The web of swampland conjectures and the TCC bound

Niccolò Cribiori

TECHNISCHE UNIVERSITÄT WIEN

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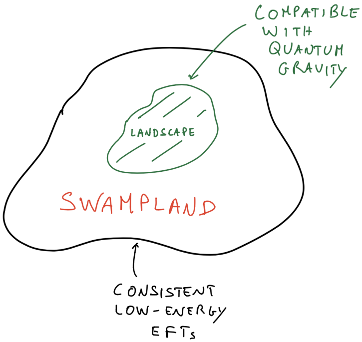
Based on 2004.00030, with D. Andriot and D. Erkinger

Introduction

The swampland program

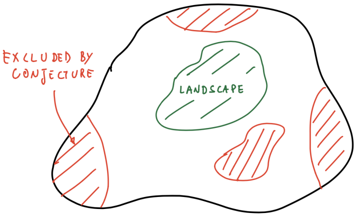
[Vafa '05; reviews: Brennan, Carta, Vafa '17; Palti '18]

- NOT everything goes in quantum gravity/string theory.
- **Swampland program**: distinguish effective theories which can be completed into quantum gravity in the UV from those which cannot



The present approach

- String theory is not completely understood.
- Try to guess general properties from (few) known examples.
- Formulate conjectures (heavily tested).



The programm: a (work in progress) list

1 no global symmetries

2 gravity is the weakest force (WGC)

3 non-susy AdS is unstable

4 no scale separation in AdS

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n-2 (no) de Sitter conjecture

n-1 transplanckian censorship conjecture

n distance conjecture

Three swampland conjectures

(no) de Sitter conjecture

[Obied, Ooguri, Spodyneiko, Vafa '18]

Conjecture:
Any scalar potential consistent with quantum gravity satisfies

$$|\nabla V| \geq \frac{c}{M_P} V, \qquad \textit{with} \quad c \sim \mathcal{O}(1) \quad \textit{and positive}$$

- No neat de Sitter vacuum from string theory (nevertheless, recall KKLT and LVS)
- No-go theorems against classical dS, under assumptions.
- No dS stationary point ($\partial V = 0$). Refined to allow for local maxima and considering asymptotic regions in [Andriot '18; Garg, Krishan '18; Ooguri, Palti, Shiu, Vafa '18; Andriot, Roupec '19; Rudelius '19].

Transplackian censorship conjecture

[Bedroya, Vafa '19]

Conjecture:
Sub-Planckian quantum fluctuations should remain quantum and never become larger than the Hubble horizon

$$\frac{a_f}{a_i} < \frac{M_P}{H_f}$$

- Motivated by a physical principle.
  (see e.g. [Dvali, Kehagias, Riotto '20] for criticism)
- When applied to a FLRW model with $V(\phi)$, gives ($M_P = 1$)

$$\left\langle \frac{|\nabla V|}{V} \right\rangle_{\Delta\phi\to\infty} = \left(\frac{1}{\Delta\phi} \int_{\phi_i}^{\phi_f} \frac{|\nabla V|}{V} \right)_{\Delta\phi\to\infty} \geq \frac{2}{\sqrt{(d-1)(d-2)}} \overset{d=4}{=} \sqrt{\frac{2}{3}}$$

Distance conjecture

[Ooguri, Vafa '06; Baume, Palti '16; Klaewer, Palti '16]

Conjecture:
As the geodesic distance between two points in field space $\Delta\phi \to \infty$*, an infinite tower of states with mass*

$$M \sim M_0 e^{-\frac{\lambda}{M_p}\Delta\phi}, \qquad \text{with} \quad \lambda \sim \mathcal{O}(1) \quad \text{and positive,}$$

become light.

- Infinite external light states would enter the EFT.
- The EFT breaks down in the asymptotic regions of field space.

Summary: three conjectures

In the asymptotic limit $\Delta\phi \to \infty$

- (no) de Sitter conjecture

$$\frac{|\nabla V|}{V} \geq c$$

- distance conjecture

$$M \sim M_0 e^{-\lambda \Delta\phi}$$

with unspecified parameters

$$c \sim \mathcal{O}(1), \qquad \lambda \sim \mathcal{O}(1).$$

Also

- transplanckian censorship conjecture

$$\left\langle \frac{|\nabla V|}{V} \right\rangle_{\Delta\phi \to \infty} \geq \sqrt{\frac{2}{3}}$$

General comments

- Conjectures suggest to look into promising directions. Helpful, since string theory is vast.
- It is believed that conjectures should be related: **web of conjectures**.
- Three directions to make progress:
  1. Test existing conjectures $\rightarrow$ **bound parameters**
  2. Relate conjectures one another $\rightarrow$ **relate the bounds**
  3. Propose new conjectures

1. Testing and bounding

Testing dS conjecture: setup

[Andriot, NC, Erkinger '20]

Framework: type II SUGRA with sources (Dp/Op) compactified on group manifolds

$$ds_{10}^2 = ds_4^2 + ds_6^2 = g_{\mu\nu}(x)dx^\mu dx^\nu + g_{mn}(y)dy^m dy^n$$

possibly corresponding to classical string backgrounds.
We considered two sets of 4d scalars = fluctuations

