The web of swampland conjectures and the TCC bound

Niccolò Cribiori

Summer Series on String Pheno,
June 23rd, 2020

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 program: 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
   
   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*

\[ |\nabla V| \geq \frac{c}{M_P} V, \quad \text{with} \quad c \sim O(1) \quad \text{and positive} \]

- 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 \( (M_P = 1) \)

\[
\left\langle \frac{|\nabla V|}{V} \right\rangle_{\Delta \phi \to \infty} = \left( \frac{1}{\Delta \phi} \int_{\phi_i}^{\phi_f} \frac{|\nabla V|}{V} \right)_{\Delta \phi \to \infty} \geq \frac{2}{\sqrt{(d - 1)(d - 2)}} \equiv \sqrt{\frac{2}{3}}
\]
Conjecture:
As the geodesic distance between two points in field space $\Delta \phi \to \infty$, an infinite tower of states with mass

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

with $\lambda \sim O(1)$ 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
  \[ c \sim O(1), \quad \lambda \sim O(1). \]

Also
- transplanckian censorship conjecture
  \[ \left< \frac{|\nabla V|}{V} \right>_{\Delta \phi \to \infty} \geq \sqrt{\frac{2}{3}} \]
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]

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

2. \( \{r, \tau\} \)

\[ ds_6^2 = \delta_{ab}e^a(y)e^b(y) \]

\[ e_1^m = r\tilde{e}_m, \quad e_1^{a\neq1} = \tilde{e}_m^{a\neq1}, \quad \tau = e^{-\delta\phi}r^{\frac{1}{2}} \]

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 $\partial V$. Under assumptions, we arrived at no-go theorems

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

- 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 proposed bound:

  $$c \geq \sqrt{\frac{2}{3}}$$

  [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 $\lambda$

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

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**: $M \sim \frac{1}{L_{\text{compact}}}$ [Blumenhagen, Klaewer, Schlechter, Wolf'18; Erkinger, Knapp '19]
The distance conjecture parameter $\lambda$

- We considered 19 (known) + 3 (new - KK) values of $\lambda$.

- All of them (BPS & KK) satisfy the proposed bound:
  \[ \lambda \geq \frac{1}{2} \sqrt{\frac{2}{3}} \]
  
  [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 $\lambda$ are calculated in well defined but completely different setups.

• A priory, no relation between them: $\lambda$ and $c$ might have been generic order 1 numbers.

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

\[ \lambda \geq \lambda_0, \quad c \geq c_0, \quad 2\lambda_0 = c_0 = \sqrt{\frac{2}{3}} \]
Relating the conjectures

- $M$ is the mass of an external state, not of some scalar $\phi$ 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]

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

with

$$\alpha \sim \mathcal{O}(1)$$
3. Proposals
Some (speculative) proposals

- **Proposal 1**: generalized distance conjecture

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

  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

  \[ \frac{M}{M_i} \simeq \left| \frac{V}{V_i} \right|^{\alpha}, \quad \alpha = \frac{1}{2}, \]

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