, \gamma)$ DoF 4 < fermion DoF 6

if we have ≥ 2 axions !!

Majorana $\Rightarrow$ 2 axions !!

Option 2: "dS conjecture"

[List-Palti-Vafa]

$$|\nabla V| \geq c\,|V|$$

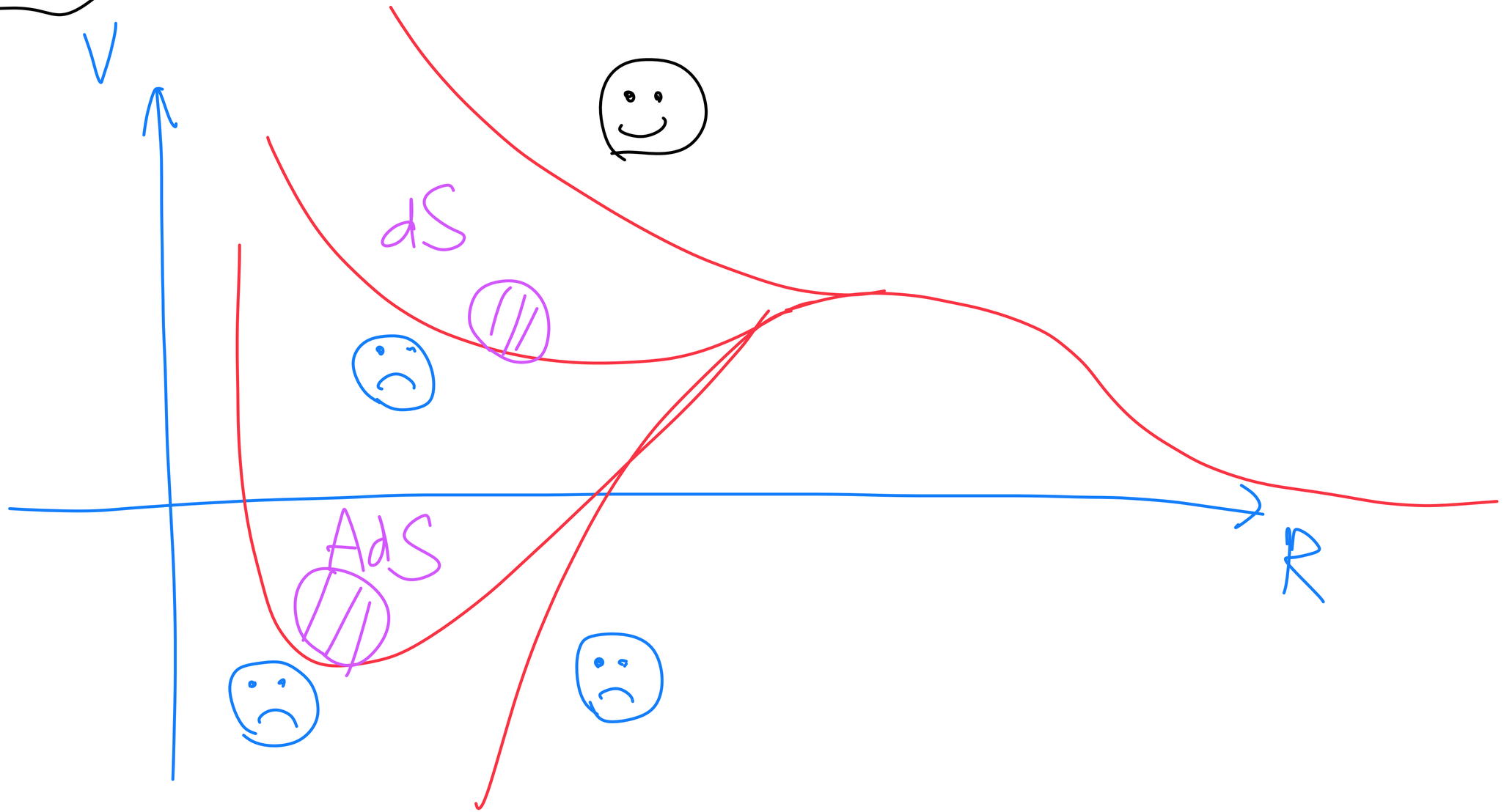
[Obied-Ooguri-Spodyneiko-Vafa]

