

# A Strong Scalar Weak Gravity Conjecture and Some Implications

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



# 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  $m \leq gqM_p$

- 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  $\phi HH$ .
- 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.
- It needs to be consistent with periodic potentials (axions in String Theory)  $\rightarrow$  add quartic term.

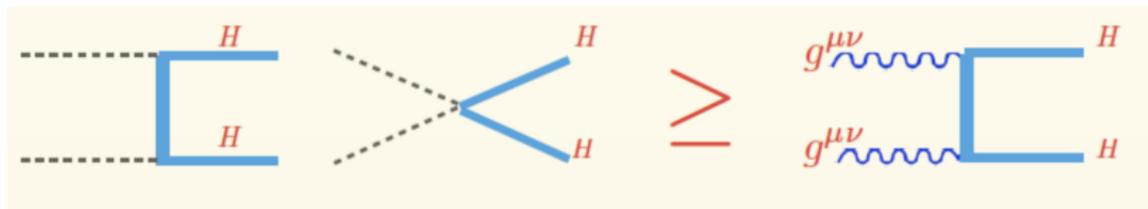
The potential of any canonically normalized real scalar,  $V(\phi)$ , must verify for any value of the field the constraint:

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

[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 (MORE ON IBAÑEZ TALK).
- 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

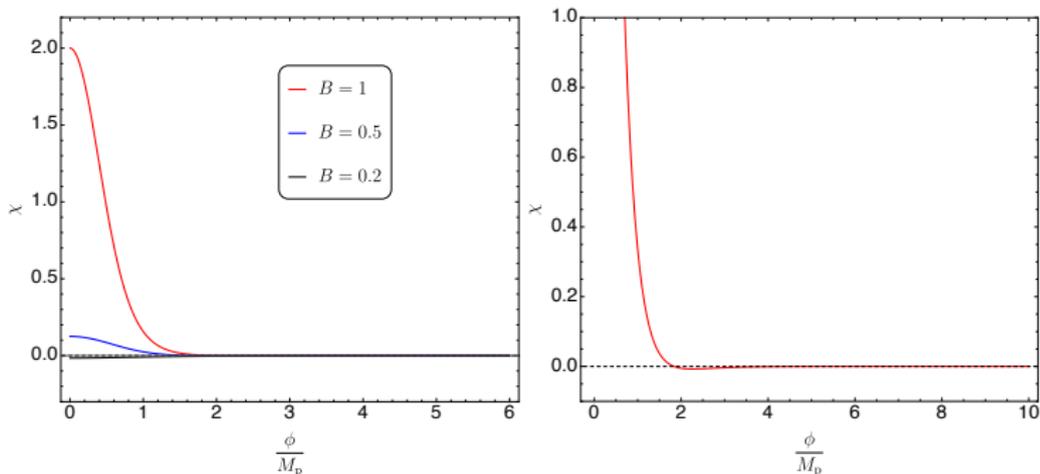
- $V = -\cos(\phi/f) \rightarrow f^2 \leq M_p^2(1 + 2 \tan^2(\phi/M_p)).$
- $V(\phi) = \frac{1}{2}m^2\phi^2 + \frac{1}{4}\lambda\phi^4$   
 $\lambda(\frac{3\lambda}{2}\phi^2 - m^2) \geq \frac{1}{M_p^2}(m^2 + \frac{\lambda}{2}\phi^2)^2$
- For  $\phi^2 \ll M_p^2$  the constraint amounts to the left hand side being positive.
- Automatic for  $m^2 < 0$  and  $\lambda$  positive, as in the SM. For values of  $\phi$  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:  $\phi^a$ 

- For  $0 \leq a < 1$  the potential has only tiny violations of the bound at small  $\phi$ .
- 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  $\chi$  for  $A = 1$  and  $B = 0.2, 0.5, 1.0$ . The SSWGC implies  $\chi \geq 0$ . b) The value of  $\chi$  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  $R = r e^{\frac{\phi}{M_{\text{p}}^{3d} \sqrt{2}}}$ .
- Well below the electron threshold, 3D one-loop effective potential for  $R$  is given by:

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

$$V_C [R, m_{\nu_i}] = \frac{n_{\nu_i} m_{\nu_i}^2}{8\pi^4 R^4} \sum_{n=1}^{\infty} \frac{K_2(2\pi m_{\nu_i} nR)}{n^2}.$$

# Neutrino Bounds

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

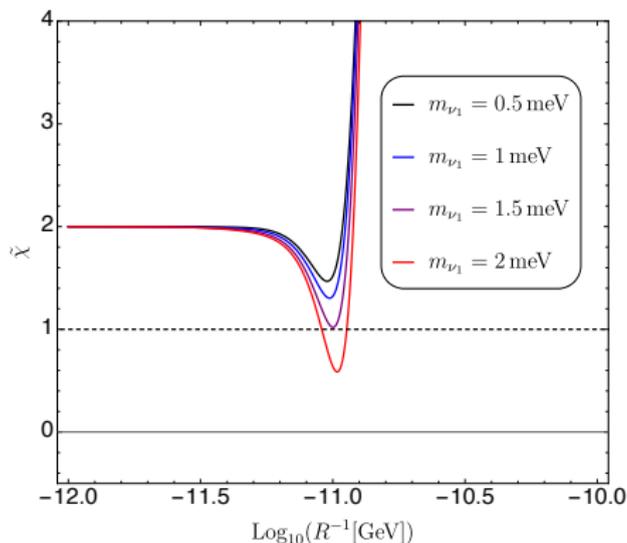


Figure:  $\frac{\tilde{\chi}}{M_{\text{P}}^2} \equiv 2 \left( \frac{V''''}{V''} \right)^2 - \frac{V'''''}{V''}$ . NH neutrino lighter than  $1.5 \times 10^{-3}$  eV.

# Neutrino Bounds

- Similar constraints were obtained using another Swampland Conjecture:

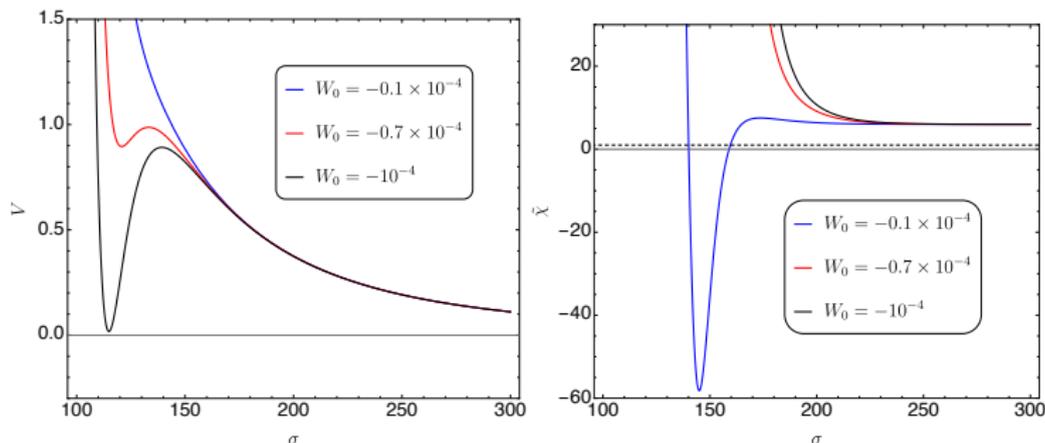
A theory such that any of its compactifications has a stable AdS, non susy vacuum is in the swampland.

- 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  $W = W_0 + ce^{2\pi aT}$



**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.