AdS flux vacua, swampland and holography

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based on

2209.09330 with Joe Conlon, Sirui Ning and Filippo Revello,

2202.00682 with Miguel Montero, Thomas Van Riet and Timm Wrase,

upcoming work

Plan

Do scale separated AdS vacua exist in string theory?

1. AdS flux vacua with scale separation: DGKT vacua
2. Swampland conjectures
3. **Holographic duals**

Flux compactifications

When compactifying 10d string theory on a 6d manifold, we want to obtain 4d AdS vacua $\boldsymbol{AdS_4 \times M_6}$ with

- Full **moduli stabilization**
- **Parametric control**: large internal volume, small string coupling
- **Scale separation**: AdS radius large in comparison with Kaluza-Klein scale

$$\frac{m_{kk}^2}{\Lambda} \gg 1$$

Flux compactifications: DGKT

- The **4d $\mathcal{N}=1$ AdS DGKT vacua** achieve this with fluxes only,
  - Compactification of massive IIA on Calabi-Yau
  - Unbounded flux $F_4 \sim \boldsymbol{N}$
  - Parametric scale separation $\frac{\boldsymbol{m_{kk}^2}}{\boldsymbol{\Lambda}} \sim \boldsymbol{N}^{1/2}$
- In a very similar way: 3d $\mathcal{N}=1$ FTV vacua with scale separation from unbounded flux
  - Interesting because of CFT_2 duals?

DeWolfe, Giryavets, Kachru, Taylor (2005), Farakos, Tringas, Van Riet (2020)

