Constraints on the SM from the Weak Gravity Conjecture

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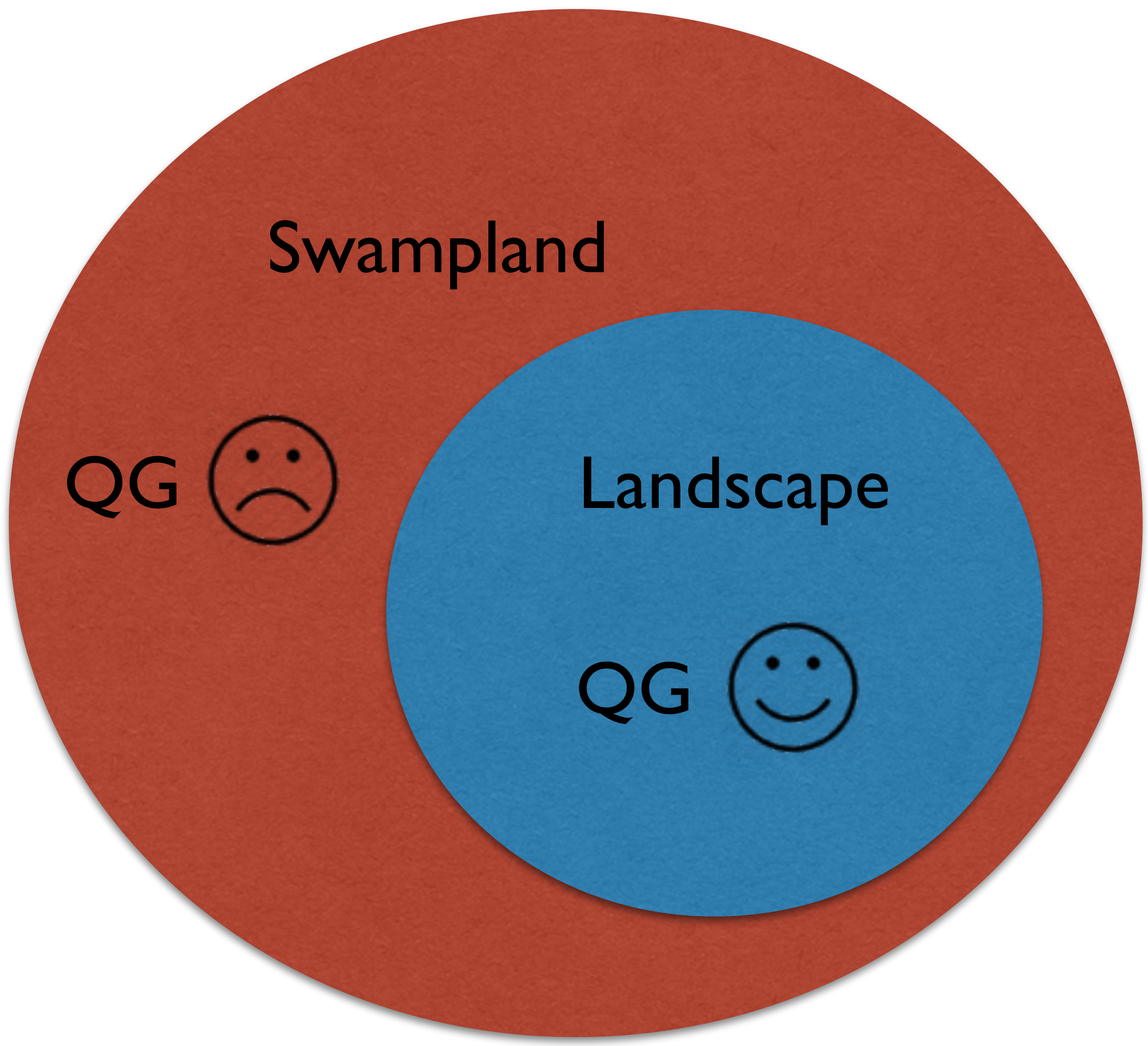
Ibanez,Martin-Lozano,IV [arXiv:1706.05392 [hep-th]]

Ibanez,Martin-Lozano,IV [arXiv: 1707.05811 [hep-th]]

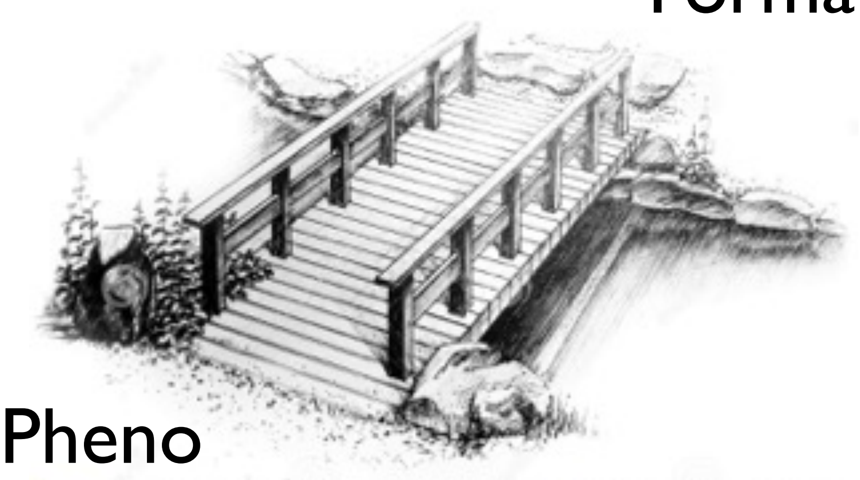
DESY Theory Workshop, 2017

What are the constraints that an effective theory must satisfy to be embedded in quantum gravity?



Quantum Gravity Conjectures

Motivated many times by observing recurrent features of the string landscape and "model building failures"



They can have significant implications in low energy physics!

