A Strong Scalar Weak Gravity Conjecture and Some Implications

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Based on: E. Gonzalo, L.E. Ibáñez [1903.08878]

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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]
- The most widely studied example is U(1) gauge boson coupled to gravity.

> There must always exist a charged particle with mass m and charge q such that $m \leq gqM_{\rm p}$

- Generalized to several U(1)'s and antisymmetric tensor couplings.

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

Approaches to WGC

- Which is the physical origin?:
  1. Something primarily related to black-holes and their stability.
  2. General principle of gravity being the weakest force.
- Potentially there many physical instances in which interactions weaker than gravity, consider ϕHH.
- Palti's Scalar Weak Gravity Conjecture says that: $(\partial_\phi m)^2 \geq \frac{m^2}{M_p^2}$

[3] Palti '17. The Weak Gravity Conjecture and Scalar Fields.

Strong Scalar Weak Gravity Conjecture

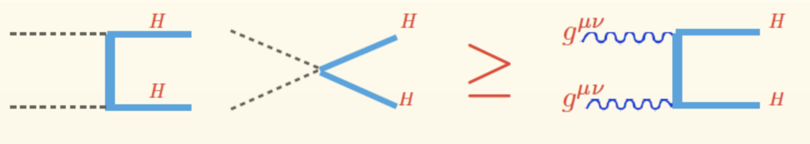
- We search for a generalization that applies to any scalar in the theory.
- Palti's conjecture would be inconsistent with periodic potentials (axions in String Theory) $\rightarrow$ add quartic term.

> The potential of any canonically normalized real scalar, $V(\phi)$, must verify for any value of the field the constraint:
> $$2\,(V''')^2 - V''V'''' \geq \frac{(V'')^2}{M_p^2}$$

[4] E. Gonzalo and L. Ibañez '19

Strong Scalar WGC

- Factor of 2 motivated by the exchange diagram in $\phi HH + \phi\phi HH$ theory.



$$2\,(V''')^2 - V''V'''' \geq \frac{(V'')^2}{M_p^2}$$

Motivation

- I will not go more into the reasoning for the precise factors in the constraint.
- Some interesting implications are obtained only for this choice.
- There is a work in progress towards a better understanding of the physical origin.
- In this future work we re-write the constraint in a way that it's easy to generalize to multiple scalar fields.

$$2\,(V''')^2 - V''V'''' \geq \frac{(V'')^2}{M_p^2}$$

First checks

- $V = -\cos(\phi/f)) \longrightarrow f^2 \leq M_{\rm p}^2(1+2\tan^2(\phi/M_{\rm p}))$.
- $V(\phi) = \frac{1}{2}m^2\phi^2 + \frac{1}{4}\lambda\phi^4$
  $\lambda(\frac{3\lambda}{2}\phi^2 - m^2) \geq \frac{1}{M_p^2}(m^2 + \frac{\lambda}{2}\phi^2)^2$
- For $\phi^2 \ll M_p^2$ the constraint amounts to the left hand side being positive.
- Automatic for $m^2 < 0$ and λ positive, as in the SM. For values of ϕ close to the Planck mass the Higgs potential requires an UV completion.
- For $m^2 > 0$ the constraint is only obeyed for $\phi^2 > (2/3)m^2$.

Inflation: ϕ^a

- For $0 \leq a < 1$ the potential has only tiny violations of the bound at small ϕ.
- For $a > 2$ the violations are large but are trans-Planckian for $a > 2.7$.
- For $1 < a \leq 2$ the bound is irremediably violated at all points of field space. By itself a massive field is inconsistent with quantum gravity.
- $a = 0$ and $a = 1$ are the only pure monomials which satisfy the bound at all points of field space.
- Among chaotic inflation models the linear potential is singled out as the unique class which can lead to sufficient inflation.
- Linear potentials may yield 50-60 e-folds and tensor perturbations with $r \simeq 0.07$.

Inflation

- $V(b) = A(1 + B\, b^2)^{1/2}$ and $V = \left(1 - e^{-\sqrt{2/3}\phi/M_p}\right)^2$
- We define $\chi \equiv 2\,(V''')^2 - V''''V'' - \left(\frac{V''}{M_p}\right)^2$

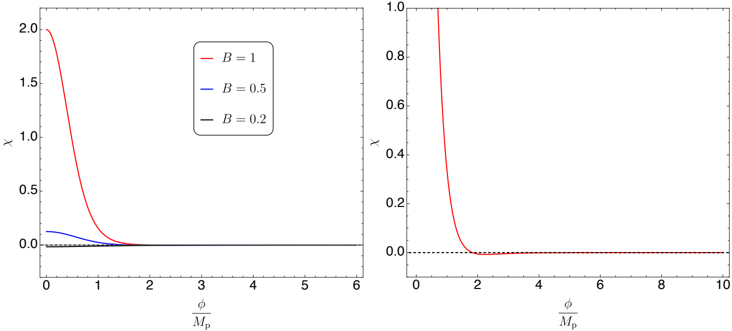


Figure: a) The value of χ for $A = 1$ and $B = 0.2, 0.5, 1.0$. The SSWGC implies $\chi \geq 0$. b) The value of χ for the Starobinsky potential. They require modifications at large trans-Planckian distances.