Swampland and scale separation

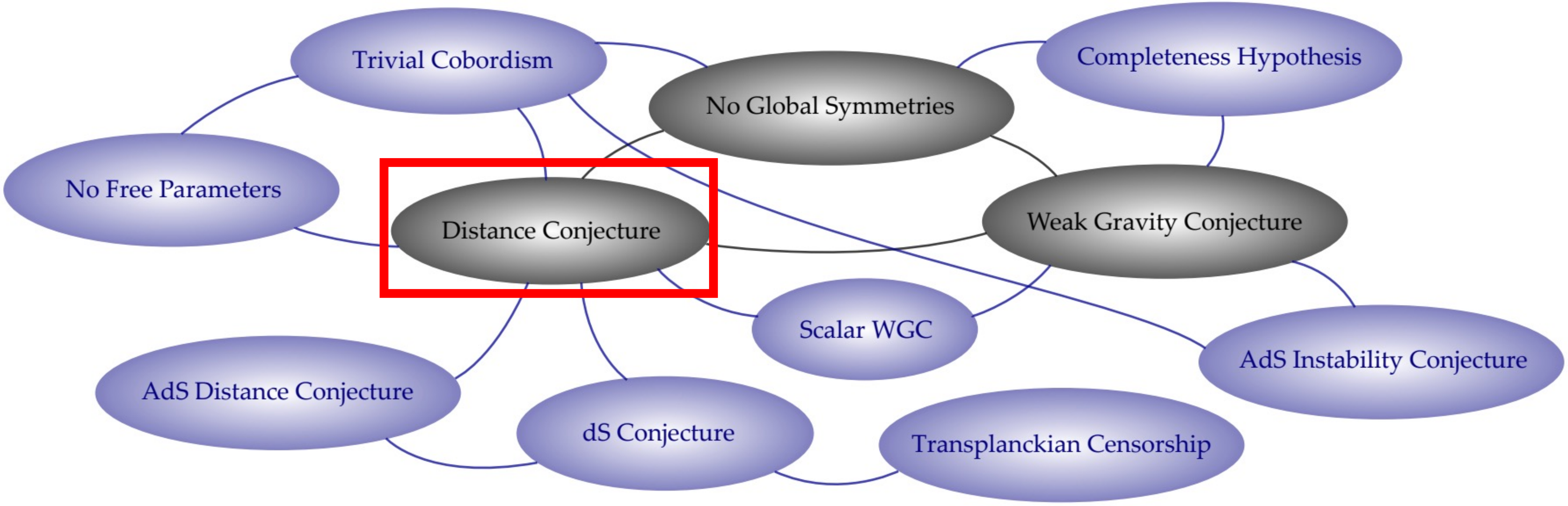
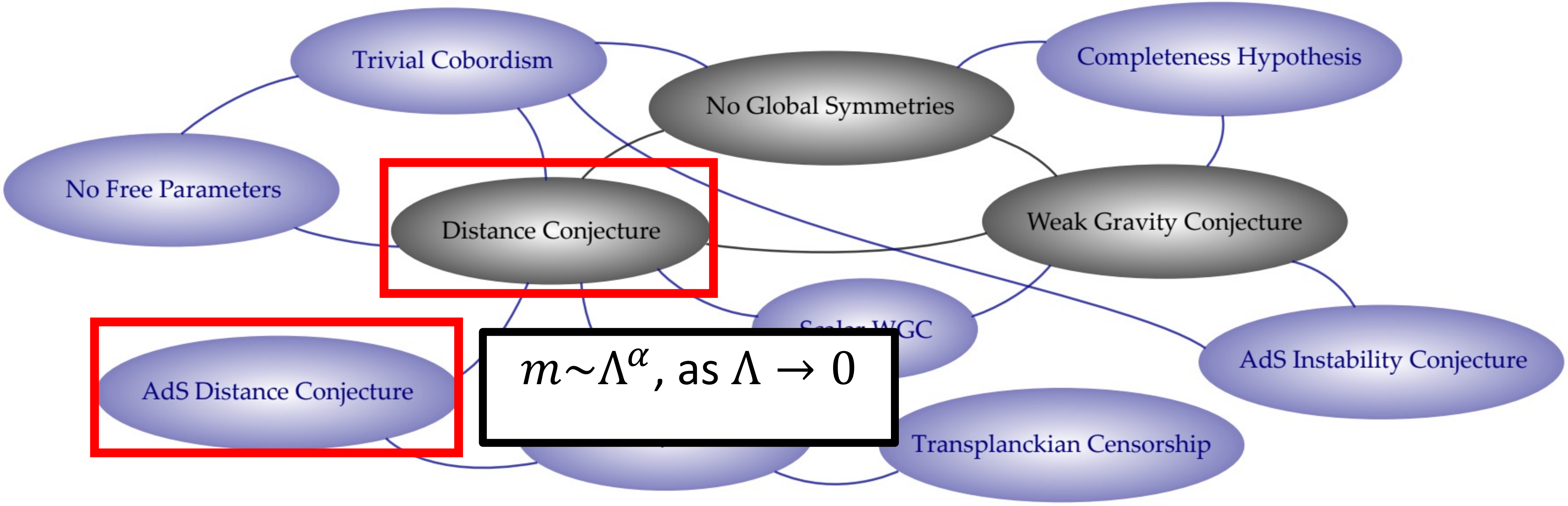


