Brane Probes, Finiteness, and Distance Conjecture

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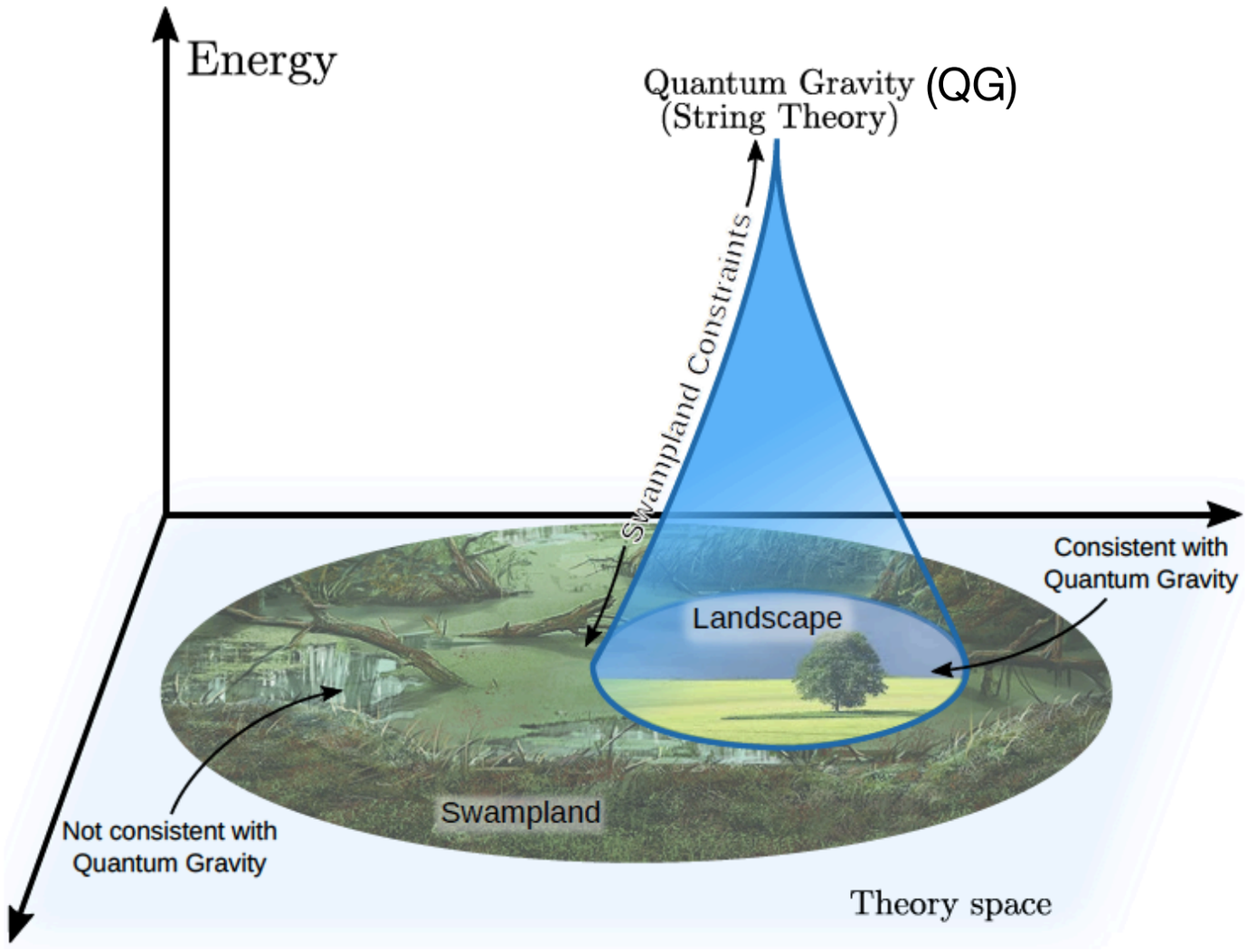
2021/11/17 KEK/FSU workshop on “New ideas in particle physics”

[Vafa ’05, Ooguri-Vafa ’06]