1. $\{\rho, \tau, \sigma\}$ [Danielsson, Shiu, Van Riet, Wrase '12; Andriot '18, '19]

$$ds_6^2 = \rho(\sigma^{p-9}(d\tilde{s}_{||})^2 + \sigma^{p-3}(d\tilde{s}_{\perp}^2)), \qquad \tau = e^{-\delta\phi}\rho^{\frac{3}{2}}$$

2. $\{r, \tau\}$ $[ds_6^2 = \delta_{ab}e^a(y)e^b(y)]$

$$e_m^1 = r\tilde{e}_m^1, \qquad e_m^{a\neq 1} = \tilde{e}_m^{a\neq 1}, \qquad \tau = e^{-\delta\phi}r^{\frac{1}{2}}$$

giving rise to two different 4d scalar potentials: $V(\rho, \tau, \sigma)$, $V(r, \tau)$.

Testing dS conjecture: procedure

- We considered linear combinations of V and ∂V. Under assumptions, we arrived at no-go theorems

$$aV + \sum_i b_i \partial_i V \leq 0 \qquad (a > 0)$$

- Once scalars are canonically normalized, the parameter c is [Andriot '19]

$$c^2 = \frac{a^2}{\sum_i b_i^2}$$

- Notice that this is off-shell.

The parameter c and the TCC bound

- We calculated 10 different values of c corresponding to 10 different no-gos. A priori, we would have expected generic order 1 numbers.

- This is **not** what we observe. Indeed, all of them satisfy the

$$\text{proposed bound:} \qquad c \geq \sqrt{\frac{2}{3}}$$

[Andriot, NC, Erkinger '20]

with several cases of saturation.

- **It matches the TCC bound in $d = 4$!** Coincidence?

Testing the distance conjecture

The distance conjecture parameter λ

$$M \sim M_0 e^{-\lambda \Delta\phi}, \qquad \Delta\phi \to \infty$$

can also be calculated in well defined setups.

Logic: relate the mass to geometric quantities (taking advantage of SUSY). The procedure is state-dependent.

- BPS D-brane states: $M = Z$ [Grimm, Palti, Valenzuela '18; Joshi, Klemm '19; see also Enriquez-Rojo, Plauschinn '20]
- KK states: $M \sim \frac{1}{L_{compact}}$ [Blumenhagen, Klaewer, Schlechter, Wolf'18; Erkinger, Knapp '19]

The distance conjecture parameter λ

- We considered 19 (known) + 3 (new - KK) values of λ.

- All of them (BPS & KK) satisfy the

$$\text{proposed bound:} \qquad \lambda \geq \frac{1}{2}\sqrt{\frac{2}{3}}$$

[Andriot, NC, Erkinger '20]

with several cases of saturation.

- Proved independently with asymptotic Hodge theory for BPS states on CY_3 and related to WGC in [Gendler, Valenzuela '20]

2. Relating conjectures and bounds

Relating the bounds

- The parameters c and λ are calculated in well defined but completely different setups.

- A priory, no relation between them: λ and c might have been **generic** order 1 numbers.

- We found that in all examples analysed they obey a simple relation

$$\lambda \geq \lambda_0, \qquad c \geq c_0, \qquad 2\lambda_0 = c_0 = \sqrt{\frac{2}{3}}$$

Relating the conjectures

- M is the mass of an **external** state, not of some scalar ϕ in V.

- Do not relate M to $\partial_\phi^2 V$, rather to V itself [Ooguri, Palti, Shiu, Vafa '18; Luest, Palti, Vafa '19; Ibanez's talk at string pheno '19, Andriot, NC, Erkinger '20]

$$M \approx |V|^\alpha \approx e^{-\lambda \Delta\phi}, \qquad \Delta\phi \to \infty, \qquad \lambda = \alpha c$$

with

$$\alpha \sim \mathcal{O}(1)$$

3. Proposals

Some (speculative) proposals

- **Proposal 1**: generalized distance conjecture

$$0 < M \leq M_0 e^{-\lambda_0 \Delta\phi}, \qquad \text{for} \quad \Delta\phi \to \infty$$

As for TCC, this implies a bound

$$\left\langle \frac{\partial M}{M} \right\rangle_{\Delta\phi\to\infty} \geq \lambda_0 = \frac{1}{2}\sqrt{\frac{2}{3}}.$$

- **Proposal 2**: correspondence ($\simeq$) between conjectures

$$\frac{M}{M_i} \simeq \left|\frac{V}{V_i}\right|^{\alpha}, \qquad \alpha = \frac{1}{2},$$

with M_i, V_i constants. We **verified** that this holds in all of our examples and in particular $V = V_i e^{-c\Delta\phi}$, for $\Delta\phi \to \infty$

Conclusion

- **Motivation:** understanding general properties of quantum gravity/string theory. Conjectures are the starting point of quantitative analysis.

1. We checked the conjectures quantitatively to a non-trivial extent. We found evidence that some parameters are bounded.

2. We studied relations among conjectures

3. We proposed (generalizations of) conjectures.

- Higher dimensions? Need examples.

- Physical principle underlying (the web of) conjectures?

Thank you!