Weak Gravity Conjecture

Weak Gravity Conjecture: [Arkani-Hamed et al.'06]

Given an abelian p-form gauge field, there must exist an electrically charged state with

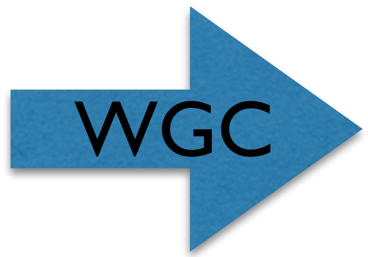
$$T \leq Q$$

Sharpened WGC: [Ooguri-Vafa'16]

Bound is saturated only for a BPS state in a SUSY theory

AdS Instability Conjecture

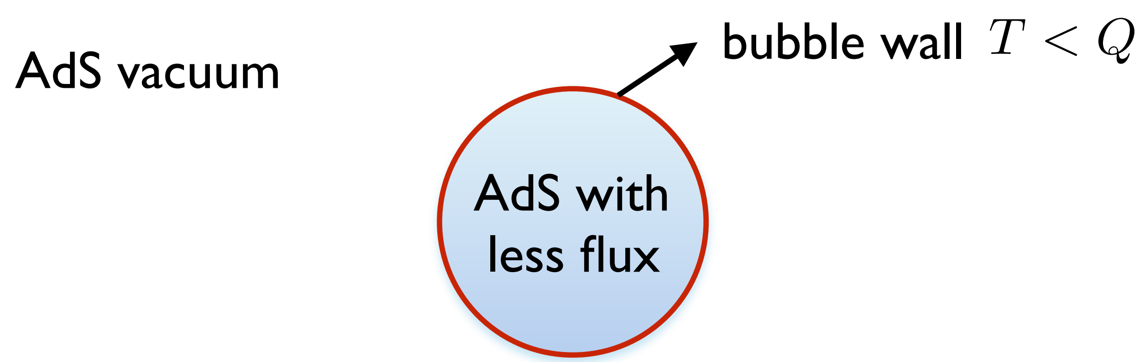
Geometry supported by fluxes



Brane charged under the flux with $T \leq Q$

[Maldacena et al.'99]

‼ In AdS, a brane with $T < Q$ describes an instability



AdS Instability Conjecture

Geometry supported by fluxes → **WGC** → Brane charged under the flux with $T \leq Q$

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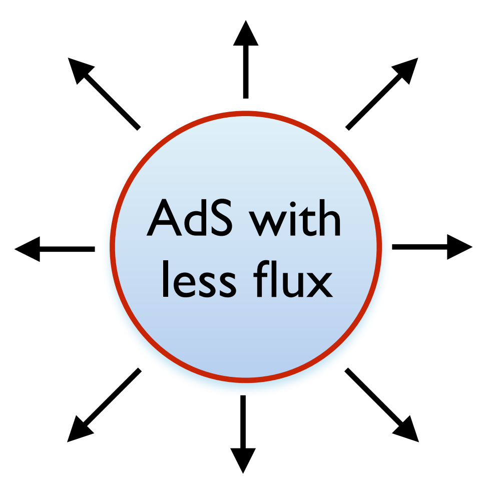
AdS vacuum



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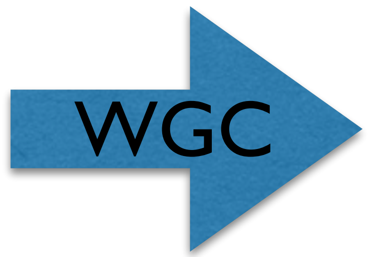

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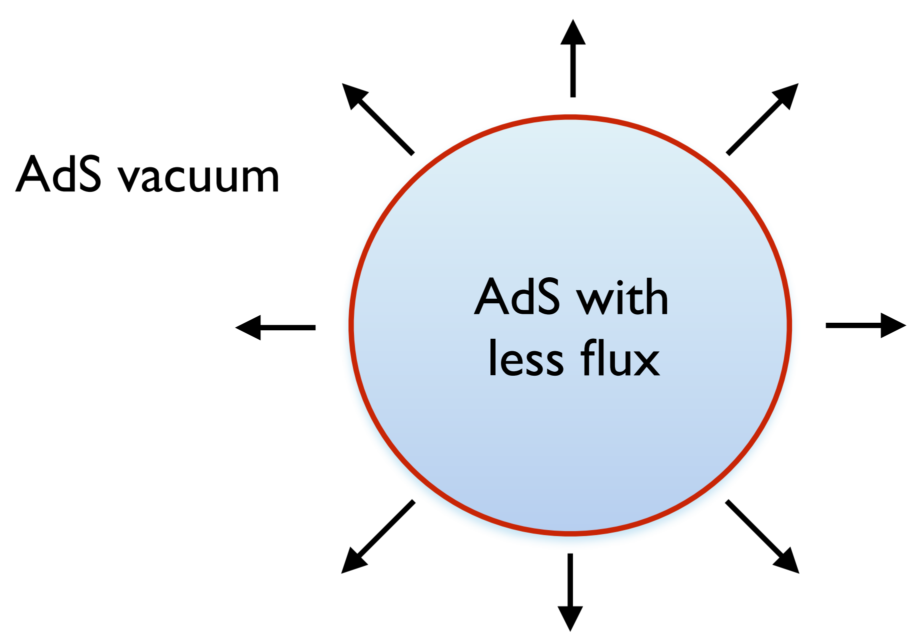
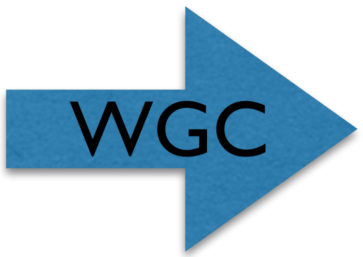


AdS Instability Conjecture

(non-susy)
Geometry supported by fluxes



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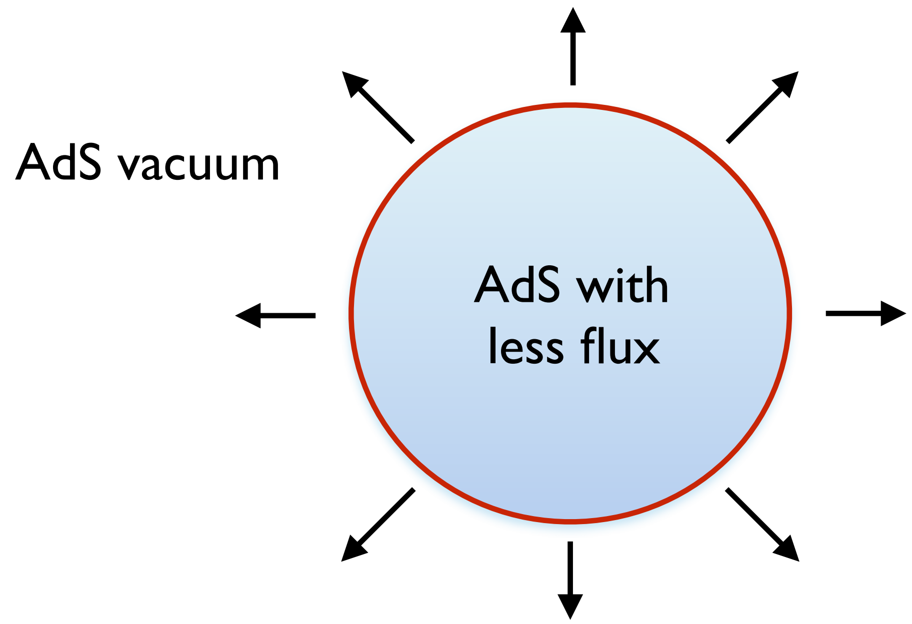

