Constraints on SM from AdS conjectures

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Strings 2021

Based on work with: **L. Ibáñez and I. Valenzuela.**

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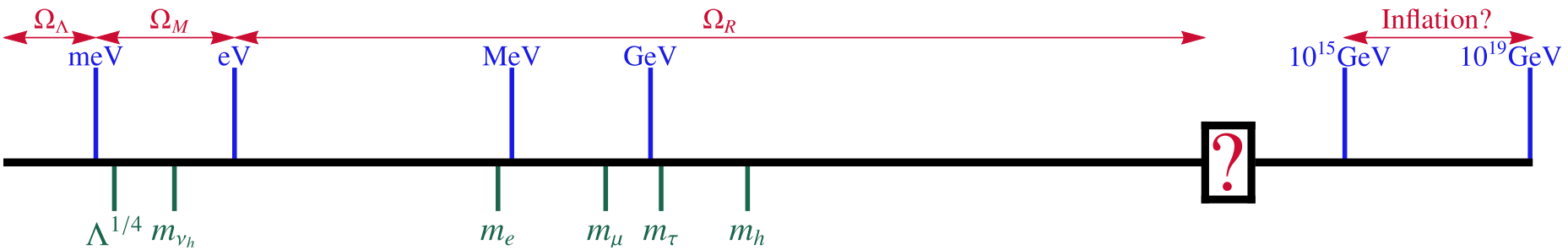
Dirac vs Majorana

- Why do the scale of neutrino masses and dark energy coincide?
- Nature of neutrinos?
  1. Dirac neutrinos (12 light d.o.f.)
  2. Majorana neutrinos (6-12 light d.o.f depending on how large M is)

$$\mathcal{L}_M = -\frac{m_A^D}{2}(\overline{N_R^A}\nu_L^A + \overline{\nu_L^c}N_R^c) - \frac{M_{AB}}{2}\overline{N_{RA}^c}N_{RB} + h.c.$$

- We will see that See-Saw scenarios $M \gg m_D$ lead to inconsistencies with several Swampland Conjectures.



- SM and its circle compactification should be in the landscape.

$$g_{\mu\nu} = \begin{bmatrix} \frac{r^2}{R^2} g_{ij} & 0 \\ 0 & (R/r)^2 \end{bmatrix}$$

- Check Swampland conjectures (through the effective potential) in the deep IR.

$$\Gamma(R) = \int d^3x \sqrt{-g_3} \left[2\pi r \frac{\partial^i R \partial_i R}{\left(R/M_p^{4d}\right)^2} - 2\pi r \left(\frac{r}{R}\right)^2 \rho_{\Lambda_{4d}} - V_{1\mathrm{L}}(R) \right]$$

$$V_{1\mathrm{L}}(R) = -\frac{n_b r^3}{720\pi R^6} + \sum_{i=1}^{3} n_\nu \frac{r^3 m_{\nu_i}^2}{4\pi^3 R^4} \sum_{n=1}^{\infty} \frac{K_2(2\pi n R m_{\nu_i})}{n^2}$$

AdS Instability Conjecture

Non-susy (AdS) Instability Conjecture [1]

Any non-supersymmetric (AdS) vacuum is metastable at best.

- Radion effective potential has 3d AdS vacua.
- Avoided only if neutrinos are (Pseudo-)Dirac with $m_{\nu_l} \lesssim \Lambda_{4d}^{1/4}$ [1-4].
- Need to assume they are stable and this requires UV information.
- Idea: check other swampland conjectures which require only IR information.

[1] H. Ooguri and C. Vafa '16
[2] L. Ibáñez,V. Martin-Lozano, I. Valenzuela '17
[3] G. Shiu, Y.Hamada '18
[4] E.G., A. Herráez and L. Ibáñez '18

AdS Distance Conjecture

AdS Distance Conjecture [5]

As $\Lambda_D \to 0$ a tower $m_n^{(D)} \sim |\Lambda_D|^{\alpha_D} M_D^{1-2\alpha_D}$ becomes light, where α_D to be a positive constant.

- Radion effective potential vacua depend on m_ν.
- According to the conjecture, if in a certain direction of field space (i.e Higgs field, Yukawa) $\Lambda_3 \to 0$, then some tower of states $m \sim |\Lambda_3|^\alpha = |V_0|^\alpha$ also become light.