Landscape vs Swampland

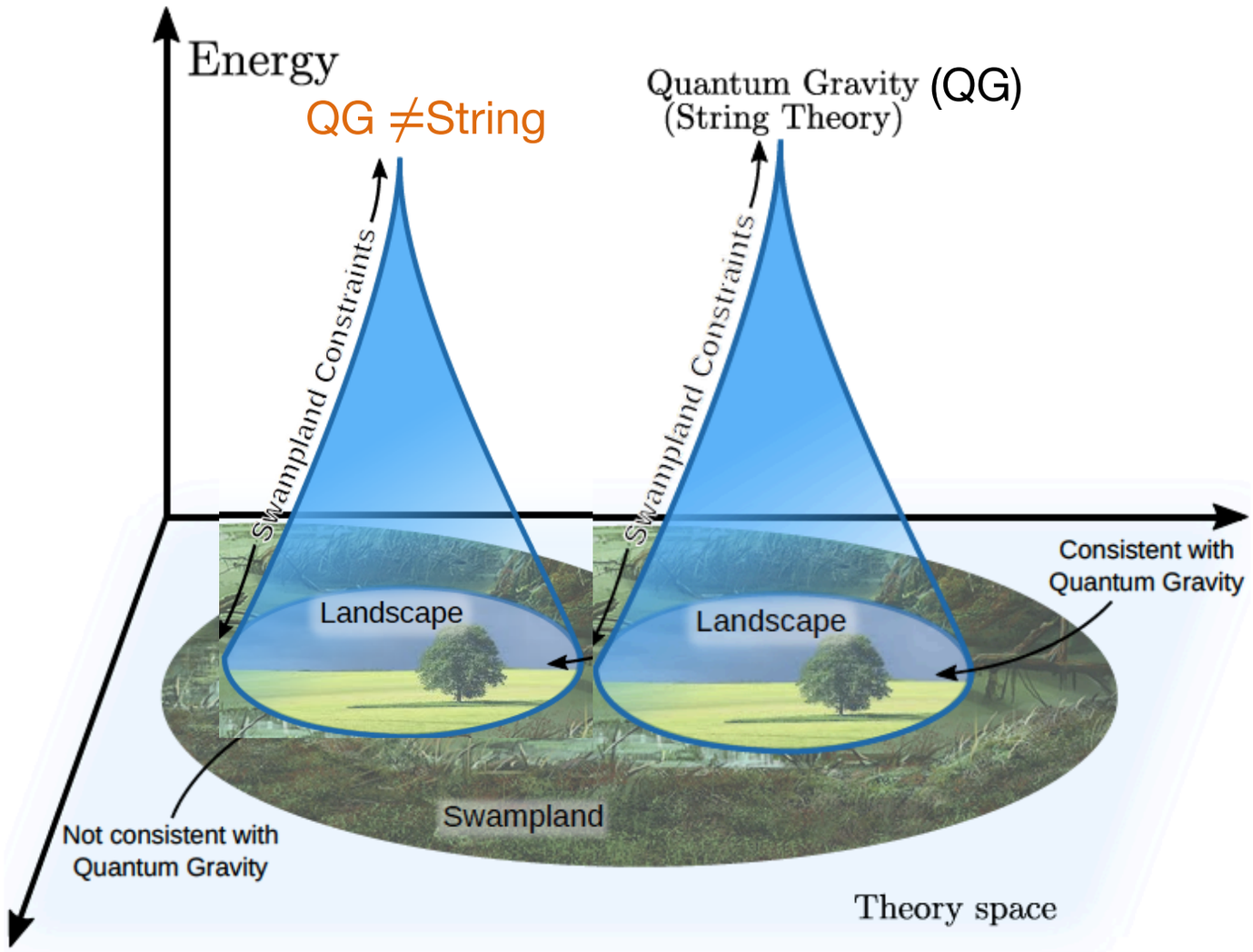


[Figure from Beest, Calderon-Infante, Mirfendereski, Valenzuela ’21]

and String Lamppost Principle

String Lappost Principle (or String Universality):

All consistent theories of QG are in the String Landscape.



[Figure from Beest, Calderon-Infante, Mirfendereski, Valenzuela ’21]

[Vafa ’05, Ooguri-Vafa ’06]

Swampland Program

Swampland program is trying to find the boundary between the Landscape and Swampland as well as establishing the String Lamppost Principle.

Talk Plan

1. Compact brane moduli
2. Finiteness and Distance Conjecture

In first part, I demonstrate the validity of the String Lamppost Principle for minimal SUSY theories in $d = 8$.

(See [Bedroya-YH-Montero-Vafa '21] for $d = 7$ and $d = 9$).

In second part, I propose a connection between the Distance Conjecture and the finiteness of QG amplitude.

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$d = 8$ SuperGravity

I will consider $d = 8$ minimal SUSY theories.

Field contents are

- Gravity multiplet $(g_{\mu\nu}, B_4, \cdots)$,
- Vector multiplet $(A_\mu, \cdots)$.

Massless spectrum is completely determined by gauge group.

No perturbative gauge anomaly.

Some constraints from global gauge anomaly.

