

Title: Swampland Constraints on Neutrino Masses and Dark Energy

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Swampland Constraints on Neutrino Masses and Dark Energy



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In collaboration with Luis Ibanez and Victor Martin-Lozano

(1706.05392, 1707.05811...)

Simplicity III, Perimeter Institute, Sept 2019

What does 'swampland' mean?

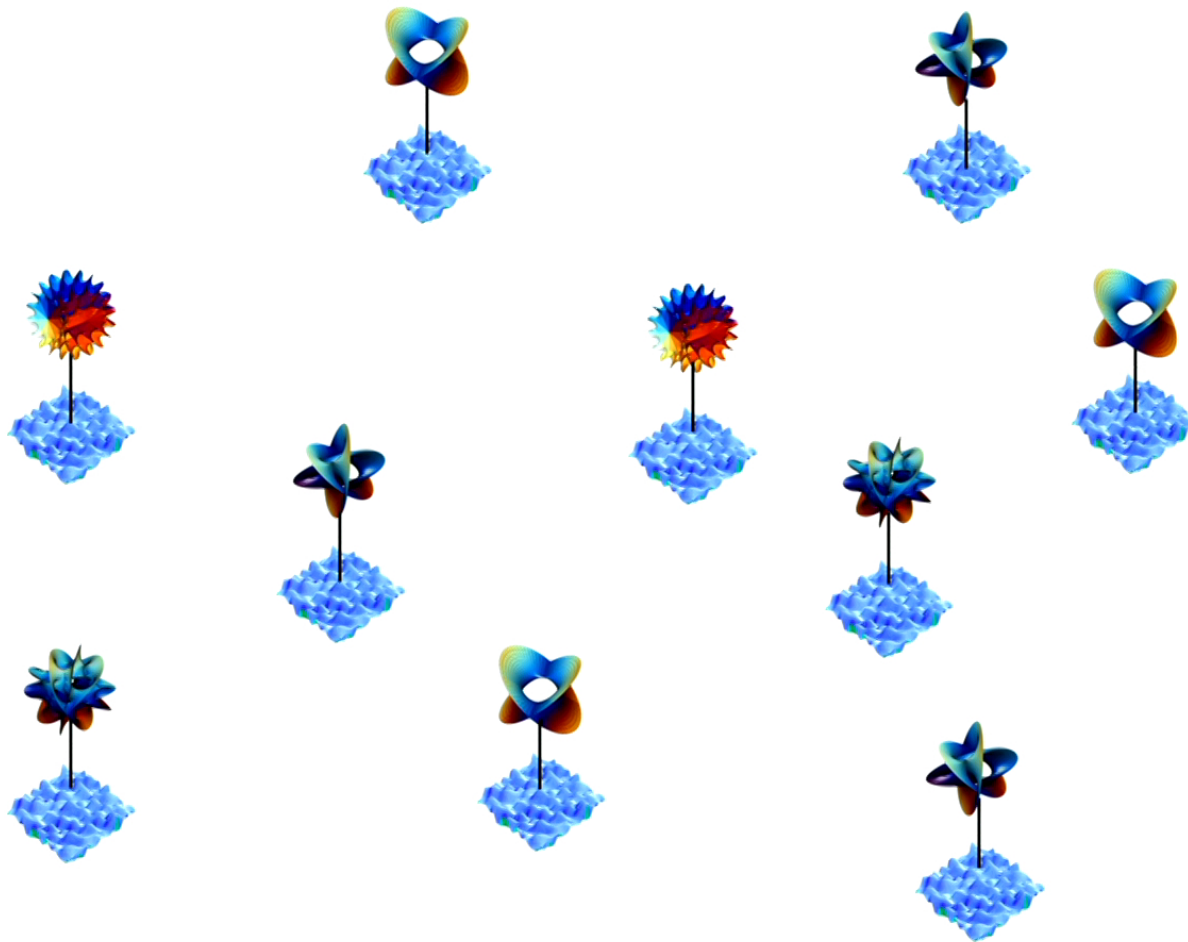
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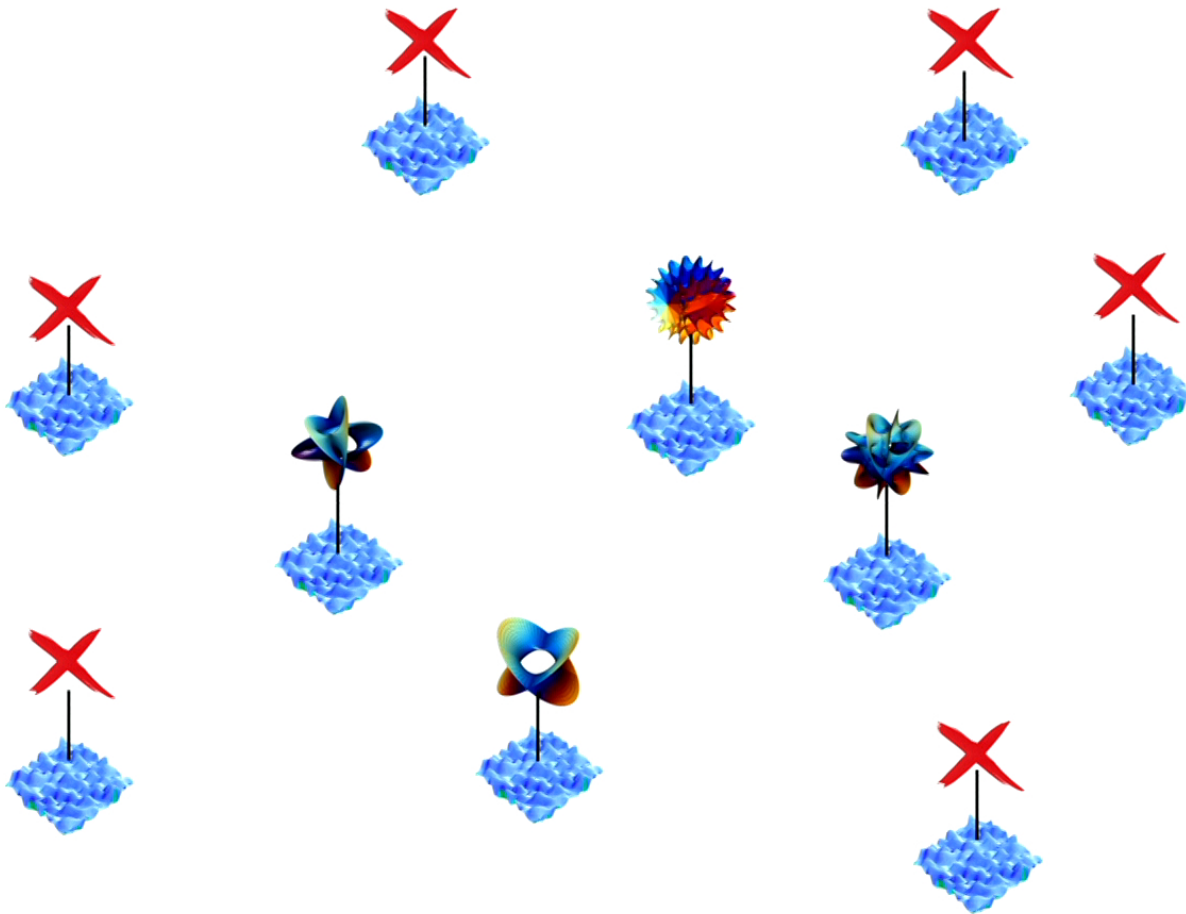


