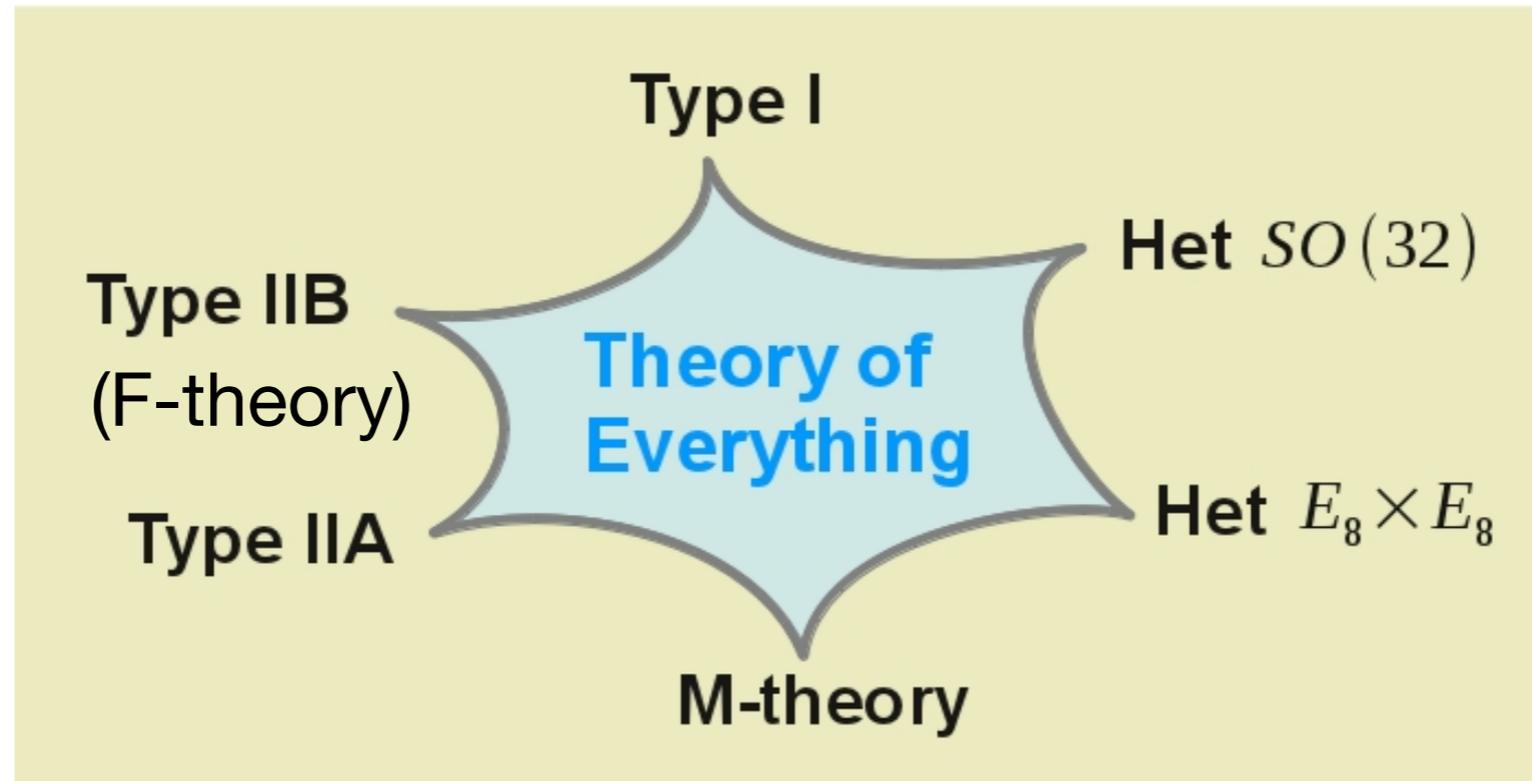# Swamplandy physics

Yuta Hamada (KEK, SOKENDAI)

2025/09/30 mini workshop on new ideas in particle physics and cosmology
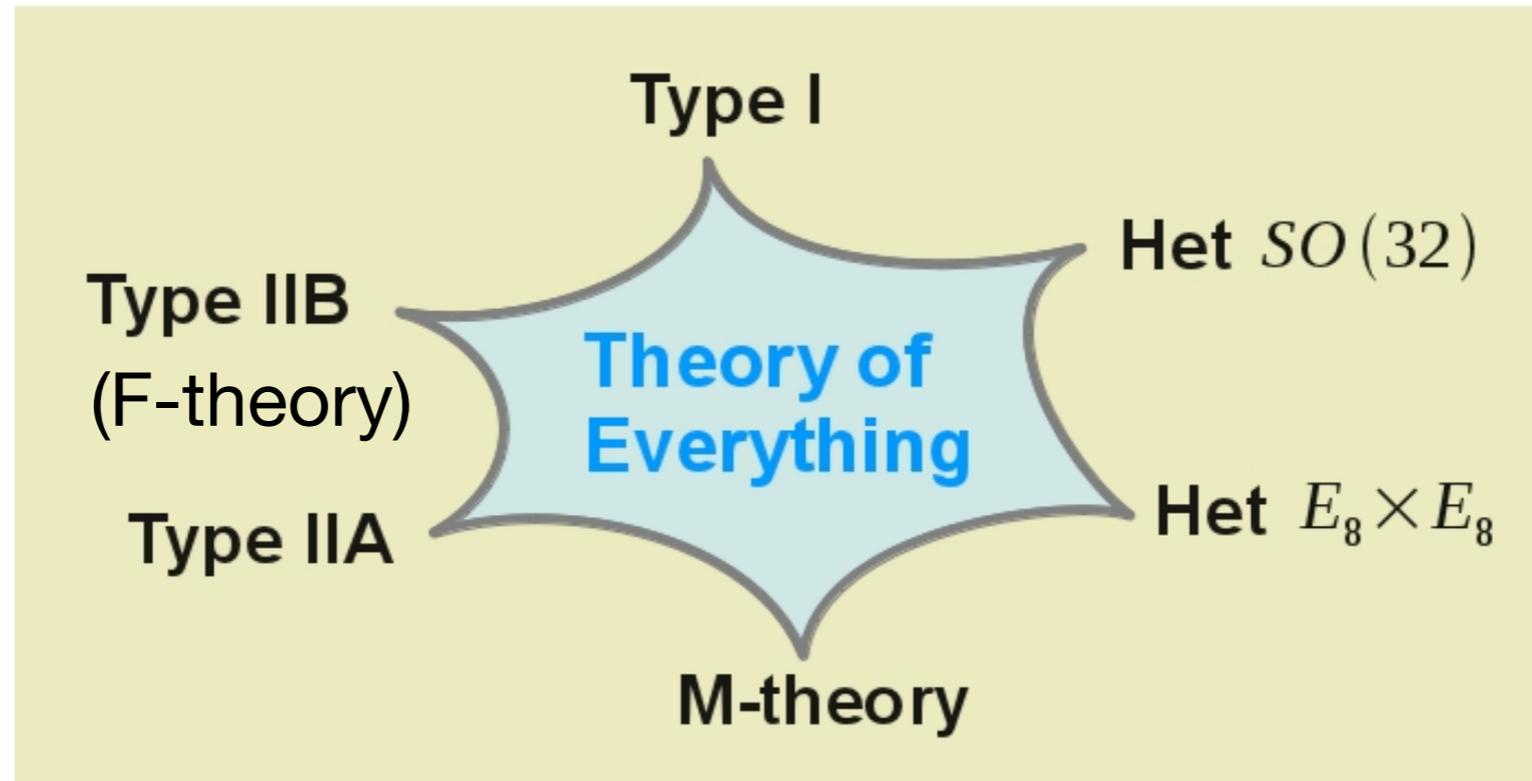
I will talk random topics related to
Standard Model Landscape.

X: 6 or 7 dim compact space

Standard Model + Einstein gravity

Type I

Het $SO(32)$

Type IIB
(F-theory)

Theory of
Everything

Type IIA

Het $E_8 \times E_8$

M-theory

X: 6 or 7 dim compact space

$X \times Y$

Standard Model + Einstein gravity

(Standard Model + Einstein gravity) on Y

3

Standard Model + Einstein gravity,

(Standard Model + Einstein gravity) on $Y = S^1, T^2, \cdots$

Standard Model Landscape $\subset$ String Landscape

Apply Swampland conjectures to constrain SM parameters.