Landscape vs Swampland

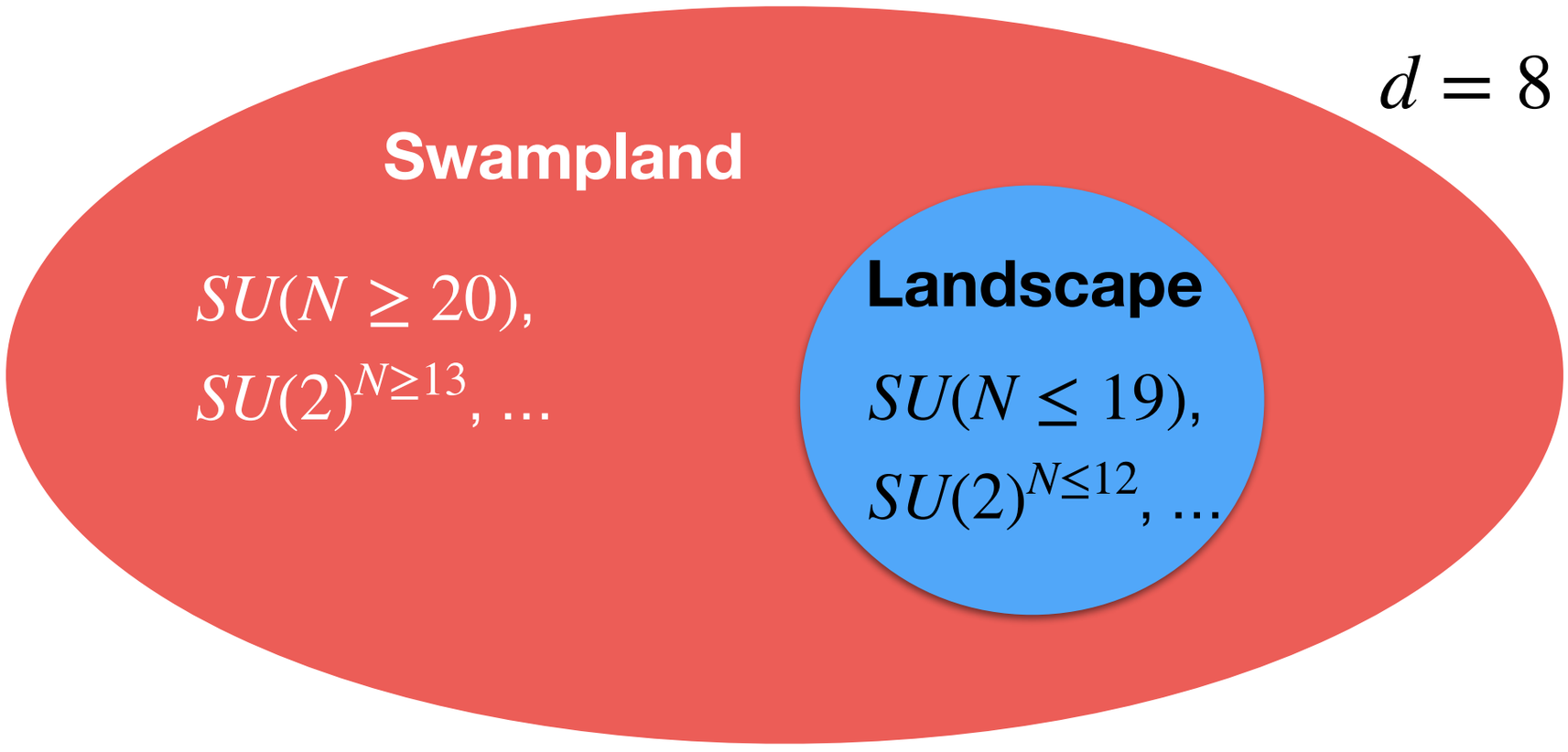
Field theory

Any anomaly-free

gauge group is fine.

QG (String theory)

Very constraining.



Number of theory in the Landscape is finite,

while that in the Swampland is infinite.

Brane Probe

QG is not consistent with

infinitely many EFTs which are naively consistent.

Do we miss some compactification of string theory?

Theories in the Swampland is UV completed by other QG?

We argue that the answers are No.

The consistency condition of the defect in the theory.

[YH-Vafa ’21, Bedroya-YH-Montero-Vafa ’21]

[YH-Vafa ’21, Bedroya-YH-Montero-Vafa ’21]

Instanton Brane

Non-trivial profile of gauge field in 8d.

Take 4d slice of 8d space, and consider gauge instanton configuration in this slice. This is 3-brane.

The dynamics of the 3-brane should be described by 4d field theory with $\mathcal{N} = 2$ SUSY.

Swampland bound from consistency of brane field theory.

IR degrees of freedom of brane field theory are instanton moduli (deformation of solution w/o changing energy, massless mode).

Instanton Moduli space

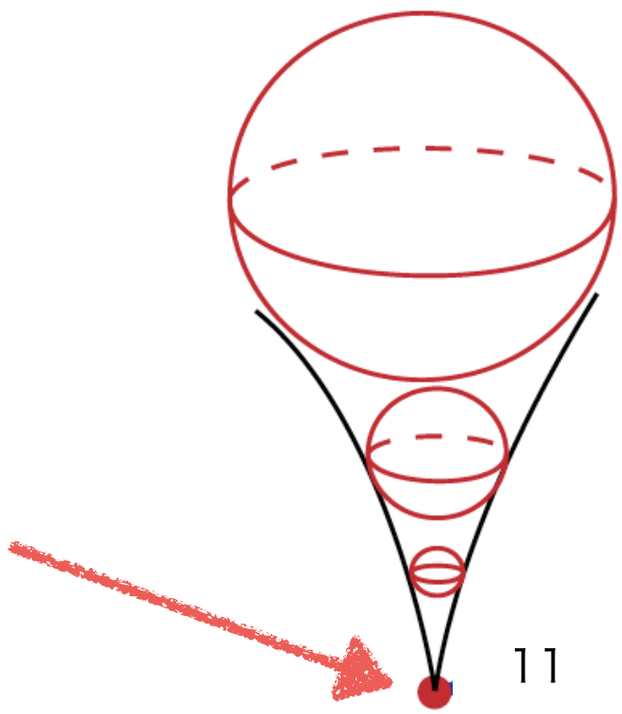
1: Position of instanton.