$$\hat{S}_{p \rightarrow 0} = -m_q \langle \bar{q} q \rangle$$
$$\hat{\Pi}_{p \rightarrow 0} = -m_b \langle \bar{b} b \rangle$$



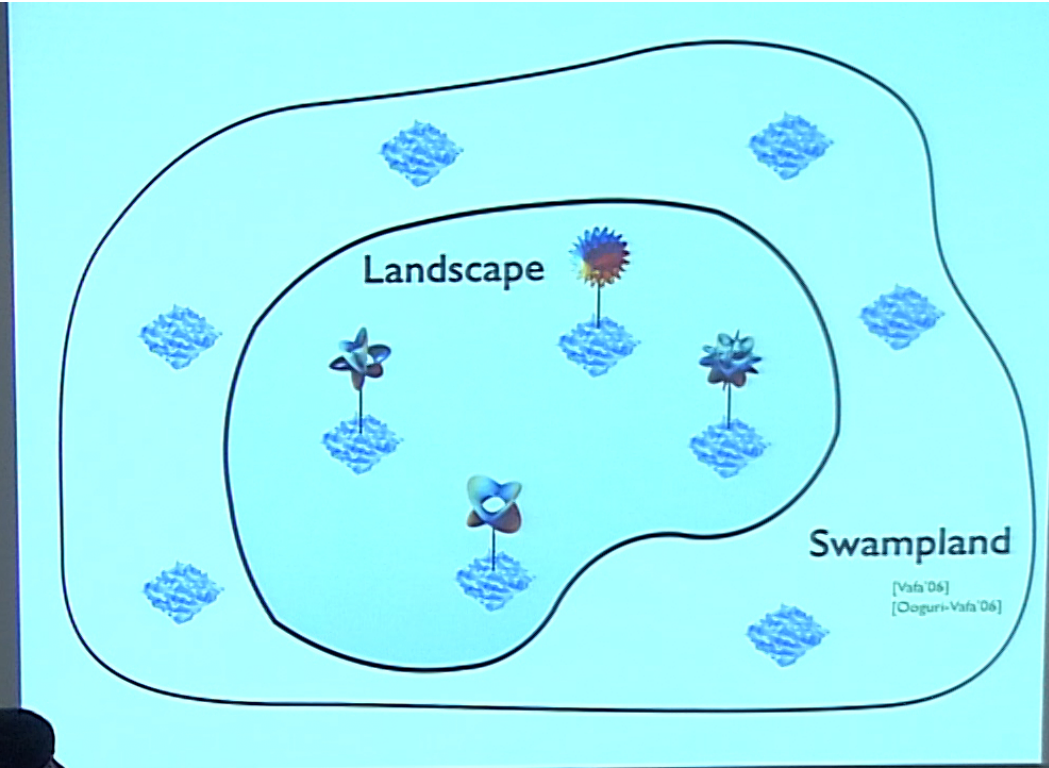
CAUTION
NE PAS TOUCHER LES WIRTES ENFONCES,
RISQUE D'AVANTAGE DE LES ENDOMMAGER
NE PAS TOUCHER LES BOUTS
DES BOUTS ENFONCES ENFIN
NE PAS TOUCHER ENFIN