Talk Plan

1. Neutrino masses

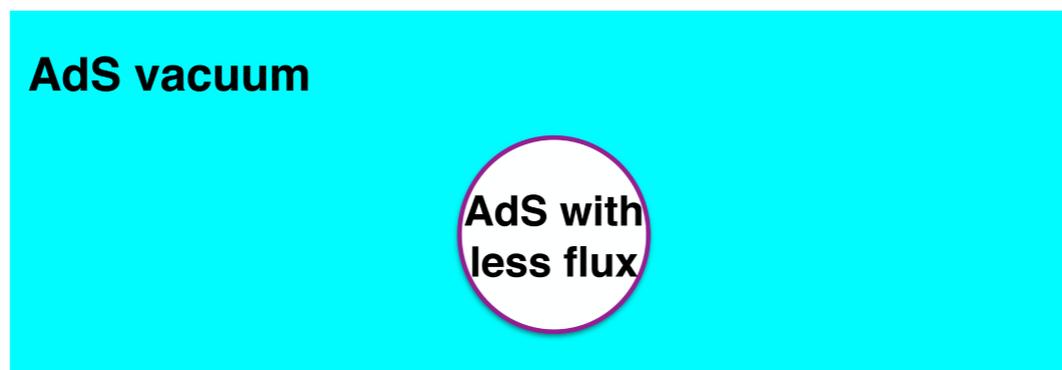2. Black string in Standard Model

Talk Plan

1. Neutrino masses

2. Black string in Standard Model

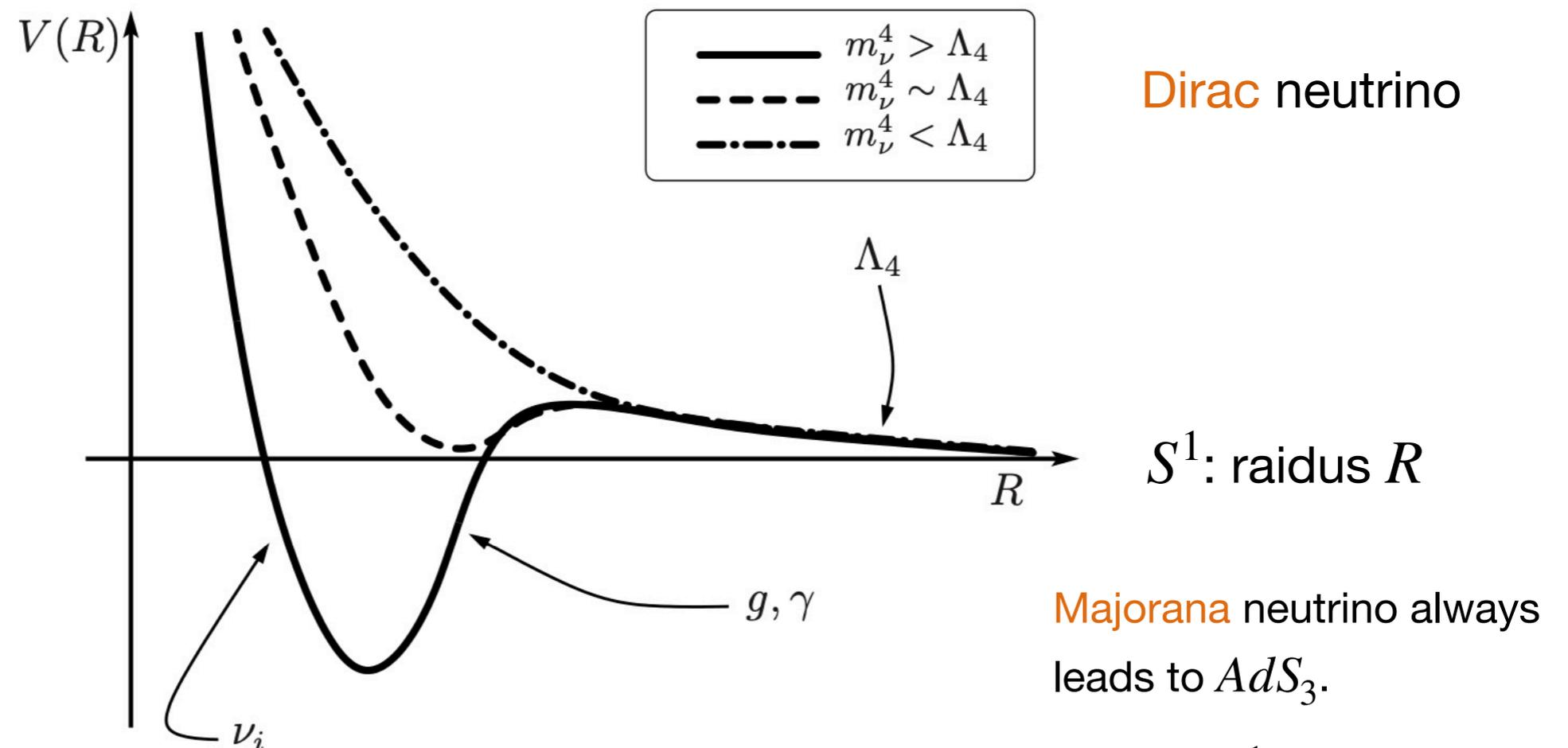# Non-SUSY AdS conjecture

- Conjecture: All non-SUSY AdS vacua are unstable.

  (as long as low energy action is Einstein gravity with finite number of fields)

AdS vacuum in SM

(Standard Model + Einstein gravity) on S^1.

Periodic b.c. for fermions.

Dirac neutrino

S^1: raidus R

Majorana neutrino always leads to AdS_3.

Depending on neutrino mass and type (Dirac/Majorana), $AdS_3 \times S^1$ appears.

Bound from Conjecture?

If $AdS_3 \times S^1$ is stable, it is contradiction.

→ Potential Bound on neutrino masses. [Ibanez, Martin-Lozano, Valenzuela '17]

$$m_{\text{lightest}} < 7.7 \, \text{meV} \,\, (\text{Normal}), \qquad m_{\text{lightest}} < 2.56 \, \text{meV} \,\, (\text{Inverted})$$

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$\rightarrow$ Potential Bound on neutrino masses. [Ibanez, Martin-Lozano, Valenzuela '17]

$$m_{\text{lightest}} < 7.7 \,\text{meV} \,(\text{Normal}), \qquad m_{\text{lightest}} < 2.56 \,\text{meV} \,(\text{Inverted})$$

However, we find [YH, Shiu '17]
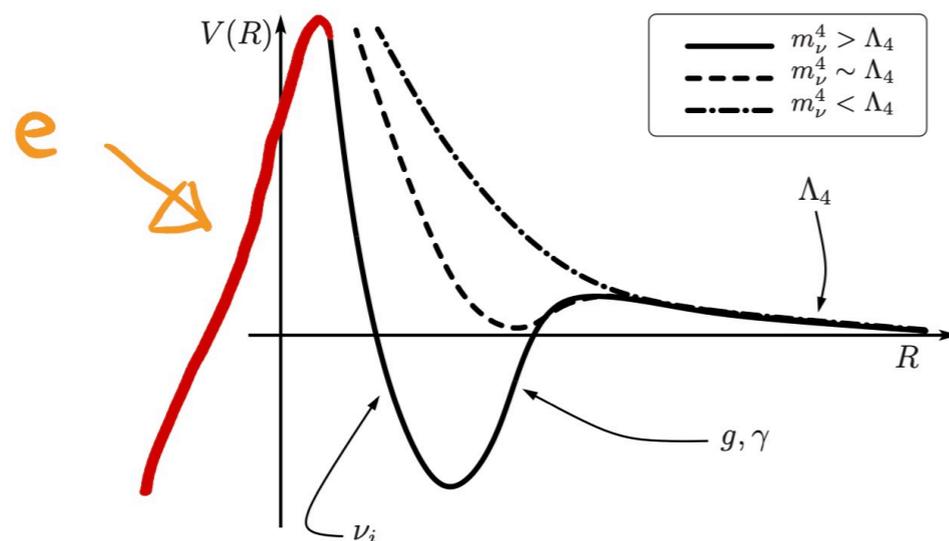

Decay rate is
estimated in [Mirbabayi, Villadoro '25].

Multiple point principle (MPP)

- Hypothesis:

  The parameters of the theory are tuned so that many vacua are

  degenerate in energy.

- Possible principle to extract predictions

  from vast landscape.

MPP as an alternative

Hypothesis: parameters are tuned so that multiple vacua degenerate in energy.
successfully predict Higgs mass, and postdict top mass.