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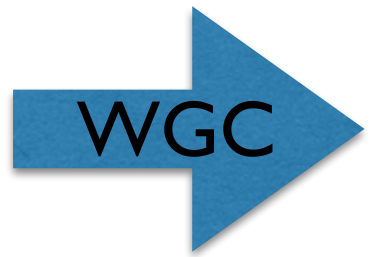

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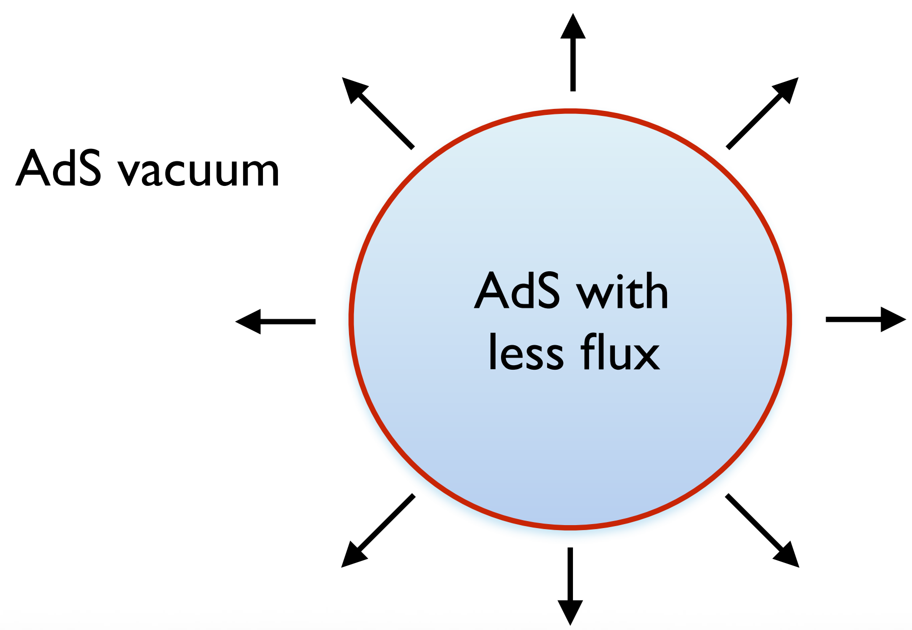

Non-susy AdS vacua supported by fluxes are at best metastable

AdS Instability Conjecture

[Ooguri-Vafa'16]

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Non-susy AdS vacua are at best metastable

Same conjecture in [Freivogel-Kleban'16]

AdS Instability Conjecture

[Ooguri-Vafa'16]

Non-susy AdS vacua are at best metastable

Same conjecture in [Freivogel-Kleban'16]

Non-susy stable AdS vacua cannot be embedded in quantum gravity!

Implications for:
- Holography
- String landscape
- Low energy physics?

Compactification of the SM to 3d

Standard Model + Gravity on S^1: [Arkani-Hamed et al.'07] (also [Arnold-Fornal-Wise'10])

$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} \quad + \text{ Casimir energy}$$

$\frac{2\pi r^3 \Lambda_4}{R^2}$ ↓ tree-level

Casimir energy ↓ one-loop corrections

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Depending on the light mass spectra and the cosmological constant, we can get AdS, Minkowski or dS vacua in 3d

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Depending on the light mass spectra and the cosmological constant, we can get AdS, Minkowski or dS vacua in 3d

But AdS vacua are not consistent with quantum gravity!

Compactification of the SM to 3d

Assumption: Background independence

If our 4d SM is consistent with QG → Compactifications of SM should also be consistent

We should not get stable non-susy AdS vacua from compactifying the SM!

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Compactification of the SM to 3d

Assumption: Background independence

A 4d bubble instability also yields a 3d instability if

$$R_b < l_{AdS_3}$$

We ... !

Therefore, the 3d vacuum will be **stable** if:

$$l_{AdS_3} < R_{\text{bubble}} < l_{dS_4}$$

$$(l_{dS_4} \sim 2 - 200\ l_{AdS_3})$$

$\longrightarrow$ large bubbles, nearly BPS

(periodic b.c. $\longrightarrow$ no bubbles of noth...

- Instability already in 4 dimensions $\longrightarrow$ Transfered to 3d

?

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    $l_{AdS_3} < R_{\rm bubble} < l_{dS_4}$

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Standard Model + Gravity on S^1:

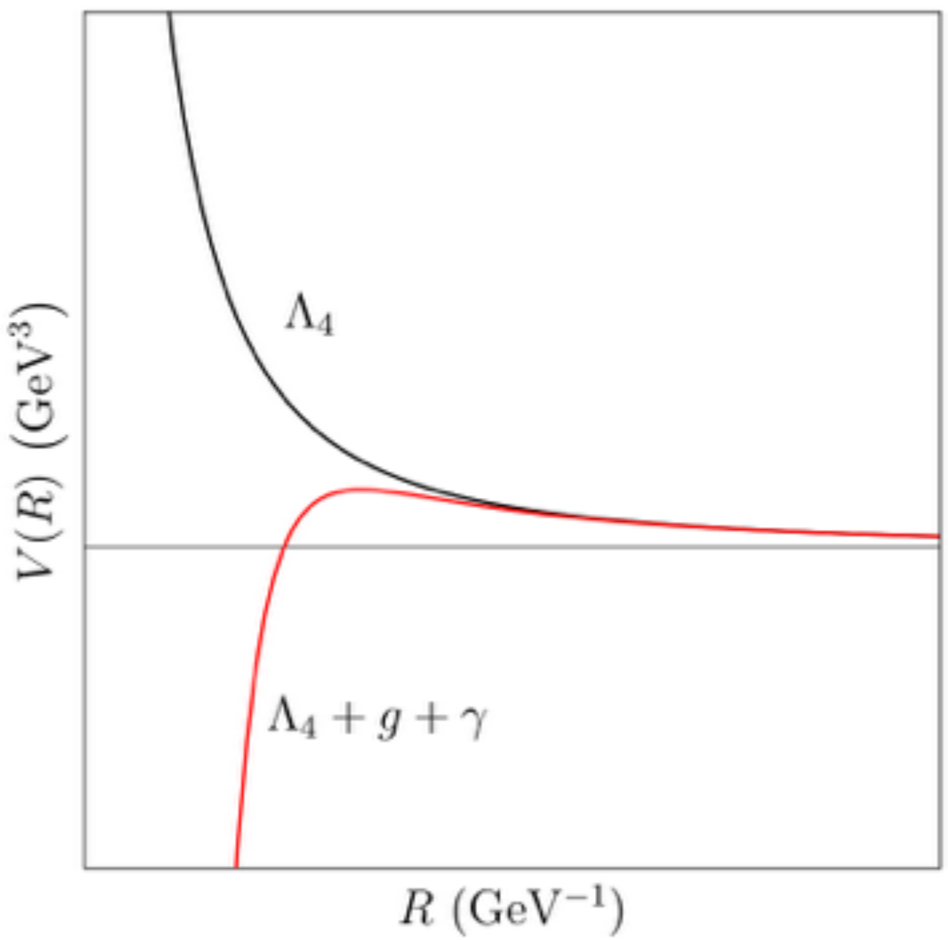
$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} \quad + \text{Casimir energy}$$

