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]
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: 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
[3] H. Ooguri, C. Vafa ’17
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.

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: $\langle H \rangle \lesssim \Lambda_4^{1/4} / Y_{\nu_i}$.

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.

\[ V[R] = \frac{1}{R^2} \left[ 2\pi \Lambda_4 \right] + \sum_p V_p, \text{ with } V_p = (-1)^{2s_p+1} n_p V_C[R, m_p, \theta]. \]

\[ V_C[R, 0, 0] = \frac{1}{720\pi R^6}, \text{ but } V_C \propto e^{-m_p R} \text{ if massive.} \]
A world with no Higgs

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 $m_{ij}^2 \sim (\alpha_{\text{em}}/4\pi)\Lambda_{\text{QCD}}^2$.

- One becomes massive because of QCD anomaly and three are eaten by $W^\pm$ and $Z$ bosons: $M_W = \sqrt{n_g} g f / 2$, $M_Z = m_W / \cos \theta_W$.

- Compute $\Lambda_{\text{QCD}}$ using the one-loop beta function.

- $(N_F - N_B)^{<\Lambda_{\text{QCD}}} = 4n_g (2 - n_g)$

- $(N_F - N_B)^{>\Lambda_{\text{QCD}}} = 32n_g - 24 - 2$. 
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!!
Leptons are massive \( m_l = Y_l \langle H \rangle \).

Goldstone bosons are given mass:
\[
m^2_{ij} \simeq (\alpha_{\text{em}}/4\pi)\Lambda_{\text{QCD}}^2 + Y_q \langle H \rangle \Lambda_{\text{QCD}}.
\]

As the Goldstones get more massive their contribution moves to the right.

Eventually their contribution is delayed beyond \( \Lambda_{\text{QCD}} \) so the AdS does not develop.
Higgs lower bound

\[ \langle H \rangle \geq \Lambda_{\text{QCD}} \]

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

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

Figure: Constraints on the Higgs vev as a function of the c.c. scale \( \Lambda^{1/4} \) for fixed neutrino Yukawa couplings.
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
  \[
  \frac{\langle \Delta H^0 \rangle}{\langle H^0 \rangle} \leq \frac{(a\Lambda_4^{1/4} - m_{\nu_i})}{m_{\nu_i}}.
  \]

- 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.
Conclusions

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.