$$m_t < 171\text{GeV}$$

Higgs potential

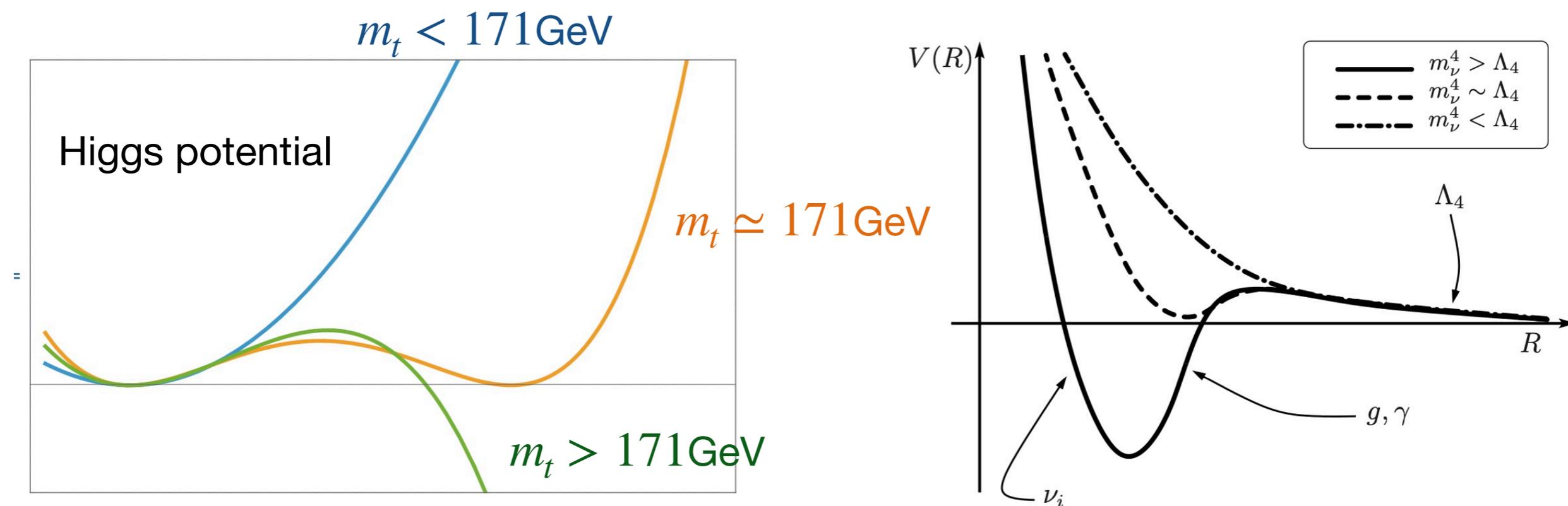$$m_t \simeq 171\text{GeV}$$

$$m_t > 171\text{GeV}$$
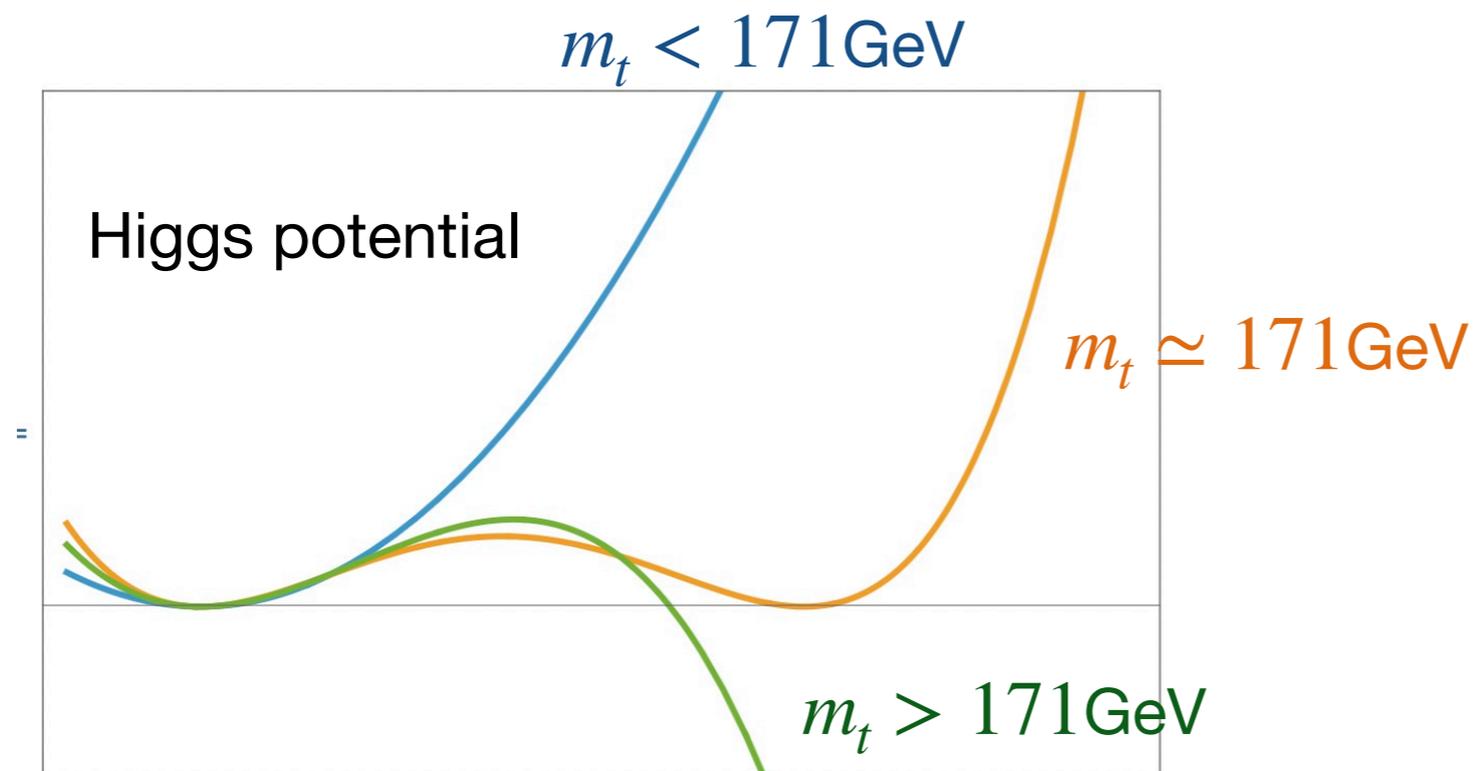
Motivated by an analogy with statistical mechanics.
Similarity to theory of Euclidean wormhole [Coleman '88, YH, Kawai, Kawana '15].

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successfully predict Higgs mass, and postdict top mass.

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Similarity to theory of Euclidean wormhole [Coleman '88, YH, Kawai, Kawana '15].

Prediction of equality

	model	AdS	flat	dS
S^1	$U(1)$, neutral	$\Lambda_4 \lesssim 10^{-2.8} M_e^4$	$\Lambda_4 \simeq 10^{-2.8} M_e^4$	$10^{-2.8} M_e^4 \lesssim \Lambda_4 \lesssim 10^{-2.6} M_e^4$
	$U(1)$, charged	–	–	–
	SM, ν_M	always	–	–
	SM, ν_D, NH	$8.4\,\mathrm{meV} \lesssim m_{\nu,\mathrm{lightest}}$	$m_{\nu,\mathrm{lightest}} \simeq 8.4\,\mathrm{meV}$	$7.3\,\mathrm{meV} \lesssim m_{\nu,\mathrm{lightest}} \lesssim 8.4\,\mathrm{meV}$
	SM, ν_D, IH	$3.1\,\mathrm{meV} \lesssim m_{\nu,\mathrm{lightest}}$	$m_{\nu,\mathrm{lightest}} \simeq 3.1\,\mathrm{meV}$	$2.5\,\mathrm{meV} \lesssim m_{\nu,\mathrm{lightest}} \lesssim 3.1\,\mathrm{meV}$
	SM, ν_M, high scale	–	–	–
	SM, ν_D, high scale	$\Lambda_4 \ll (\text{neutrino mass})^4$	–	–
	axion	$\Lambda_4 < 0$	–	–

$$m_2^2 - m_1^2 = 7.53 \times 10^{-5} \mathrm{eV}^2, \qquad |m_3^2 - m_2^2| = 2.44 \times 10^{-3} \mathrm{eV}^2.$$

Normal: $\sum m_\nu = 7.1 \times 10^{-2} \mathrm{eV},$

Inverted: $\sum m_\nu = 1.0 \times 10^{-1} \mathrm{eV}$

Astrophysics > Cosmology and Nongalactic Astrophysics

Constraints on Neutrino Physics from DESI DR2 BAO and DR1 Full Shape

W. Elbers, A. Aviles, H. E. Noriega, D. Chebat, A. Menegas, C. S. Frenk, C. Garcia-Quintero, D. Gonzalez, M. Ishak, O. Lahav, K. Naidoo, G. Niz, C. Yèche, M. Abdul-Karim, S. Ahlen, O. Alves, U. Andrade, E. Armengaud, S. BenZvi, D. Bianchi, S. Brieden, A. Brodzeller, D. Brooks, E. Burtin, R. Calderon, R. Canning, A. Carnero Rosell, L. Casas, F. J. Castander, M. Charles, E. Chaussidon, J. Chaves-Montero, T. Claybaugh, S. Cole, A. P. Cooper, A. Cuceu, K. S. Dawson, A. de la Macorra, A. de Mattia, N. Deiosso, A. Dey, B. Dey, Z. Ding, P. Doel, D. J. Eisenstein, S. Ferraro, A. Font-Ribera, J. E. Forero-Romero, L. H. Garrison, E. Gaztañaga, H. Gil-Marín, S. Gontcho A Gontcho, A. X. Gonzalez-Morales, G. Gutierrez, S. He, M. Herbold, H. K. Herrera-Alcantar, C. Howlett, D. Huterer, S. Juneau, R. Kehoe, D. Kirkby, T. Kisner, A. Kremin, C. Lamman, M. Landriau, L. Le Guillou, A. Leauthaud, M. E. Levi, Q. Li, K. Lodha, C. Magneville, M. Manera, P. Martini, W. L. Matthewson, A. Meisner, J. Mena-Fernández, R. Miquel, J. Moustakas, S. Nadathur, J. A. Newman, E. Paillas, N. Palanque-Delabrouille, W. J. Percival, M. M. Pieri, C. Poppett, F. Prada, I. Pérez-Ràfols, D. Rabinowitz, C. Ramírez-Pérez, M. Rashkovetskyi, C. Ravoux, H. Rivera-Morales, J. Rohlf, A. J. Ross, G. Rossi, V. Ruhlmann-Kleider, L. Samushia, E. Sanchez, D. Schlegel et al. (19 additional authors not shown)

$$\text{DESI DR1 (FS+BAO) + CMB (plik):}$$

$$\sum m_\nu < 0.071\,\text{eV} \quad (95\%). \tag{2}$$

Will be tested soon?