2: Moduli corresponding to SSB pattern. (e.g. $SU(N) \to SU(N-2) \times U(1)$)

3: Instanton size moduli. Singularity at the zero size point.

→ Signal of the degrees of freedom which become massless there.

E.g. monopole and dyon points in pure 4d $SU(2)$ $\mathcal{N} = 2$ theory [Seiberg-Witten '94].



Instanton Moduli space

Let us consider 8d $SU(N)$ gauge symmetry as an example.

Instanton solution breaks $SU(N) \to SU(N-2) \times U(1)$.

There are moduli corresponding to the SSB pattern.

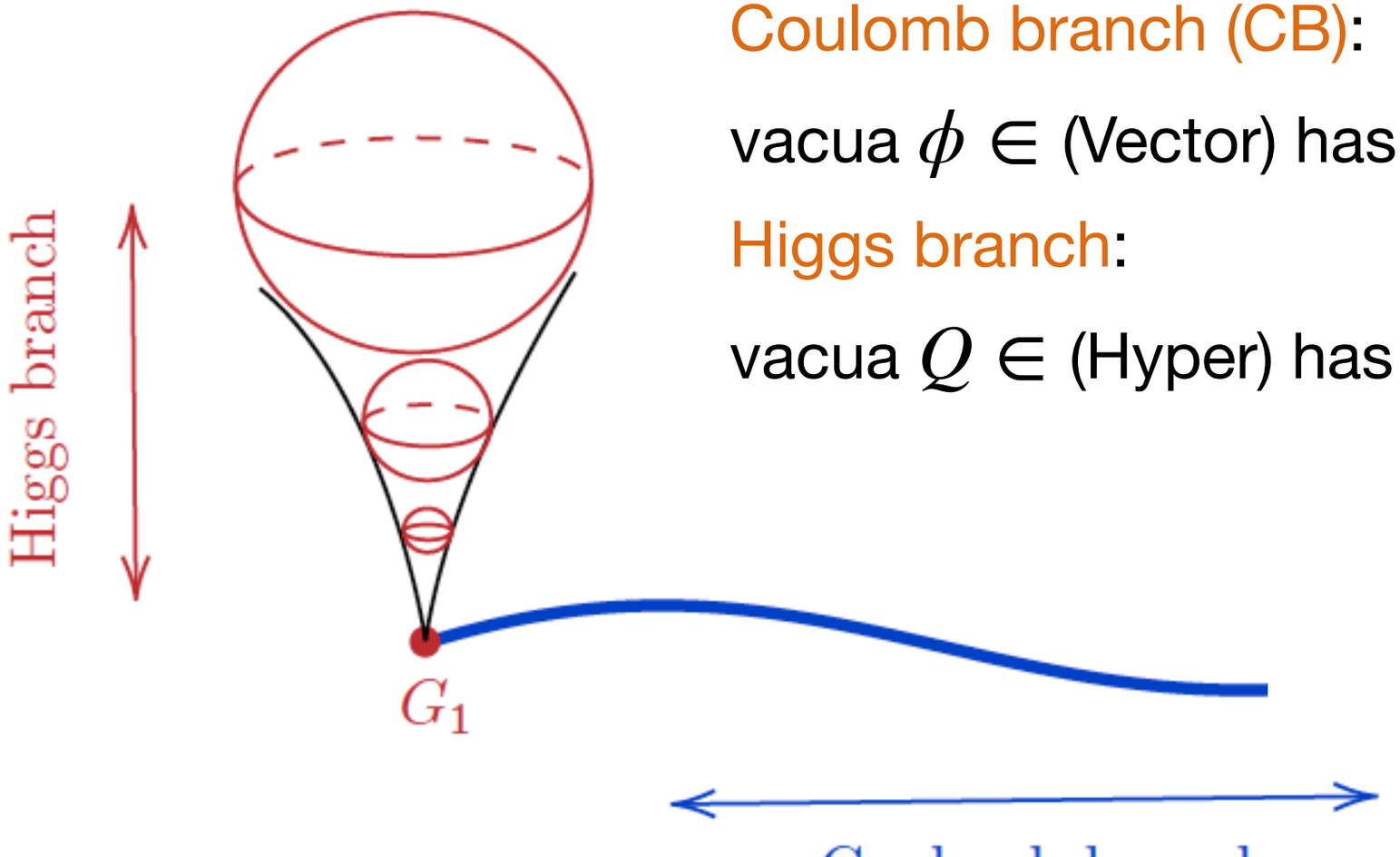
Singularity at zero size limit.