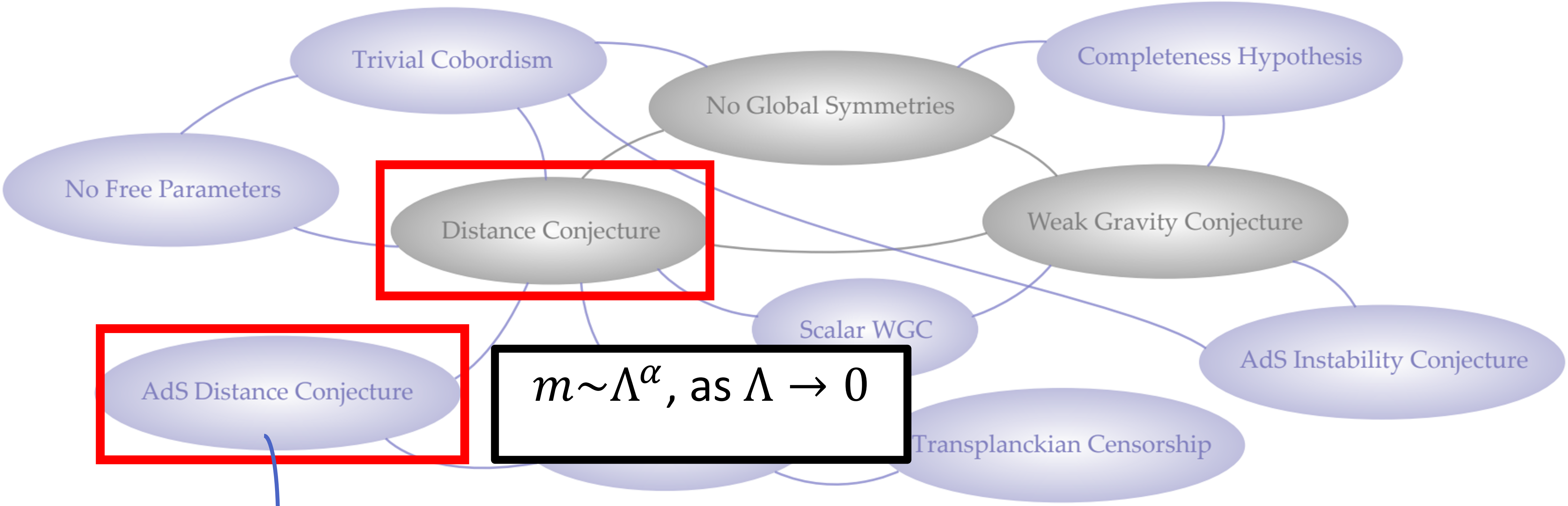
Figure from 2102.01111

Swampland and scale separation



$m \sim \Lambda^{\alpha}$, as $\Lambda \to 0$

Figure from 2102.01111



$$m \sim \Lambda^{\alpha}, \text{ as } \Lambda \to 0$$

Strong AdS Distance Conjecture

$$m \sim \Lambda^{1/2}, \text{ as } \Lambda \to 0$$

For SUSY AdS

Lust, Palti, Vafa, 2019

Holographic swampland

- Relation between swampland conjectures and CFT bootstrap constraints?

F.e. Conlon, Quevedo (2018), Conlon, Revello (2020)

- New perspective on scale separation issue with CFTs?

- List properties that the would-be holographic duals of DGKT should have

  1. Central charge

  2. Spectrum of conformal dimensions

Central charge

- The central charge for the DGKT CFTs scales like

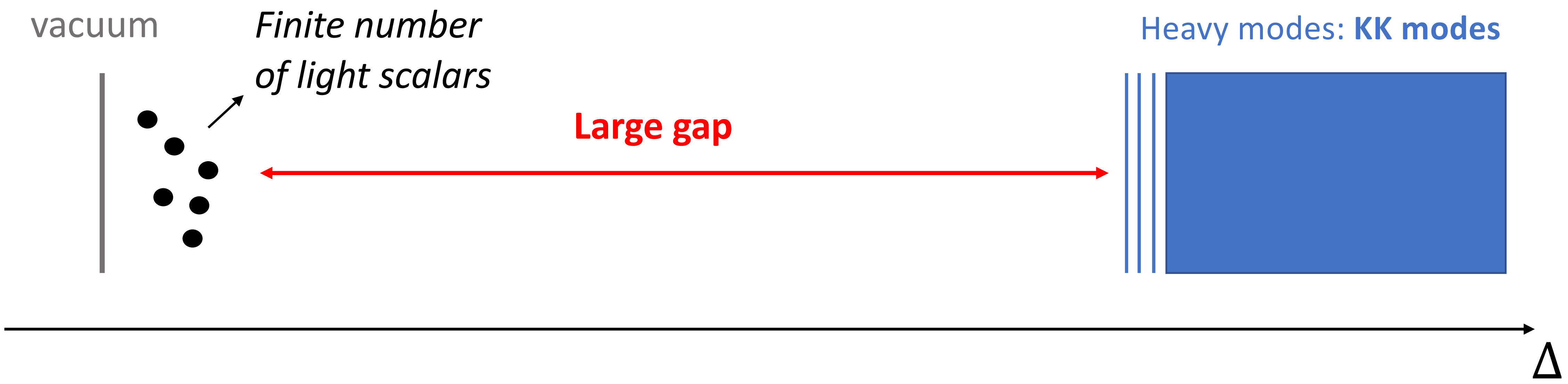
$$c \sim \boldsymbol{N^{9/2}}$$

- For the AdS_3 FTV vacua, this is

$$c \sim \boldsymbol{N^{4}}.$$

- There is no known brane system that would lead to that many degrees of freedom.