Talk Plan

1. Neutrino masses

2. Black string in Standard Model

From now on,

I will talk about something different from so far.

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	SM, ν_M, high scale	$-$	$-$	$-$
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So far

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From now on

So far

15

AdS_3/CFT_2

AdS_3/CFT_2 for neutrino vacua? [Arkani-Hamed+ '07]

SM on $AdS_3 \times S^1$

AdS_3/CFT_2

AdS_3/CFT_2 for neutrino vacua?   [Arkani-Hamed+ '07]
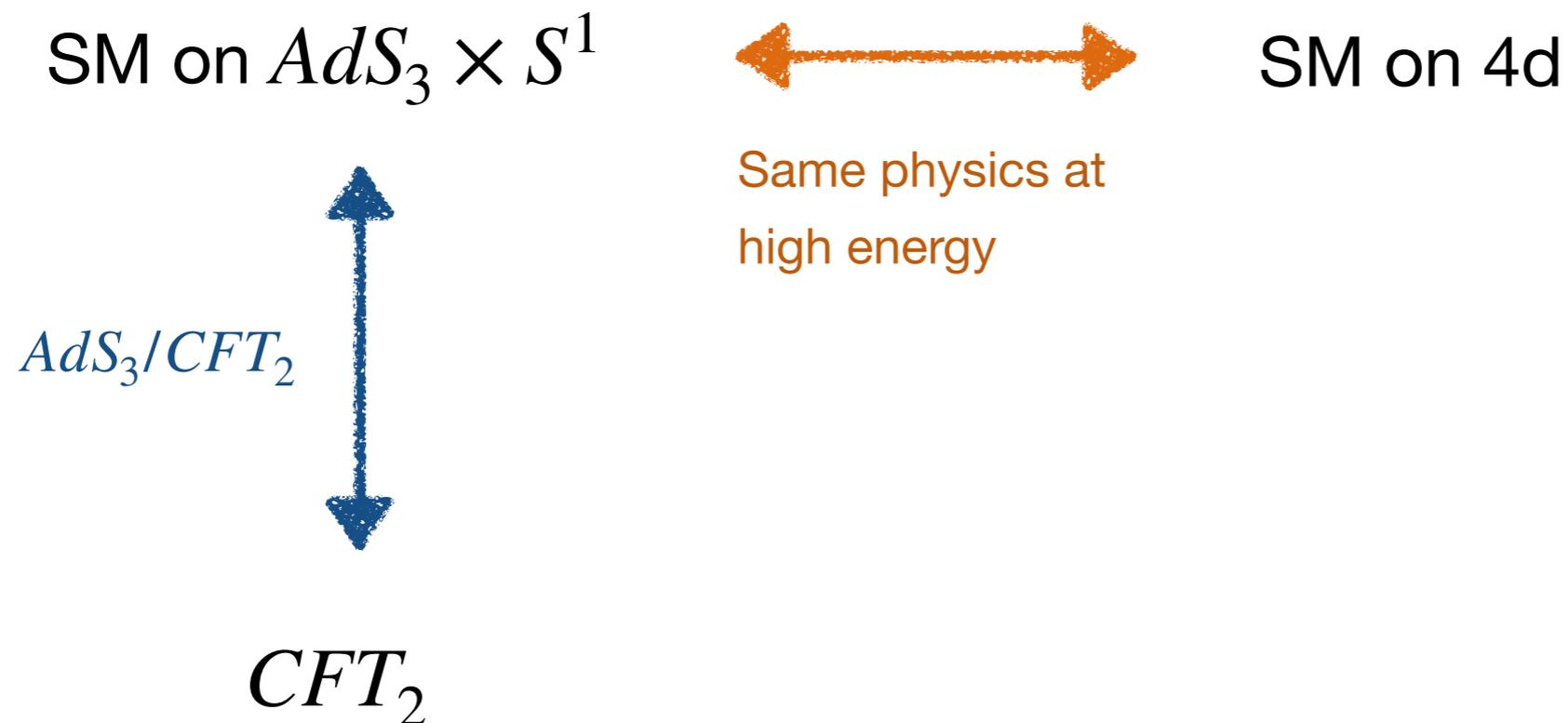
SM on $AdS_3 \times S^1$ ⟷   SM on 4d

Same physics at
high energy

AdS_3/CFT_2

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CFT_2

This should contain all information
such as dark matter, inflaton, …

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Same physics at high energy

AdS_3/CFT_2

CFT_2

Consistency conditions of CFT_2 is strong.

New pathway to BSM physics?

This should contain all information such as dark matter, inflaton, …

Peculiar features.

1: Huge central charge

$$c \sim \ell_{AdS_3} M_3 \sim \ell_{AdS_3}^2 M_4^2 \sim \left(\frac{M_4}{m_\nu} \right)^4 \sim 10^{120}$$

ℓ_{AdS_3}: (AdS_3 radius) $\sim M_4/m_\nu^2$,

$M_{3,4}$: 3(4)d Planck mass

2: Wilson line of A_3^{EM} is slightly massive,

$$V \sim e^{-m_e/m_\nu} \cos \left(\int A_3^{\mathrm{EM}} \right), \qquad e^{-m_e/m_\nu} \sim e^{-10^9}.$$

$\rightarrow$ Very small anomalous dim. , and huge gap above it.

I don't know how I can study such CFT.

Instead, I will talk about new object
suggested by holography/Swampland.

AdS/CFT

IIB string on $AdS_5 \times S^5$.
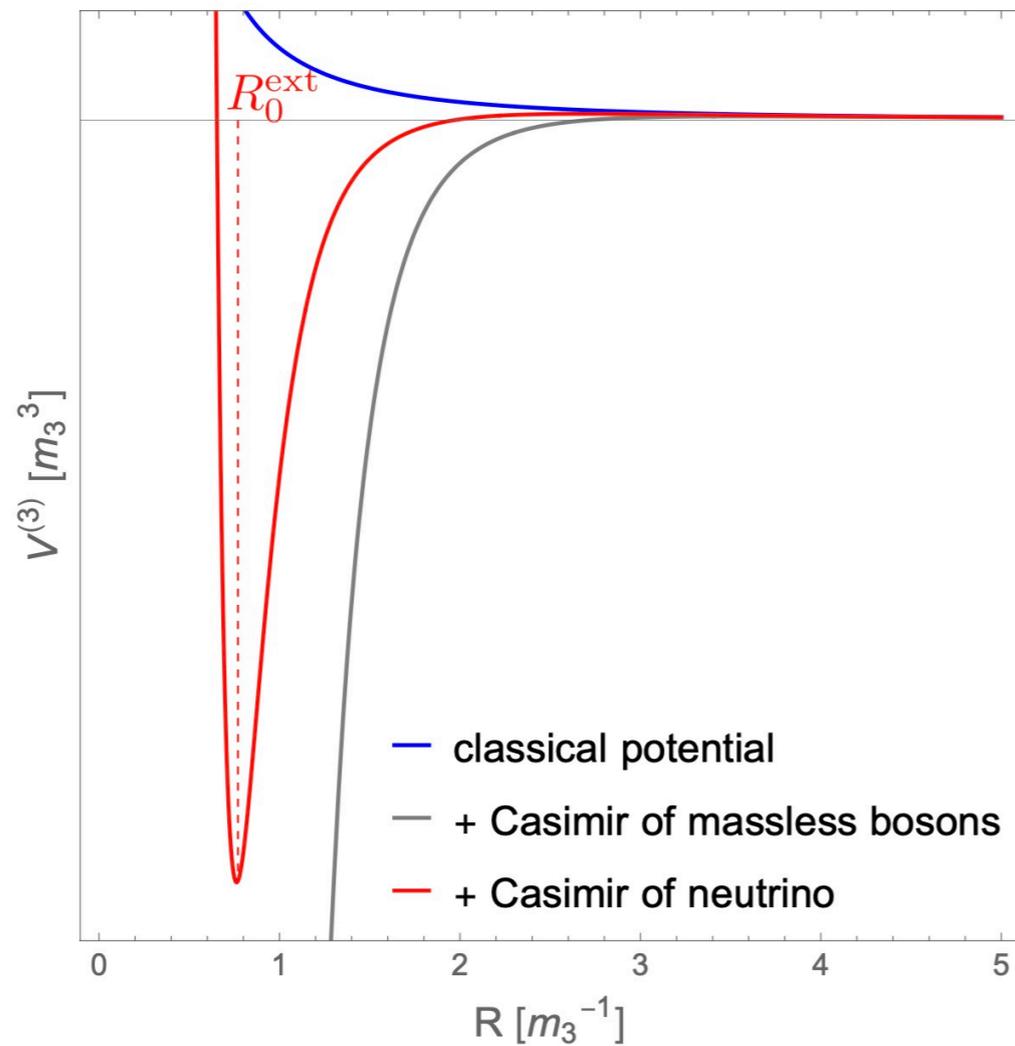
near horizon of
black 3-brane

