Sharpening the Distance Conjecture in Diverse Dimensions

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String Pheno
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Overview

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On the Geometry of the String Landscape and the Swampland

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Today, I will focus on their “Conjecture Number 2”.

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"The Distance Conjecture"

[1] [Ooguri and Vafa, 2007]

Prerequisites

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Conjectures 0 and 1 pertain to

- Moduli space
- Metric on moduli space
- Infinite distances

Conjecture 0

Let $\mathcal{M}$ denote the moduli space of a consistent quantum gravity.

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I'll refer to these scalar fields ϕ^a as the moduli.

Metric on moduli space

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Definition

The metric on moduli space is given by $g_{ab}(\phi)$, where $g_{ab}(\phi)$ is the kinetic term of the scalar fields,

$$\frac{1}{2}g_{ab}(\phi)\partial_\mu\phi^a\partial^\mu\phi^b.$$

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Definition

We can use the metric to define a distance function d,

$$d : \mathcal{M} \times \mathcal{M} \to \mathbb{R}_{\geq 0}$$

$$d : (p_1, p_2) \mapsto \begin{array}{c}\text{length of shortest path}\\ \text{connecting } p_1 \text{ and } p_2\end{array}$$

Conjecture 1

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For any point $p_0 \in \mathcal{M}$ and any $T \in \mathbb{R}_{>0}$, there is another point $p \in \mathcal{M}$ such that

$$d(p, p_0) > T.$$

Conjecture 2

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Compared to the theory at point $p_0 \in \mathcal{M}$, the theory at a point p, with $d(p, p_0)$ sufficiently large, has a tower of exponentially light particles with

$$m \sim \exp\left(-\kappa_d \lambda d(p, p_0)\right),$$

for some $\lambda > 0$. This is the Distance Conjecture.

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Many papers[2] have been written about λ, yet there has heretofore not been a consensus on which values of λ are allowed.

[2] For example, see [Blumenhagen et al., 2018, Grimm et al., 2018, Andriot et al., 2020, Gendler and Valenzuela, 2021, Lanza et al., 2021a, Bedroya, 2020, Lanza et al., 2021b]

The Sharpened Distance Conjecture

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The Sharpened Distance Conjecture

We propose that, for a theory with *d* spacetime dimensions, the *lightest* tower in any infinite-distance limit has

$$\lambda_{\text{lightest}} \geq 1/\sqrt{d-2}.$$

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- In all of the examples we have checked, this bound has always been true.
- In naïve counterexamples, heavier towers with $\lambda < 1/\sqrt{d-2}$ are always accompanied by lighter towers satisfying our bound.
- This bound is saturated in many examples.

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- Inequality SWGC[3]

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I'll first introduce the notion of scalar charge to mass ratio vectors.

[3] [Palti, 2017, Lee et al., 2019, Andriot et al., 2020]
[4] [Calderón-Infante et al., 2021]

Scalar charge to mass ratio vectors, “ζ-vectors”

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The scalar charge μ_a of a particle with mass $m(\phi)$ is

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For a particle with mass $m(\phi)$, the scalar charge to mass ratio vector at a point in the moduli space is

$$\zeta_a := \frac{\mu_a}{m} = \frac{1}{\kappa_d} \frac{\partial}{\partial \phi^a} \log m(\phi),$$

where we have canonically normalized the moduli ϕ^a so that $g_{ab}(\phi) = \delta_{ab}$.

Scalar charge to mass ratio vectors, “ζ-vectors”

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Example

Scalar charge to mass ratio vectors, “ζ-vectors”

Example

Given a single canonically-normalized modulus ϕ and a particle with mass scaling like

$$m(\phi) \sim \exp(\kappa_d \lambda \phi),$$

then the ζ-vector is

$$\zeta_\phi = \frac{1}{\kappa_d} \frac{\partial}{\partial \phi} \log m(\phi) = \lambda.$$

Scalar Weak Gravity Conjecture (SWGC)

Inequality SWGC

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Inequality SWGC

Definition

The Inequality SWGC[a] states that there exists a particle with a ζ-vector satisfying

$$|\vec{\zeta}| \geq \lambda_{\text{min}},$$

where $|\vec{\zeta}|$ is the length of $\vec{\zeta}$.

[a] [Palti, 2017, Lee et al., 2019, Andriot et al., 2020]

Scalar Weak Gravity Conjecture (SWGC)

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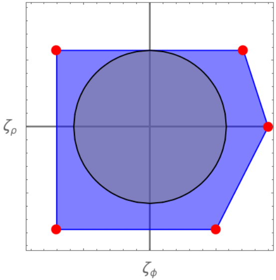
Convex Hull SWGC

Definition

The Convex Hull SWGC[a] states the convex hull generated by the set of ζ-vectors contains a ball of radius $\lambda_{\min}$ centered at the origin.



[a] [Calderón-Infante et al., 2021]

Sharpened Scalar Weak Gravity Conjecture (SWGC)

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We propose that, in a theory with d-spacetime dimensions, the λ_{min} appearing in the Inequality SWGC and Convex Hull SWGC satisfies

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Why $1/\sqrt{d-2}$?

- This bound behaves nicely under dimensional reduction.
- This bound is satisfied in all of the examples we have checked.
- This bound is saturated in examples.