Resolution: $U(1)$ gauge theory with N charge 1 Hypermultiplets.

The same can be done for other gauge groups.

The brane theory is rank one which gives rise hidden direction.

Instanton Moduli space



Coulomb branch (CB):

vacua $\phi \in$ (Vector) has VEV.

Higgs branch:

vacua $Q \in$ (Hyper) has VEV.

(CB) The CB is real 2d.

[YH-Vafa ’21]

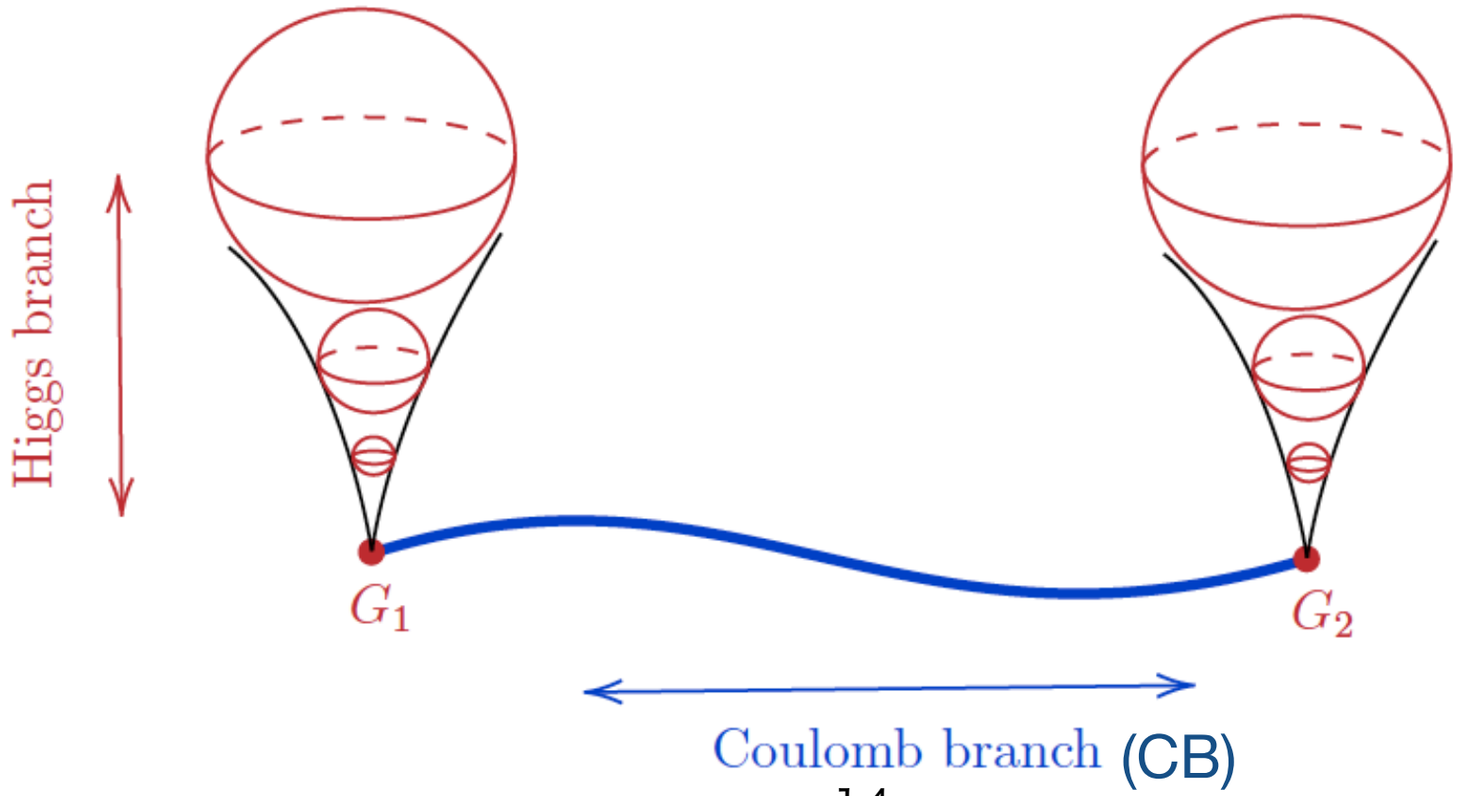
One theory for all instantons

Suppose that there are two non-Abelian gauge groups, G_1 and G_2.

The instanton has B_4 charge one. $S \sim \int B_4 \wedge \left(\mathrm{Tr} F_i^2 + \cdots \right)$.