Potential

Positive contribution from flux.

r_*

S^5 Radius

Negative contribution from curvature
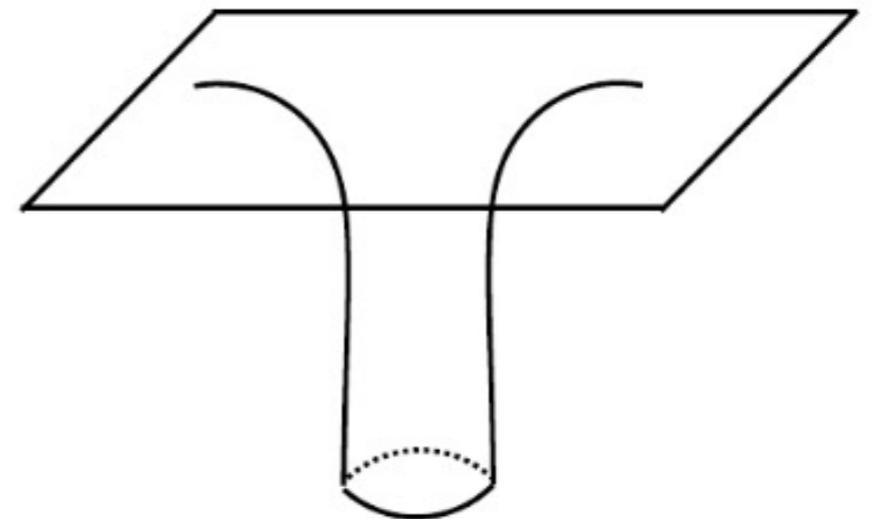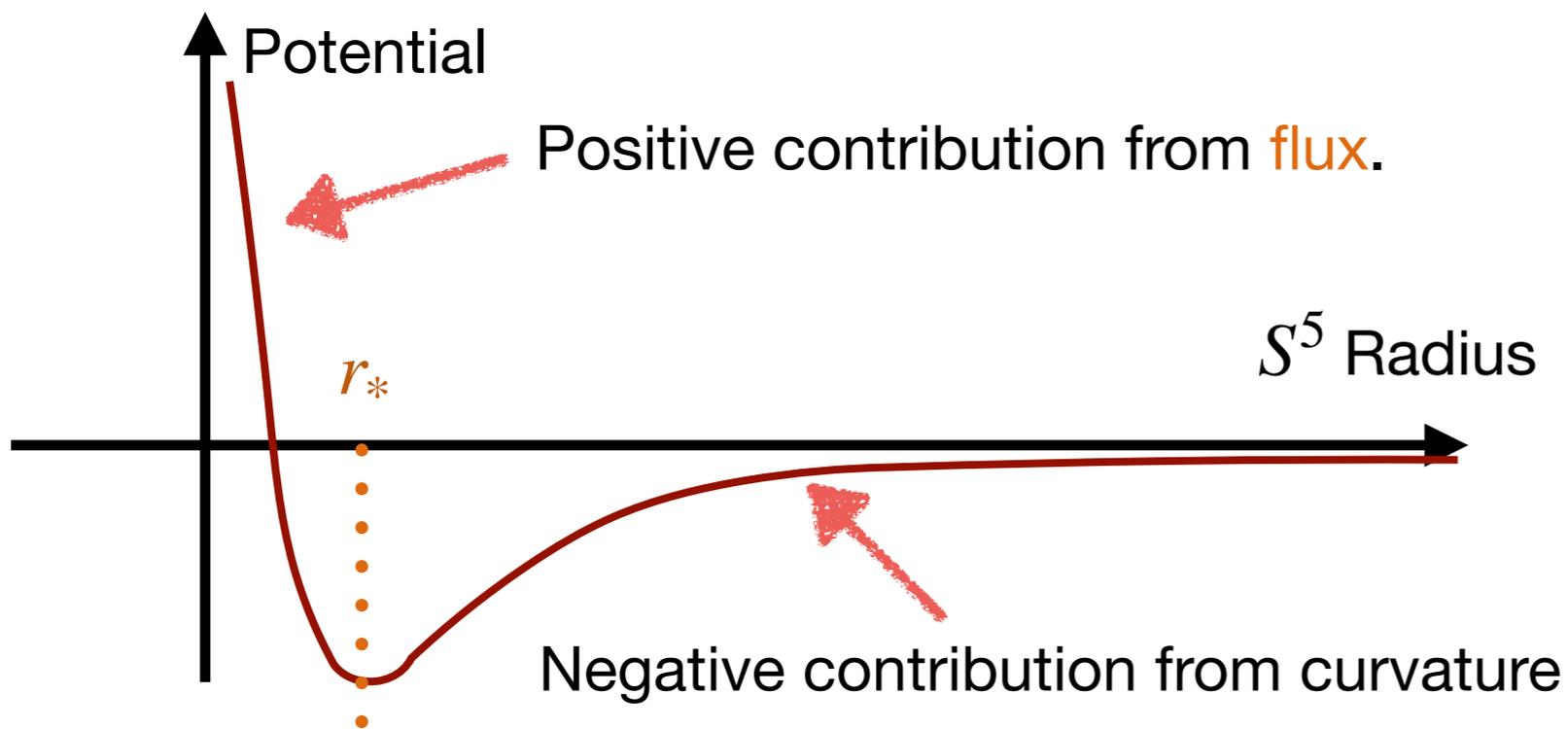
Extremal Black Hole

4d Einstein-Maxwell on S^2.

$$ds^2 = -f(r)dt^2 + f(r)^{-1}dr^2 + r^2d\Omega^2$$

$$f(r) = \frac{(r - r_*)^2}{r^2}$$

Potential

Positive contribution from flux.

S^2 Radius

r_*

Negative contribution from curvature

Flat 4d

$AdS_2 \times S^2$
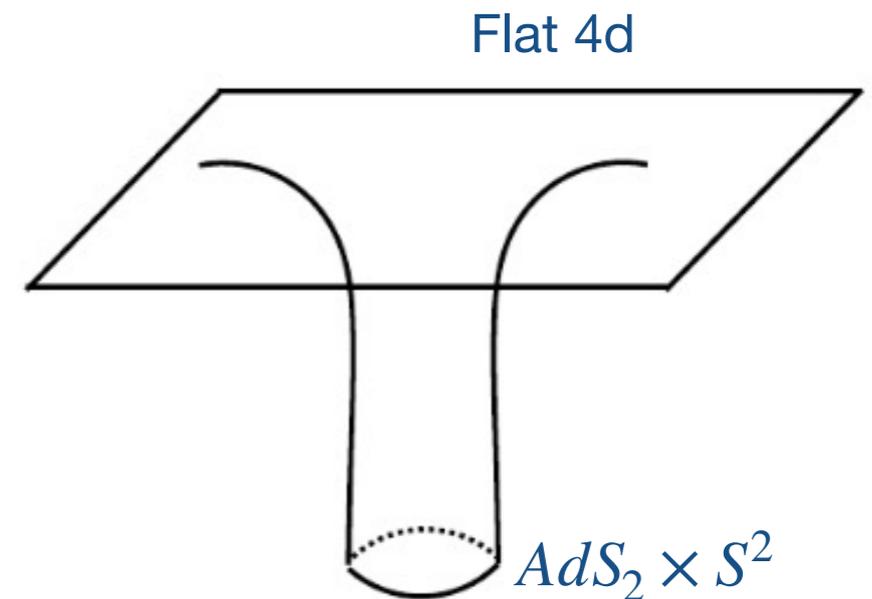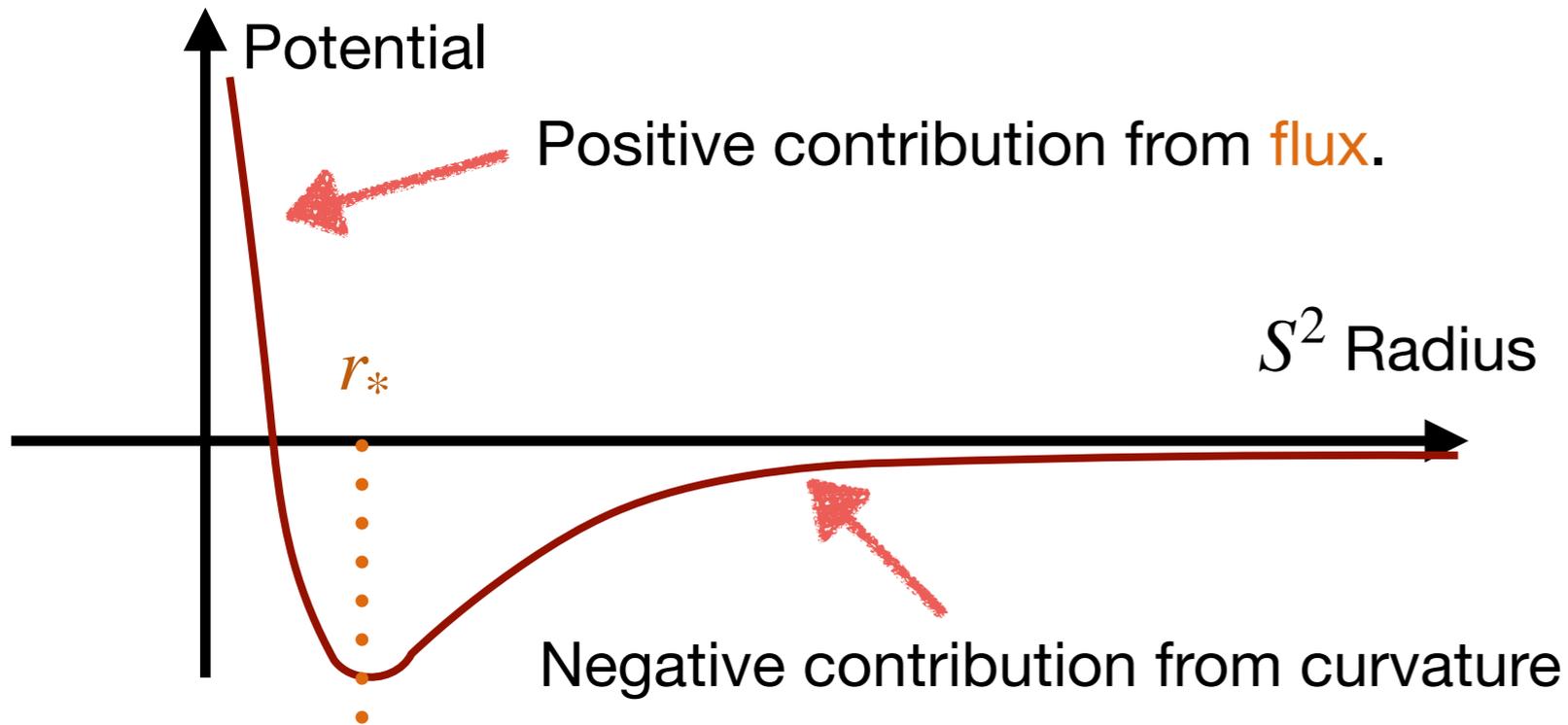
Extremal BH is a solution interpolating different dimensions.