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- Other rigorously tested Swampland conjectures, such as the
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  - Weak Gravity Conjecture (WGC)
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  are exactly preserved under dimensional reduction.[5]

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- The Inequality SWGC is exactly preserved under dimensional reduction when $\lambda_{\text{min}} = 1/\sqrt{d-2}$.

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  are exactly preserved under dimensional reduction.[5]
- The Inequality SWGC is exactly preserved under dimensional reduction when $\lambda_{\text{min}} = 1/\sqrt{d-2}$.
- Many examples of the Distance Conjecture and Convex Hull SWGC are exactly preserved under dimensional reduction when $\lambda_{\text{lightest}} = \lambda_{\text{min}} = 1/\sqrt{d-2}$.

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Let's reduce this on a circle to a $(d = D - 1)$-dimensional theory using $\lambda_D = 1/\sqrt{D-2}$.

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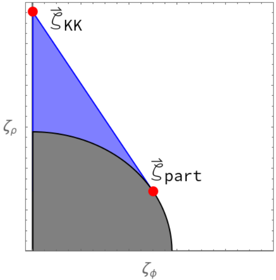

$$\vec{\zeta}^{(d)}_{\rm KK} = \begin{pmatrix} 0 \\ \sqrt{\frac{d-1}{d-2}} \end{pmatrix}, \qquad \vec{\zeta}^{(d)}_{\rm part} = \begin{pmatrix} \frac{1}{\sqrt{d-1}} \\ \frac{1}{\sqrt{(d-1)(d-2)}} \end{pmatrix}.$$

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CH SWGC and DC preservation example

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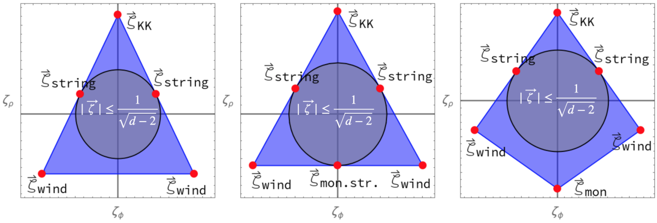
$$\vec{\zeta}^{(d)}_{\text{KK}} = \begin{pmatrix} 0 \\ \sqrt{\frac{d-1}{d-2}} \end{pmatrix} \qquad \vec{\zeta}^{(d)}_{\text{wind}} = \begin{pmatrix} \pm\frac{2}{\sqrt{d-1}} \\ -\frac{d-3}{\sqrt{(d-1)(d-2)}} \end{pmatrix}$$

$$\vec{\zeta}^{(5)}_{\text{mon.str.}} = \begin{pmatrix} 0 \\ -\frac{2}{\sqrt{4\times 3}} \end{pmatrix} \qquad \vec{\zeta}^{(4)}_{\text{mon}} = \begin{pmatrix} 0 \\ -\sqrt{\frac{3}{2}} \end{pmatrix}$$



$d > 5$ $\qquad$ $d = 5$ $\qquad$ $d = 4$

M-theory toroidal compactification

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The Distance Conjecture and Convex Hull SWGC are satisfied with $\lambda_{\text{min}} = 1/\sqrt{d-2}$.

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(dilaton) ϕ, we have

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The Distance Conjecture and Convex Hull SWGC are satisfied with $\lambda_{\text{min}} = 1/\sqrt{d-2}$. The Distance Conjecture and Convex Hull SWGC also for type I and IIB string theory.

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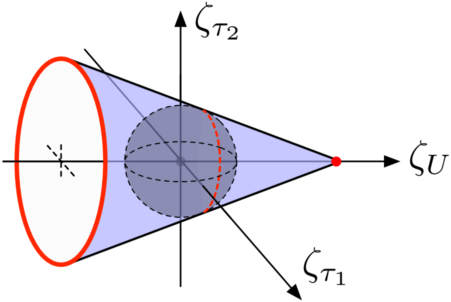
T^2

M-theory toroidal compactification

T^2



$$ds_D^2 = ||g||^{-\frac{1}{d-2}} g_{\mu\nu} dx^\mu dx^\nu + g_{mn} dy^m dy^n \qquad g_{mn} = e^U \frac{1}{\tau_2} \begin{pmatrix} 1 & \tau_1 \\ \tau_1 & |\tau|^2 \end{pmatrix}$$

$$\tau = \tau_1 + i\tau_2 \qquad m_{p,q,w}^{1/4\,\text{BPS}} = \frac{|p+\tau q|}{\sqrt{\tau_2}} e^{-\frac{9}{14}U} + |w| e^{\frac{6}{7}U} \qquad \lambda_{\text{min}}^{(d)} = 1/\sqrt{d-2}$$

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This is nontrivial!

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This is nontrivial! For T^3, T^4, T^5, T^6, T^7, there are respectively 7, 14, 25, 42, and 70 moduli, and many sources of particles. See our 22 page appendix for details.

Other Evidence

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We have found evidence in minimal supergravity in $d \in \{5, 6, 7, 8, 9\}$ dimensions.

Future work and sharpening

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We would like to extend our results to scalar fields with potentials.

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- These bounds behave nicely under dimensional reduction.
- There are many examples where these bounds are satisfied and saturated.
- We know of no examples where our proposal is violated.

The End

Thank you!

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