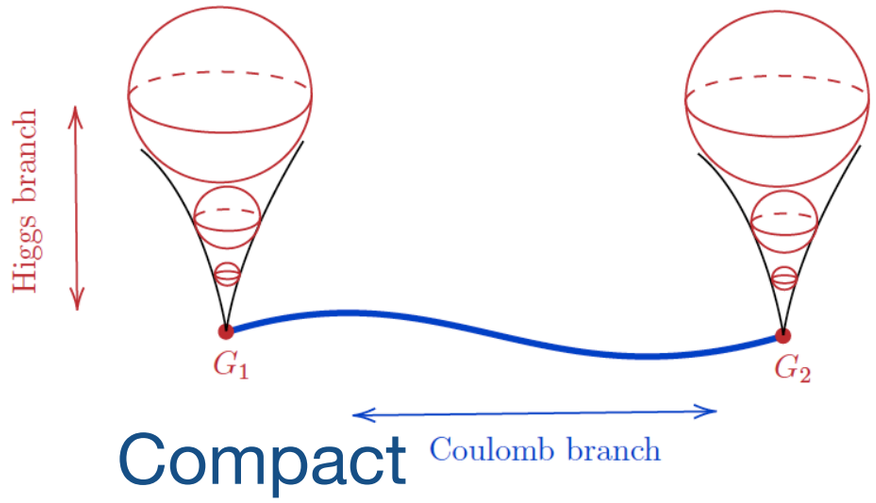
B_4: gauge field of 3-form gauge symmetry ($B_4 \to B_4 + d\Lambda_3$).

(Stronger) Cobordism conjecture: The two configurations having same gauge charge are connected in a supersymmetric way. [McNamara-Vafa ‘19]



[YH-Vafa '21]

Compact moduli space

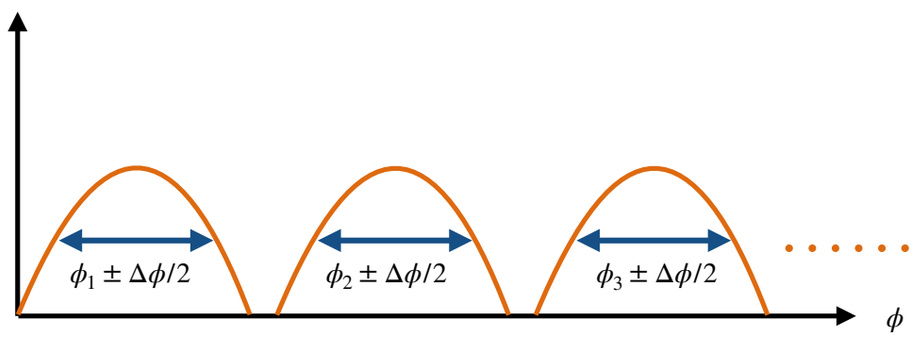


Compactfy on T^3: 5d theory with 0-brane [Quantum Mechanics (QM)].

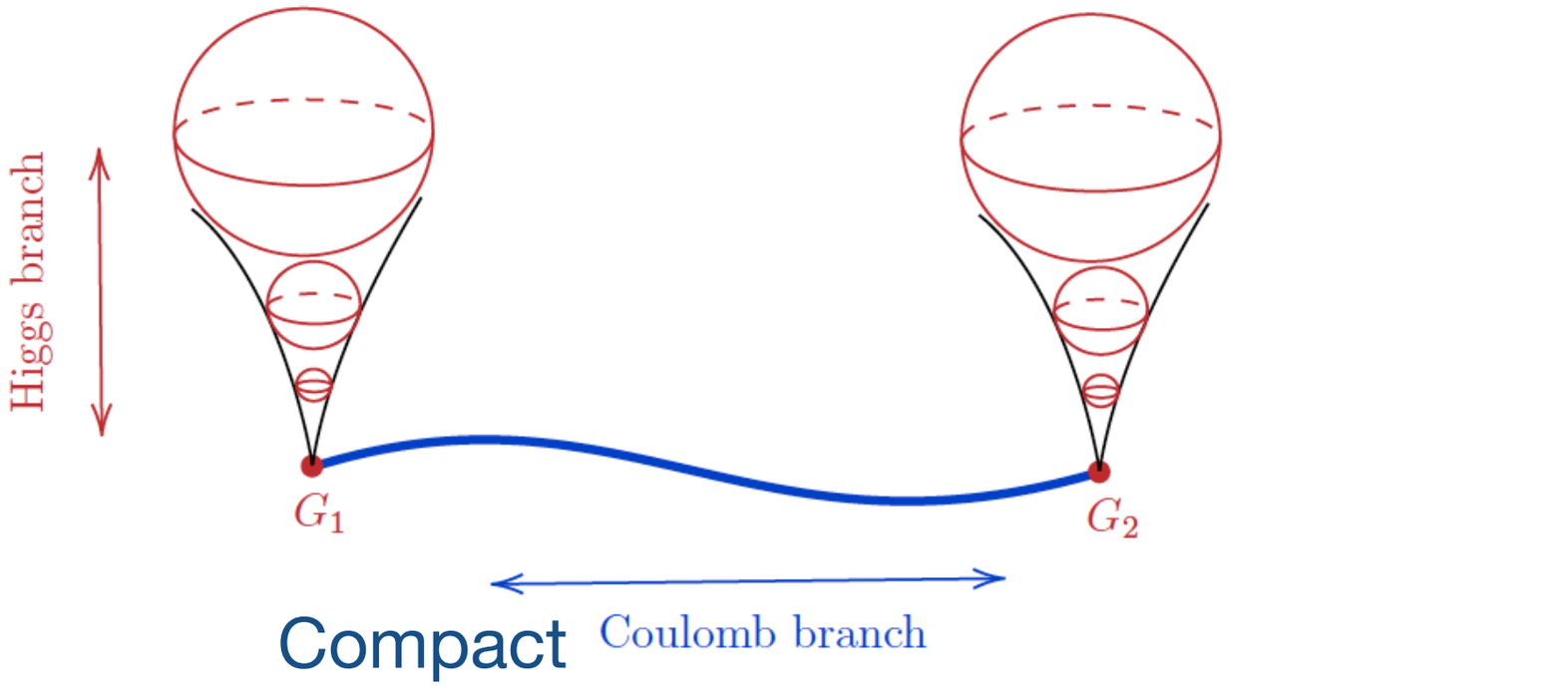
QM state of 0-brane ← wavefunction of massless scalar ϕ in CB.