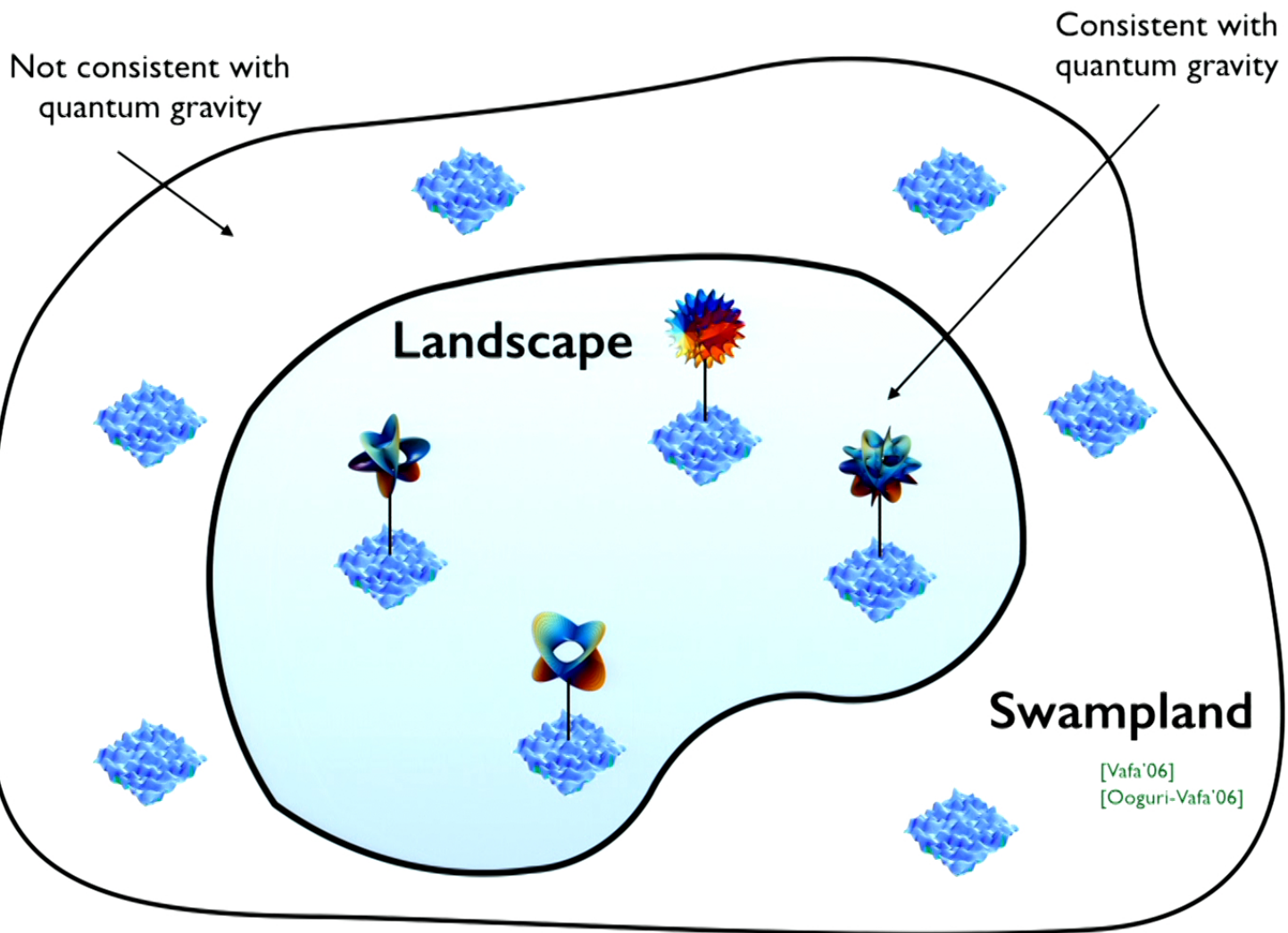




$$G = AdA - \frac{3}{2} AAA, \quad \langle G \hat{G}_1 \hat{G}_2 \rangle_{p=0} = -m_q \langle qq \rangle$$

$$G = PdA - \frac{3}{2} PPA, \quad \langle R \hat{R}_1 \hat{R}_2 \rangle_{p=0} = -m_c \langle cc \rangle$$





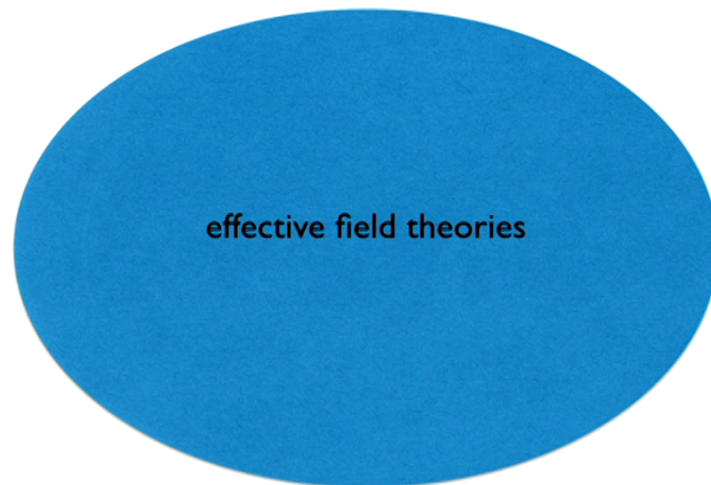
Not everything is possible in
string theory/quantum gravity!!!

(String) **Swampland:**

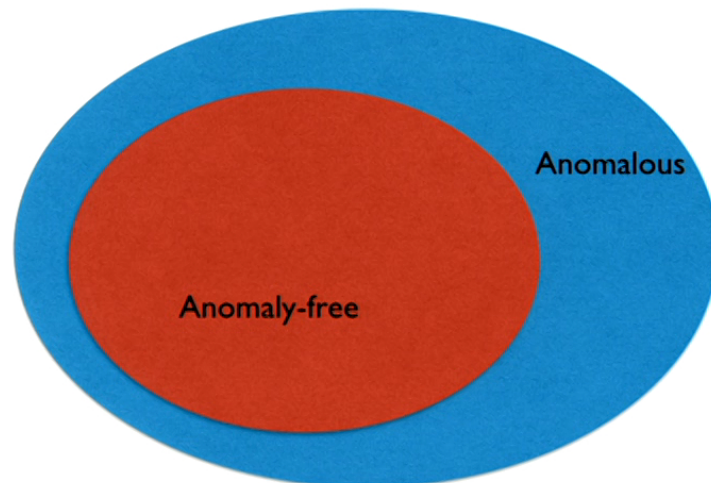
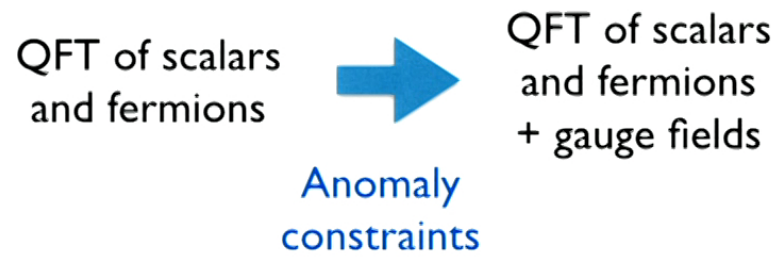
Apparently consistent (anomaly-free) quantum **effective field theories** that **cannot** be UV embedded in **quantum gravity**
(they cannot arise from string theory)

