Distance Conjecture and Potentials

Eran Palti
Max-Planck-Institut für Physik, Munich

Lüst, EP, Vafa (1906.05225)

String Phenomenology 2019, CERN

String theory is a framework where the vacuum energy is calculable

It allows to study relations between the vacuum energy and other properties of the vacuum

Guided by simple vacua, attempt to relate properties of vacuum energy to general principles of string theory/quantum gravity

Difficult: No proofs, but worthwhile endeavour

Could it be that there is an infinite tower of states whose mass is related to the magnitude of the cosmological constant (minimum of potential)?

$$|\Lambda| \to 0 \quad \Rightarrow m \to 0 \ \ ??$$

Any string theory potential sources vanish in the decompactification limit

$$\mathrm{Vol}\left(\mathrm{Y_p}\right) \to \infty \ \Rightarrow \begin{cases} |\Lambda| \to 0 \\ m \to 0 \end{cases}$$

General arguments?

The Swampland Distance Conjecture states that given scalar fields (with no potential) with kinetic terms

$$\mathcal{L}_{kin} = -p_{ij}\partial\phi^i\partial\phi^j$$

One can associate a distance in field space to a path with parameter τ

$$\Delta = \int_{\tau_i}^{\tau_f} \left(p_{ij} \frac{\partial\phi^i}{\partial\tau}\frac{\partial\phi^j}{\partial\tau} \right)^{\frac{1}{2}} d\tau$$

The conjecture states that for $\Delta \gg 1$, there is an **infinite tower of states** with mass m which behaves as

$$m(\tau_f) \sim m(\tau_i)e^{-\alpha\Delta}, \qquad \alpha > 0, \alpha \sim \mathcal{O}(1)$$

[Ooguri, Vafa '06]

Appears to also apply to fields with potentials (?) [Baume, EP '16; Klaewer, EP '16;]

Axions most subtle [Silverstein, Westphal '08; ...
Burrati, Calderon, Uranga '18; Hebecker, Junghans, Schancher '18]

de Sitter space associates an entropy to the cosmological constant

$$S \sim \Lambda^{-1} \sim Log\,\dim H$$

[Gibbons, Hawking ’77]

[Banks ’00; Witten ‘01]

Entropy of single field (microstates not forming BHs) only goes as

$$S \sim \Lambda^{-\frac{3}{4}}$$

[Page ’81; Banks ‘05]

Suggests an infinite number of light fields as $\Lambda \to 0$

Identification with tower of distance conjecture for any potential with apparent horizon leads to refined de Sitter conjecture

$$\left|\underline{\nabla} V\right| \geq \frac{c}{M_p} V \qquad \textbf{or} \qquad \min(\nabla_i \nabla_j V) \leq -\frac{c'}{M_p^2} V$$

[Ooguri, EP, Shiu, Vafa ‘18]

IIB on Calabi-Yau, can related potential from RR flux, to gauge coupling matrix

$$C_4 = A_I \alpha^I \qquad\qquad C_6 = c_I^{(3)} \alpha^I$$

$$S = \int d^4x \left[-\frac{1}{8} Z_{AB} F_4^A \wedge \star\, F_4^B + \frac{1}{4} F_4^A q_A \right] \Rightarrow V = \frac{1}{8} Z^{AB} q_A q_B$$

[Dvali ‘05; Kaloper, Sorobo ‘08; Bandos, Bielleman, Carta, Dudas, Escobar, Farakos, Harraez, Ibanez, Lanza, Marchesano, Martucci, Montero, Staessens, Sorokin, Tenreiro, Uranga, Valenzuela, Zoccarato ’15-19]

Z_{AB} is the gauge kinetic matrix, and V is the magnitude of the gauge force between charged particles

Weak Gravity Conjecture, cannot send force to zero $\quad V \rightarrow 0 \;\; \Longrightarrow m \rightarrow 0$

More generally, would be a Weak Gravity force statement for (d-2)-branes ?

Relation could be causal: potentials could be emergent from integrating out towers of domain walls (localised membranes) ?

[EP ‘19]

Can we associate an infinite distance to $\Lambda \to 0$ directly?

Recall origin of scalar fields in distance conjecture are higher tensors

$$\Delta = \int_{\tau_i}^{\tau_f} \left(p_{ij} \frac{\partial \phi^i}{\partial \tau} \frac{\partial \phi^j}{\partial \tau} \right)^{\frac{1}{2}} d\tau = \int_{\tau_i}^{\tau_f} \left(\frac{1}{V_M} \int_M \sqrt{g} g^{MN} g^{OP} \frac{\partial g_{MO}}{\partial \tau} \frac{\partial g_{NP}}{\partial \tau} \right)^{\frac{1}{2}} d\tau$$

Distance conjecture is a statement about variations of all fields, not just scalars

$$\mathcal{L}_{kin} = -G^{M_1 \dots M_n N_1 \dots N_n} D\mathcal{O}_{M_1 \dots M_n} D\mathcal{O}_{N_1 \dots N_n} \qquad \Delta\mathcal{O} = \int_{\tau_i}^{\tau_f} \left(\frac{1}{V_M} \int_M G \frac{\partial \mathcal{O}}{\partial \tau} \frac{\partial \mathcal{O}}{\partial \tau} \right)^{\frac{1}{2}} d\tau$$