If CB is non-compact, there are infinitely many states for given energy range.

This violates Bekenstein entropy bound $S(M)$.



Gauge Group



(Gauge Group) ↔ (Singularity in CB)

[YH-Vafa ’21, Bedroya-YH-Montero-Vafa ’21]

Gauge Group: 8d

[Argyres-Lotito-Lu-Martone ’15]

(Gauge Group) ↔ (Singularity in CB)

The singularity is cusp or cone in real 2d CB. (cone→deficit angle).

The geometry does not make sense if the deficit angle is too big.

This explains e.g. why $SU(2)^{N\geq 13}$ is in the Swampland.

All possible patterns of singularity are known [Shimada ’05].

The gauge group of string theory is reproduced.

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Distance Conjecture (DC)

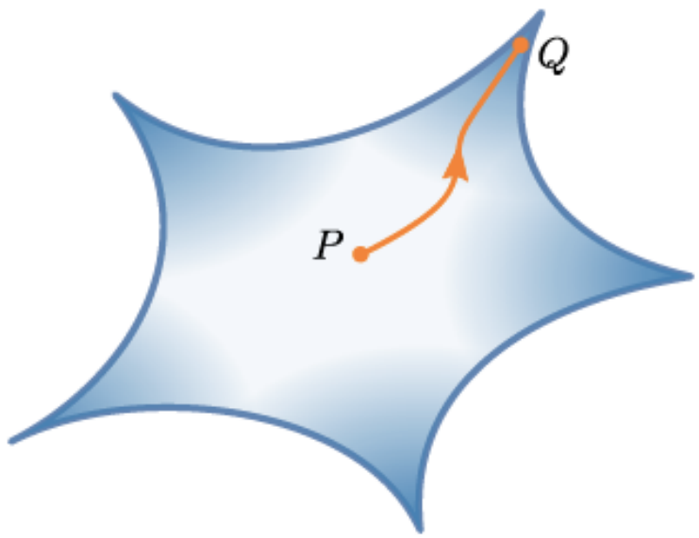
Distance Conjecture:

The EFTs can only be valid for a finite variation of the scalar fields.

An infinite tower of states becomes exponentially light at infinite field distance limit.

$M_{\text{tower}}(Q) \sim e^{-\lambda \Delta\phi}$ for $\Delta\phi \to \infty$ and fixed M_P.

$\Delta\phi := \text{distance}(P, Q)$.



[Figures from Beest, Calderon-Infante, Mirfendereski, Valenzuela ’21]

Decompactification Limit

$D = d + 1$ dimensional spacetime compactified on S^1.

The radius R corresponds to the radion field ϕ.