First guess: Anomalies

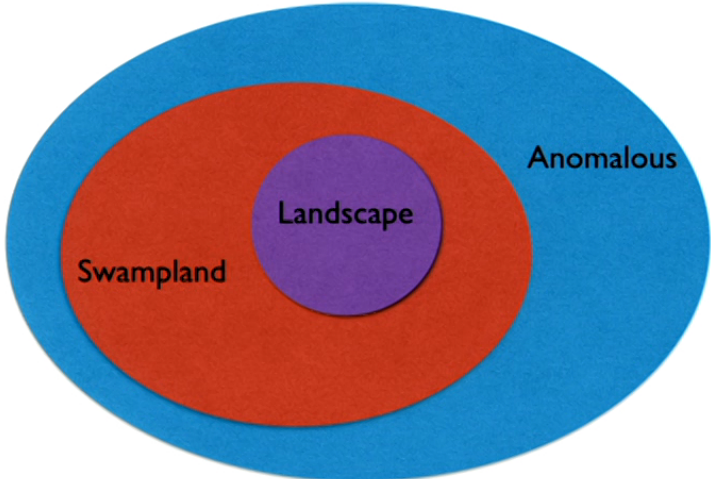
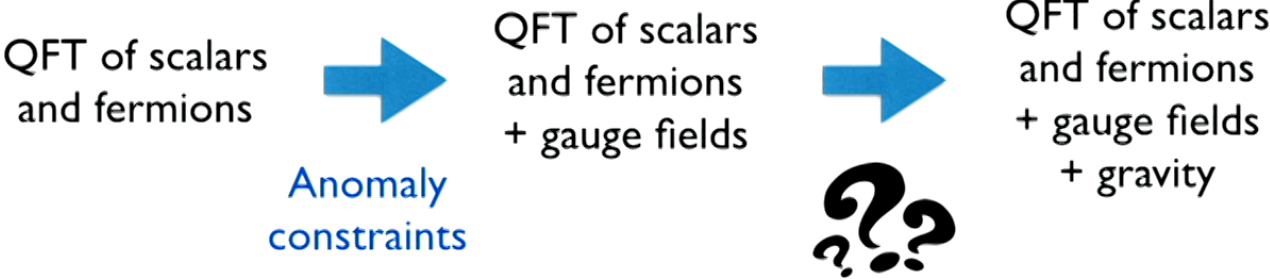
QFT of scalars
and fermions



First guess: Anomalies



First guess: Anomalies



There are additional (swampland/QG) constraints that any effective QFT must satisfy to be consistent with quantum gravity



UV imprint of quantum gravity at low energies

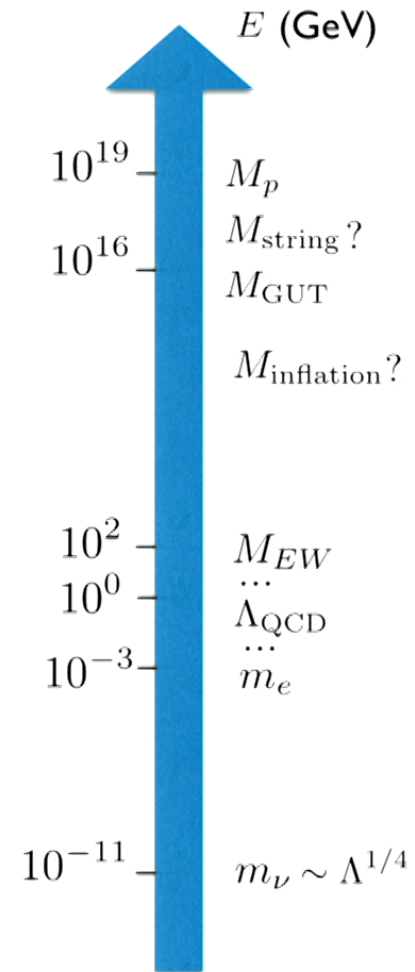
Outstanding phenomenological implications!

Effective field theories

Modern physics based on a Wilsonian effective field theory approach

Expectation of 'separation of scales':

IR effective theory not very sensitive to UV physics



Effective field theories

Modern physics based on a Wilsonian effective field theory approach

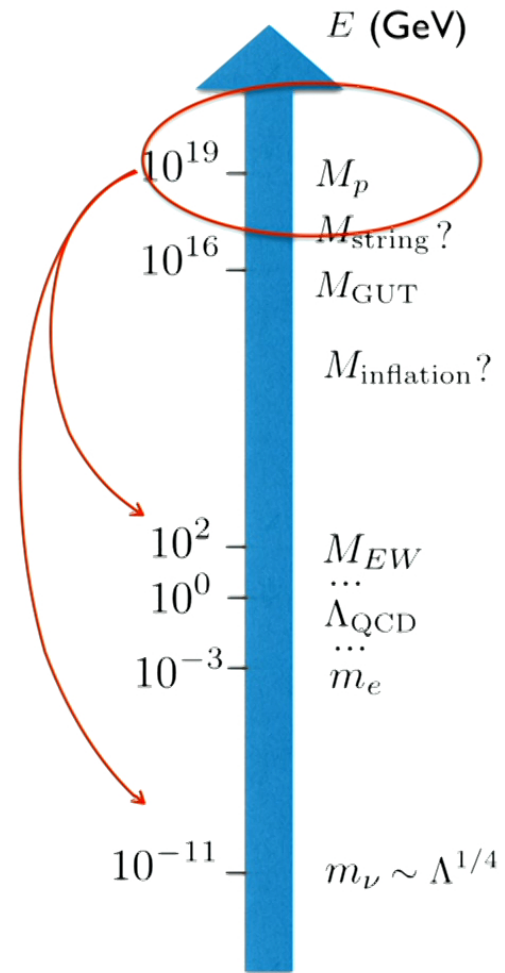
Expectation of 'separation of scales':

IR effective theory not very sensitive to UV physics

This picture can fail!



non-trivial implications at low energies!