Do we have extremal black object?

Yes.

[Arkani-Hamed+ '07]
[Yu Hamada, YH, Kimura '25]

Relation to Swampland

$\mathbb{R}^{1,3} = \mathbb{R}^{1,1} \times \mathbb{R}_{\geq 0} \times S^1$. Periodic for fermions.

Cobordism Conjecture:

S^1 can shrink without singularity.

S^1

$\mathbb{R}_{\geq 0}$

S^1

$\mathbb{R}_{\geq 0}$
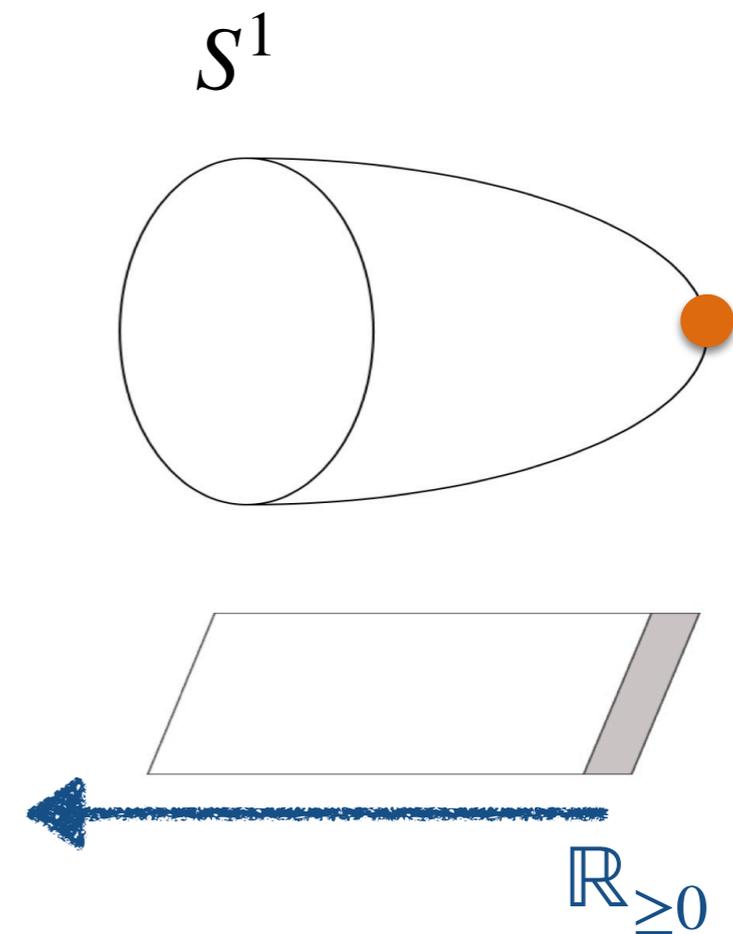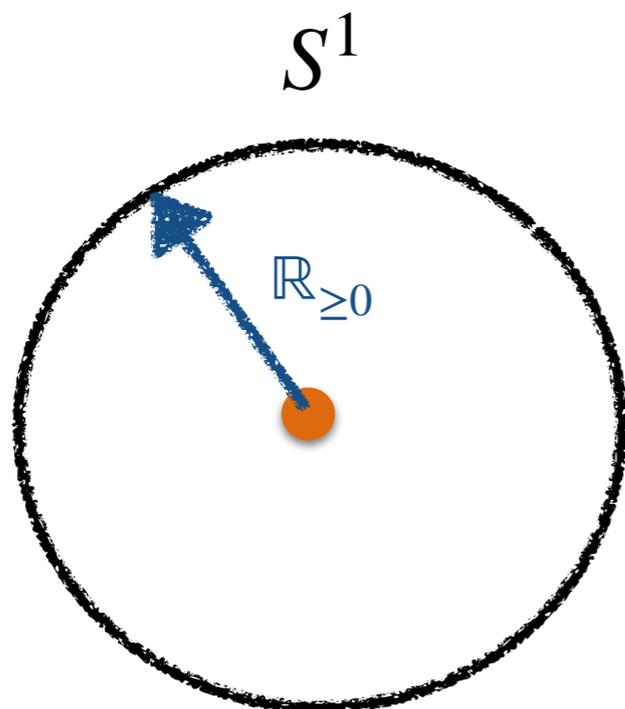
Extremal case

Metric ansatz:

$$ds^2 = A(z)^2(-dt^2 + dx^2) + \frac{M_P^2}{m_3^4}dz^2 + R(z)^2 d\phi^2$$

Einstein equation reduces to

$$R'' + \gamma R' = -\partial_R U(R), \qquad \frac{A'}{A} = -\frac{R'}{R} - \sqrt{\frac{R'^2}{R^2} - \frac{V_1^{(4)}}{M_4^2}}.$$