$$2\pi R = e^{\sqrt{\frac{d-2}{2(d-1)}}\phi},$$

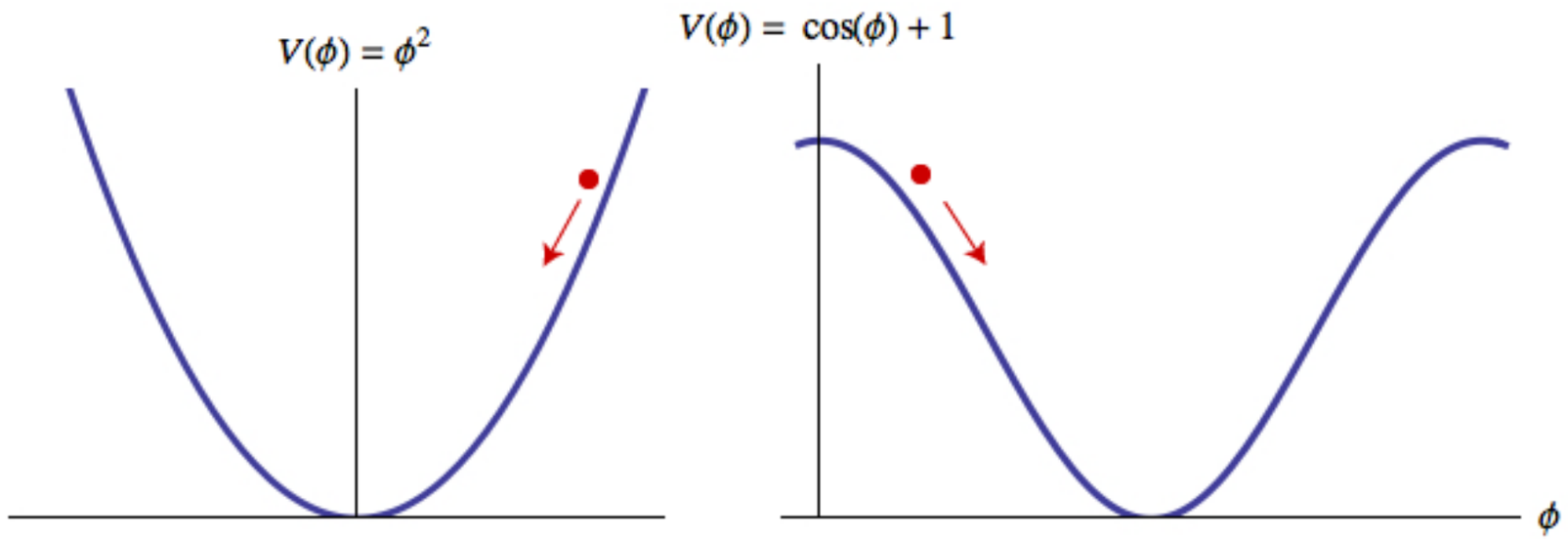
$$M_{KK}^2 \sim e^{-\sqrt{\frac{2(d-1)}{d-2}}\phi}.$$

For $\phi \to \infty$, d-dimenaional EFT breaks down.

Why do we care?

Implications for inflation:

For large field inflation model, the field excursion is order of the Planck scale. The light tower $M_{\text{tower}} \sim e^{-\lambda \Delta\phi}$ may affect the physics.



Evidence from string theory

DC is tested by various string compactifications.

Vector multiplet in 4d $\mathcal{N} = 2$ compactifications (Type IIB on CY_3).

Tower of D3-branes wrapping internal 3-cycle becomes light.

$\lambda \geq 1/\sqrt{6}$ in this case. ($M_{\text{tower}} \sim e^{-\lambda \Delta \phi}$)

5d $\mathcal{N} = 1$ M-theory (M-theory on CY_3):

Tower of M2-branes wrapping internal 3-cycle becomes light.

So far, main support comes from examples in string theory.

Any argument w/o string theory? → [YH-Montero-Vafa-Valenzuela '21]

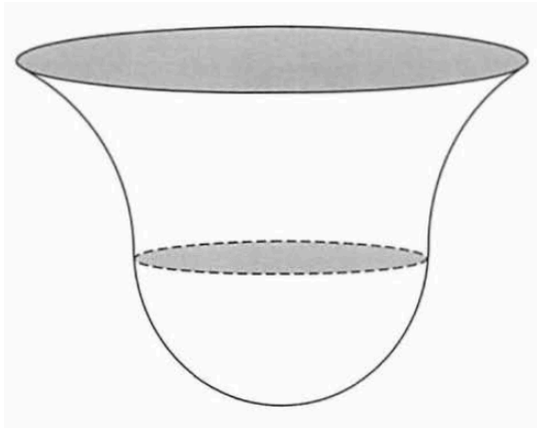
[YH-Montero-Vafa-Valenzuela '21]

Finiteness argument

We require the finiteness of the amplitude in QG.

In QG, closed universes would be created with finite probability.

Let us consider EFT with scalar ϕ and cutoff Λ.



The compact closed universe is characterized

by QM wavefunction of ϕ.

If there are infinite orthogonal states below Λ,

infinitely many universes are created with finite probability,

and the total amplitude may diverge!

So the number of states below Λ should be finite.

[YH-Montero-Vafa-Valenzuela '21]

Non-stringy argument

For non-compact scalar ϕ, infinitely many orthogonal states for fixed Λ.

The compact scalar (radius $\Delta\phi$, $\phi \sim \phi + \Delta\phi$) avoids the problem.

We can take the $\Delta\phi$ to be large only when

$\Lambda \lesssim 1/\left(\Delta\phi\right)^2$ for $\Delta\phi \to \infty$.

This is a non-stringy argument for weaker version of DC.

Because we argue it is power cutoff rather than exponential cutoff.

Our argument gives a support to Emergence proposal :

the infinite distance is IR emergent and is absent in full theory (UV theory)

[Grimm-Palti-Valenzuela '18, Heidenreich-Reece-Rudelius '18].

Summary

- We demonstrate the validity of the String Lamppost Principle – that all consistent theories of quantum gravity are in the String Landscape – for supersymmetric theories in $d = 8$.

- We have argued that Distance conjectures is viewed as the prism of the finiteness of black hole entropy.