Effective field theories

Modern physics based on a Wilsonian effective field theory approach

Expectation of 'separation of scales':

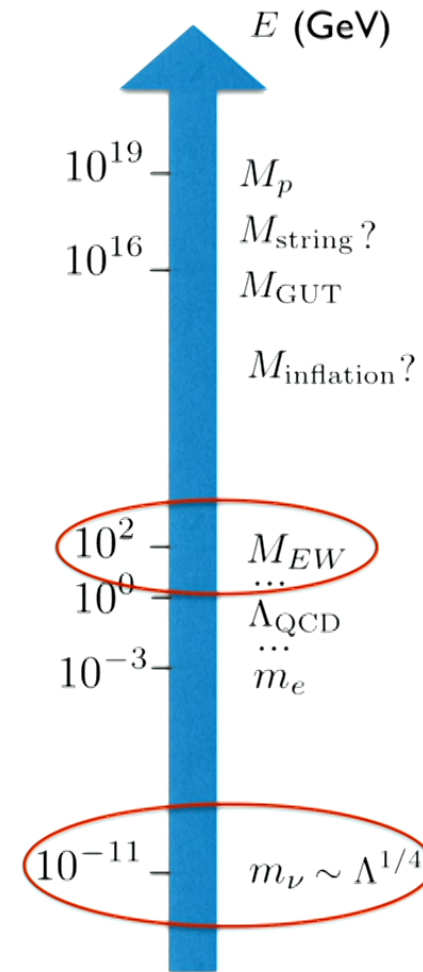
It is already failing...

Naturalness problems:

- ☹️ Cosmological constant
- ☹️ EW hierarchy problem

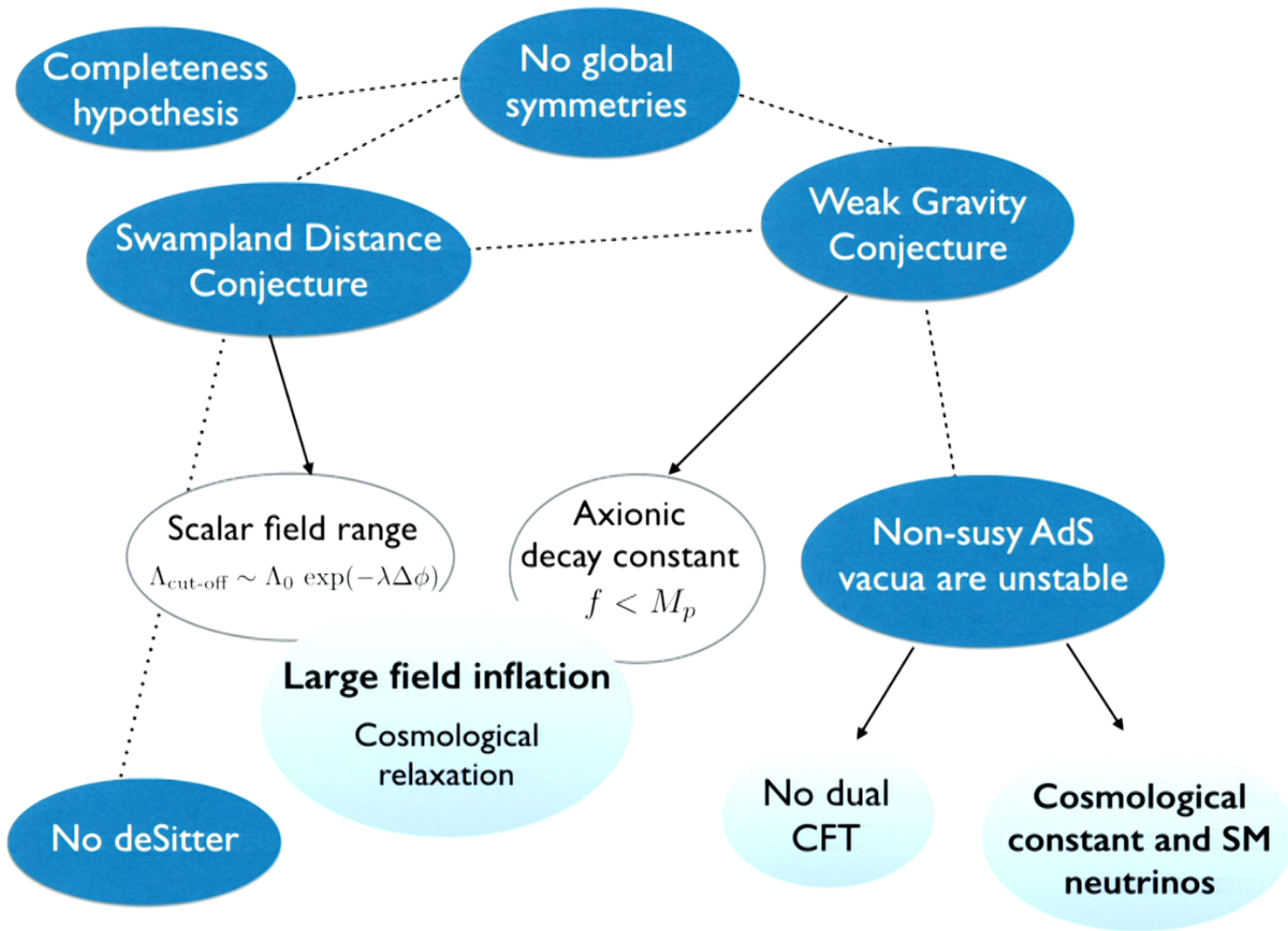
New approach?

Quantum gravity constraints = Missing piece for hierarchy problems?



What are the constraints that an effective theory must satisfy to be consistent with quantum gravity?

What distinguishes the landscape from the swampland?



