Constraints on the SM Higgs from the WGC

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Based on: E. Gonzalo, L.E. Ibáñez [1806.09647]
E. Gonzalo, A. Herráez, L.E. Ibáñez [1803.08455]

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Motivation

- We have a poor understanding of the origin of the fundamental mass scales in the SM.
- Three separate regions: deep IR, QCD-EW and Planck scale plus unification/string scale.
- No fundamental need for a Higgs: not part of the families and not required by gauge theories.
- Why is the Higgs vev so small and not affected by quantum corrections?
- Why precisely three families?
- Neutrino masses are very close to the cosmological constant $\Lambda_4^{1/4} = 2.25$ meV.

Swampland and WGC

- Swampland: Set of effective field theories that do not admit a string theory UV completion. [1]
- Swampland criteria like WGC: Gravity is always the weakest force. [2]
- Sharpening of WGC by OV: There cannot be stable non-SUSY AdS vacua in quantum gravity. [3]

[1] C. Vafa '05
[2] N. Arkani-Hamed, L. Motl, A. Nicolis and C. Vafa '06
[3] H. Ooguri, C. Vafa '17

AdS-phobia and the SM

- Adding background independence we arrive at AdS-phobia:

> A theory such that any of its compactifications has a stable AdS, non susy vacuum is in the swampland.

- The compactification of the SM to 2D, 3D had been done for different reasons [4], [5].
- An AdS vacua around the neutrino scale was found.
- Consistency with the OV conjecture implies
  1. Majorana neutrinos are ruled out.
  2. An upper bound on the masses of Dirac neutrinos.

[4] N. Arkani-Hamed, S. Dubovsky, A. Nicolis and G. Villadoro '07
[5] J.M. Arnold, B. Formal and M. B. Wise '10

AdS-phobia and the SM

- Thorough analysis of these compactifications was carried out last year [6],[7] and [8].
- Essentially the same results for S^1 and T^2 but to ensure stability need to get rid of WLs with orbifolds. See Alvaro's talk for more on this.
- Interesting hints towards BSM physics were found.
- Neutrino bounds were related to cosmological constant and EW hierarchy: $\langle H \rangle \lesssim \Lambda_4^{1/4}/Y_{\nu_i}$.

[6] L.E. Ibáñez, V. Martin-Lozano and I. Valenzuela '17
[7] Y. Hamada and G. Shiu '17
[8] E. Gonzalo, A. Herráez and L. Ibañez '18

Casimir Potential

- Need to compute the one loop effective action from the SM model compactified action.
- The result, after fixing the WLs to zero and the Higgs at its vev is a potential depending on one scalar field.
- $V[R] = \frac{1}{R^2}\left[2\pi\Lambda_4\right] + \sum_p V_p$, with $V_p = (-1)^{2s_p+1} n_p V_{\mathcal{C}}\left[R, m_p, \theta\right]$.
- $V_{\mathcal{C}}\left[R, 0, 0\right] = \frac{1}{720\pi R^6}$, but $V_{\mathcal{C}} \propto e^{-m_p R}$ if massive.

The SM without a Higgs is in the Swampland

- (Approximate) $U(2n_g)_L \times U(2n_g)_R$ accidental global symmetry in the quark sector.
- Spontaneously broken by the QCD condensate of the quarks generating a total of $4n_g^2$ massless Goldstone bosons.
- Charged ones have a small EW mass $m_{ij}^2 \simeq (\alpha_{\rm em}/4\pi)\Lambda_{\rm QCD}^2$.
- One becomes massive because of QCD anomaly and three are eaten by $W^\pm$ and Z bosons: $M_W = \sqrt{n_g}\frac{gf_\pi}{2}$, $M_Z = m_W/\cos\theta_{\rm W}$.
- Compute $\Lambda_{\rm QCD}$ using the one-loop beta function.
- $(N_F - N_B)^{<\Lambda_{\rm QCD}} \;=\; 4n_g(2-n_g)$
- $(N_F - N_B)^{>\Lambda_{\rm QCD}} \;=\; 32n_g \;-\; 24-2.$