Compactification of the SM to 3d

Standard Model + Gravity on S^1:

massless particles: graviton, foton

$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} - 4\left(\frac{r^3}{720\pi R^6}\right)$$

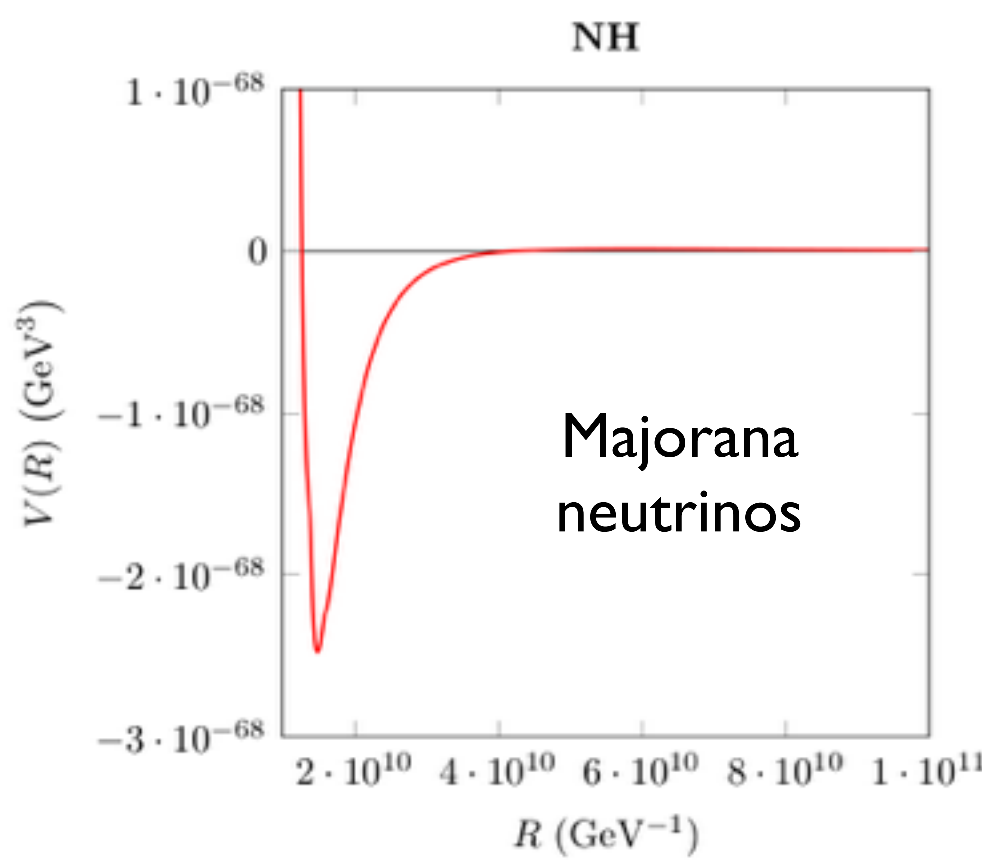


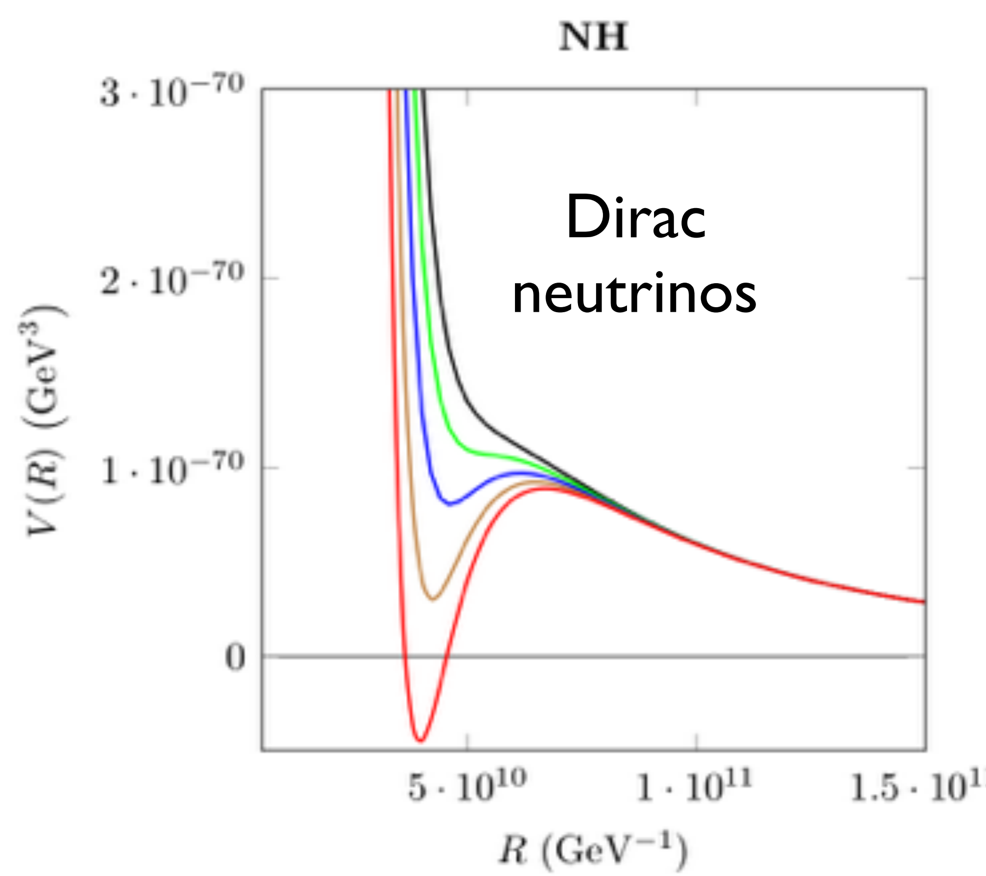
Compactification of the SM to 3d

Standard Model + Gravity on S^1:

massive particles: neutrinos,…

$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} - 4\left(\frac{r^3}{720\pi R^6}\right) + \sum_i (2\pi R)(-1)^{s_i} n_i \rho_i(R)$$





The more massive the neutrinos, the deeper the AdS vacuum

Constraints on neutrino masses

- Majorana:

There is an AdS vacuum for any value of m_ν $\longrightarrow$ **Majorana neutrinos ruled out!**

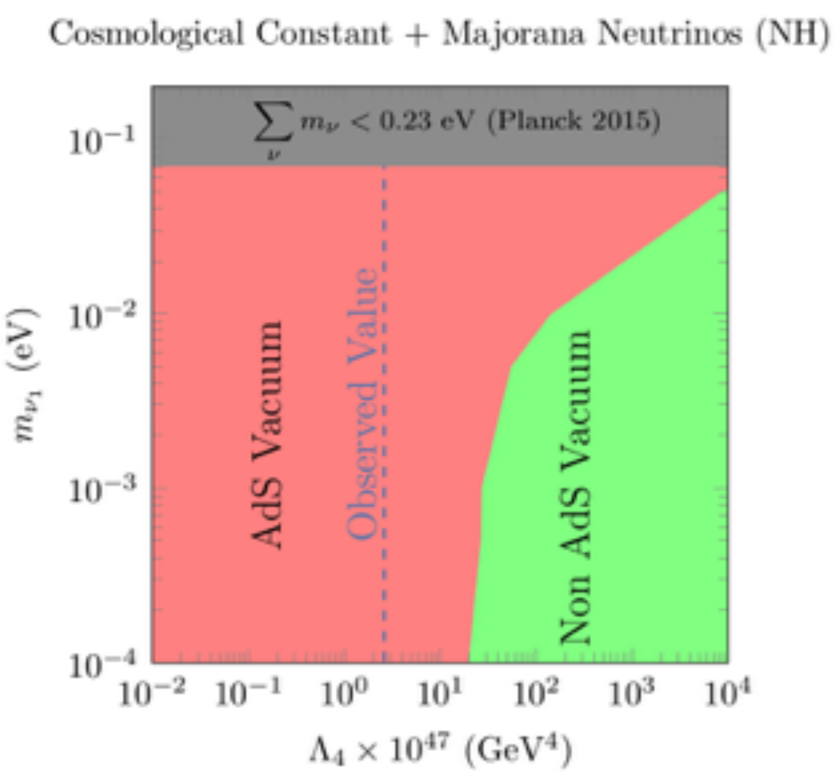
- Dirac:

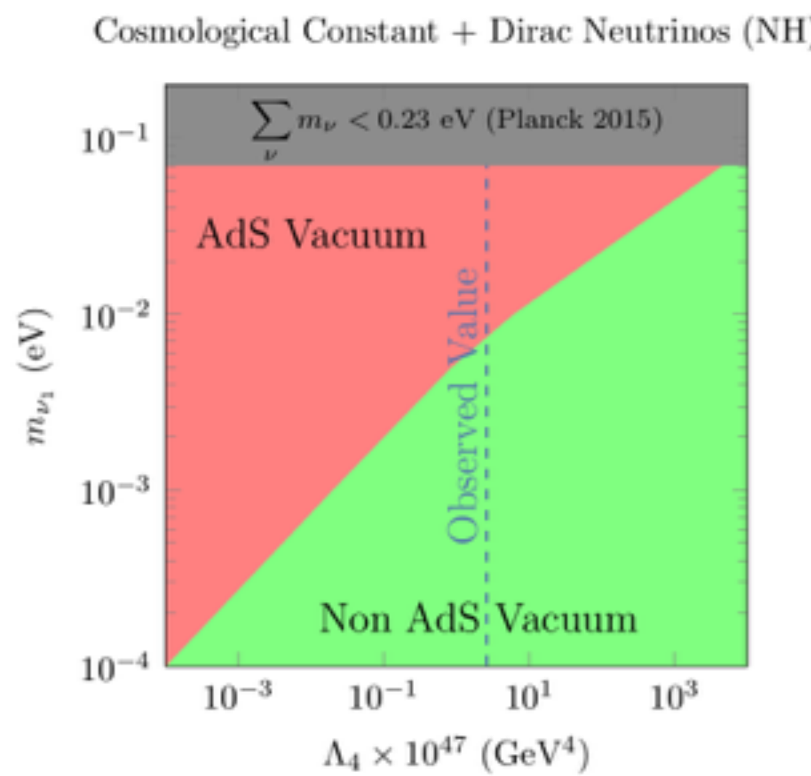
	NH	IH
No vacuum	$m_{\nu_1} < 6.7$ meV	$m_{\nu_3} < 2.1$ meV
dS_3 vacuum	$6.7 \text{ meV} < m_{\nu_1} < 7.7$ meV	$2.1 \text{ meV} < m_{\nu_3} < 2.56$ meV
AdS_3 vacuum	$m_{\nu_1} > 7.7$ meV	$m_{\nu_3} > 2.56$ meV

Absence of AdS vacuum requires

$$m_{\nu_1} < 7.7 \text{ meV (NH)}$$
$$m_{\nu_1} < 2.1 \text{ meV (IH)}$$

Lower bound on the cosmological constant





The bound for Λ_4 scales as m_ν^4 (as observed experimentally)

$$\Lambda_4 \geq \frac{a(n_f)30(\Sigma m_i^2)^2 - b(n_f, m_i)\Sigma m_i^4}{384\pi^2}$$

with $a(n_f) = 0.184(0.009)$, $b(n_f, m_i) = 5.72(0.29)$ for Majorana (Dirac)