Weak Gravity
Conjecture

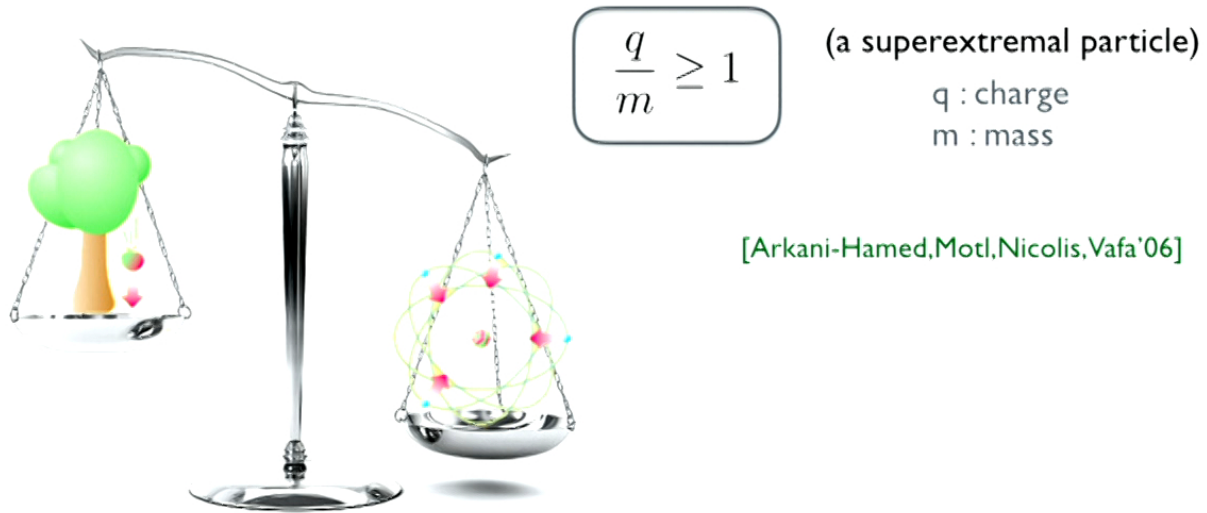
+
evidence
-

Non-susy AdS
vacua are unstable

Cosmological
constant and SM
neutrinos

Weak Gravity Conjecture

There exist at least a particle in which gravity acts weaker than the gauge force



Weak Gravity Conjecture

There exist at least a particle in which gravity acts weaker than the gauge force

$$\frac{q}{m} \geq 1$$

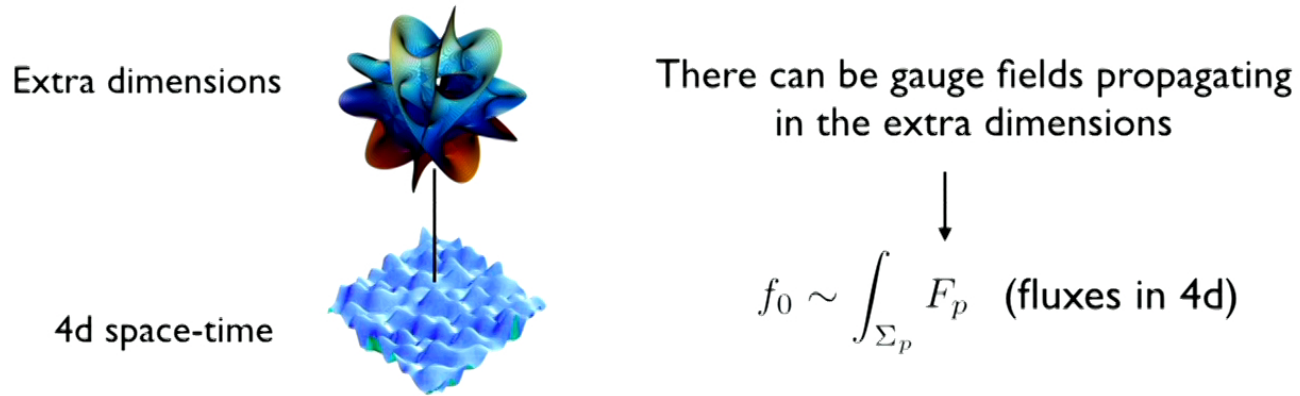
(a superextremal particle)

q : charge
m : mass

Evidence:

- Plethora of examples in string theory (not known counter-example)
- Derivation from modular invariance of the 2d CFT [Heidenreich et al'16] [Montero et al'16]
- Relation to entropy bounds, unitarity and causality [Cottrell et al'16] [Andriolo et al'18]
- Derivation from higher derivative corrections to BH's [Fisher et al'17] [Hamada et al'18]
[Cheung et al'18] [Charles'19] [Jones et al'19]
- Relation to cosmic censorship [Crisford et al'17]
- Relation to thermodynamic arguments [Hod'17.] [Urbano'18]
- Relation to entanglement entropy [Montero'19]

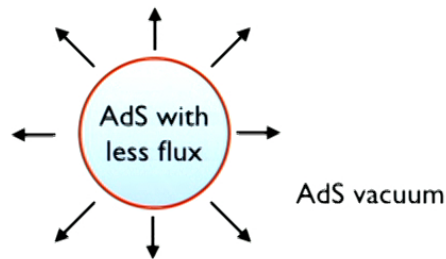
Weak Gravity Conjecture for fluxes



WGC applied to the fluxes (in a non-susy vacuum) implies: [Ooguri-Vafa'17]

∃ Brane (domain wall) with $T < Q$ **Bubble instability of the vacuum!**

[Maldacena et al.'99]



AdS-Phobia Conjecture

Non-susy vacua are at best metastable

[Ooguri-Vafa'16]

[Freivogel-Kleban'16]

Non-susy stable AdS vacua are in the Swampland
(inconsistent with Quantum Gravity)!

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Implications for our universe:

👤 Our universe must be metastable ✓

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Non-susy stable AdS vacua are in the Swampland
(inconsistent with Quantum Gravity)!

Implications for our universe:

- 👤 Our universe must be metastable ✓
- 👤 Still, non-susy stable AdS vacua can arise when compactifying SM to lower dimensions !!