where $\partial_R U(R) = \frac{R}{M_4^2}\left(V_1^{(4)} - \frac{1}{2}R\partial_R V_1^{(4)}\right), \quad \gamma = -2\left(\frac{R'}{R} + \sqrt{\frac{R'^2}{R^2} - \frac{V_1^{(4)}}{M_4^2}}\right).$
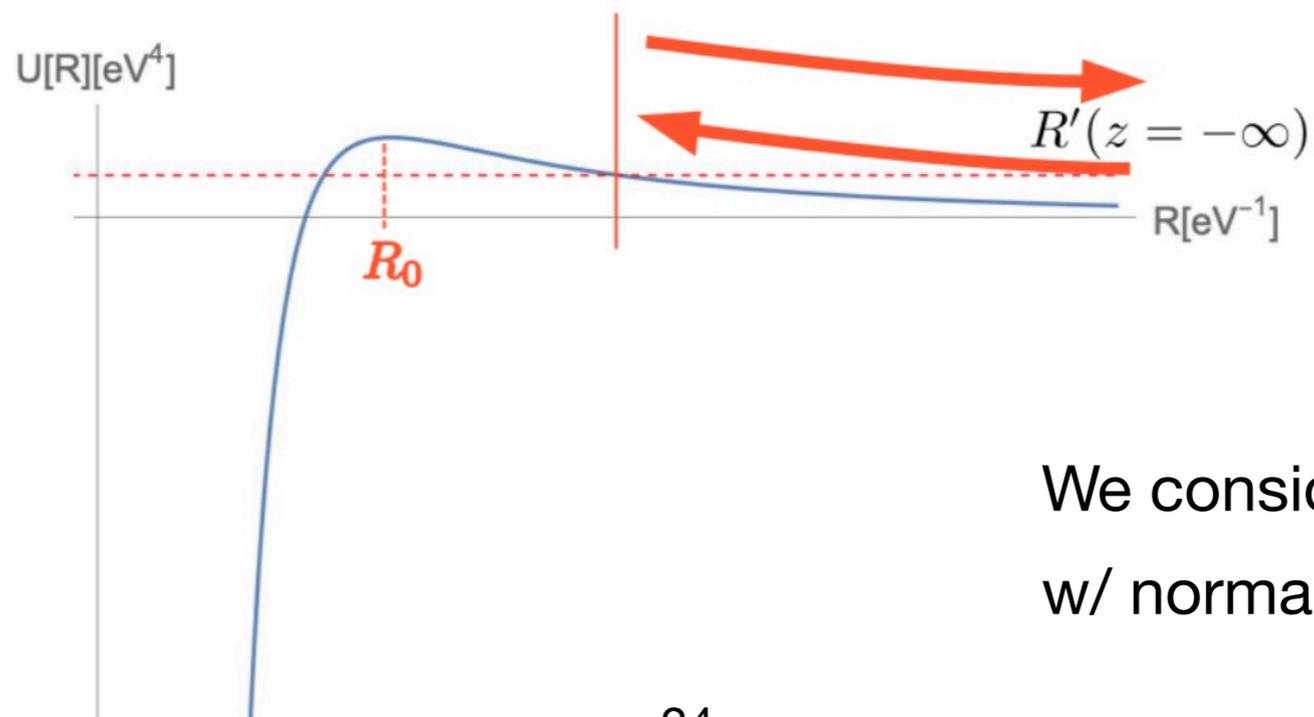
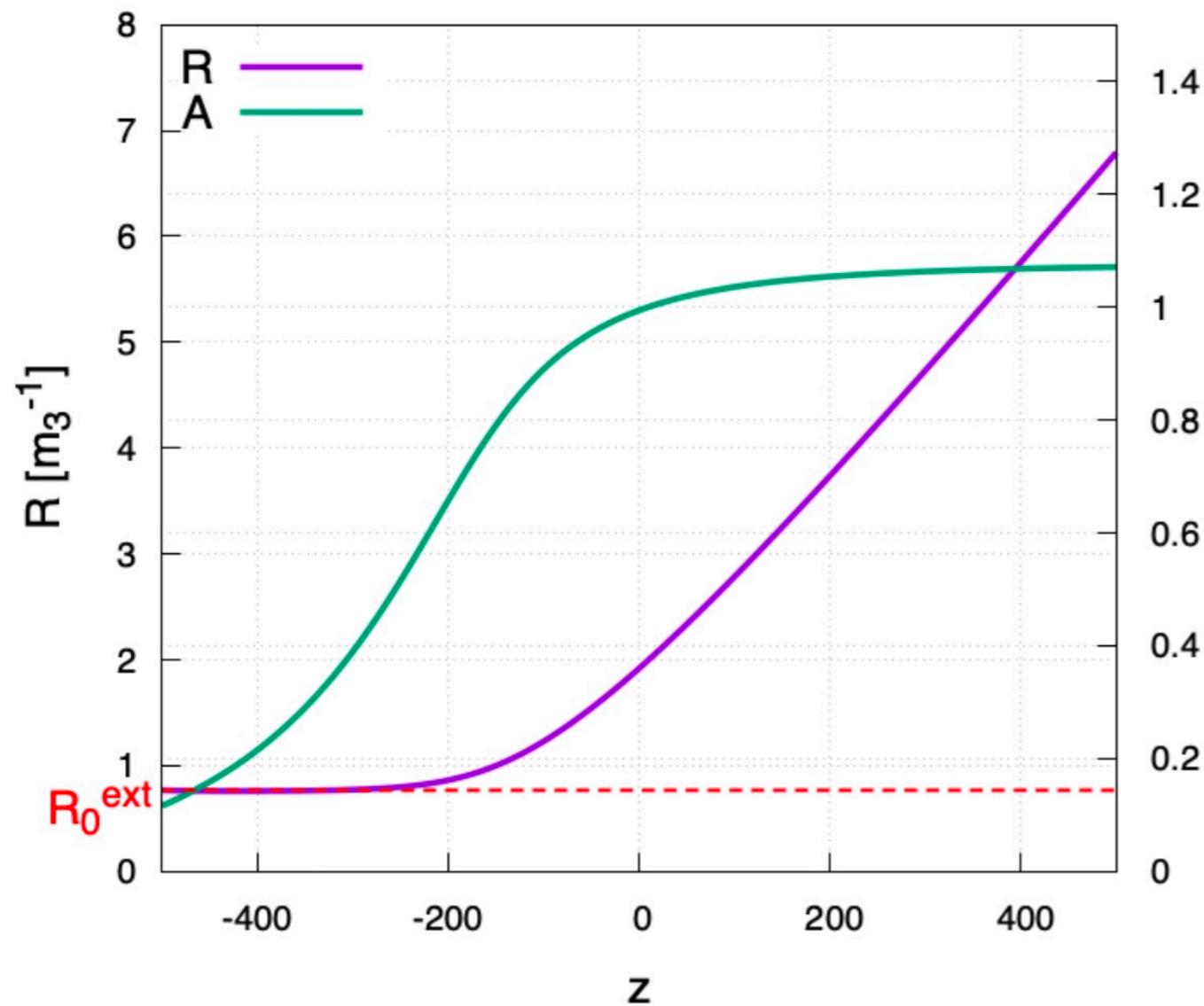$R(z)$ is determined by first equation. Then, $A(z)$ is fixed by second equation.

Shooting method

$$R'' + \gamma R' = -\partial_R U(R)$$

where $\partial_R U(R) = \dfrac{R}{M_4^2}\left(V_1^{(4)} - \dfrac{1}{2}R\partial_R V_1^{(4)}\right), \quad \gamma = -2\left(\dfrac{R'}{R} + \sqrt{\dfrac{R'^2}{R^2} - \dfrac{V_1^{(4)}}{M_4^2}}\right).$

classical mechanics w/ friction γ and potential $U(R)$.

We consider Majorana ν

w/ normal hierarchy.

Numerical solution: $R(z)$

$$ds^2 = A(z)^2(-dt^2 + dx^2) + \frac{M_P^2}{m_3^4}dz^2 + R(z)^2 d\phi^2$$
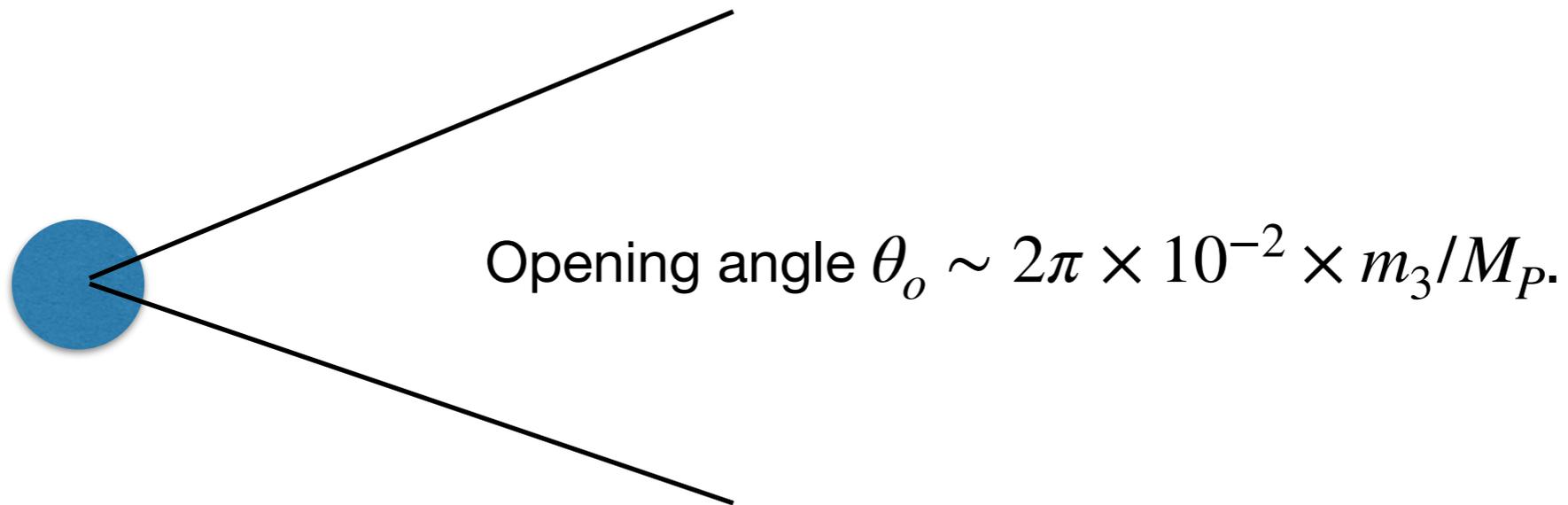

$z \to -\infty$: horizon.

$z \to +\infty$: away from string.

Near horizon geometry is

$AdS_3 \times S^1$

$$ds^2 \to e^{2\frac{M_P}{m_3^2}\frac{z}{l_{\text{AdS}}}}(-dt^2 + dx^2)$$
$$+ dz^2 + (R_0^{\text{ext}})^2 d\phi^2$$

25

Deficit angle $\sim 2\pi$

Opening angle $\theta_o \sim 2\pi \times 10^{-2} \times m_3/M_P$.