First argument (not based on cosmology) to have $\Lambda_4 \neq 0$

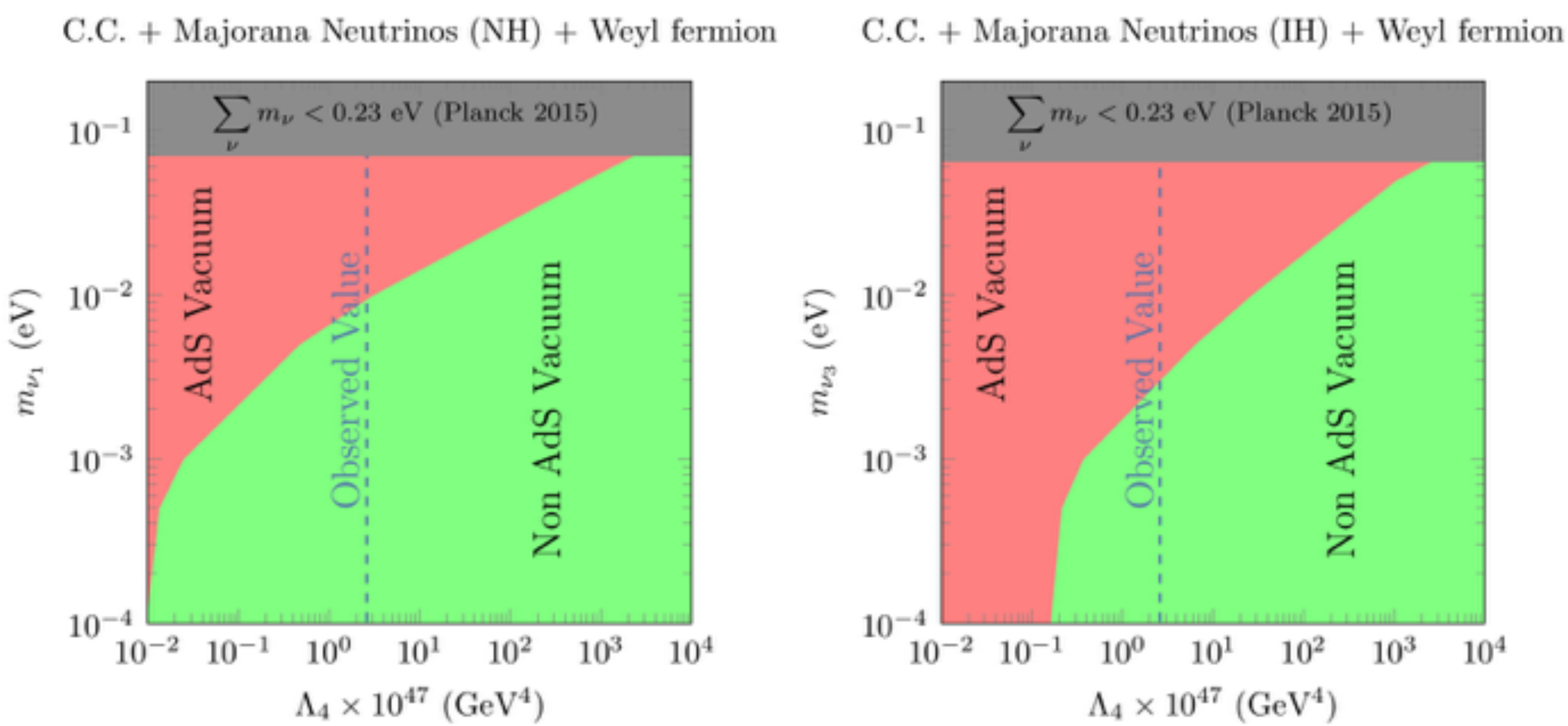
Adding BSM physics

- **Light fermions**

Positive Casimir contribution $\longrightarrow$ helps to avoid AdS vacuum

Majorana neutrinos are consistent if adding $m_\chi \lesssim 2\ \mathrm{meV}$

example. For $m_\chi = 0.1\ \mathrm{meV}$:

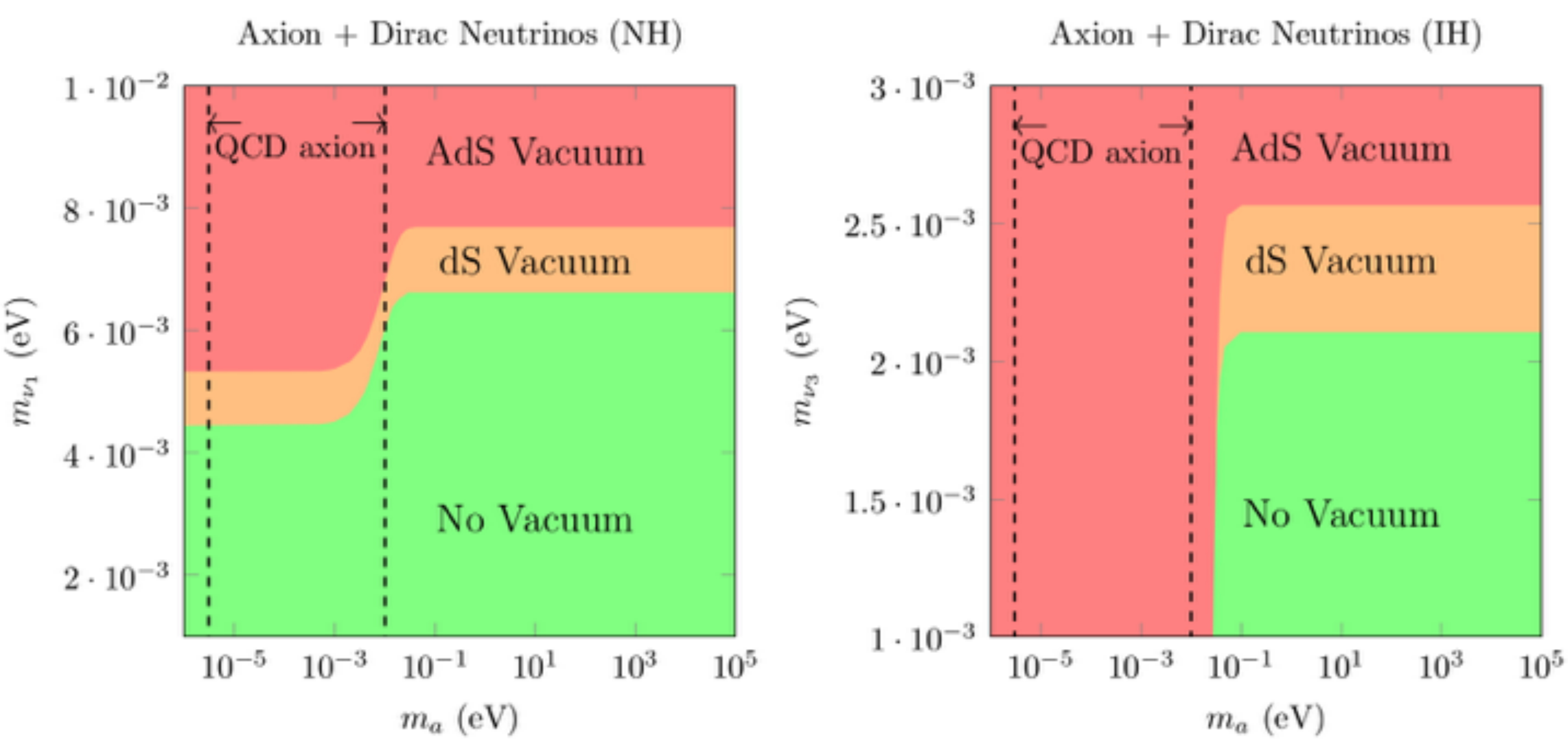


Adding BSM physics

- **Axions**

1 axion: negative contribution ⟶ bounds get stronger

Multiple axions: can destabilise AdS vacuum



Bounds on the SM + light BSM physics

Model	Majorana (NI)	Majorana (IH)	Dirac (NH)	Dirac (IH)
SM (3D)	no	no	$m_{\nu_1} \leq 7.7 \times 10^{-3}$	$m_{\nu_3} \leq 2.56 \times 10^{-3}$
SM(2D)	no	no	$m_{\nu_1} \leq 4.12 \times 10^{-3}$	$m_{\nu_3} \leq 1.0 \times 10^{-3}$
SM+Weyl(3D)	$m_{\nu_1} \leq 0.9 \times 10^{-2}$ $m_f \leq 1.2 \times 10^{-2}$	$m_{\nu_3} \leq 3 \times 10^{-3}$ $m_f \leq 4 \times 10^{-3}$	$m_{\nu_1} \leq 1.5 \times 10^{-2}$	$m_{\nu_3} \leq 1.2 \times 10^{-2}$
SM+Weyl(2D)	$m_{\nu_1} \leq 0.5 \times 10^{-2}$ $m_f \leq 0.4 \times 10^{-2}$	$m_{\nu_3} \leq 1 \times 10^{-3}$ $m_f \leq 2 \times 10^{-3}$	$m_{\nu_1} \leq 0.9 \times 10^{-2}$	$m_{\nu_3} \leq 0.7 \times 10^{-2}$
SM+Dirac(3D)	$m_f \leq 2 \times 10^{-2}$	$m_f \leq 1 \times 10^{-2}$	yes	yes
SM+Dirac(2D)	$m_f \leq 0.9 \times 10^{-2}$	$m_f \leq 0.9 \times 10^{-2}$	yes	yes
SM+1 axion(3D)	no	no	$m_{\nu_1} \leq 7.7 \times 10^{-3}$	$m_{\nu_3} \leq 2.5 \times 10^{-3}$ $m_a \geq 5 \times 10^{-2}$
SM+1 axion(2D)	no	no	$m_{\nu_1} \leq 4.0 \times 10^{-3}$	$m_{\nu_3} \leq 1 \times 10^{-3}$ $m_a \geq 2 \times 10^{-2}$
$\geq 2(10)$ axions	yes	yes	yes	yes

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$\geq 2(10)$ axions	yes	yes	yes	yes

Majorana neutrinos are consistent if adding:

- A Weyl (or Dirac) fermion $m_f \leq 10\ \mathrm{meV}$
- Multiple axions

Bounds on the SM + light BSM physics

Model	Majorana (NI)	Majorana (IH)	Dirac (NH)	Dirac (IH)
SM (3D)	no	no	$m_{\nu_1} \lesssim 7.7 \times 10^{-3}$	$m_{\nu_3} \lesssim 2.56 \times 10^{-3}$
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$\geq 2(10)$ axions	yes	yes	yes	yes

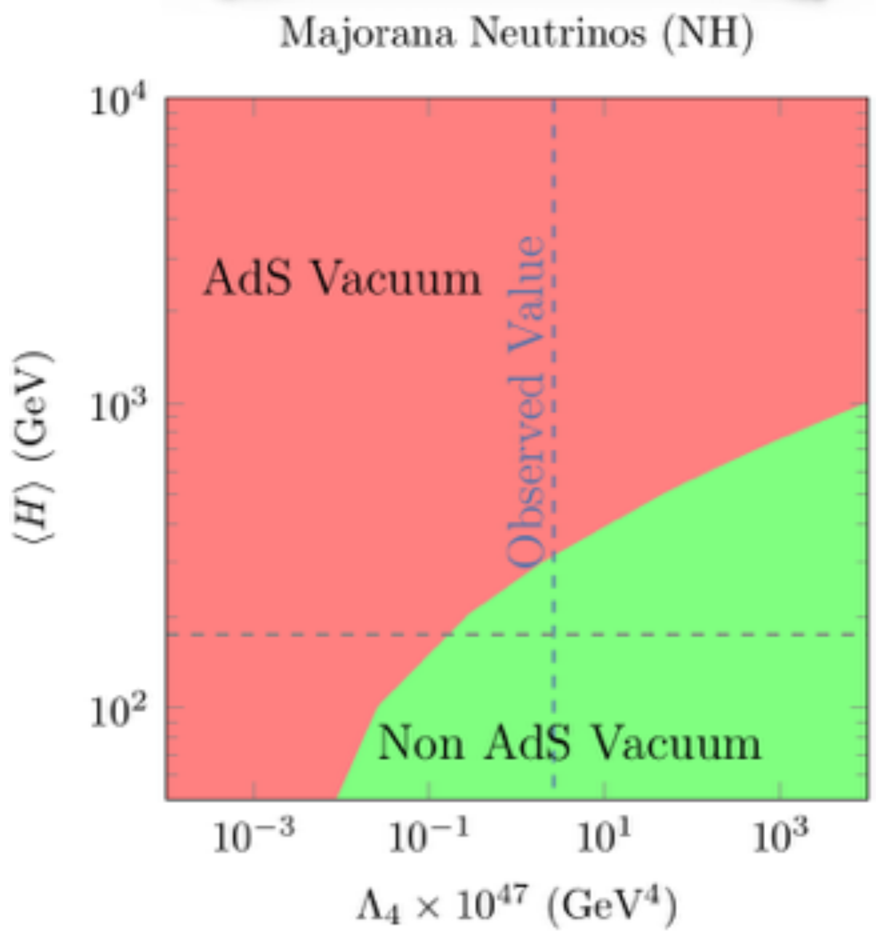
Compactifications of SM on T_2 $\longrightarrow$ qualitatively similar, but a bit stronger

(see also [Hamada-Shiu'17])