AdS-Phobia Conjecture

Background independence of QG:

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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Solution: [Ibanez, Martin-Lozano, IV'17]

We impose the absence of
non-susy stable 3d AdS vacua



Constraints on light
spectra of SM

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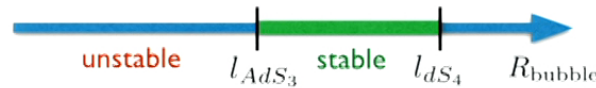
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Assumption: 4d instabilities are not transferred to 3d

$$R_{\text{bubble}} > l_{AdS_3} \quad (\text{large bubbles})$$



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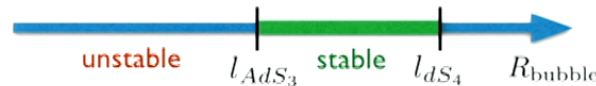
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Constraints on light
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Compactification of the SM to 3d

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

$$V(R) = \frac{2\pi\Lambda_4}{R^2} + \text{Casimir energy}$$

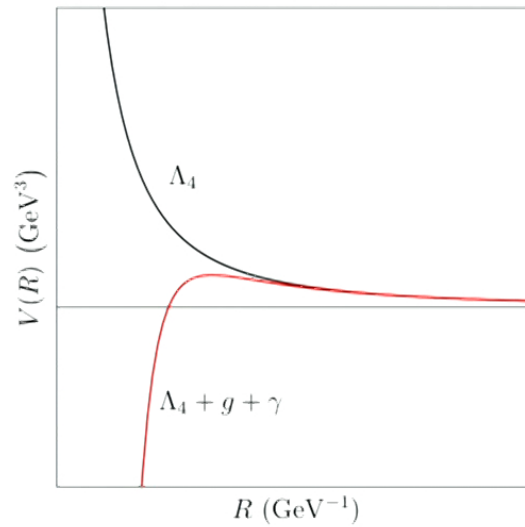
$R \equiv$ scalar parametrising the radius of the circle S^1

Compactification of the SM to 3d

Standard Model + Gravity on S^1 :

massless particles:
graviton, photon

$$V(R) = \frac{2\pi\Lambda_4}{R^2} - \frac{4}{720\pi R^6}$$



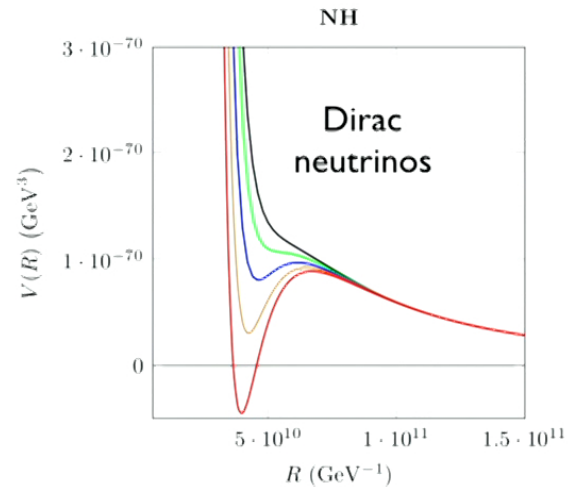
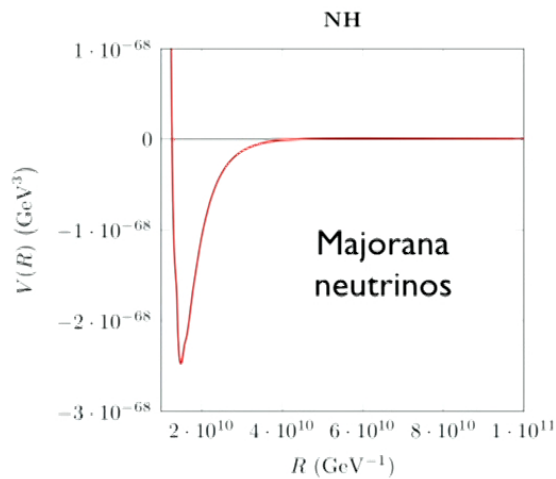
Compactification of the SM to 3d

Standard Model + Gravity on S^1 :

massless particles:
graviton, photon

massive particles:
neutrinos,...

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



The more massive the neutrinos, the deeper the AdS vacuum

[Ibanez, Martin-Lozano, IV'17] (see also [Hamada-Shiu'17])

Compactification of the SM to 3d

Standard Model + Gravity on S^1 :

Absence of AdS vacua implies:

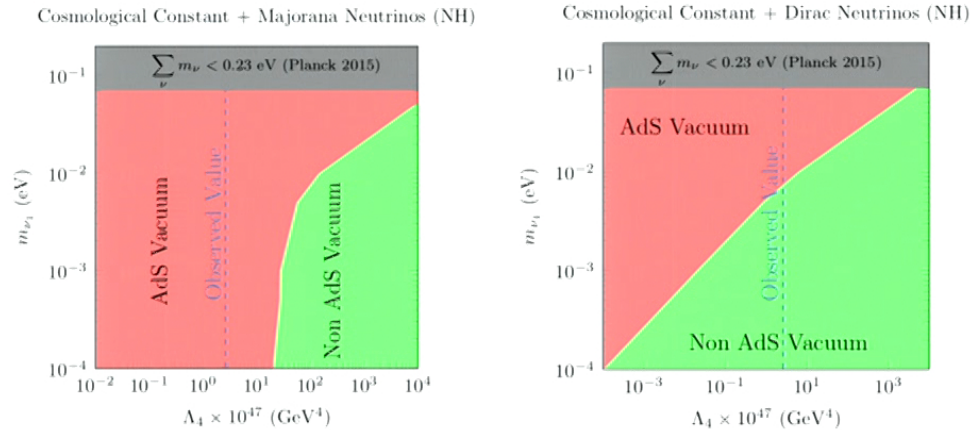
Majorana neutrinos
ruled out!

Upper bound for
Dirac mass!