The SM without a Higgs is in the Swampland

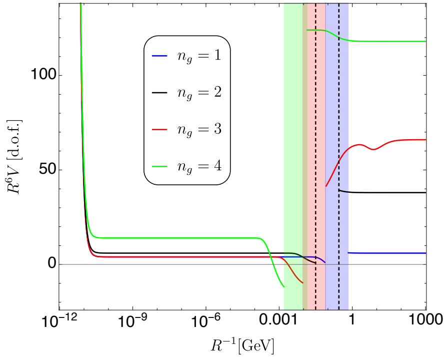
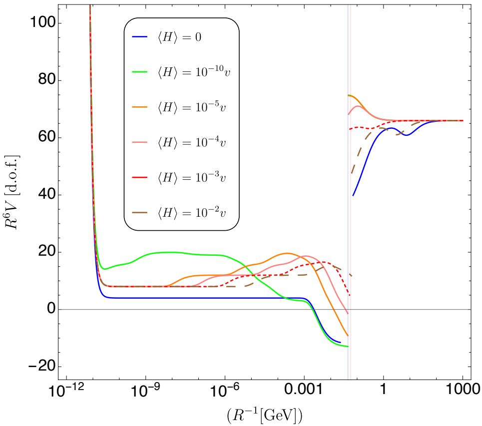


Figure: Effective radion potential for different numbers of quark/lepton generations n_g. Higgs is needed for 3 or more generations!!

Higgs lower bound

- Leptons are massive $m_l = Y_l \langle H \rangle$.
- Goldstone bosons are given mass: $m_{ij}^2 \simeq (\alpha_{\text{em}}/4\pi)\Lambda_{\text{QCD}}^2 + Y_q \langle H \rangle \Lambda_{\text{QCD}}$.
- As the Goldstones get more massive their contribution moves to the right.
- Eventually their contribution is delayed beyond Λ_{QCD} so the AdS does not develop.

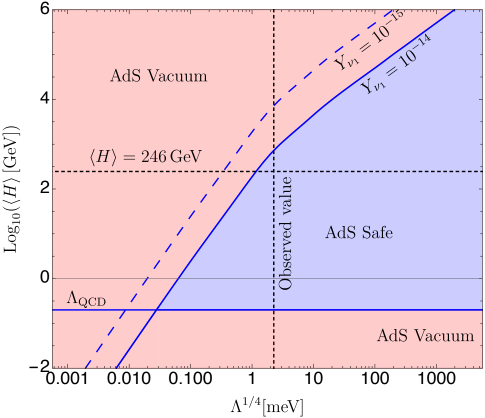
Higgs lower bound



$$\boxed{\langle H\rangle \geq \Lambda_{\mathrm{QCD}}}$$

Figure: Effective radion potential for different values of the Higgs vev $\langle H\rangle$ in units of the SM value $v = 246$ GeV. The Yukawa couplings are fixed at their SM values. For Higgs vevs larger than $10^{-3}v \simeq \Lambda_{\mathrm{QCD}}$ the AdS vacua ceases to develop.

Combined bounds on Higgs vev



$$\boxed{\frac{\langle \Delta H^0 \rangle}{\langle H^0 \rangle} \leq \frac{(a\Lambda_4^{1/4} - m_{\nu_i})}{m_{\nu_i}}}$$

Figure: Constraints on the Higgs vev as a function of the c.c. scale $\Lambda^{1/4}$ for fixed neutrino Yukawa couplings.

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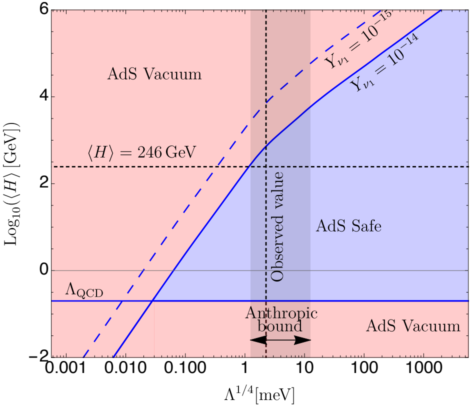

Figure: Constraints on the Higgs vev as a function of the c.c. scale $\Lambda^{1/4}$ for fixed neutrino Yukawa couplings.

Conclusions

- Reassess the hierarchy problem $\boxed{\frac{\langle \Delta H^0 \rangle}{\langle H^0 \rangle} \leq \frac{(a\Lambda_4^{1/4} - m_{\nu_i})}{m_{\nu_i}}}$.
- Majorana neutrinos ruled out and upper bound on Dirac neutrino masses.
- There must be a non-zero cosmological constant.
- A Higgs with non-vanishing vev and Yukawa couplings must exist.
- There is an upper and a lower bound on the Higgs vev that forces the QCD and EW scales must be relatively near.
- Higgs is related to having three or more generations.

Outlook

- Important to find additional evidence for the *sharpened* Weak Gravity Conjecture of OV.
- If there is an additional source of instability the constraints and predictions disappear.
- Interesting to explore the possible constraints on axions, sterile neutrinos or dilatons in detail.
- Explore why the WGC is relating these scales and forbidding the Higgs vev to be affected by quantum corrections.