Generalised Distance Conjecture:

For $S_d \times Y_p$, with S_d homogeneous, then in S_d Einstein frame

$$m(\tau_f) \sim m(\tau_i) e^{-\Delta\mathcal{O}}, \qquad \alpha > 0, \alpha \sim \mathcal{O}(1)$$

[Lüst, EP, Vafa ‘19]

Internal volume rescalings must be treated differently, due to Einstein frame

Take $M = S_d \times Y_{\mathrm{k}}$ $\qquad g_{mn} \to e^{2\tau} g_{mn}$ $\qquad \mathcal{L}_{kin} = -k^2 \left[\frac{d-1}{d-2} - \frac{k-1}{k}\right] (\partial\tau)^2$

Distance of Weyl rescalings goes as τ

Consider AdS space in global coordinates

$$ds^2 = e^{2\tau}[-(\cosh\rho)^2 dt^2 + d\rho^2 + (\sinh\rho)^2 d\Omega_{d-2}^2\,]$$

$$\Lambda = -\frac{1}{2}(d-1)(d-2)e^{-2\tau}$$

Distance in metric space of Weyl rescaling goes as $\Delta \sim \mathcal{O}(1)\,\tau$

Flat limit of AdS is at infinite distance

Generalised Distance Conjecture:

$$m \sim e^{-\lambda\tau} \sim |\Lambda|^{\alpha}$$

Caution: we are not sure how to implement the Einstein-frame condition…

(A)dS Distance Conjecture:

[Lüst, EP, Vafa '19]

AdS_d space in quantum gravity has infinite tower of states whose mass scale m, as $\Lambda \to 0$, behave as

$$m \sim |\Lambda|^{\alpha}$$

In string theory, any 10/11D exact solution has $\alpha = \frac{1}{2}$

Strong AdS Distance Conjecture: for supersymmetric vacua

$$m \sim |\Lambda|^{\frac{1}{2}}$$

This implies no separation of scales between the AdS radius and the mass scale of the tower (usually KK modes)

No separation of scales relates to obstruction to unbounded space-filling massless matter

[Vafa '06]

In Minkowski space the rank of the gauge group appears bounded

M-theory on $AdS_7 \times S^4/Z_k$ gives an $SU(k) \times SU(k)$ gauge group on AdS_7

Resolved by noting that there is no sense in which the space is AdS_7

This perspective suggests should have $AdS_d \times Y_p \rightarrow Mink_{d+p}$

There are no AdS_d spaces in quantum gravity, only spaces with AdS_d factors

Some arguments suggest that in general AdS (not susy) $\alpha \geq \frac{1}{2}$

Refined de Sitter conjecture **adjustment**: $\left(\underline{\nabla} V\right)^2 \geq \frac{c}{M_p} V^2$

AdS minimum then requires: $\min(\nabla_i \nabla_j V) \leq -\frac{c'}{M_p^2} V$

Bound on mass of lightest state $m \leq |\Lambda|^{\frac{1}{2}}$ [Gautason, Van Hemelryck, Van Riet '18]

Such bounds familiar from (scalar) WGC, which satisfied by towers of states

$$M_p^2 \left(\partial_\phi m\right)^2 \geq m^2 \qquad\qquad m \sim e^{-\phi}$$

On the other hand, for dS expect $\alpha \leq \frac{1}{2}$

(must be so if tower contains spin-2 or higher - Higuchi bound: $m_{spin-2} \geq \Lambda^{\frac{1}{2}}$)

Evidence for from string examples:

- No known 10/11D counter examples (many, infinite, sets of examples)
- No separation of scales ($\Longrightarrow \alpha = \frac{1}{2}$) in supergravity (require orientifolds). Require scalar gradients. [Gautason, Schillo, Van Riet '15]
- Scalar gradients not allowed for any coset manifolds - no consistent truncation to finite number of fields? [Gauntlett, Varela '07]

Evidence against from string examples:

- Strong version violated for IIA on CY (not 10D solution)
- Expect to be violated by smeared source approximations
- Both conjectures violated by KKLT (may be implicitly satisfied, by light towers controlled by complex-structure moduli)
- Some other counter-proposals

Related to a number of ongoing discussions:

CFT duals:

- $\alpha = \frac{1}{2}$ implies no parametric gap between dimension of finite and infinite number of operators.
- Proposal that strong version related to gauge symmetries rather than SUSY

[Alday, Perlmutter ‘19]

dS vacua:

- AdS Distance conjecture suggests no effective theory can have family of vacua interpolating between AdS/Mink/dS
- **If** our universe is dS , then suggests tower of states at $10^{-120\,\alpha} M_p$

Summary

- Proposed AdS Distance Conjecture:

$$m \sim |\Lambda|^{\alpha}$$

- Strong AdS Distance Conjecture for SUSY (and some arguments that even without):

$$m \sim |\Lambda|^{\frac{1}{2}}$$

- Proposed generalised distance conjecture for any field

- Flat limit of AdS (and dS) is at infinite distance, so light towers

Thank You