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

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

Lower bound on the cosmological constant



The bound for Λ_4 scales as m_{ν}^4

(as observed experimentally)

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

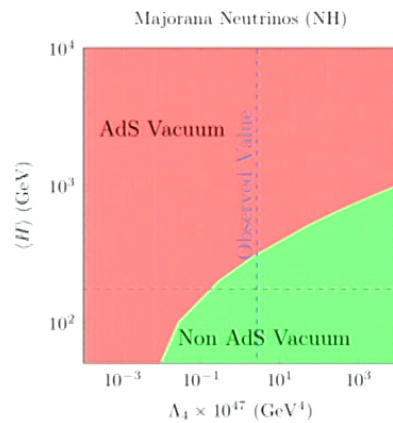
with $a(n_f) = 0.184(0.009)$ for Majorana (Dirac)
 $b(n_f, m_i) = 5.72(0.29)$

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

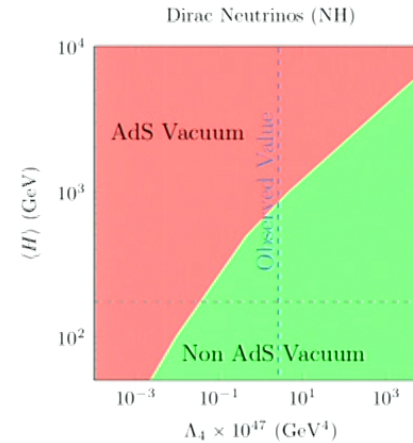
Upper bound on the EW scale

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

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



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



$Y = 10^{-14}$

Parameters leading to a higher EW scale do not yield theories consistent with quantum gravity



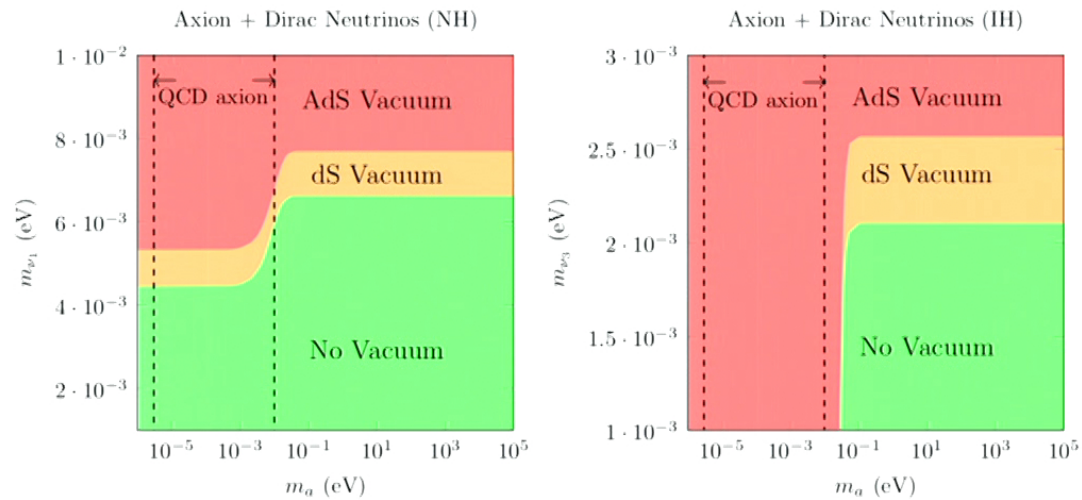
No EW hierarchy problem

Adding BSM physics

▶ Axions

1 axion: negative contribution \longrightarrow bounds get stronger

☹ IH Dirac neutrinos are ruled out in the presence of QCD axion



Multiple axions: can destabilise AdS vacuum \longrightarrow bounds disappear

Other SM compactifications

👤 Circle compactification on S^1 ✓ [Ibanez, Martin-Lozano, IV'17]

👤 Toroidal compactifications on T^2 → qualitatively similar,
but a bit stronger bounds
[Ibanez, Martin-Lozano, IV'17]

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There are not new minima (no new bounds) arising at smaller radius when adding the rest of SM particles

... but there can be runaways due to Wilson lines
[Hamada-Shiu'17]

👤 Orbifold compactifications on S^1/Z_2 and T^2/Z_4 (no Wilson lines)
[Gonzalo, Herrera, Ibanez'18]

→ Same bounds on neutrino masses

→ New minima that cannot be avoided unless SM is completed with more bosons, like **MSSM**
(but MSSM at a multi-TeV region at least)

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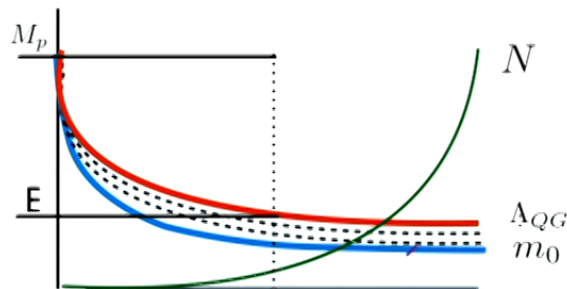
Naturalness and Swampland

👤 Space of parameters is smaller than expected, not everything goes!

➔ Provide IR rules to identify non-trivial correlations among parameters of the EFT

👤 Emergence from integrating out large number of states [Grimm, Palti, IV'18]
[Heidenreich, Reece, Rudelius'18]

Swampland conjectures imply the presence of new light states (and a drop-off of the quantum gravity cut-off) whenever we try to recover a global symmetry



N = number of species becoming light
(below Λ_{QG})

$$\Lambda_{QG} = \frac{M_p}{\sqrt{N}}$$

➔ global symmetry limit = (infinitely many massless species)
 e.g. $g \rightarrow 0$

Summary

👤 String Landscape vs Swampland

Not every EFT can be UV embedded in String Theory

↪ Quantum Gravity Constraints

👤 Consistency with quantum gravity implies constraints on low energy physics:

Conjecture: Non-susy stable AdS vacua are inconsistent with QG

↪ Low energy constraints on SM and BSM light spectra



Upper bound on the EW scale in terms of the cosmological const.

New approach to hierarchy problems? UV/IR mixing?

Assumptions:

- Conjecture holds (motivated from WGC if there are fluxes in extra dimensions)
- No additional 3d non-perturbative instabilities transferred from higher dimensions