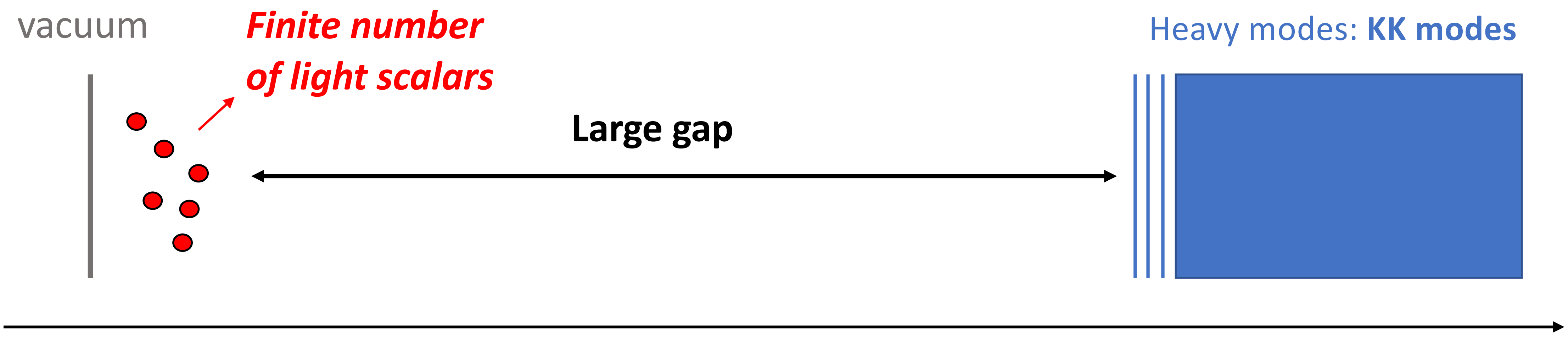
Spectrum of the DGKT dual



No known CFTs with a large gap in the spectrum!

Collins, Jafferis, Vafa, Xu, Yau (2022)

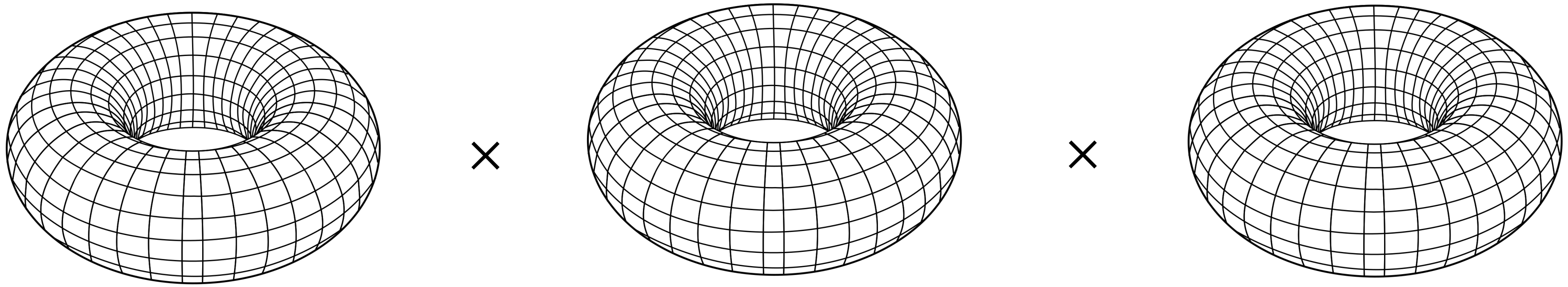
Spectrum of the DGKT dual



$$\Delta(\Delta - d) = m^2 L_{AdS}^2$$

Spectrum of the DGKT dual

on a toroidal orientifold T_6/Z_3^2



$\rightarrow$3 Kahler moduli v_1, v_2, v_3 and dilaton ϕ

$$V = \frac{p^2}{2}\frac{e^{2\phi}}{vol^2} + \frac{1}{2}\left(e_1^2 v_1^2 + e_2^2 v_2^2 + e_3^2 v_3^2\right)\frac{e^{4\phi}}{vol^3} + \frac{m^2}{2}\frac{e^{4\phi}}{vol} - \sqrt{2}|mp|\frac{e^{3\phi}}{vol^{3/2}}$$