$O(1)$ number

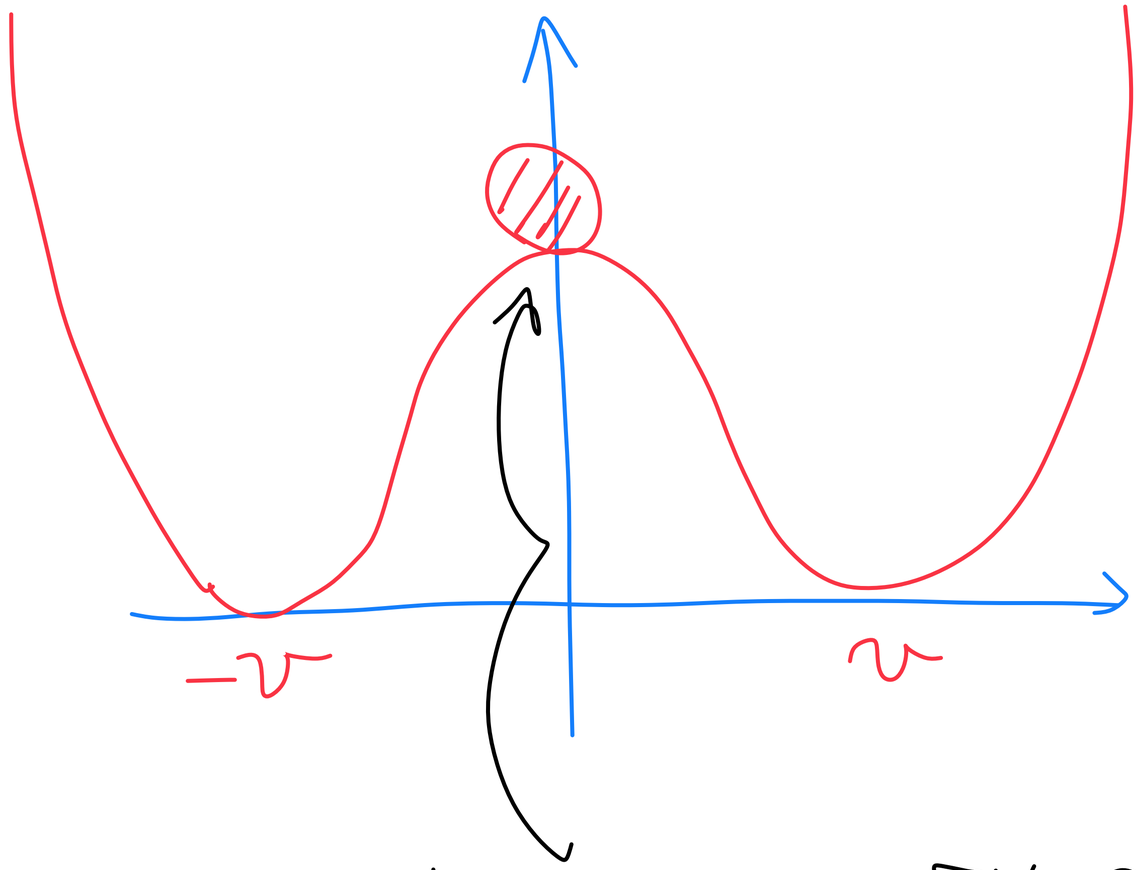
(cf. $|\nabla V| \geq c\,V$)

$\not{\exists}$ excludes $\nabla V = 0\,,\ V \neq 0$

Option 2: "dS conjecture"



※ These conjecture: almost excluded already



$$V_{Higgs} = \left(|H|^2 - v^2\right)^2$$

local maximum $\nabla V = 0,\ V > 0$

[Denef-Hebecker-Wrase]

[Murayama-Yanagida-MY]

Option 2'

Way out ?

"refinement" [Murayama - Yanagida - MY]

$$|\nabla V| \geq c\,V \quad \text{or} \quad \min\left(\nabla_i \nabla_j V\right) \leq 0$$

(OU)

$$|\nabla V| \geq c\,V \quad \text{or} \quad \min\left(\nabla_i \nabla_j V\right) \leq -c'\,V$$

(OU)

[Gorg - Krishnan
Ooguri - Shiu - Palti - Vafa]

Summary

Landscape of SM on S^1

$\rightsquigarrow$ AdS, dS vacua

$\curvearrowright$ conjecturally forbidden in QG

interplay of
- multiple ultralight axions
- neutrinos (Dirac / Majorana) (NH / IH)