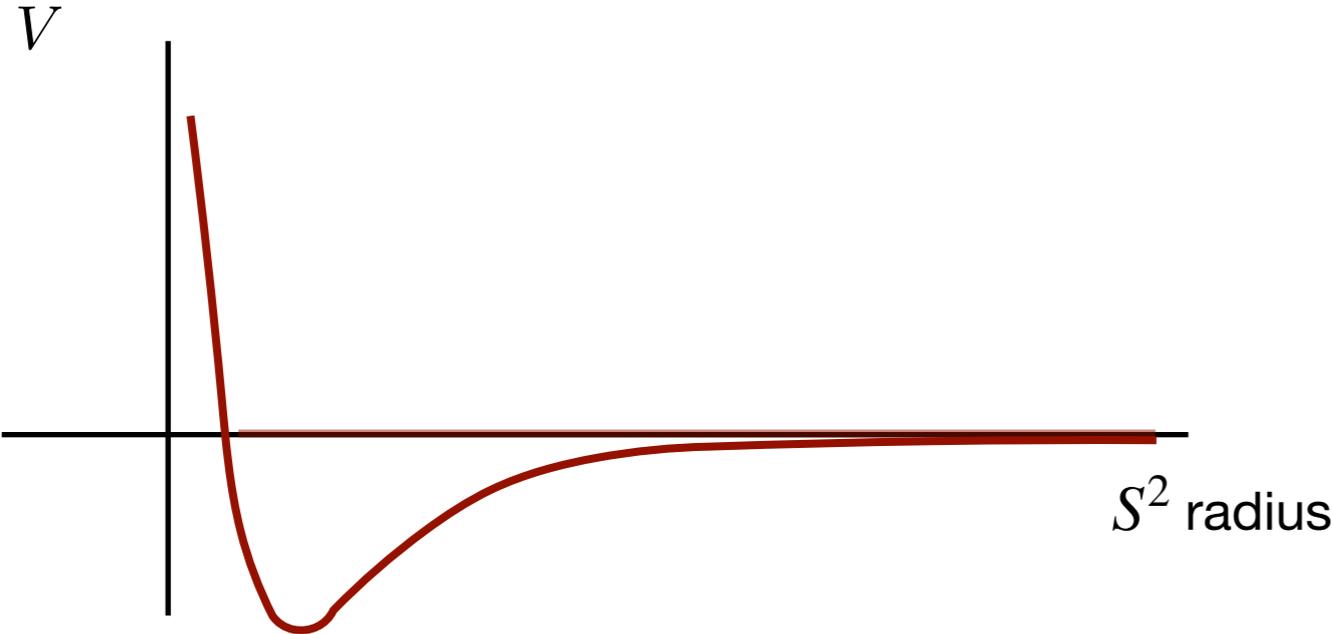Most space region is cut off by the black string.

Incompatible if it exists now.

Extremal solution and AdS vacua

(Charged) black hole
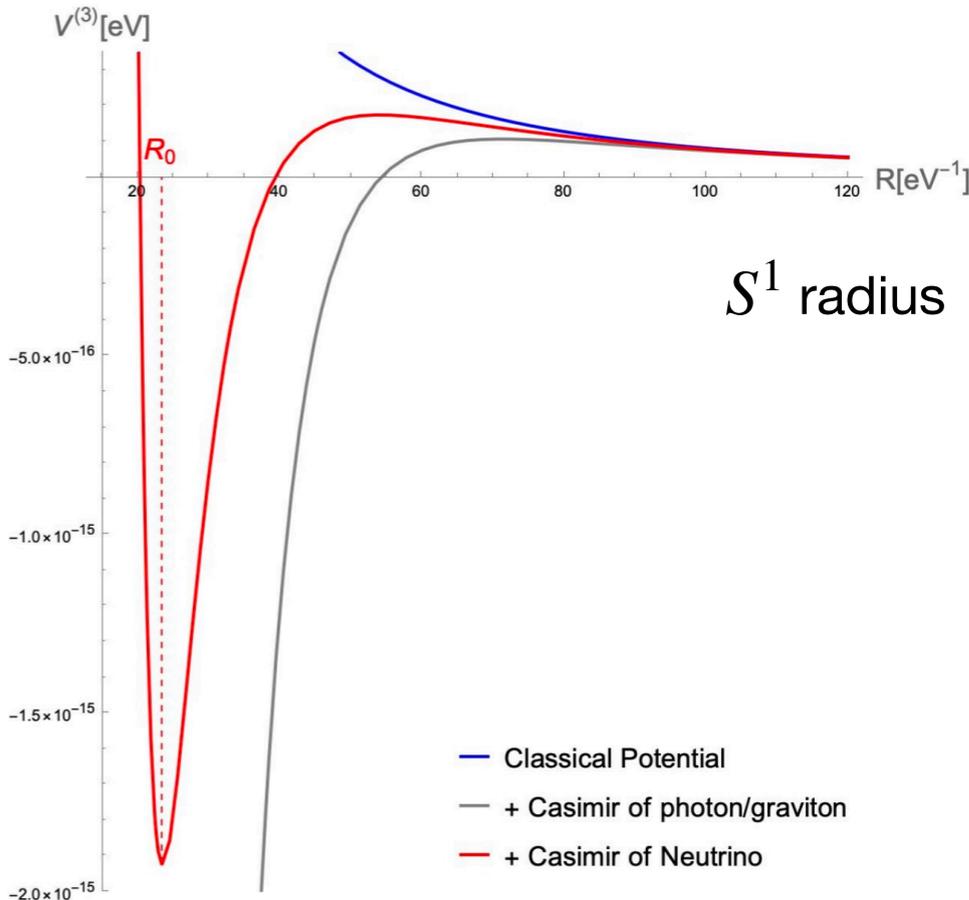
Near horizon geometry: $AdS_2 \times S^2$
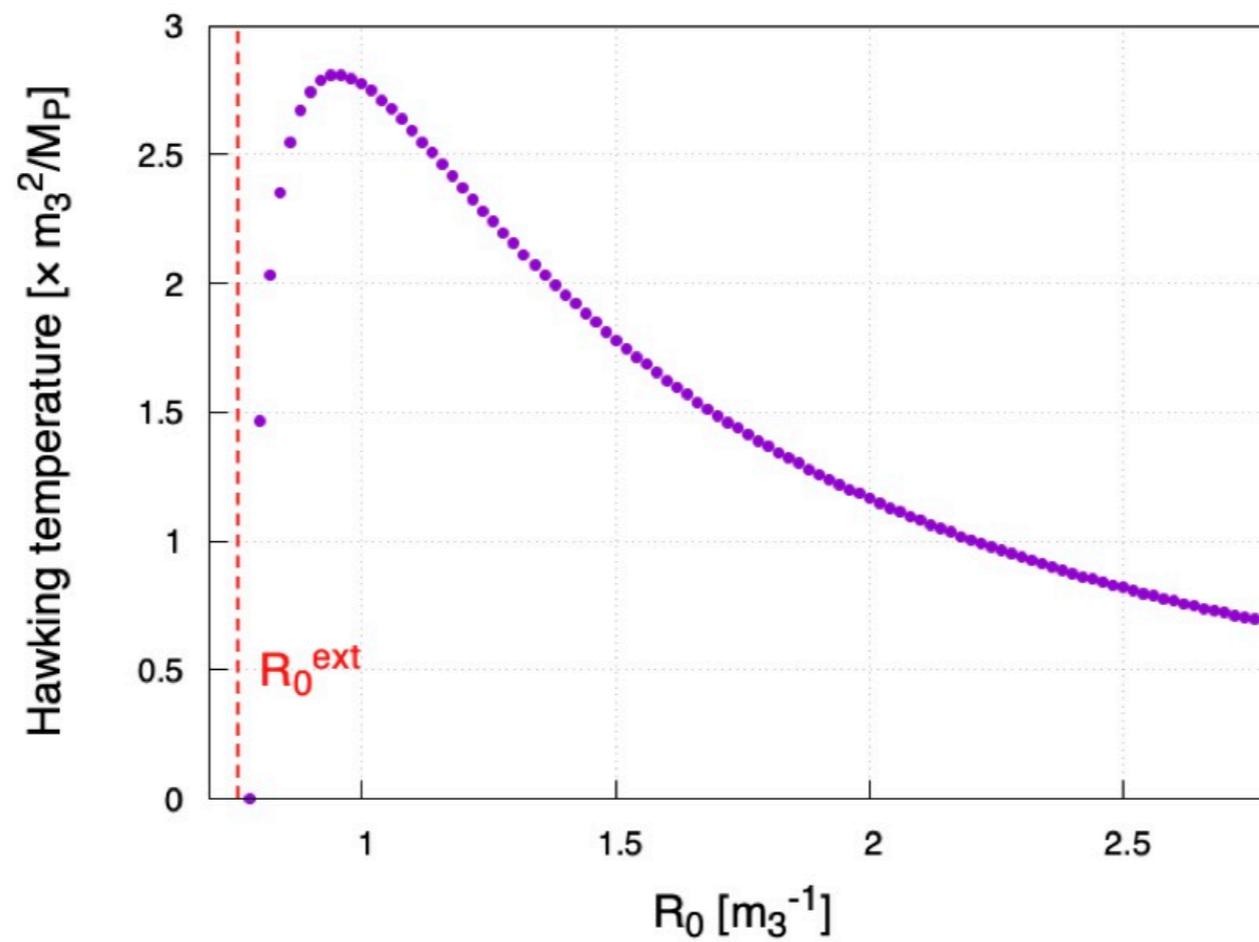
Effective potential

black string

Near horizon geometry: $AdS_3 \times S^1$

Effective potential

Non-extremal

Non-extremal solutions are constructed too.

Summary/Outlook

- Landscape of the Standard Model.

- Prediction of neutrino masses from MPP.

- Black string in the Standard Model, predicted by cobordism conjecture.