Neutrino bounds

- Consider the SM compactified in a circle of radius R down to 3D, canonical kinetic term given by $R = re^{\frac{\phi}{M_p^{3d}\sqrt{2}}}$.
- Well below the electron threshold, 3D one-loop effective potential for R is given by:

$$V(R) = \frac{2\pi r^3 \Lambda_4}{R^2} - 4\left(\frac{r^3}{720\pi R^6}\right) + \sum_{\nu_e,\nu_\mu,\nu_\tau} r^3 V_{\mathcal{C}}\left[R, m_{\nu_i}\right]$$

$$V_{\mathcal{C}}\left[R, m_{\nu_i}\right] = \frac{n_{\nu_i}\ m_{\nu_i}^2}{8\pi^4 R^4} \sum_{n=1}^{\infty} \frac{K_2(2\pi m_{\nu_i} n R)}{n^2}.$$

Neutrino Bounds

- Unless the lightest Dirac neutrino is sufficiently light for some value of R the scalar interaction becomes weaker than gravitation.

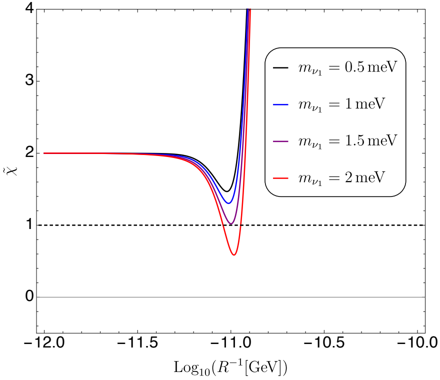


Figure: $\frac{\tilde{\chi}}{M_{\mathbf{p}}^{\mathbf{2}}} \equiv 2\left(\frac{V'''}{V''}\right)^2 - \frac{V''''}{V''}$. NH neutrino lighter than 1.5×10^{-3} eV.

Neutrino Bounds

- Similar constraints were obtained using another Swampland Conjecture:

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

- We can combine this bound with the results in [5] to conclude that, if both conjectures are true, then neutrinos must have a Dirac mass term with normal hierarchy.
- Normal hierarchy is therefore another non-trivial prediction that arises from the conjecture.

[5] E. Gonzalo, A. Herráez and L. Ibañez '18

Moduli fixing in String Vacua

- KKLT $W = W_0 + ce^{2\pi a T}$

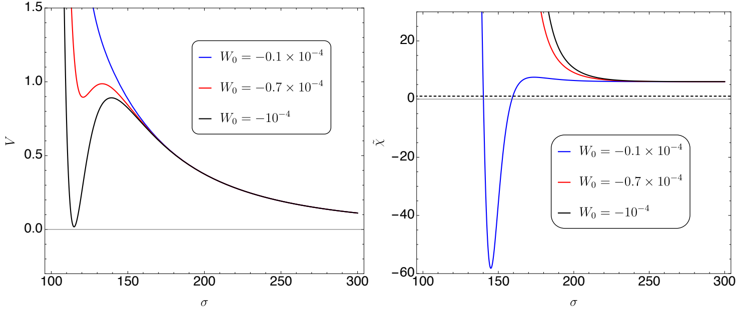


Figure: As long as W_0 is large enough to generate a minimum the bound is verified. We obtain constraints on the parameters of the model.

Conclusions

- We have proposed a new Swampland conjecture which is very predictive.
- It is a generalization of the Weak Gravity Conjecture for scalar fields that works for axions.
- Linear potentials are singled out so the conjecture points towards tensor perturbations with $r \simeq 0.07$.
- There is an upper bound on the mass of the lightest Dirac neutrino.
- Combined with an extra Swampland criteria it rules out inverse hierarchy and pure Majorana masses.

Outlook

- Further efforts should be made to understand its physical origin as coming from a "Gravity as the Weakest Force" condition.
- Diagrammatic interpretation needs to be better understood.
- What would actually go wrong? Is there an analogy with Black-Hole instability?
- Generalization to more complex situations. The case with multiple scalar fields is being worked out at present.