[5] D. Lust, E. Palti and C. Vafa '19

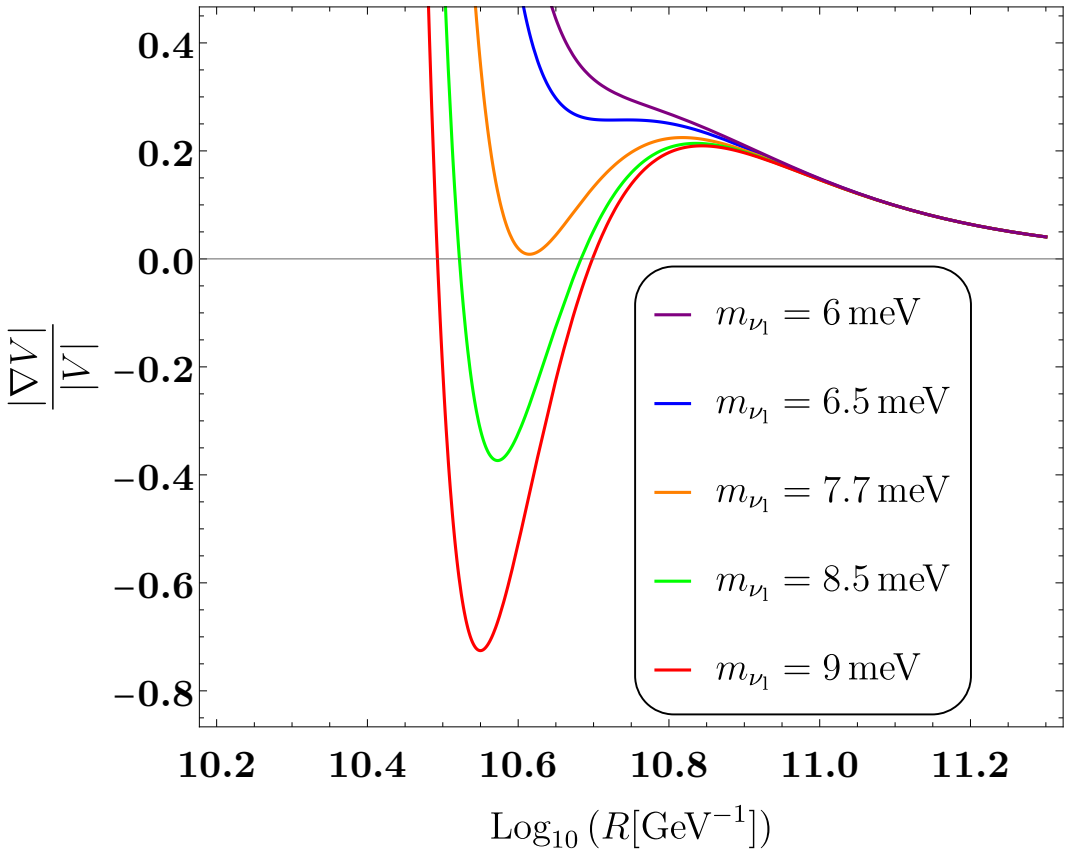


Figure: NH Dirac. If we change the mass of the neutrinos the vacuum smoothly goes from AdS to dS. When $\Lambda_{3d} \to 0$ a tower of states should become massless at a **finite** value of R.

Other scannings

- Festina Lente [6,7]: $\left(\frac{g^2 q^2 M_p^2 \Lambda}{3\Omega_\Lambda}\right)^{1/4} < m$ for every charged particle in the spectrum so that large charge black holes evaporate back to empty dS space.
- If $m_\nu, m_e \propto \lambda$ then Λ should also change if we scan along the Higgs.
- FL requires $\Lambda \propto \lambda^\alpha$ with $\alpha > 4$.
- To also preserve $m_\nu \lesssim (\Lambda_{4d} M_p^2)^{\frac{1}{4}}$ the only scanning that is in agreement with Non AdS, AdC and Festina Lente is $\alpha = 4$.

[6] M. Montero, T. Van Riet and G. Venken '19
[7] M. Montero, C. Vafa, T. Van Riet and G. Venken '21

Results

1. For NH Dirac (Non AdS,AdC) require $M < 0.069$ eV. Planck '18: $M < 0.12$ eV and could be lowered to our bound in the next ~ 20 years.

2. The simplest See-Saw explanation of why active neutrinos are so light seems inconsistent.

3. The only consistent scanning with Non-AdS+AdC+FL seems to be with $\alpha = 4$ so perhaps (right-handed) neutrinos are part of a tower.

4. Perhaps QG provides a deeper explanation of why $m_\nu \sim \rho_{\Lambda_{4d}}^{1/4}$.