$p, m, e_i \sim H_3, F_0, F_4$- fluxes

$vol = v_1 v_2 v_3$

$$K = -\log(vol) - 4\log(e^{\phi} vol^{-1/2})$$

Spectrum of the DGKT dual

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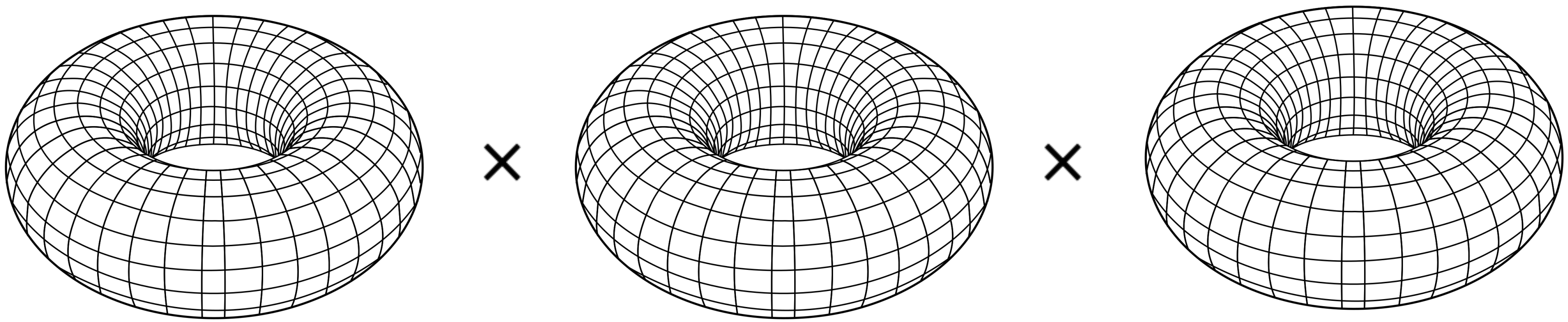


The dimensions of the light scalars (moduli) are: **6,6,6,10**

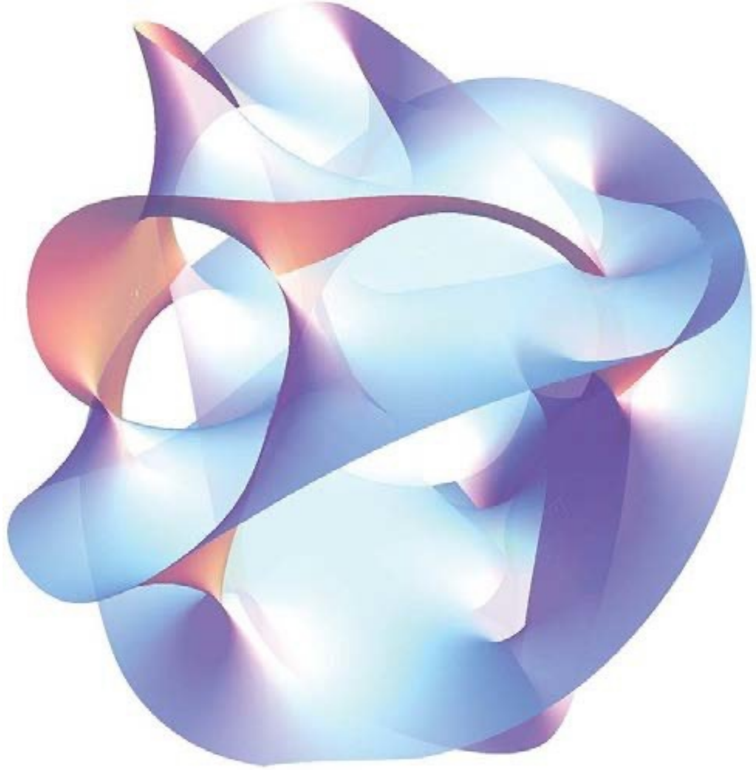
And for the axions: **5,5,5, 11**

Independent of all fluxes, and integers!