Upper bound on the EW scale

Majorana case

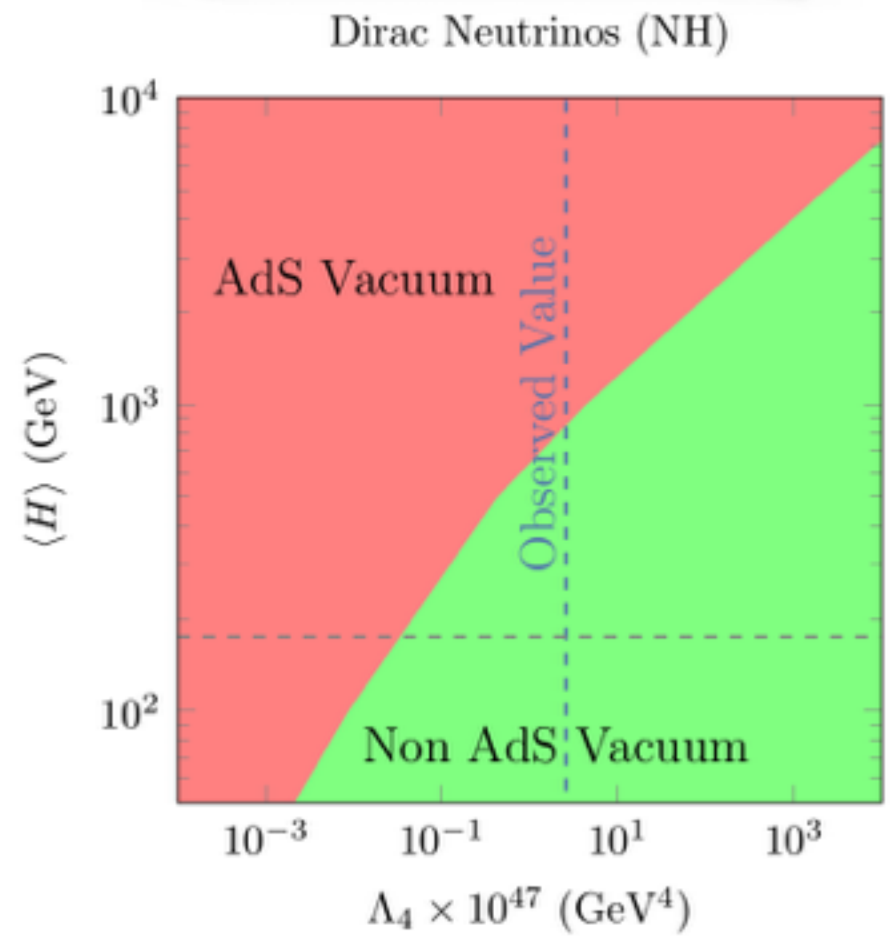
$$\langle H \rangle \lesssim \frac{\sqrt{2}}{Y_{\nu_1}} \sqrt{M \Lambda^{1/4}}$$



$$M = 10^{10}\ \text{GeV},\ Y = 10^{-3}$$

Dirac case

$$\langle H \rangle \lesssim 1.6 \frac{\Lambda^{1/4}}{Y_{\nu_1}}$$



$$Y = 10^{-14}$$

Conclusions

- **Consistency with quantum gravity implies constraints on low energy physics:**
  - Lower bound on the cosmological const. of order the neutrino masses
  - Upper bound on the EW scale in terms of the cosmological const.

- **Assumptions taken:**
  - Validity of the Ooguri-Vafa Conjecture
  - Non-perturbative stability of 3D SM vacua

- **New approach to fine-tuning or hierarchy problems? UV/IR mixing?** (see also [Luest-Palti'17])

Thank you!

back-up slides

Casimir energy

Potential energy in 3d:

$$V(R) = \frac{2\pi r^3 \Lambda_4}{R^2} + \sum_i (2\pi R) \frac{r^3}{R^3} (-1)^{s_i} n_i \rho_i(R)$$

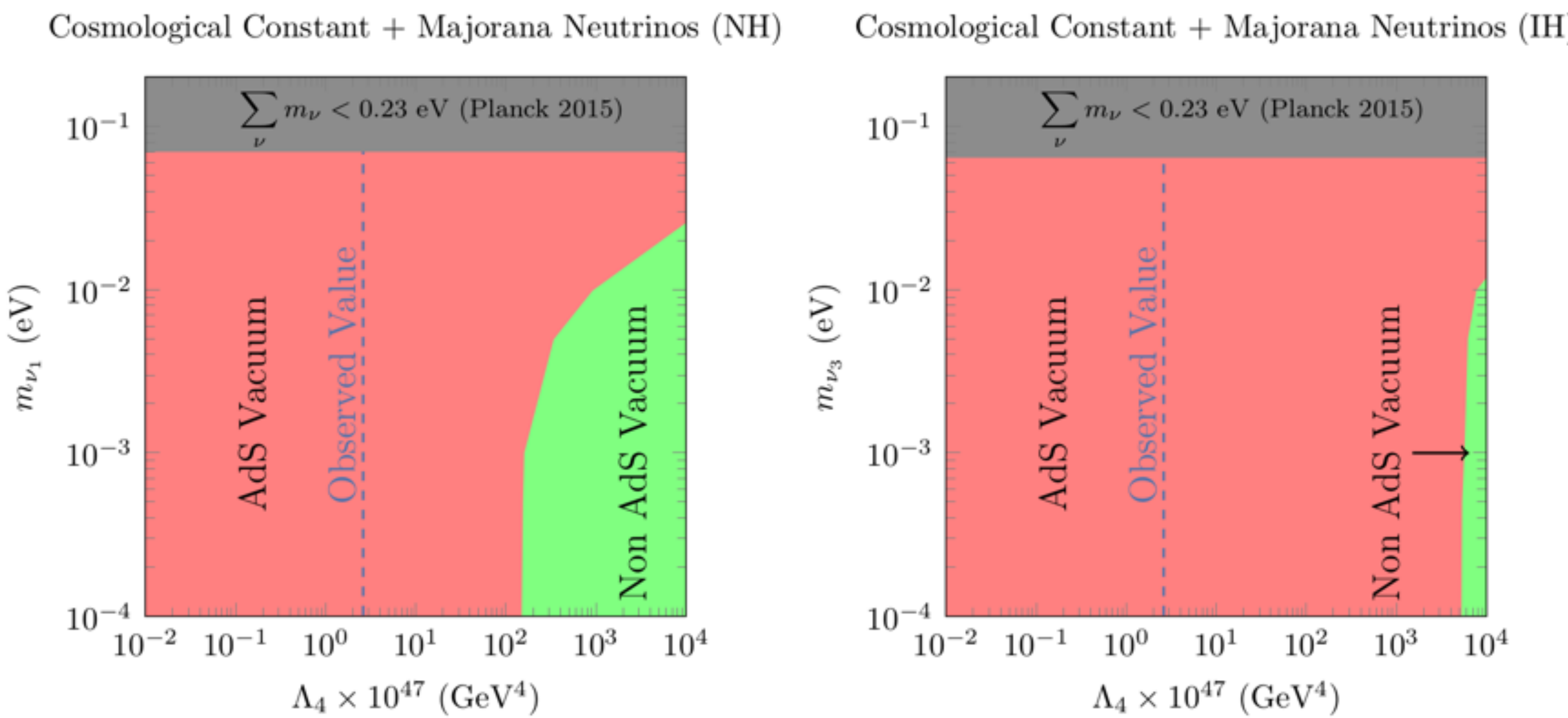
Casimir energy density:

$$\rho(R) = \mp \sum_{n=1}^{\infty} \frac{2m^4}{(2\pi)^2} \frac{K_2(2\pi Rmn)}{(2\pi Rmn)^2}$$

For small mR:

$$\rho(R) = \mp \left[\frac{\pi^2}{90(2\pi R)^4} - \frac{\pi^2}{6(2\pi R)^4}(mR)^2 + \frac{\pi^2}{48(2\pi R)^4}(mR)^4 + \mathcal{O}(mR)^6 \right]$$

Compactification of the SM to 2d



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