Conlon, Ning, Revello (2021)

Integer dimensions in DGKT

- The toroidal orientifold seems quite a symmetric choice for the internal manifold
- Take **any** Calabi-Yau manifold:



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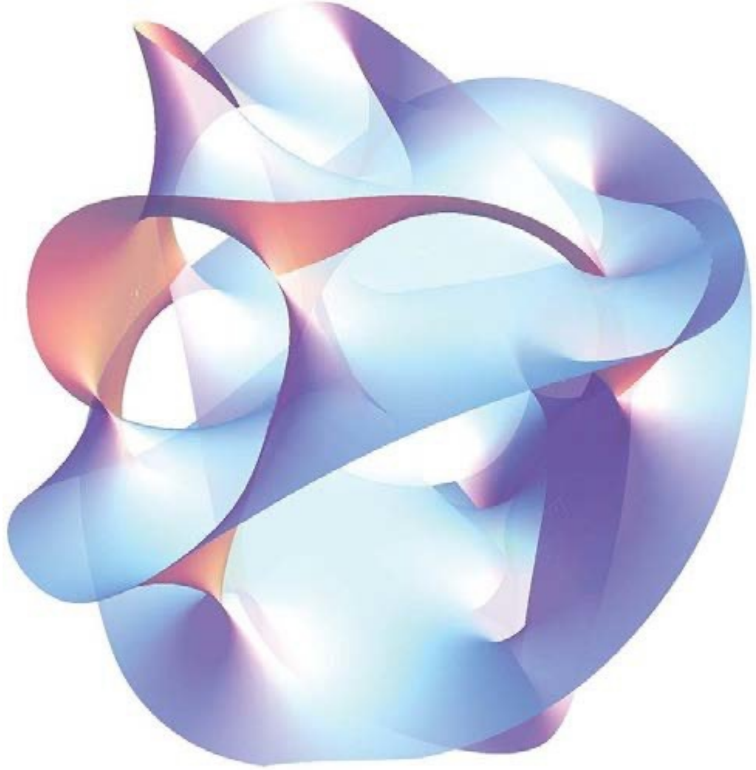

The dimensions of the moduli are: **6,…,6, 10**

And for the axions: **5,…,5, 11**

Independent of all fluxes and intersection numbers

Why integers?

Marchesano, Quirant (2019), FA, Montero, Van Riet, Wrase (2022), FA, Conlon, Ning, Revello (2022)

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Independent of all fluxes and intersection numbers

$3d\ \mathcal{N}=1$ SUSY

Hidden $\mathcal{N}=2$ SUSY?

Marchesano, Quirant (2019), FA, Montero, Van Riet, Wrase (2022), FA, Conlon, Ning, Revello (2022)

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- Continuous constant shifts $\phi \to \phi + c$
  - ϕ massless and so $\Delta_\phi = 3$
- Polynomial shift symmetries in Minkowski:
  - A free massless field ϕ in flat spacetime is symmetric under

$$\boldsymbol{\phi \to \phi + c + c_\mu x^\mu + c_{\mu\nu} x^\mu x^\nu + \cdots} .$$

Polynomial shift symmetries in AdS

A field ϕ in $\mathrm{AdS_d}$ is symmetric under

$$\boldsymbol{\phi \to \phi + c_{\mu_1 \dots \mu_k} x^{\mu_1} \dots x^{\mu_k}|_{AdS}},$$

with x^{μ} embedding flat space coordinates, if

- ϕ is a free field,
- The mass takes certain discrete values: $m_{\phi} = \frac{k(k+d-1)}{R_{AdS}^2}$.

Bonifacio, Hinterbichler, Joyce, Rosen 2018

Polynomial shift symmetries in AdS

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with x^μ embedding flat space coordinates, if

- ϕ is a free field, ✓ **$N \to \infty$ limit of DGKT**
- The mass takes certain discrete values: $m_\phi = \frac{k(k+d-1)}{R_{AdS}^2}$. ✓ **Integer dimensions $\Delta_\phi = k + d - 1$.**

Bonifacio, Hinterbichler, Joyce, Rosen 2018

Integer dimensions from polynomial axion shift symmetries?

- In scale separated $\boldsymbol{AdS_3}$ FTV vacua: **irrational** dimensions

Moduli: $(11.44\ldots, 4.48\ldots, 3.84\ldots, 3.09\ldots, 3.09\ldots, 3.09\ldots, 3.09\ldots)$ **No axions**

- **Non-susy DGKT** by swapping the sign of the F_4-flux: **integer** dimensions

Moduli: (6, …, 6, 10) and Axions: (2, …, 2, 8) ✓ **All integer**

- **Other non-susy DGKT** vacua: **integers + irrational** numbers

Moduli: $(\frac{3+\sqrt{201}}{2}, \ldots, \frac{3+\sqrt{201}}{2}, \frac{3+\sqrt{393}}{2})$ *and Axions:* $(6, \ldots, 6, \frac{3+\sqrt{33}}{2})$

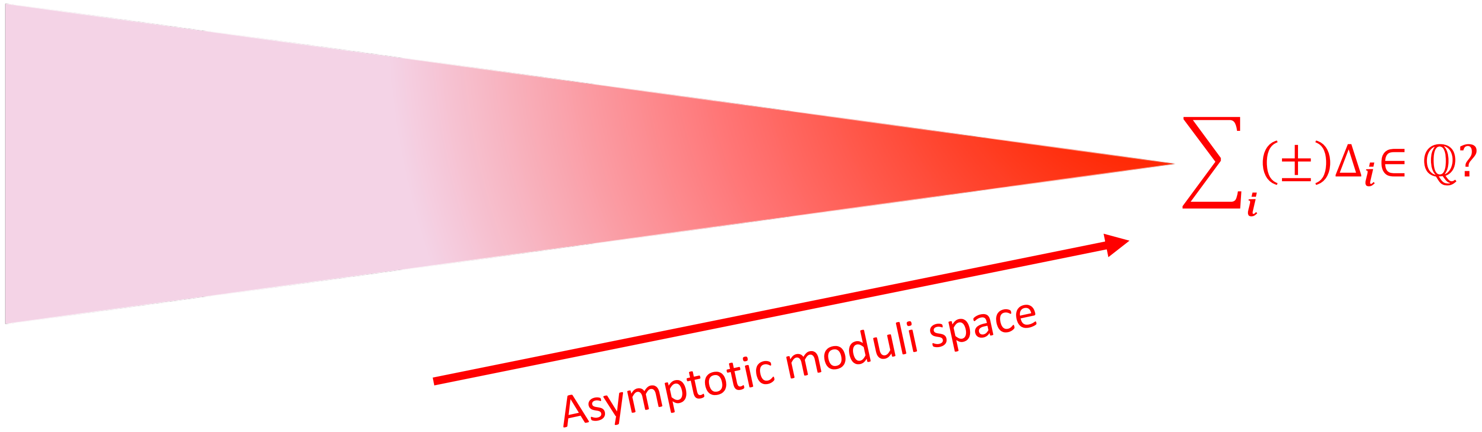
Quirant (2022), FA, Montero, Van Riet, Wrase (2022)

More general asymptotic AdS flux compactifications

- Vacua "near the boundary of moduli space" are more constrained.

f.e. Grimm, Li, Valenzuela (2019)

- 4d $\mathcal{N} = 1$ AdS vacua with 3 fluxes, 2 moduli: $\Delta_1 + \Delta_2$ **or** $\Delta_1 - \Delta_2$ **is rational**



Conclusion: Remarkable properties of the DGKT CFT duals

1. **Large number of degrees of freedom**
2. **Large gap in the spectrum**
3. **Universal low-lying spectrum**
4. **Integer conformal dimensions**

Do such CFTs exist?

Thank you!